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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Final Report of Investigations
Contract No. NAS 9-14235
Site No. 222198

December, 1975

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Prepared for:

NASA - Lyndon B. Johnson Space Center
Houston, Texas 77058

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FINAL REPORT

1 July 1974 - 31 December 1975

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ABSTRACT

This report summarizes the results of investigations into the applications of Skylab EREP data to resources exploration in the southwest United States. Studies were conducted in a variety of geologic and tectonic environments to analyze the characteristics, qualities, and advantages of Skylab imagery. Information which supplies indirect evidence for the presence of resource deposits can be derived from imagery analyses including recognition of most structural features and discrimination of rock and soil boundaries. Arcuate, linear, and color anomalies detected in Skylab films have been genetically and spatially related to known resource deposits. Skylab data gives the exploration geologist high-resolution imagery that retains the value of synoptic coverage. The data are excellent for interpreting regional lithologic and structural relationships and determining areas with the greatest potential for containing economic mineral, geothermal, or petroleum deposits.

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I. INTRODUCTION

Study Objectives

The overall purpose of this study was to utilize imagery and other data from the Skylab Earth Resources Experiment Package (EREP) for applications to geologic investigations.

The objectives of the study were twofold:

1. To analyze and evaluate the qualities and characteristics of Skylab EREP data and imagery; to compare the products to other space-orbiting and aerial remote sensing techniques -- including ERTS imagery, X-15, and Apollo spacecraft photography, and high-altitude aircraft photography -- for an appraisal of the usefulness of EREP products to geologic investigations.
2. To analyze Skylab data and imagery for evidences of geologic phenomena that can be interpreted as significant indicators of mineral, petroleum, geothermal, or water resources. Interpretations were to be confirmed and extended by studies of published geological and geophysical reports and maps, as well as by on-site field reconnaissance surveys. Results were to be applied to investigations of potential resources for specific sites within a test area.

Anticipated results from studies of imagery included:

1. Mapping of geologic units.

2. Detection of geologic structures -- faults, fractures, joints, folds, foliation, etc. -- that are genetically related to known resources.

3. Detection of subtle expressions of eroded or buried intrusions that may be indicative of mineral or geothermal resources.

4. Detection of altered rocks and other evidences of hydrothermal activity.

5. Suggestions of new areas and extensions of old ones that should be thoroughly explored by remote sensing and by conventional geological and geophysical methods for potential mineral, petroleum, geothermal, or water resources.

Test Area

The area chosen for the study is a 180,000-square kilometer rectangle encompassing parts of Arizona, California, Nevada, and Utah (Fig. 1A). Most of the area is a part of the Basin and Range physiographic province and is characterized by elongate, partially-buried fault blocks of variable structure and rock type separated by alluvium-filled basins. Parts of the Colorado Plateaus province, a region of relatively unfaulted, flat-lying Paleozoic and Mesozoic sedimentary rocks, and the granitic Sierra Nevada massif are also included in the test area. Thus, investigations of remote sensing data and imagery were conducted over a variety of geologic environments.

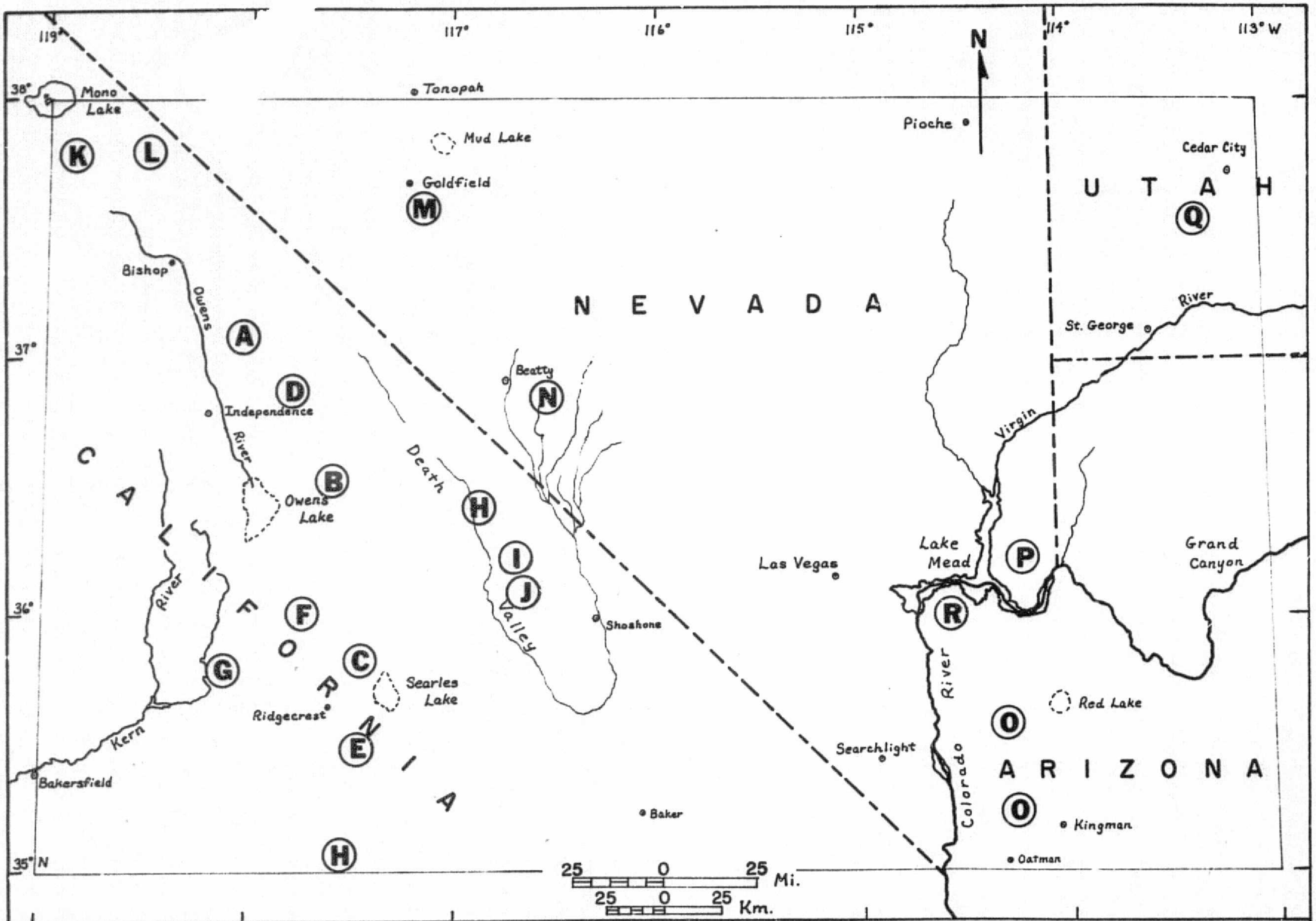

Fig. 1A Map of Test Area (Lettered investigation sites listed in Table of Contents)

The mineral wealth of the area is exemplified by the large deposits currently being mined, such as the Duval copper porphyry deposit in northwestern Arizona, the iron deposits of southwestern Utah, the Goldfield-Tonopah and Pioche gold deposits in Nevada, and the borax deposits in California. Numerous mining districts currently inactive produced millions of dollars in mineral wealth. Many small mines are active in the test area and abandoned shafts, pits, and tunnels signify that the region has been extensively explored for mineral deposits.

Substantial geothermal energy resources are located within the test area, as evidenced by the Coso known geothermal resource area (KGRA) and the Long Valley depression region, California. Geothermal activity in the form of hot springs and fumaroles is common in the test area. It is usually associated with granitic intrusions and comparatively recent volcanics that are typical in the Basin and Range province.

Petroleum resources are confined to the extreme southwest corner of the test area in the Kern River oil and gas fields near Bakersfield. Minor hydrocarbon accumulations have also been tested in southwestern Utah and northeastern Nevada.

A detailed description of lithology, structure, and known resources of the entire test area, including discussion of prior workers' theories on geologic and tectonic history, will not be presented in this report. The reader is referred to "A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra to the Colorado Plateau" by Liggett and others of Argus Exploration Company (1974), an earlier NASA study for which Ira C. Bechtold (PI of the present project) was also PI, for a summary of the geologic literature pertinent to the test area. The Argus study which was an ERTS-1 investigation encompassed the same area as the present Skylab investigation. Compilations of mineral and geothermal deposits, earthquake epicenters, tectonic features, and Cenozoic volcanic and plutonic outcrops were accomplished by Argus for the entire test area. To avoid needless duplication, similar compilations were not attempted during this study.

This report includes discussions on Skylab (EREP) and correlative imagery, methods of analysis, imagery enhancement procedures, applications of Skylab imagery to resources exploration, detailed analyses and interpretations for sixteen specific sites, and recommendations for further work. Appendices containing supporting data are also included.

II. METHODOLOGY

Skylab EREP and Supporting Data

S190A Multispectral Camera Photography

More than 70% of the 180,000-square kilometer test area was photographed at least once by the S190A cameras. Five Skylab tracks traversed the test area, three descending (63, 20, 6) and two ascending (16, 59) (Fig. 1B). There were 14 different S190A data-gathering EREP passes over those tracks; NASA supplied BESTEC with photography from eight of the 14 passes (42 frames).

As specified in the data requirements section of BESTEC's Skylab contract, NASA supplied only that imagery exhibiting less than 30% cloud cover. On several occasions, however, we requested copies of S190A frames over sites of particular interest even though catalogs and reference maps indicated cloud cover of the frame was greater than 30%. Cloud-covered frames were requested only if no other Skylab data was available over the site of interest. Fortunately, windows in the clouds were located over the sites in some of the requested frames.

A few areas were photographed on more than one EREP pass, which permitted evaluations under different climatic conditions and different sun angles. For example, photography for the Lake Mead region is available from S190A magazines 04 (SL2 - June 1973), 28 (SL3 - September 1973), and 4B (SL4 - February 1974).

S190A photography was received in sleeved 70mm film positives and in 9-inch (4X) film positives and negatives (for black and white films only).

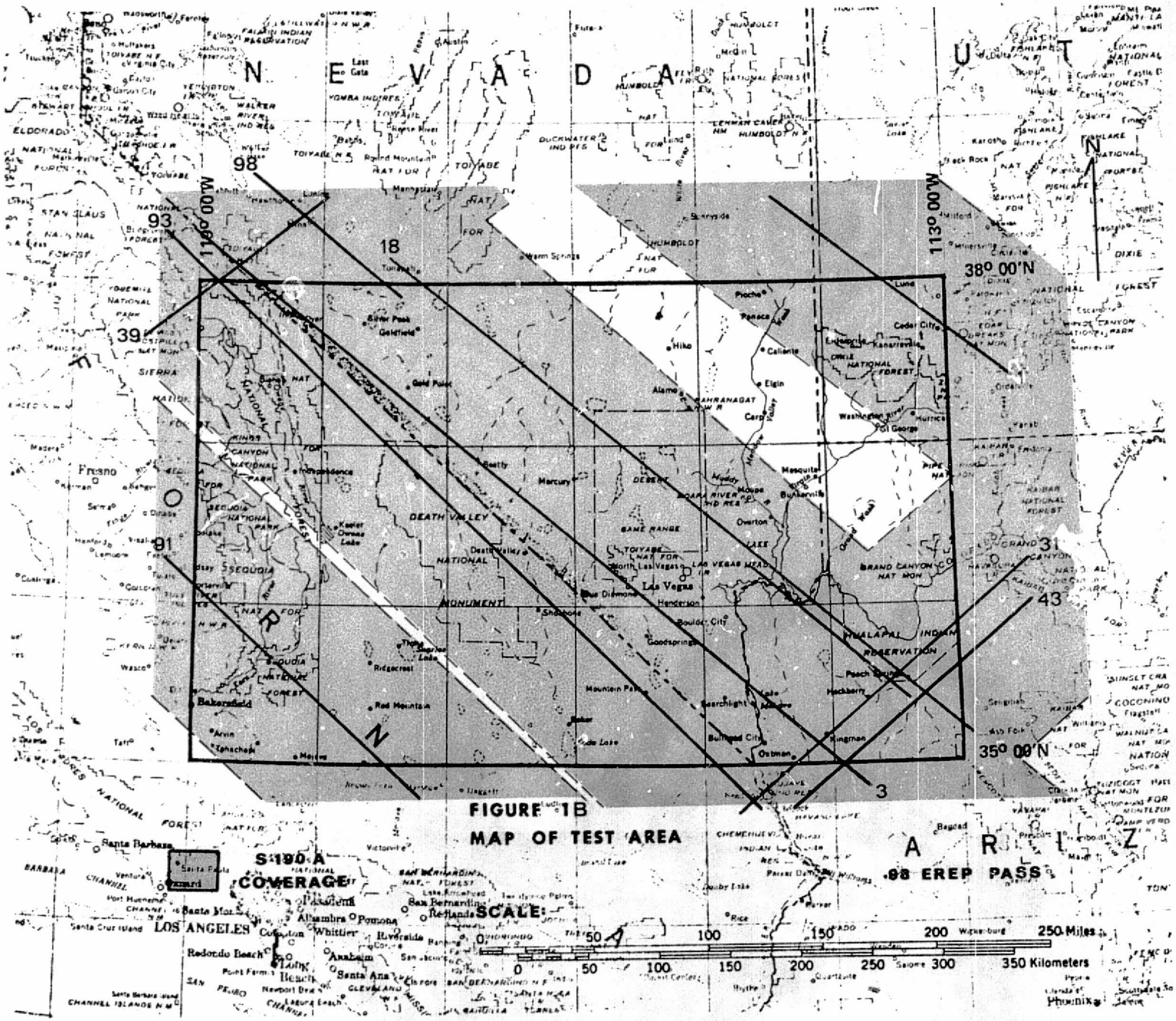

FIGURE 1B
MAP OF TEST AREA

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The quality of the films is generally excellent regarding fogging, spots, and scratches due to processing. The small scale of the film chips (1:2,850,000) makes geological analysis difficult, but it is adequate for an evaluation of quality, cloud cover, and geographic area covered by the frame as well as an appraisal of the resolution and color contrast. The chips are interpreted in an International Imaging Systems (I^2S) multispectral viewer which enlarges them 6.67X to a scale approximately 1:425,000.

The projection results in some loss of detail and also stereo, especially in the Ektachrome films, but this is attributed mostly to the Polacoat screen and optical degradation inherent in the viewer.

70mm chips have been composited (four at a time) with no registration problems. No single configuration of light intensities, color filters, and spectral bands has proven best for investigations of all magazines.

The black and white infrared film has relatively poor resolution (graininess) and generally detracts from the composited image. Ektachrome chips are perhaps overall the most useful; but the black and white band 5 usually has the best resolution.

Projecting S190A chips through the rear of the I^2S viewer permits enlargements of 20X from the 70mm size. In this way, S190A can be registered directly onto published maps of conventional scales: 1:250,000 and 1:62,500. The image is still very useful if viewed in a darkened room where incident light does not detract from the image. Obviously, some resolution and color contrast is lost at enlargements of this magnitude; we interpret the frame at 6.67X before the larger projection.

Photographic enhancement of S190A films has been accomplished using the same procedures developed for ERTS films described below. Contrast is improved, and enhanced films, when composited, yield better color discrimination, particularly in alluvium-covered areas. S190A Ektachromes have been processed into prints after producing enhanced internegatives from NASA-supplied color positives. Generally, a better color balance is obtained.

Stereo-viewing capabilities of S190A have been investigated and utilized effectively during examinations of test sites. Stereo viewing is particularly useful on images exhibiting low sun angles, where subtle topographic relief is accentuated. For example, frame SL4-4B-029 over the Lake Mead area and northwest Arizona has been examined using a sterescope. Several short linears observed are interpreted to be vertical faults, with the mountain block of the fault up, relatively. The linears were not observed during conventional monoscopic analysis. Stereo viewing has been successfully used on transparencies as well as prints. For some Skylab frames, stereo viewing is possible with alternating scenes as well as consecutive ones.

Several features of the S190A multispectral camera photography are especially useful to geological investigations: 1) availability in several bands of the spectrum; 2) capability of false-color compositing in a multispectral viewer; 3) resolution: better than ERTS; 4) endlap: stereo-viewing capabilities; and 5) Ektachrome films: more subtle color variations can be detected than is possible with ERTS. The color contrast in many S190A frames is comparable to that in Apollo 6 photography which exhibits excellent tone contrast and enhancement of topography due to a low sun angle.

Some of the principal advantages that analysis of S190A imagery can contribute to geologic investigations are: 1) discrimination of soil and rock types, 2) distinction between materials of high reflectance such as clays and snow, 3) delineation of vegetation patterns, 4) identification of geologic structures, and 5) detection of alteration products.

S190B Earth Terrain Camera Photography

The very high resolution of S190B photography makes it the most useful of Skylab EREP products, although it does not have the multispectral capabilities of S190A or S192 imagery. Approximately 60% of our test site was photographed with the S190B camera; the largest expanse of territory not photographed is in southwestern Utah-eastern Nevada (Fig. 1C). Thirty-four frames were supplied by NASA in 5- and 9-inch film positives. All 5- and 9-inch films have been processed into our storage system and analyzed.

The resolution of 5- and 9-inch S190B is excellent. Linear, high-contrast features as narrow as 4m can be delineated, such as dirt roads cutting alluvial fans in a desert. The black and white films (e.g., magazine 85) appear to have the best optical resolution, but it is easier to identify small features in the Ektachrome films. Although the color infrared films we received have the poorest resolution of all the S190B film types, resolution is still sufficient to enable identification of features in an urban environment approximately 15m square (magazine 87).

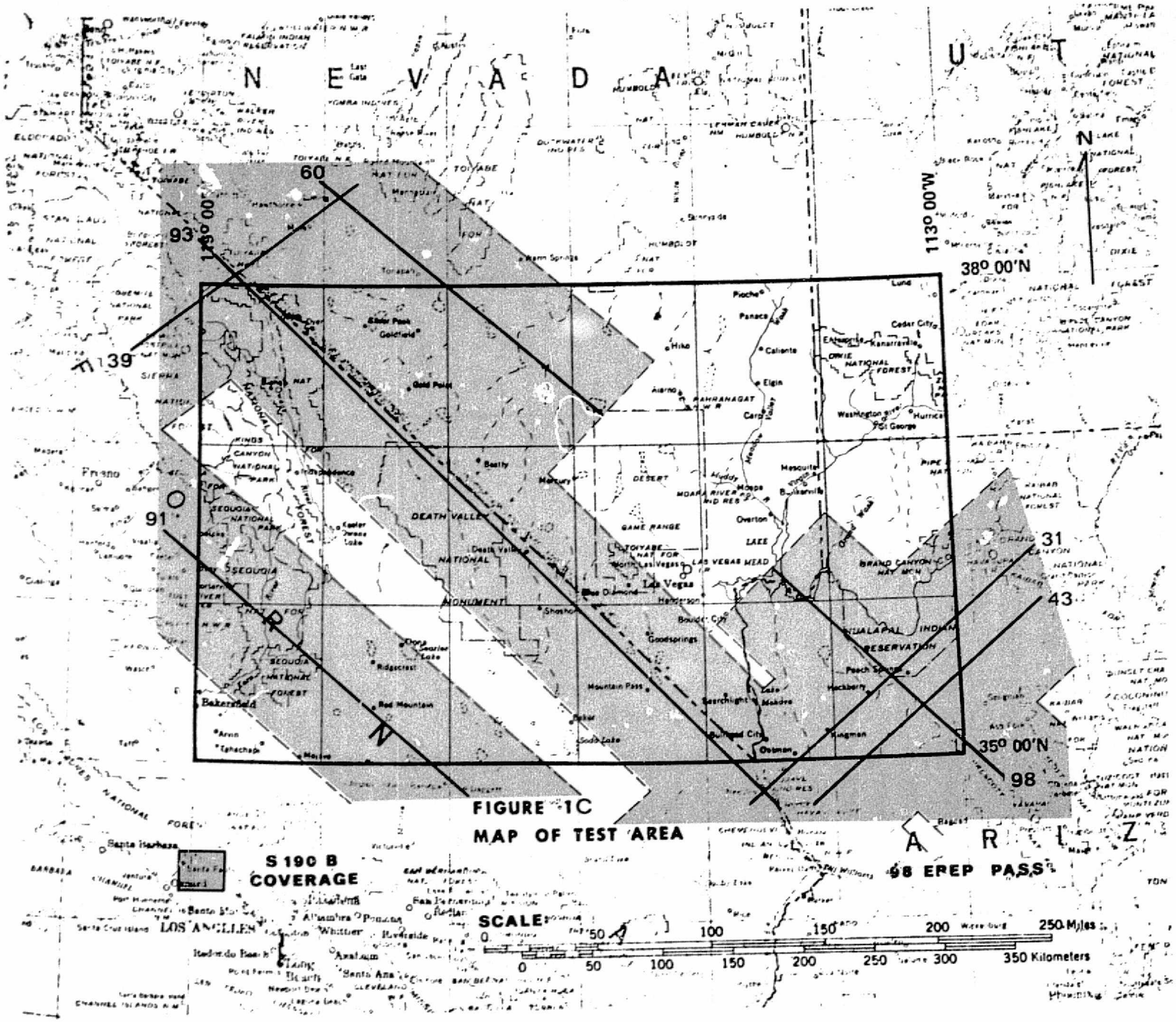

FIGURE 1C
MAP OF TEST AREA

An additional advantage of high resolution camera imagery is that it permits identification of man-made features such as roads and stock tanks that aid in the registration of projected films directly onto published topographic or geologic maps. Thus, items of geologic interest -- color anomalies or linears -- can be accurately located on the map, which makes field reconnaissance less time-consuming and more apt to be successful.

The S190B films we received are generally excellent in quality; very few processing flaws have been noted in frames analyzed. Parts of some magazines (e.g., 94) are overexposed -- color contrast is minimal. Because overexposure is especially apparent in 2X films, we suspect the problem is sometimes in processing, and the originals were not overexposed; the 5-inch transparencies often appear monochromatic. We are attempting to bring out colors on certain frames by enhancing internegs made from NASA transparencies.

S190B 5-inch (scale 1:950,000) and 9-inch (scale 1:500,000) film positives have been analyzed on light tables with monoscopic and stereoscopic viewing devices. Although the I^2S multispectral viewer is designed to accept film chips no larger than 70mm, we have successfully utilized the enlargement capabilities of the viewer on 5- and 9-inch films. The technique devised is simple: the film is taped to the underside of the platen, such that the area of interest appears in the opening where a 70mm chip is normally mounted. In this way, the 5-inch film can be enlarged to approximately 1:140,000 using the 6.67X front projecting facility and to as large as 1:45,000 using the rear facility. S190B films supplied at 2X enlargement can be projected to 1:75,000 and to 1:24,000 (scale of 7½' topographic maps).

S190B photography complements S190A very well, because anomalous features noted in S190A composited multispectral products can usually be located on S190B films and analyzed as to geologic significance using the better resolution films.

The most important advantage of the S190B photography from a geologic standpoint, is that the resolution makes it possible to discern faults, fractures, and other linear features not visible in S190A, ERTS, Apollo, or Gemini imagery. Low sun angles seem to be especially useful in S190B frames to enhance linear features, particularly short-length faults that cut Holocene deposits of uniform color. Lithologic contacts can frequently be resolved and accurately mapped using Ektachrome films.

S192 Multispectral Scanner Imagery

Analysis of several segments of S192 imagery over test sites including northwestern Arizona and southwestern Utah has resulted in the conclusions that S192 13-channel multispectral scanner (MSS) data can be extremely useful for geologic investigations. S192 imagery is most effectively analyzed in a line-straightened, 70mm chip format, utilizing false-color compositing techniques developed for ERTS MSS and Skylab S190A films (see Plate X).

Registration of films of different channels from one S192 scene presents no problems. Various combinations of two, three, and four different channels when viewed through different color filters with varying light intensities produce many different false-color composites. Different composites have proved useful for investigating varied aspects of the geologic environment. For example, channels in the visible part of the spectrum, when viewed in combination, emphasize drainage patterns and textures in alluvial areas; conversely, composites produced from channels 8 through 12 emphasize outcrops and structural features within the mountain blocks because the valleys exhibit abnormally high reflectances that mask detail. These observations are generalized and may not apply to all S192 scenes.

Projection of S192 films to scales as large as 1:250,000 has been accomplished for an area in northwestern Arizona without significant loss of detail (see Plate X).

Resolution limits of S192 films examined have been very difficult to ascertain. Two-lane dirt roads, even in areas of high contrast, could not be located on any channels. As expected, resolution varied considerably throughout the 13 channels; channel 7 appears to have the best over-all resolution. The low resolution (less than ERTS) permits observations of large arcuate features and linears, however.

Geologic features that can be detected in S192 composites include large faults, fracture and drainage patterns, and alteration anomalies. Various rock types can be discriminated. For example, in the Black Mountains in northwestern Arizona, linear gneiss outcrops have been differentiated from nearby schists and granites using channel 11 imagery (see p. 239). Coloration zones and anomalies within valley alluvium which have been correlated with vegetation concentrations and soil distributions are noticeable in the blue to yellow channels.

Investigation results indicate S192 imagery is potentially useful for analyses of sediment patterns in lakes and for studies of shallow bottoms of lakes.

S191 Infrared Spectrometer

Very little effort has been expended for investigations of the usefulness of S191 data to resources exploration and no significant results were achieved. Analysis of S191 16mm film indicates that the resolution is inadequate for geologic investigations.

S193 Microwave Radiometer, Scatterometer, and Altimeter

S193 data was not examined or plotted in detail. From theoretical considerations and discussions of Eagleman (1974), it is expected a relation between moisture content and S193 values can be determined.

S194 L-Band Radiometer

S194 data was plotted for Skylab orbit 68 over the Sierra Nevada and the Mojave Desert as antenna temperature versus ground position of spacecraft. No definite conclusions can be formulated as to significance of results, but it is suspected a relation exists between temperature values and presence of snow on the ground.

ERTS (now LANDSAT; the acronym ERTS is used in this report)

Over 300 frames from many different ERTS cycles over the test area have been received to complement the Skylab data. Nine-inch prints, positive transparencies, and 70mm negative and positive films were delivered to BESTEC and filed. All of the area was imaged at least once by ERTS sensors under optimum conditions, yielding high-contrast, cloud-free imagery.

Prints are generally poor-quality reproductions, useful only for quick scanning for indexing and coverage purposes. Nine-inch transparencies are good quality and useful at the scale of 1:1,000,000. The 70mm negatives are of little use, and we find it desirable to enhance 70mm positives photographically to increase contrast for use in the multispectral viewer.

The common map scales (1:1,000,000) at which ERTS 9-inch products are reproduced is a particular advantage of ERTS. In addition, the I^2S multispectral viewer was designed to enlarge ERTS 70mm chips to 1:500,000, a convenient scale, as many geological and geophysical maps of the same resolution are published at that scale; e.g., the geology, Bouguer gravity, and residual aeromagnetic map series of Arizona. The 1:500,000 scale is especially valuable as 2X enlargements of S190B photography are also at 1:500,000 which will allow a ready comparison of the products as well as evaluation of features noted in ERTS at the higher resolution of S190B.

The coverage of large regions afforded by ERTS imagery and the ease of mosaicking adjacent scenes remains a principal advantage, especially regarding identification of major lineaments and fracture systems. The consistent and repetitive coverage of ERTS allowing temporal evaluations of features of interest is another distinct advantage over Skylab photography.

Apollo 9 and X-15 Spacecraft Photography

Supporting imagery available over the test area included Apollo 9 and X-15 photography which covered primarily the Mojave Desert-Colorado River region. All photography was oblique, to different degrees, and thus each frame was characterized by varying scales and resolutions. Apollo 9 photography is similar to ERTS imagery in resolution, but the trueness of the color is comparable to S190A Ektachrome photography. The Apollo 9 does exhibit synoptic qualities, and thus is useful for regional geologic investigations. This imagery was analyzed in a 9-inch print format.

X-15 photography was available as panchromatic black and white, and near-infrared color 5- and 9-inch transparencies. The data is comparable to U-2 photography in scale and can be substituted for it when no U-2 is available. The X-15 color infrared films are especially useful for discrimination of playa surfaces.

High-Altitude Aircraft Photography

U-2 and RB-57 color and black and white transparencies were available over parts of the test site. Primary use of the high resolution data was to study, in detail, anomalies that had been noticed in lower resolution imagery. A secondary use of the imagery was to function as base maps to update topographic maps with information regarding roads and mine localities.

Much of the U-2 photography over the test site was overexposed and therefore of minimal value. Enlarged S190B transparencies were frequently used in place of high-altitude aircraft photography because features noted in aircraft data could often be discerned in S190B with the added advantage of synoptic view.

Data from various missions have been compared for the Lake Mead area (p. 106), to graphically exhibit the relative merits of high altitude aircraft photography, spacecraft photography, and satellite scanner imagery.

III. GEOLOGIC INVESTIGATIONS

A very large number of sites in our 180,000 square kilometer test area have been observed in Skylab imagery to display unusual or anomalous spectral signatures, linear patterns, arcuate features, or lineaments. Many of these sites have been investigated thoroughly and correlations established between the anomalies and occurrences of known mineral deposits, and geothermal activity. The correlations are based on examination of published geologic reports and maps and, for some of the sites, on field reconnaissance surveys. Studies of several sites have resulted in delineation of additional areas to explore for potential resources.

Summaries, abstracts, and preliminary reports for the majority of the site investigations have been included with interim progress reports previously submitted to NASA (Appendix A). This section contains detailed reports for eighteen areas selected from all sites studied on the basis of most significant results and best demonstration of applications of Skylab imagery to resources exploration.

A. Inyo Mountains

Investigation of Plutonic Stocks and Potential Ore Deposits

A section of the Inyo Mountains north and east of Independence, California, was studied to determine mineralized zones from imagery analyses of the structure, outcrop pattern, and host rock alteration related to plutonic bodies occurring throughout the range. Numerous plutons easily visible in Skylab imagery as bodies of contrasting coloration and texture exhibit distinctly curved boundaries, often defining circular or oblong shapes. In this remote sensing study, four major plutons were studied and field work subsequently performed in some areas identified from images to be zones likely to possess ore mineralization.

The very prominent arcuate and oblong features visible in Skylab S190A (SL2-04-188) and S190B (SL4-94-011,012) images appear generally lighter in color than the surrounding terrain, and often display bright white rims. Careful image study and comparison with geologic maps at a scale of 1:62,500 revealed the bodies to represent major granitic stocks intruded into Precambrian and Paleozoic rocks. The white areas correspond to limestones and dolomites thermally metamorphosed at the plutonic margins and further hydrothermally altered rock. The relations of these intrusive bodies in contact with the carbonate rocks suggest the possibility of economic ore deposits lying in and near the altered zones. Study of satellite images does not reveal the compositions of the granitic rocks, but color tone differences indicate compositional facies, predominantly mafic and silicic variations, most pronounced within one plutonic body.

The Papoose Flat pluton occurs about 24km northeast of Independence in a relatively inaccessible, high region of the Inyo Mountains and includes Waucoba Mountain (3,360m elevation) near the eastern edge (Fig. 2). The pluton's border describes a teardrop shape with apex pointing directly west to Owens Valley; it appears dark gray and brown (in SL2-04-188) and fairly homogeneous in texture and coloration, but its borders are most easily discerned

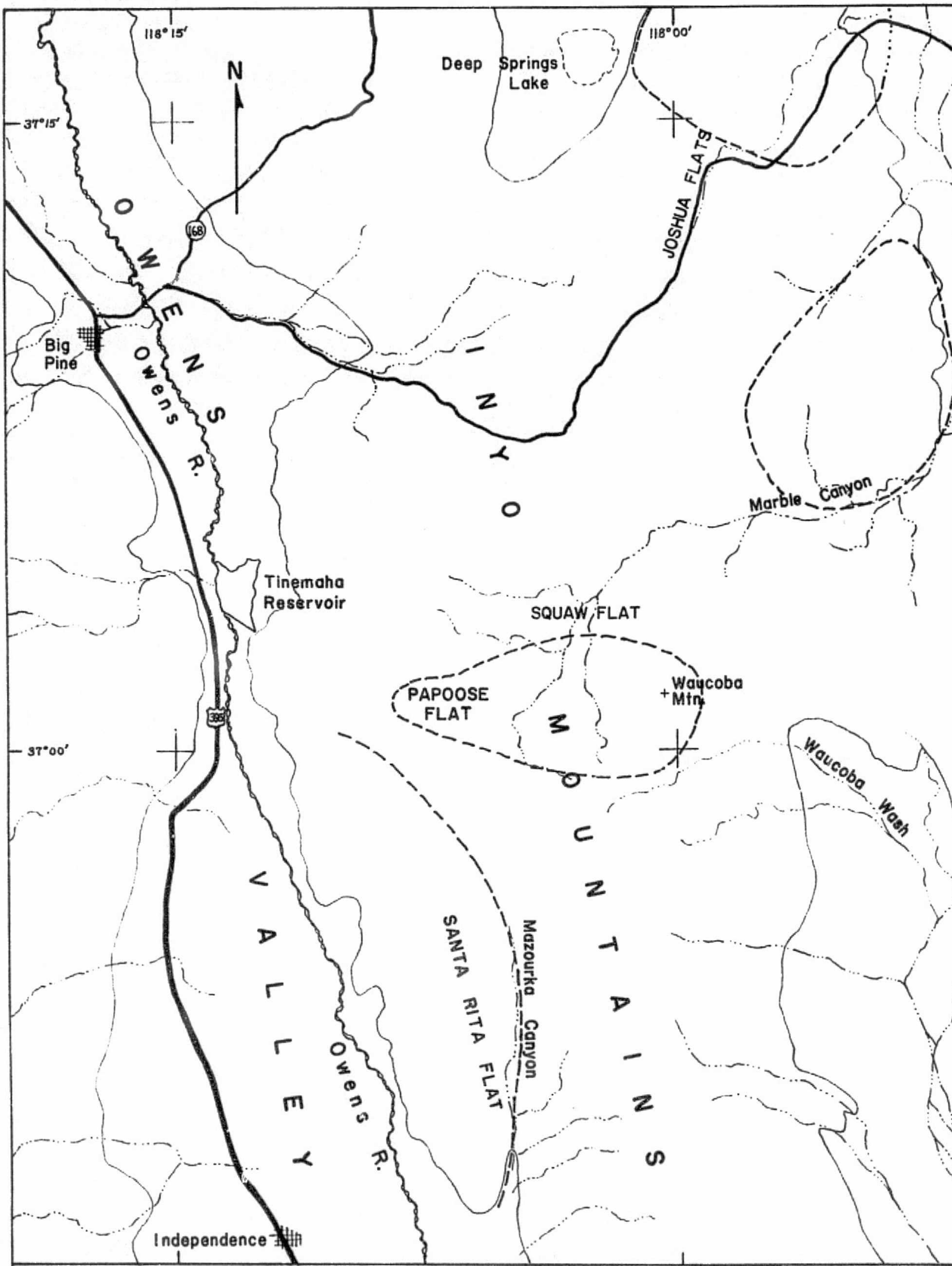

Fig. 2 General Location Map of Inyo Mtns., Scale: 1:250,000

Pluton Borders
Bedrock Outcrops

5 0 5 Miles
5 0 5 Kilometers

CALIF.

in ERTS images. The body is mapped as "light-colored, coarse-grained, porphyritic quartz monzonite, strongly foliated in border zone" (Nelson, 1966b).

The contacts do not show significant alteration or intrusion into the wall rock, and mineralization possibilities appear very limited, except perhaps just north of Squaw Flat away from the granitic stock where the Cambrian bedding clearly strikes north, perpendicular to the contact. Bordering the quartz monzonite are mostly Precambrian and Cambrian sediments with some limestone, but probably not extensive enough to host significant ore deposits. A few small white zones occur to the east that apparently correspond to limestone beds of Precambrian age metamorphosed to calc-silicate rocks near the pluton border.

The Marble Canyon pluton, exposed 24km northeast of Big Pine (Fig. 2), appears in tones of gray and exhibits a curved border with a narrow white band describing most of its periphery. The body is mapped as a complex of diorite and monzonite (Nelson, 1971). Internal structure is manifested in Skylab images as concentric bands of slight coloration and possible topographic differences shown on the Waucoba Spring geologic quadrangle map. Minor amounts of marble occur within the body and along its margins, expressed as bright white areas.

Of possible significance to ore deposition is a region of brown coloration (in SL2-04-188) on the northern edge of the pluton with scattered spots of white rock within it. In general appearance, it roughly forms a circular figure. The supposition is that two rock types occur here, but the map shows the same beds outcropping across the area. Also shown are abundant curved faults, outcrops of younger Cambrian rocks containing more limestone, and small patches of igneous rock (aplite and fine-grained granite) occurring on the edge of the circular feature. Dikes also have been mapped which trend in directions tangential and radial to the structure, thereby giving credence to the arcuate structure representing an unexposed pluton. This body lies directly between the Marble Canyon and the Joshua Flat plutons.

The Joshua Flat pluton appears similar to the Marble Canyon, having a diameter of about 10km and a broad white alteration zone along its southern border, immediately east of Deep Springs Valley. It intrudes much of the Cambrian strata, including beds of dolomite which comprise much of the white zone seen.

Particularly striking in Skylab imagery is a semi-circular structure which corresponds with the Santa Rita Flat pluton and the tilted Paleozoic rocks on its eastern edge. The structure contains a light gray and brown subdued interior, bordered by alternating bands of dark and light rock forming a highly symmetrical arcuate zone. The interior corresponds with the exposure of granodiorite of the Santa Rita Flat pluton; the surrounding rocks are Paleozoic marine sediments in part metamorphosed and faulted, especially near the granitic rock. Due to their white reflectance, limestones in direct contact with the pluton's edge appear altered and the combined occurrences of these rocks and arcuate faults and radial lineaments suggest the probability of ore deposition in the border zone.

Reconnaissance field work was done early in March, 1975, to investigate the arcuate structures observed and to determine what alteration and evidence of economic mineralization might occur at their margins. Borders of the Marble Canyon, Joshua Flat, and Santa Rita Flat plutons were visited and sampled.

The access route to Marble Canyon is a very narrow (0.2km wide), straight, and long (approximately 6km) canyon striking east-west tangential to the southern boundary of the pluton. In the west are exposed Precambrian and Cambrian strata composed of siltstones and dolomite. Some limestones interbedded with shale and sandstone occur near the contact of diorite of the Marble Canyon pluton. Numerous mine shafts pierce the alluvium in the canyon floor, dug presumably for placer gold. Marble Canyon itself appears to represent a long fault or fractured zone likely associated with the intrusion of the pluton. A contact of monzonite and brecciated limestone was found with large euhedral pyrite cubes, indicating sulfide deposition probably accompanied emplacement of the pluton in the Cambrian sedimentary rocks. The area lies at the junction of the edge of the arcuate structure, in general representative of the pluton periphery, and the linear canyon which deeply dissects it.

The Joshua Flat pluton to the north was sampled along its southwestern edge where it has intruded Cambrian limestones and dolomites, forming a white reflectance zone interpreted as marble and calc-silicate metamorphic facies. Associated are minor pegmatite dikes and sulfides in limestone. A broader white zone not visited is visible in imagery to the east of Joshua Flat as well as what appear to be contorted beds of the same. In conjunction with these relations, the occurrence of many faults in the area and a hypothesized buried intrusive immediately south (substantiated in part by isolated mapped outcrops of aplite and granite) indicate the region should be studied as a potentially ore-bearing area.

Of greatest significance are the types of intrusion, alteration, and mineralization at the margins of the Santa Rita Flat pluton east of Independence. The intrusion of quartz monzonite into Paleozoic strata of diverse types with accompanied fracturing apparently created very favorable circumstances for deposition of later stage metal-bearing fluids. The area chosen by image analysis for field investigation proved to be an area replete with small mining operations and prospects.

Skylab S190B photography defines the details of the Mazourka Canyon area best, and although overexposed, shows zones of white reflectance and numerous linears along the arcuate canyon representative of the edge of the Santa Rita Flat pluton. Radial fractures appear abundant in the southern half of the 20km long arcuate zone. In combination with the major tangential faults and apparent deformation at the contact, the area appears to be a potentially well-mineralized zone. The Mazourka Canyon alluvium was worked in the early 1900's for placer gold deposits, and apparently only small prospects have been active except in the southernmost region where some activity still proceeds.

The Santa Rita Flat granitics appear well-weathered and dissected, but the eastern edge contacting the Paleozoic sediments stands in relief and exhibits a white appearance, probably due to silicification. Mazourka Canyon is the result of downwarping during intrusive emplacement and weathering along the arcuate outcrop of steeply dipping Paleozoic shales, siltstones, and limestones directly east of the plutonic intrusion. The majority of the altered-appearing zones lie amidst thinly bedded limestones of the Keeler Canyon Formation. Adjacent beds of Rest Spring shale directly to the east appear dark brown, but limestones further east appear somewhat altered and faulted in places, indicating possible small zones of mineralization. The curvature of the beds appears to be directly related to the intrusion of quartz monzonite; beds dipping westward into the pluton and only deformed close to the contact indicate a substantial amount of assimilation of wall rock by the igneous body. Additionally, the deformed and faulted area would provide excellent channels for ore deposition, especially in the abundant limestones.

Ore minerals are found in the altered, light areas in the vicinity of granitic rocks contacting the Paleozoic rocks, where some later hydrothermal activity prevailed. Observed minerals in these contact metamorphic zones include abundant copper oxides, some sulfides in pegmatite and limestone, locally dense masses of magnetite and tactite, and abundant quartz in veins. This assemblage occurs at the south end of the canyon where the Paleozoic rocks are considerably metamorphosed, faulted and further altered. To the north along the canyon, the outcrop pattern is similar. The far eastern edge of the granitic body is well-fractured, quartz is abundant, and salts are readily apparent on the soil surface near small (fault-controlled?) bluffs, indicating some vestigial hydrothermal activity is still occurring. Small amounts of copper mineralization were observed, and in one area, a highly fractured mafic phase of granitic rock is riddled with veinlets of copper oxide and shows substantial alteration of its feldspars. Minor iron sulfides are also present in the igneous rock and in pegmatite.

Economic grade ore mineralization is suggested to occur in the arcuate zone in proximity to the igneous-limestone contact, and may extend both into the Paleozoic host rocks and the granitic rocks where they are fractured and altered. Accumulations of copper oxides and magnetite seem most worthy of future consideration, and non-metallic resources such as dolomite and limestone are plentiful and accessible. Image linears trend north-south and northwest through the granitic body and in places appear white; Ross (1965) maps these as faults and shear zones and indicates small gold and silver workings have produced in the past. Further exploration along the contact zones should indicate the extent of the deposits of ore-bearing tactite and concentrations of copper.

B. Hunter Mountain

Application of Skylab Imagery to Resource Exploration in the Death Valley Region

The Hunter Mountain plateau in the northern Panamint Range, California, exhibits anomalous topographic, vegetative, color and structural features in Skylab and ERTS satellite images having strong correlation with mineralized areas of potential economic importance. The area is topographically high and occurs between two major downfaulted valleys, Saline Valley to the northwest and Panamint Valley to the south. A large arcuate feature, nearly perfectly circular, was first observed on Skylab frame SL4-94-013 to encompass Hunter Mountain and a relatively featureless plateau bounded by steep canyons (Plate II).

Comparison of the area with published geologic maps reveals that the structure lies almost entirely within quartz monzonite. Paleozoic carbonate rocks, dark gray-green and brown in Skylab images of the area, appear bright white on the north edge of the arcuate anomaly where they contact the quartz monzonite. This apparently altered region seemed a likely site for mineralization based on the occurrences of ore deposits in the quartz monzonite plutons of southern Arizona.

Field checking of the region in November, 1974, revealed a dramatic vegetation change across the arcuate zone, the interior of the pluton being virtually devoid of growth. The northern edge of the arcuate was found to be composed of a wide zone of calc-silicate metamorphic rock with tactite and significant amounts of copper oxides and some sulfides. Faults, very important in controlling mineralization in the area, as well as many other unmapped lineations readily visible in imagery are probably potentially important to locating new ore deposits.

(For full report, see Appendix A, p. 250)

PLATE I Skylab S190B SL4-94-013
Approximate Scale 1:250,000

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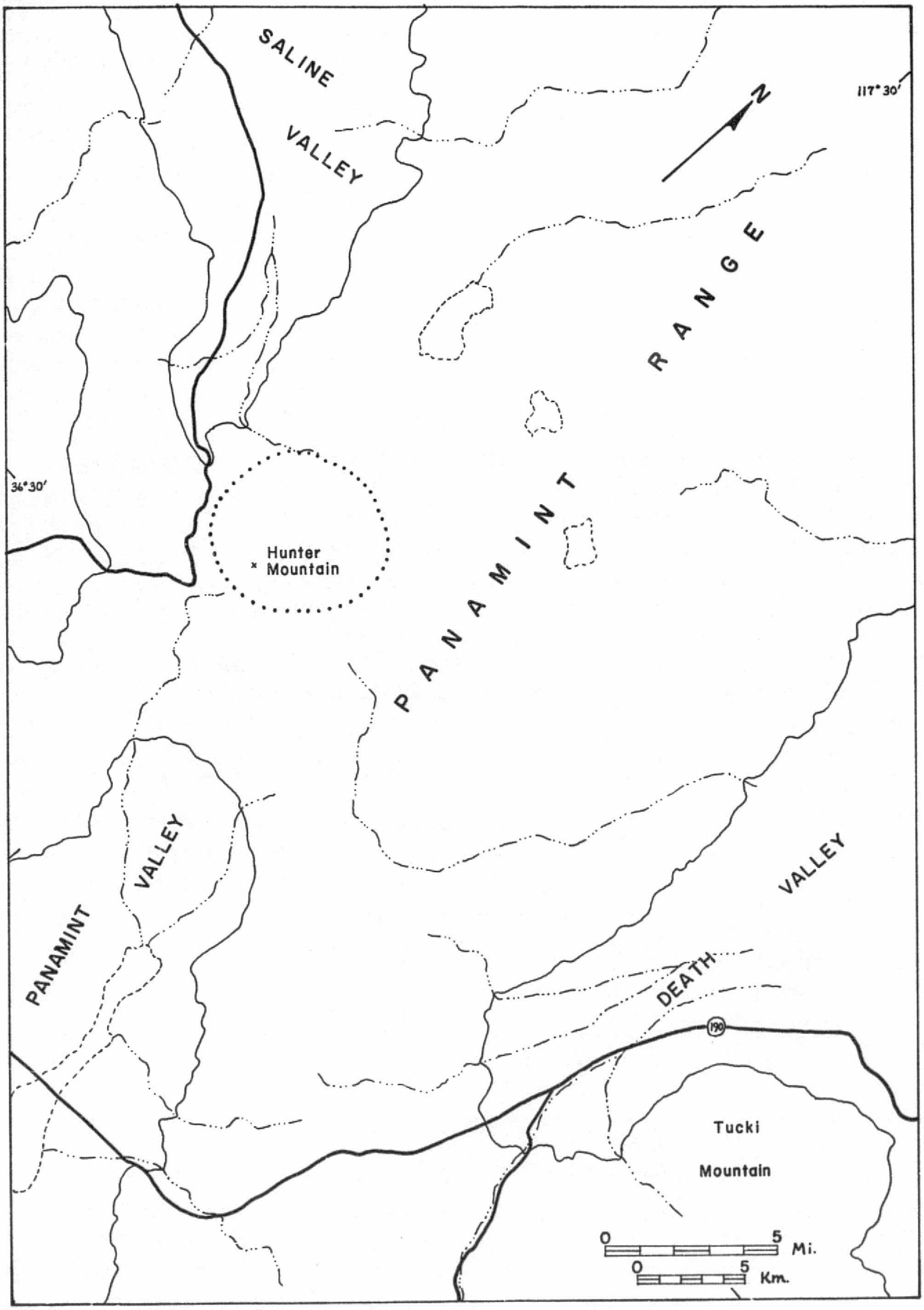

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C. Argus Range

Identification of Geologic Features

Banded Paleozoic rocks are readily discernible in the Argus Range west of Panamint Valley (SL4-76-223). Alternating beds of dark and light limestone form a spectacular outcrop pattern which apparently curves northwestward across the mountains. Image linears in the Argus Range appear directly related to mineralization in the north end of the range. Linears strike north-south in the central range, but to the north, they curve northwestward paralleling the Darwin Tear fault and related fault zones which are mapped in the nearby Darwin mining district to the west. Less prominent northeast-trending linears occur in the northern area and generally parallel linears in the Darwin area, which evidently are responsible for control of ore deposits in the district (Hall and Mackevett, 1958).

Prominent white reflecting zones visible in imagery occur amidst the intersecting lineations and probably represent thermal metamorphism of limestones by the abundant granitic intrusions in the area. As much of this area is mapped as Paleozoic sedimentary rocks with masses of granitic rocks, the north and northwest-trending structures observed are probably bedding. The northeast-trending lineations, however, appear less distinct and almost discontinuous across the range; they are perhaps pre-intrusive fractures or may be related to the intrusive process. The white areas, then, may represent areas altered and mineralized, especially where the small faults or fractures carried solutions into the most favorable beds. Alteration appears to crop out furthest north in the Modoc mining district where little detailed geologic mapping has been done and the geology is undoubtedly complex. Presumably, the rocks here are highly altered and silicified Paleozoics, and it is supposed the area may have undergone intrusion associated with ore emplacement contemporaneous with that in the Darwin district. Mapped mines appear to lie on or near linears in close proximity to the white zones, most of which appear elongated striking N60W.

The Modoc district produced lead and silver as well as some gold, but mines and prospects have long been idle (Clark, 1970). Zinc also has been produced. Similar deposits may be present to the north in the Paleozoic rocks where they are intruded by stocks of the widespread granitic rocks. A small region to the northwest near Darwin Canyon appears bright red, similar to the Darwin mining district and although lacking white alteration, it exhibits the same linear trends. This area may well prove to contain much of the mineralization present in the Darwin district.

The eastern Argus Range is bounded and dissected by numerous linears, many of which are mapped or supposed faults. The Ash Hill fault, in particular, is easily visible, offsetting alluvium in fans on the west flank of Panamint Valley (Fig. 3). This north-south striking fault is mapped (Hall, 1971), but an apparently unmapped fault (A) offsetting it is visible extending westward through the Argus Range north of Shepherd Canyon.

By study of the alluvial fans in Skylab images, the relative movement can be ascertained on the Ash Hill fault. The alluvial fans west (the Argus Range side) of the fault appear ordinary,

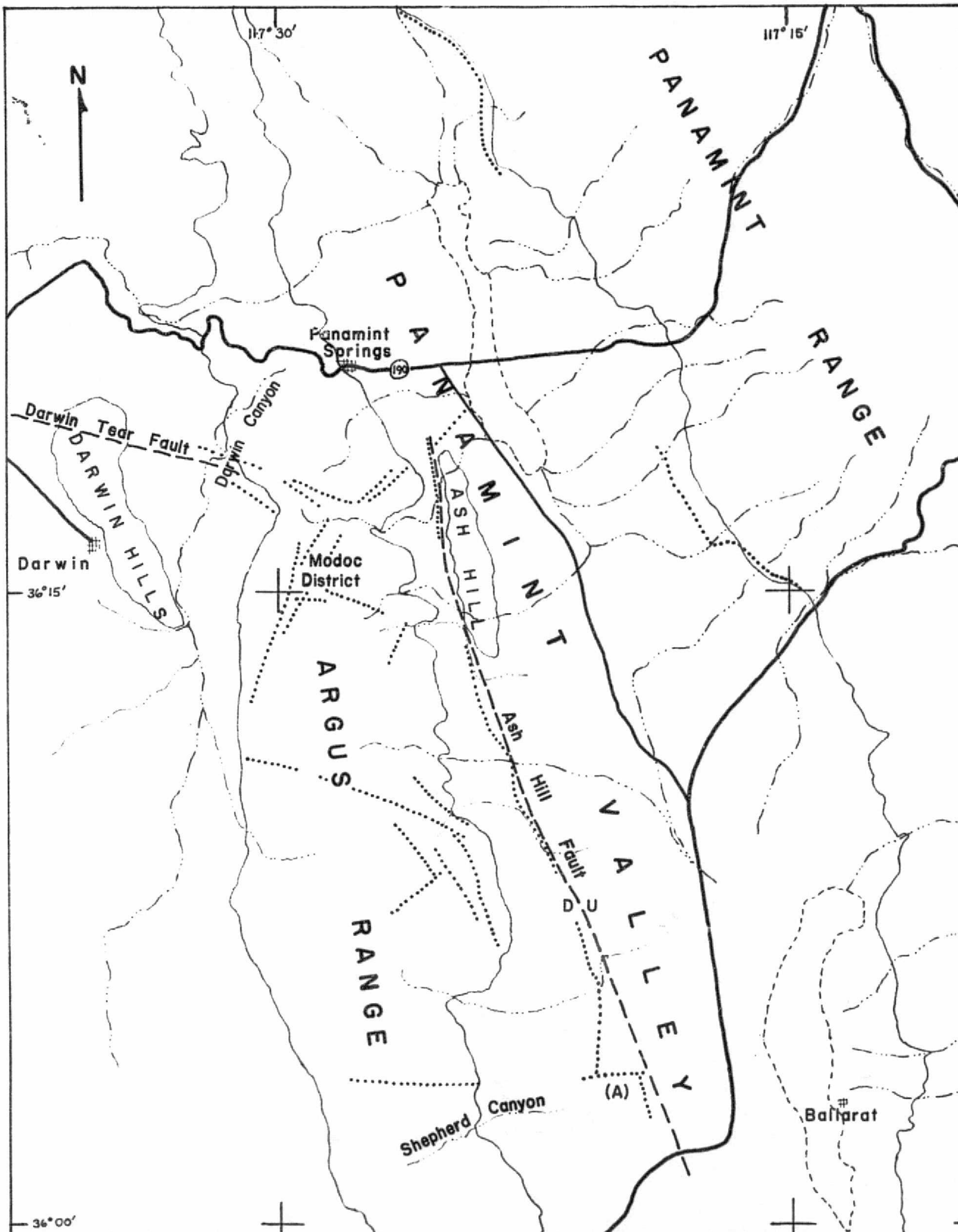

Fig. 3 Location Map of the Argus Range Region, Calif.
Scale: 1:250,000

- Image Linears
- Mapped Faults
- Bedrock Outcrops

5 0 5 Miles
5 0 5 Kilometers

CALIF.

currently-depositing stream channels, but as the drainage has reached the fault, it has been diverted either north or south. A few areas show where the drainage has broken the barrier and cut across the fault trace. In most places, however, the fan deposits east of the fault (Panamint Valley side) look much darker brown and are dissected by stream channels apparently caused by flooding over the fault scarp. The dark appearance of the alluvial material is probably due to "desert varnish," formation of an iron oxide rind that is typically found on desert rocks long exposed to the harsh climate. This seems to provide a reliable method of determining relative ages of Quaternary slope and basin sediments. By the reasoning given above, the east side of the fault has been elevated relative to the west. This movement would contradict the usual fault displacement by extension characteristic of this western edge of the Basin and Range province, but field evidence indicates the Ash Hill fault has moved with the mountain side down "200 feet relative to the east side since the late Pliocene" (Hall, 1971, p. 59). Similar image analysis of the eastern slopes of Panamint Valley indicate that again the valley side has been relatively uplifted.

Determination of relative dip-slip movement of this kind can be readily made throughout the region based on alluvial deposit outcrops, drainage patterns, surficial colorations, and occurrences of vegetation when present.

The apparent cross fault north of Shepherd Canyon (A, Fig. 3) is identified mainly by the very linear appearance of the canyon and also by offset of the Ash Hill fault at the surface; the north side is displaced to the west. Projection of the lineament across the Panamint Valley into deep canyons which dissect the Panamint Range near Ballarat provides further evidence it may be a strike-slip fault with small east-west movement. This may represent part of an ancient fracture system developed in the basement rock which has continued to be active through the present.

D. Saline Valley Region
Manifestations of Late Tertiary Volcanism

Image study of the region surrounding Saline Valley in the northern Panamint Mountains west of Death Valley has indicated areas of potential geothermal activity. A graben (Saline Valley), apparently having undergone extensive Tertiary faulting, occurs adjacent to extensive basalt flows. In addition are prominent white areas amidst the alluvium in the center of the valley floor. The lowermost of these have been identified as Palm Spring and the uppermost Warm Spring (Fig. 4). Active springs can be discerned on S190B image SL4-94-012 where the minerals of the springs have been deposited at the surface of the darker alluvial fans. These springs are located where an apparently recently faulted valley joins Saline Valley (in the vicinity of Palm Spring) on its northeast edge (Fig. 4). Similar white areas above, but on the side of the alluvial washes, correspond to "calcareous deposits forming a distinct white weathering ledge" associated with the warm springs near Quaternary lake deposits, as described and mapped by Burchfiel (1969, p. 12). Also further up the valley

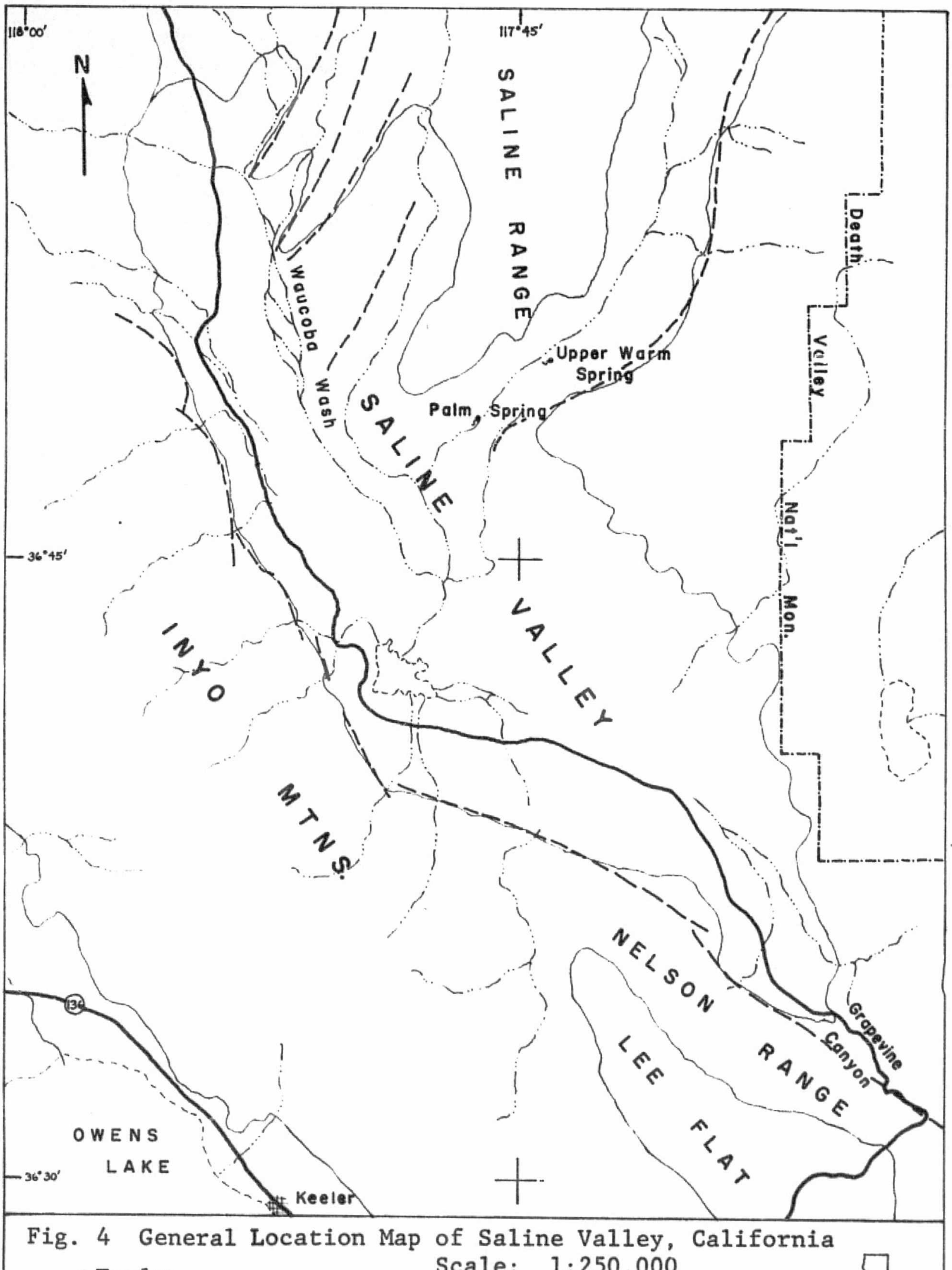

Fig. 4 General Location Map of Saline Valley, California
Scale: 1:250,000

Faults
Bedrock Outcrops
Intermittent Streams

5 0 5 Miles
5 0 5 Kilometers

are less distinct white regions which correlate with mapped pyroclastic and volcanic rocks of late Tertiary age. Although the outcrops are all grouped together by Burchfiel, differentiation can be made by image study indicating that the majority are probably tuff (based on weathering and dull color) and that one body is a siliceous, probably more resistant, rhyolite exhibiting bright white reflectance.

Geologic structure is well represented in the image, showing an abundance of strong northeasterly-trending faults. According to Burchfiel's map, these seem to define boundaries of small horst and graben blocks.

The northern Saline Range east of Saline Valley appears to exhibit anomalous fault trends relative to the surrounding region. The usual north and northwesterly trends defined by the Owens Valley, Panamint Valley-Saline Valley, and Death Valley fault systems are transected at about 60° by the dip-slip motion evident east of Saline Valley. Tensional forces have apparently arisen, perhaps by some strike-slip component on the Furnace Creek fault zone. Evidence includes the apparent right-lateral movement on the Grapevine Canyon fault (with southeasterly trend) bounding the south end of Saline Valley, and apparently causing thrusting of the Hunter Mountain block over the north end of Panamint Valley (Smith, 1975). Whatever the cause, the consequence has been extensional rifting accompanied by eruption of basaltic centers, notably those giving rise to the extensive Saline Range basalt flows and the Ubehebe Crater area, near major fault intersections.

A large, discolored portion of the basalt flows in the Saline Range (just north of upper edge of Figure 4) appears almost circular in outline and may represent older basalt. Also within the body are small patches of white sediments, presumed to be clays in small basins formed from alteration and decomposition of the basalts probably dominantly by meteoric waters; darker surrounding basalts exhibit none of these white bowls but display flow lines and recent fault scarps. The lighter, brownish appearing basalt, then, is thought to be older, having been longer-exposed to weathering. The freshest basalt appears to be that nearest Saline Valley, as well as small masses in the tributary valley along the northwest flank; other fresh basalt crops out to the southeast along the valley's edge. Active volcanism, therefore, seems to be temporally shifting towards the southeast, and in effect, extension appears to proceed in the same direction, leaving the north and east area successively fractured and plugged with basalt.

Notable in the image is a linear trend of vegetation crossing Saline Valley where the tributary valley joins. The plant life seems to occur where the gradient of washes decreases approaching the low point in the basin and where alluvial fans enter from the sides of the valley, but it also appears that their occurrence may be due partly to water conduction along a possible extension of the faults which intersect the springs. In effect, then, the vegetation may reflect a continuation of geothermal waters conducted along the northeasterly-striking rift.

The combined occurrence of a large mass of relatively fresh-appearing black basalt flow, excessive extensional faulting closely associated with the volcanism, adjacent outcrops of fine lacustrine clays as well as the close proximity of the Saline Valley evaporite basin, and the known occurrence of small amounts of borates, suggests the possibility of a substantial borate deposit buried by alluvium or basalt. At the north end of Saline Valley, the main tributary, Waucoba Wash, has obviously been covered and offset by a sheet of basalt, as the stream has been forced to a slightly higher elevation where it cuts across old alluvial fans. If any of the basalts had been extruded when water was plentiful in the basin, emanating gases including boron nitride would be retained and precipitated as salts upon reaction with the evaporating saline water. Favorable fine-grained sediments beneath the playa surface would trap not only the primary borates, but also later accumulating compounds transported in solution, readily creating enriched strata sufficient for economic extraction.

E. Lava Mountains

Evidence of a Potential Geothermal Resource

The Lava Mountains, located about 8km northeast of Johannesburg, California, appear in Skylab Ektachrome imagery as brightly-colored hills indicating various phases of volcanic activity. Black outcrops of smoothly weathered basalt flows are extensive and overlie varicolored rocks of reds, browns, and pale blues, identified as andesites. At the southwestern end of the range near Red Mountain and only 3km east of the Trona road, occurs a white to light gray zone nearly 5km long, surrounded by a blue zone about ½km wide (Plate II, p. 42). Red volcanic rocks generally occur outside of this area. The zone is irregular in outline, covered by alluvial washes in places, and elongated in a northeasterly-southwesterly direction. Contained within it are four small, sharply-peaked ridges which trend in the same direction. Much of the higher ridge crests appear brightest white, probably indicating resistant siliceous rock. Image linears are found trending in two major directions: northwest and northeast. The most siliceous-appearing zones crop out in the southwest part of the light-colored area. As the rock types appear similar and seem to be continuous, the supposition is that the light zone indicates siliceous alteration of andesites.

Three vaguely arcuate areas appear on Skylab S190B (SL4-92-347) imagery in the southeastern part of the Lava Mountains about 1½km east of the main white altered region. The structures seem to partly follow the topography of the hills, their edges usually corresponding to washes. The rock types appear similar (probably andesite) to those cropping out in the west, apparently altered in areas. A white zone again corresponds with relatively high relief, probably indicating silicification. Blue coloration seems closely related to the arcuate regions, likely produced as the surface expression of alteration by thermal waters.

The Trona sheet of the geologic map of California indicates the entire area between Klinker Mountain and Red Mountain consists of intrusive andesite flanked by extrusive andesite of Pliocene age. From image analysis, the area appears to contain brown-colored andesites compositionally zoned and altered due to a probable hydrothermal source, the white ridges representing fractures now filled by siliceous deposition from solution.

One published source (Anderson and Hall, 1973) indicates that the area was drilled in the 1920's in search of ore minerals, presumably associated with the rich Randsburg mining district deposits. Holes drilled were found hot at depth and although some were dry, one drill hole found hot rock and steam at 120m (400 feet) depth in the southwesternmost Lava Mountains, with temperature and pressure increasing with increasing depth. It was planned that this steam would be utilized for power generation but no further attempt at development was made. A series of claims (Sackawanga) were made just east of the previously drilled wells, apparently near a more plentiful water supply. These correspond precisely with the area defined as containing the three arcuate anomalies and small, altered-appearing outcrops, perhaps underlain by centers of hydrothermal activity.

Following imagery study of the area and plotting of zones identified as probably exhibiting highest geothermal potential, the observed data was compared with the detailed report on the Lava Mountains by G. I. Smith (1964). He mapped the area at a scale of 1:24,000, and comparison with Skylab-derived geology shows a remarkably close agreement between the plotted white area from imagery with the zone identified by Smith as hydrothermally altered andesite (propylite). Furthermore, the bluish zone found corresponds with his zone of "subpropylite" he refers to as "a boundary in the intensity of hydrothermal alteration" (Smith, 1964, p. 24). He also indicates the propylites are characterized by light coloration of gray, blue and green and the subpropylites vary in coloration from gray through purple and reddish purple. This same general sequence is that observed in Skylab imagery, the reddish colors forming the outermost zone of alteration. The color anomalies identified, then, represent a large hydrothermal system, with color zonation representing relative intensities of alteration.

The southern Lava Mountains region, studied only briefly in Skylab imagery, deserves serious detailed study as a potential power-producing geothermal resource location. A brief reconnaissance field excursion made in May, 1975, revealed substantial amounts of siliceous, hydrothermally altered rock judged as favorable in location for development in the southwestern end of the range. Successful evaluation of a hydrothermally altered zone from this study implies significant value for Skylab image analysis in detecting geothermal systems in other less well-known areas. The extensive siliceous alteration of volcanic rocks and past determinations of substantial heat and steam indicate an area of about 15 square kilometers is still thermally active and potentially exploitable.

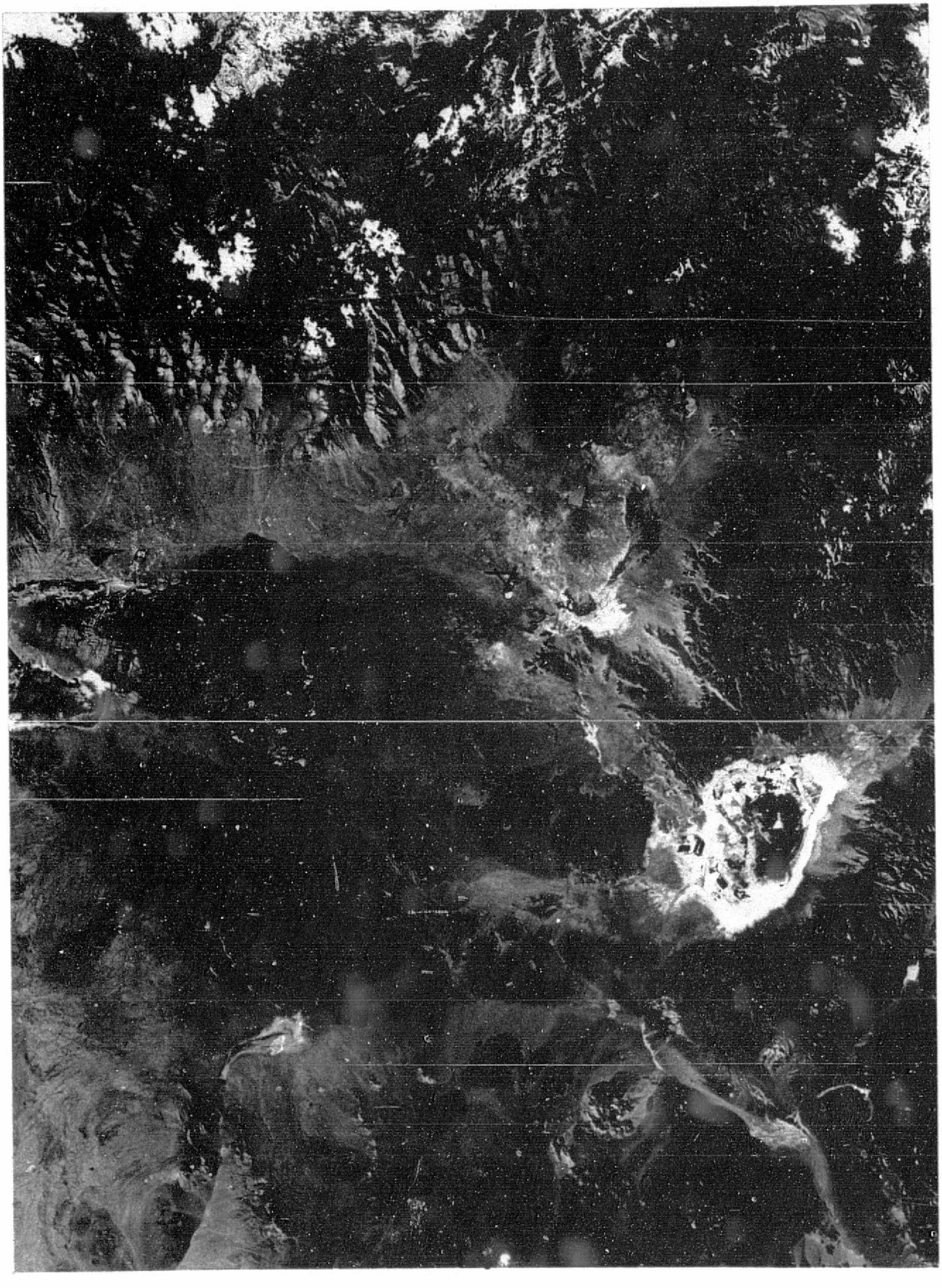

PLATE II   Skylab S190A   SL4-76-078
Approximate Scale 1:500,000

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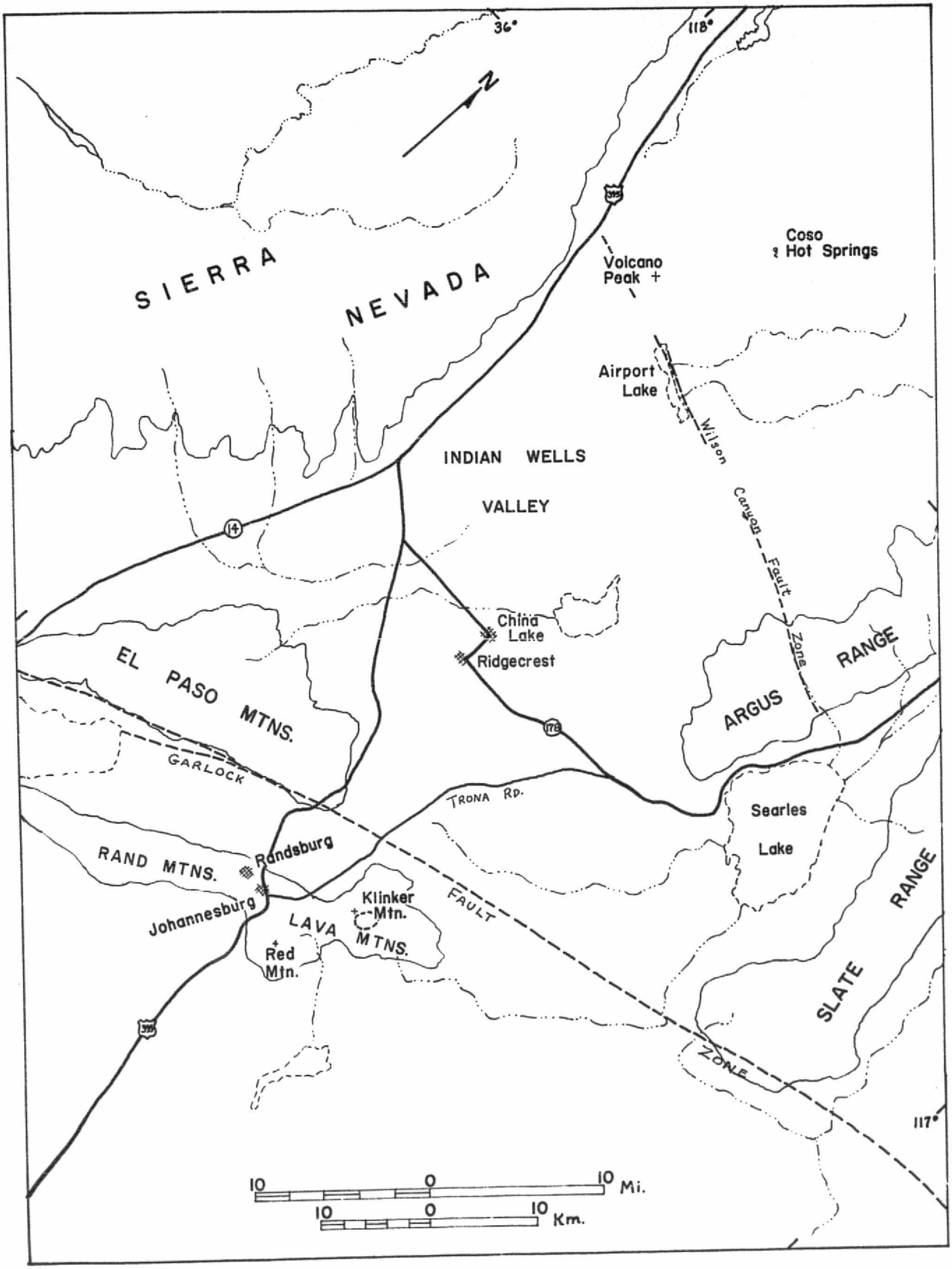

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F. Coso Geothermal Area

Imagery Analysis of Volcanic Terrane and Geothermal Region

Space imagery analysis of the Coso geothermal area, California, was undertaken to define geologic parameters of a KGRA that are detectable in imagery obtained from orbiting sensor platforms. Much conventional geologic work has been done in the area, including detailed ground and airborne geophysics, K-Ar age dating, and aerial photography. Therefore, sufficient ground truth existed to evaluate space imagery analysis results. Imagery used in the study included Skylab handheld (SL3-121-2337), S190A (SL4-76-078, see Plate II, p. 42), ERTS (many cycles), and Apollo (AS9-20-3134). The ERTS proved very useful for near-regional linear and arcuate studies, and the S190A was best for detailed analysis of the Coso hot springs area. Unfortunately, no S190B was available.

The Coso area lies on the extreme western boundary of the Basin and Range physiographic province, adjacent to the granitic Sierra Nevada massif (Fig. 5), approximately 25km south of Owens Lake. The area containing geothermal activity is underlain by a Mesozoic coarse-grained granite with inclusions of diorite and gabbro as dike-like intrusions. The granite is deeply weathered and overlain by alluvial fans and beds of volcanic breccia. Above the breccia is a basalt flow and a few cinder cones, rhyolite flows, and perlitic domes. Volcanism is as recent as Holocene (Lanphere and others, 1975). Extensional-type faulting, characteristic of the Basin and Range, forms step-faulted basaltic terrane in the eastern part of the Coso area. The left-lateral Wilson Canyon fault cuts across the area to the south, the west

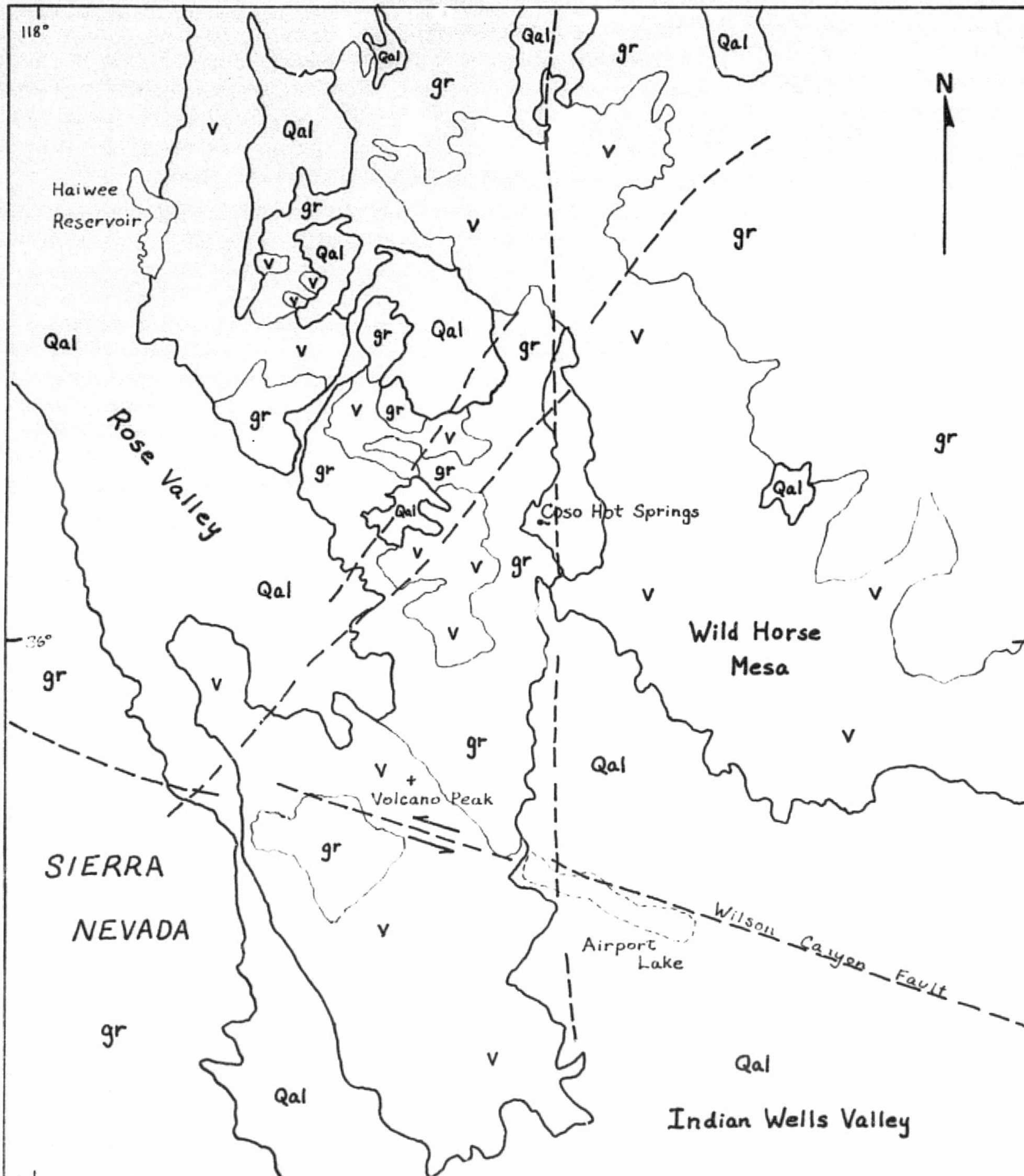


Fig. 5 Geologic Sketch Map of the Coso Hot Springs Area

Legend

Qal Quaternary Alluvium

v Volcanic Rocks

gr Granitic Rocks

Major Image-Linears

Scale: 1:250,000

5 0 5 Miles

5 0 5 Kilometers

is bounded by the Sierra Nevada front fault, and the northern edge is defined by the Darwin tear fault. Minor faults mapped in the geothermal area strike north-northeast or northeast. Sense of movement on the minor faults is dip-slip; displacement is probably only a few meters (Duffield, 1975). Many of the volcanic domes and hot springs within the Coso area are concentrated along these faults.

The principal source of heat in the Coso KGRA is a granitic intrusion of batholithic proportions, which has manifested itself at ground surface as perlitic domes, lava flows, ash deposits, and fluid leakage (Austin and others, 1971). In Plate II, the hot springs and volcanic centers that characterize the geothermal activity are located to the north of the dark basalt mass (Volcano Peak) in the center of the valley.

Imagery analysis resulted in the identification of three types of features that can be related to geothermal activity in the area -- linears, arcuates, and coloration anomalies.

Linears observed in ERTS and Skylab imagery were diverse in orientation and variable in length. Careful analysis of the plotted linears resulted in the resolution of the complex patterns into four moderately well-defined trends: northwest, north-northwest to north-south, east-west, and north-northeast. The northwest trend is exemplified by the Wilson Canyon and Darwin fault systems, but no other faults of this strike have been mapped in the Coso KGRA. The significance of this set of linears to the geothermal activity is unknown, but Austin (1971) and others report the Wilson Canyon fault is the southern boundary of the geothermal activity (Fig. 5). This fault is a very large structure, extending from Searles Lake on the east across Indian Wells Valley and Volcano Peak into the Sierras at least 12km. Many basalt cones and the Airport Lake playa are aligned along the fault. Other imagery-linears parallel this fault in Indian Wells Valley and the Volcano Peak basalt flows. Some evidence can be discerned from reconnaissance-scale aeromagnetic maps to indicate the presence of the Wilson Canyon and adjacent faults. The evidence is a northwesterly-elongate border of a closed aeromagnetic-low anomaly which corresponds, in part, to the Coso area.

Many linears striking northwest are defined in the imagery as ridges, frequently connecting rhyolite domes. If the northwest-striking faults are genetically related to geothermal activity, the fault extensions beyond the KGRA boundaries suggest areas of additional potential geothermal resources.

Linears striking north-northwest to north-south are most abundant in the area of the Coso perlite domes which appear to be aligned on the linears. Thus, these linears may represent a series of fractures that acted as conduits for hydrothermal fluids. Most of these linears terminate near the Wilson Canyon fault, enforcing the ideas of Austin and others that a boundary to the geothermal activity exists.

One long-length linear (40km), striking due north, originates south of the Airport Lake playa, which abuts against the linear. The linear traverses volcanics and granites and apparently ends near Upper Centennial Flat. Several valleys and fumaroles are aligned along its length. The linear corresponds to several short, discontinuous, normal faults. Other linears of this set noted in the imagery are the step faults in the basalt flows near Wild Horse Mesa.

East-west striking linears are the least common. The most obvious one controls a stream channel near Cactus Peak. The linear extends from the step-faulted basalts to just west of the peak.

The north-northeast linears are most apparent in granitic terrane and may represent a direction of jointing. However, several linears of this strike appear in the imagery to offset linears of other strikes, indicating the north-northeast set are faults with a strike-slip component of movement.

A substantial number of arcuates that range in diameter from one to 25km were identified in the space imagery. Most were evidenced by topographic or structural features, but some were noted as anomalous arcuate coloration zones.

Several large arcuate features that are discernible, particularly in ERTS imagery, probably represent surface expression of heat-source batholith, such as arcuate fractures and faults, collapse features, or alteration zones. Smaller arcuates evident are stocks from the batholith and may be directly responsible for the numerous hot springs and other manifestations of geothermal activity in the area.

Many of the volcanic centers, especially the rhyolite-perlite cones, are contained within smaller arcuate features. In Plate II, arcuates can be observed as light-colored curvilinear ridges, anomalous red colorations in black basalts, circular colorations in alluvium, and circular outcrop patterns. The brightest white areas seen near the volcanic domes are located on the edges of arcuates along linears, and represent fumarole activity or leaching of the rocks by hydrothermal fluids.

Duffield (1975) reports that ring faults observed in the field define an oval encompassing the Coso area. The oval extends from the basalt terrane on the east into the Sierra Nevada on the west, and to just below the Wilson Canyon fault in the south. No obvious evidence of this oval anomaly was noted in space imagery, but many imagery-linears observed correspond approximately to the edges of the oval. Furthermore, nearly all arcuates are located within this oval. Duffield theorizes the Coso ring anomaly represents a subsidence structure, originating from the collapse of an underlying magma chamber.

Coloration anomalies in the Coso area are generally light-colored and visible in the volcanic and granitic rocks. Many correspond to areas of known surface geothermal activity, such as that at Devil's Kitchen. These anomalies are located in granitic terrane, where no obvious manifestations of geothermal activity exist. The anomalies may represent discolored, mineralized, hydrothermally altered zones in the granitics caused by concealed or buried hydrothermal activity where the heated fluids did not rise to the present surface. Many anomalies of this type are in the granitics adjacent to volcanic domes, but several are to the east, beyond the limits of the geothermal activity, suggesting areas that may indicate extensions of the resource. Detailed ground magnetics over the area of the altered-appearing rocks could confirm the nature of the anomalies.

An evaluation of the results of the space imagery analyses indicates that many features observed in ground reconnaissance and interpreted to be related to geothermal activity can be identified from space. Furthermore, known fault structures can be extended and new faults identified in the imagery. Relationships between faults, fractures, and known surface geothermal activity can be established. Arcuate features, whether volcanic domes, stocks from batholiths, or subsidence phenomena, can be located, and significance to potential geothermal resources ascertained.

A comparison of the analysis of the available S190A scene over Coso with an analysis of a conventional-altitude photomosaic by Austin and others (1971) indicates high-resolution space photography is superior for geothermal exploration. Many more linears determined to be geologic in origin and related to the structure of the Coso KGRA were identified in the S190A than were plotted on the photomosaic by Austin. Furthermore, color anomalies noted in the S190A Ektachrome could not be detected on the black and white mosaic. Since many color anomalies represent hydrothermally altered rocks, their identification is valuable to geothermal exploration. Other advantages of the space imagery -- synoptic view, elimination of cultural detail, etc. -- have been enumerated by many other workers and need not be listed here.

In summary, many features of the Coso KGRA are detectable from space imagery. Most of these features are geologic in origin, and can be related to the geologic structure responsible for the geothermal activity. Many characteristics of Coso can be effectively utilized in exploring for other geothermal resources.

G. Southern Sierra Nevada

Image Analysis of Structural Features

Various major lineaments conspicuous in satellite images are observed to cut the Sierra Nevada granitic block; cursory examination of Skylab images SL4-92-345 and SL4-76-077 reveals most of these have not been mapped or previously recognized as significant features.

The most remarkably plain feature is the Kern Canyon fault, appearing as a long north-trending fault. From the view afforded by ERTS, the fault appears to extend as far north as the South Fork of the Kings River near Kearsarge Pass. The latter river valley has a relief of thousands of feet, as does the Kern River Canyon, and trends almost due east-west, thereby appearing to be fault-controlled. The Kern Canyon fault strikes almost directly north-south, bends slightly to the southeast above Lake Isabella, and continues southward where it gradually dissipates (Fig. 6). Numerous sub-parallel lineations, apparently emanating from the Lake Isabella region, are probably responsible for the disappearance of the main fault trace. The total length of the major fracture as viewed from satellite exceeds 150km. The proposed northern extension of the fault as well as the linear Kings River Canyon have not been mapped as faults, but the probability has

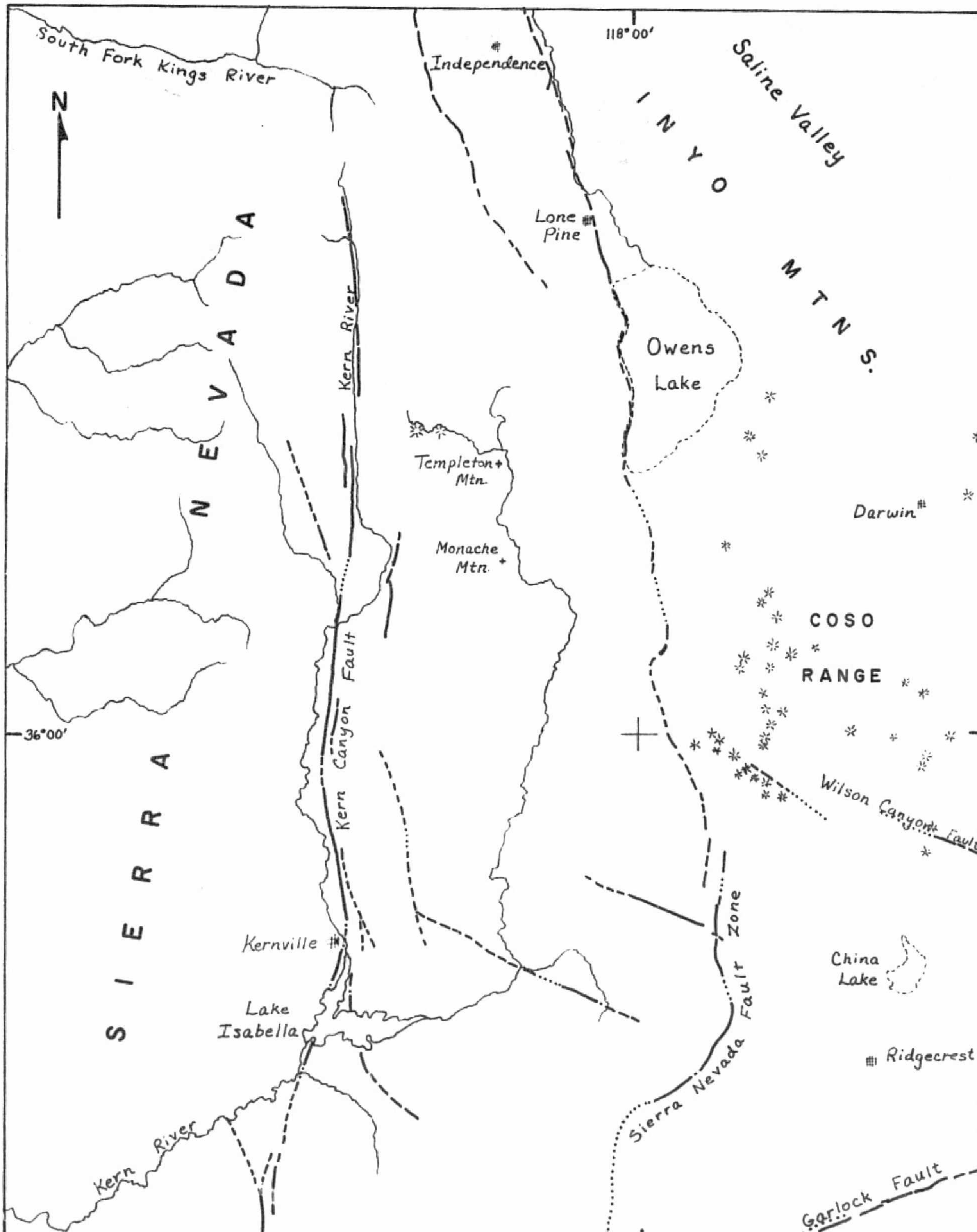


Fig. 6 General Location Map of the Southern Sierra Nevada

Faults, Approximate

Volcanic Cones

Scale: 1:750,000

10 0 10 Miles

10 0 10 Kilometers

important implications for the structural evaluation of the range and the adjacent Basin-Range province boundary.

A few linear features transverse to the trend of Kern Canyon are evident in imagery, including a possible extension of the Wilson Canyon fault penetrating the granitic block west of Coso Volcanic Field (see Plate II, p. 42). The fault has been mapped across Owens Valley and through the Argus Range, and apparently terminates at Searles Lake to the east, but has not previously been recognized as crossing the Sierra Nevada fault zone.

A fracture zone exhibiting a curious radial pattern occurs about 25km northeast of Lake Isabella. Prominent fractures lie perpendicular to the outward-trending lineaments, forming a circular pattern in the center, creating a web-like symmetry. The feature appears to have formed as the result of an intense stress exerted at a point source.

A circular feature observed to the northeast on the South Fork of Kern River, 25km northeast of Kernville, is snow-enhanced on one Skylab S190B scene and appears as a topographic depression; its interior exhibits striations trending northeast, and a series of ridges appear sheared in a different northeast trend (partly visible at far edge of Plate II, west of Coso Volcanic Field). This may be a weathered pluton carrying a sheared core of more resistant rock. The significance of these structures is not yet understood, but further study may provide enlightenment of the tectonic stresses within the Sierra block.

Monache Mountain and Templeton Mountain are prominent circular peaks apparent in all images over the southern Sierra. They are mapped as Tertiary volcanic cones and appear in imagery to be closely related to swarms of long, directly north-south trending lineaments. Other major linear features strike northeast and east-west. The weak zones represented by these lineaments presumably gave rise to the conduction of volcanic material contemporaneously with western Basin-Range volcanism.

Numerous hot springs are known to occur along the Kern Canyon fault zone from Kernville to 20km southwest of Lake Isabella. Two hot springs occur near the volcanic centers on the South Fork of the Kern River. All of these springs yield temperatures generally of about 100°F.

Relatively few significant mineral deposits are mined in the southern Sierra; barite and tungsten ore deposits occur in the area studied, mainly within metamorphic rocks near igneous intrusions. Although composed predominantly of granitic rocks, the mountains may have potential of further mineral occurrences. In much of the remote and rugged terrain and those areas which exhibit poor rock outcrops at ground level, imagery analysis can be a valuable aid in determining rock types, possible structural controls of mineralization (such as faults, fractures, joints, and cleavages), and outlines of intrusive bodies. Skylab views of the central Sierra have revealed extremely well-defined arcuate margins of plutons and the intruded host rocks, and orientations of joints and faults, most of which are rarely mapped. Synoptic views from satellites are particularly applicable to locating features, especially on a large scale, which exhibit sparse or subtle expression in the field.

H. Borates in the Test Site

Skylab Investigation of Occurrences and Environments of Deposition of Borate Minerals

The late Tertiary borate-bearing lacustrine sediments in the Death Valley region exposed in the vicinity of Furnace Creek Wash and the surrounding basin are readily identifiable in Skylab imagery as brightly reflecting (frequently overexposed) outcrops (see Plate III, p. 60). The beds apparently have been faulted, tilted, and folded considerably between the Death Valley and Furnace Creek fault zones where exposed southwest of the wash. The sedimentary beds form a large fold, probably a syncline, as strata are visible in cross-section to the outside edges of the structure, while smoother terrain, presumably bedding planes, occur toward the interior. Outcrops appear through alluvial fan deposits to the north and east, and the brightest white zones correspond generally with the Furnace Creek Formation of siltstones and evaporites which are host to the borate deposits that apparently accumulated during periods of volcanism in and adjacent to the lake basins. Individual borate deposits cannot be discerned on S190A images, and the one S190B image (SL4-94-015) covering the area of the fine sediments is slightly overexposed. Nevertheless, it is significant that these bedded deposits are the only outcrops in the region that have such a bright appearance in the imagery, excepting present-day playa surfaces. The reason seems to be that it is one of the few areas where evaporite-playa deposits have been uplifted and re-exposed, and the extensive occurrence of borates in the sediments seems to at least partly cause the high reflectivity.

According to McAllister (1970), the main occurrences of borates in the Furnace Creek region occur in the Pliocene Furnace Creek Formation composed of siltstone, evaporites, and fine tuffaceous sediments with interbedded basalt flows, intrusions, and altered fragmental basalt. Limestone and gypsiferous mudstone occur as beds throughout the formation and some borates occur with them. The imagery-observed white beds correlate with the fine-grained, borate-bearing members of the Furnace Creek Formation.

Large white outcrops north and northeast of Furnace Creek Ranch are obvious in S190B Ektachrome imagery and correspond with the mapped member of the Furnace Creek Formation identified as containing major borate deposits. These lie in the East Coleman Hills which supplied ore to the well-known Harmony Borax Works. Conglomeratic members of the formation appear light brown and are not generally borate-bearing. The bright white beds, however, are generally confined to the members containing some borates. Image study can delineate different members of the formation due to the spectral response of borate and evaporite minerals. Borate minerals undoubtedly will not be found everywhere that these white beds occur; borates seem to require the conditions of saline deposition within lake sediments and the heat and boron from basaltic rock or associated gas-saturated solutions.

Numerous small white areas crop out below the basalt flows of the Greenwater Range southeast of Ryan. These seem to be similar to the white beds of the Furnace Creek Formation and may represent an extension of the same beds, although they are mostly buried by late Tertiary volcanic flows. The Lila C. Mine is one known deposit below these basalts that has been exploited. The recently faulted Greenwater Valley may host more borate beds in lake deposits once continuous with those of the Furnace Creek area. The volcanic rocks of this area might have been directly responsible for bringing in the boron which accumulated in the surrounding lake basins.

Other regions outside of Death Valley well known for borate production include the larger playa lake beds like the ones near Kramer, Shoshone, Searles Lake and Owens Lake, as well as uplifted and deformed Tertiary lake sediments in the Resting Spring Range, the Calico Mountains, and Callville Wash north of Lake Mead (see Fig. 7). The latter exposures seem generally scarce compared with high percentage, sodium borate-producing beds from present playas. Probably most production will come in the future from as yet unlocated buried playa deposits. Some areas that appear in imagery to contain similar environments favorable for borate occurrences are the Tertiary sediments cropping out west of the El Paso Mountains, possibly the basins of Saline Valley and its northeasterly extension, and southern Eureka Valley. Also potential areas for further investigation are the Amargosa River Valley northwest of Lathrop Wells, Nevada; Gold Flat-Paiute Mesa area, Nevada; Adobe Valley and other closed basins in the Mono Lake region; and Greenwater Mountain Range and Alkali Flat near Death Valley Junction. All these areas have in common a broad lacustrine depositional basin adjacent to young faulting and basaltic

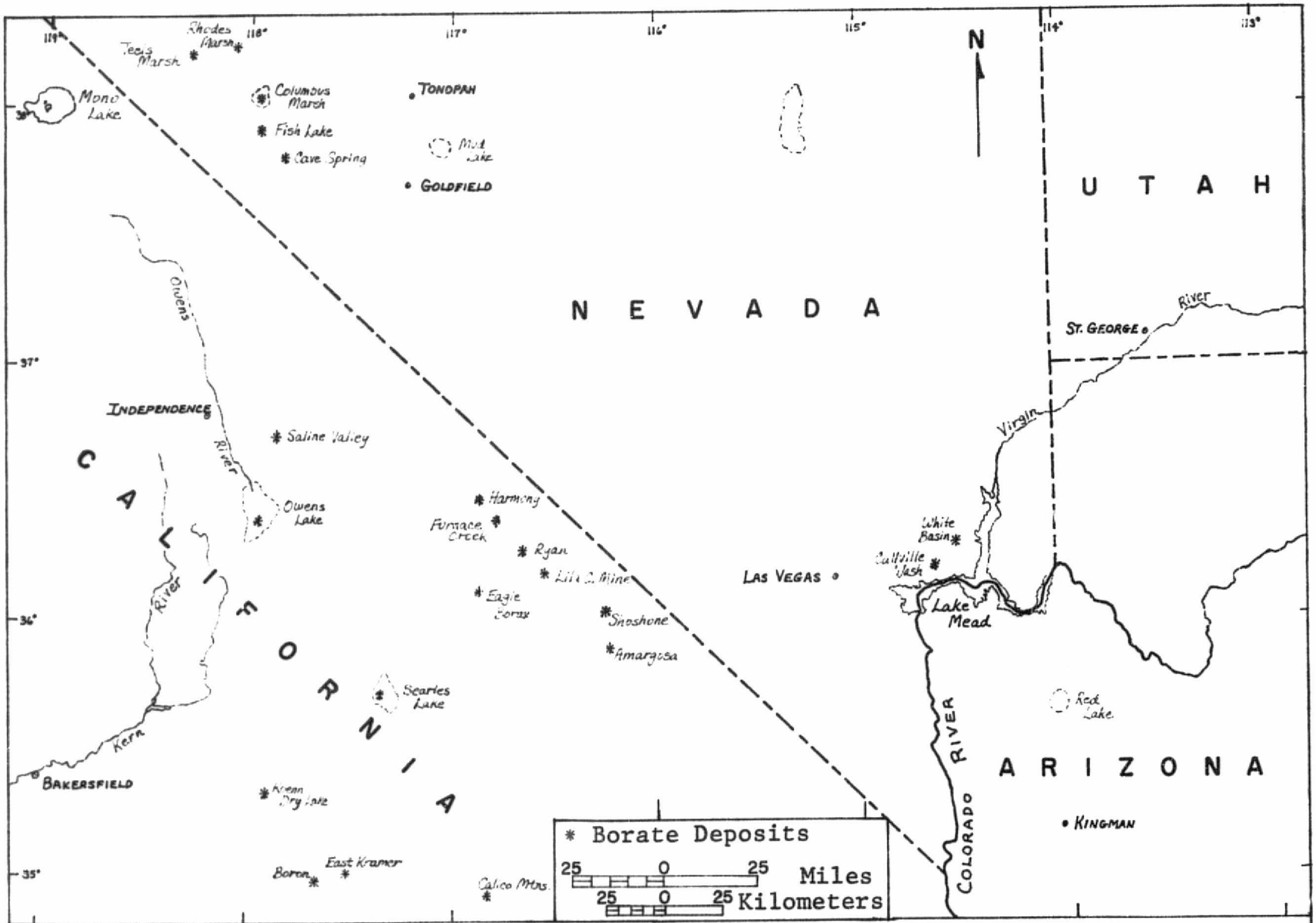


Fig. 7 Major Occurrences of Borates in the Test Site; Scale: 1:2,500,000

volcanism. Uplift and exposure of late Tertiary shale beds have been responsible for the ease of locating most of the presently known deposits of borates, with the notable exception of the Kramer borax and kernite beds. The latter occurrence is unique and was discovered accidentally by drilling for a water well. The potential of other borax deposits rivaling it in extent is still good in the relatively unexplored playa basins like those described above.

Deformation and volcanism apparently contemporaneous with closed-basin lacustrine sedimentation in the Death Valley area and in much of the Mojave Desert and Basin and Range provinces created ideal circumstances for precipitation of boron compounds, especially as calcium salts. Calcium borates (notably colemanite) occur abundantly as crusts, indicating evaporative deposition prior to the more soluble salts. Sodium borates precipitate only under more concentrated sodium solutions; thus, the depositional environment would be one of active fumaroles, springs, or basaltic extrusions directly into a highly concentrated saline lake. Theoretically, the same process may have taken place in the subsurface where basaltic material intrudes water-saturated saline clays. The presence of carbonate rocks surrounding basins provides the major source of large quantities of calcium which react with boron in solution, probably often as boric acid. With a lack of Paleozoic carbonates there may be greater likelihood of deposition of sodium borates, especially where occur large amounts of sodium-bearing basaltic or granitic rock. A relative lack of carbonates, but large quantities of granitics containing at least as much sodium as calcium exposed in the western Mojave Desert, may account for the occurrence of deposits of sodium-bearing borate minerals near Kramer.

Borate compounds, being easily dissolved, are usually released from rocks and carried by streams, eventually to ocean basins. The land-locked playa basins, however, are a physical trap for the borates and during evaporation are forced to precipitate as salts of the prevalent neighboring ions. The special physical and chemical circumstances required may have given rise to only a small number of such deposits, especially those containing sodium borates, but favorable locations should be studied carefully to discover any possibility of another large deposit.

Undoubtedly many deposits in Miocene to Pleistocene playas containing borate-rich strata exist throughout the arid and highly tectonically active southwest; those yet to be found will be mainly subsurface accumulations which usually show only subtle surface manifestations. Satellite image analysis provides many clues for locating borate deposits; the geologic environments of brightly reflecting, finely stratified sedimentary rocks adjacent to interbedded or intrusive basaltic volcanic rocks mainly in large closed basins are easily detectable in Skylab imagery. Reconnaissance study as well as detailed scrutiny of the surrounding geology is particularly necessary for identification of the late Tertiary history of the inland lake basins and for further understanding of the accumulation of borates and related economically extractable evaporite minerals.

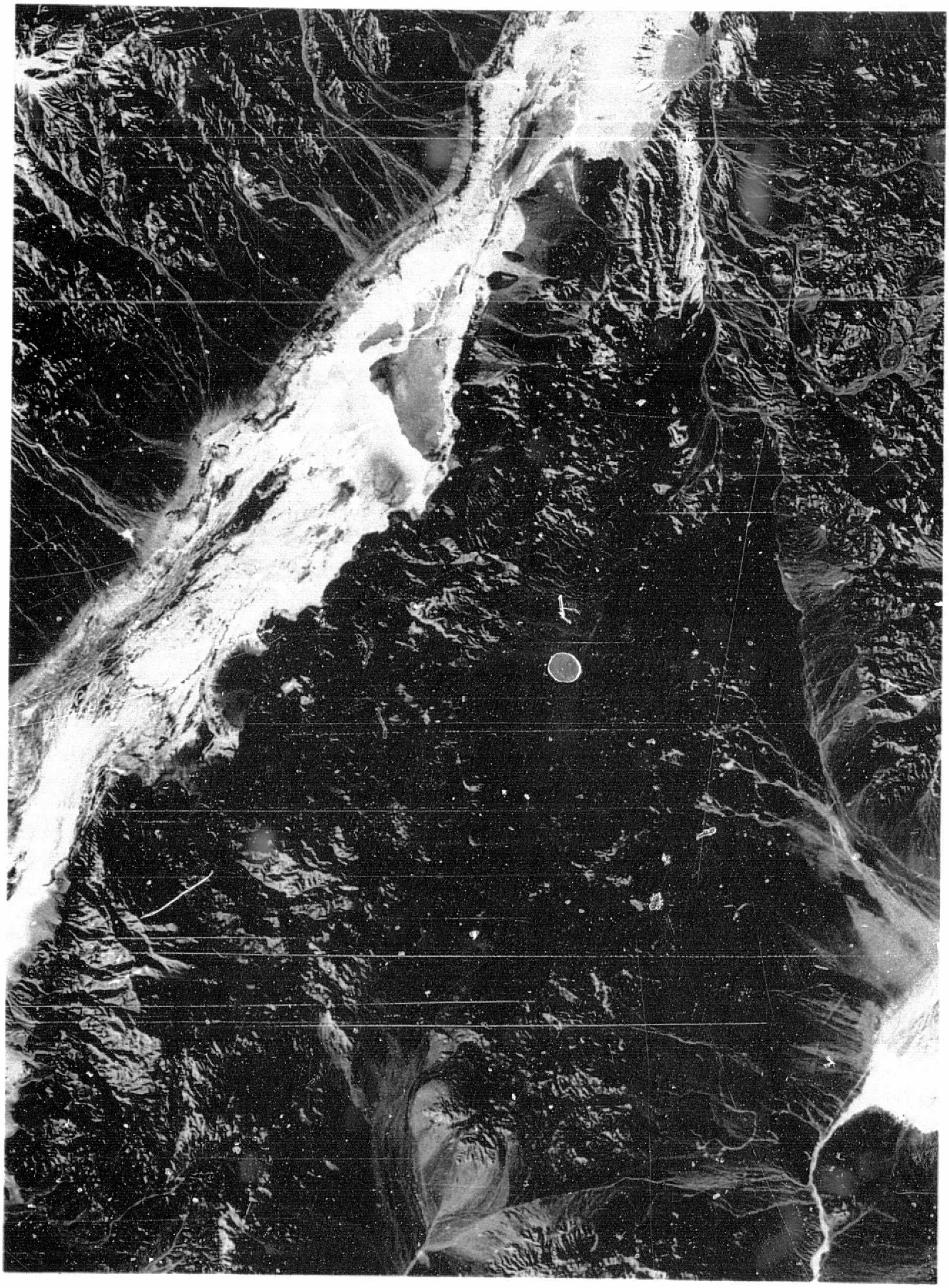
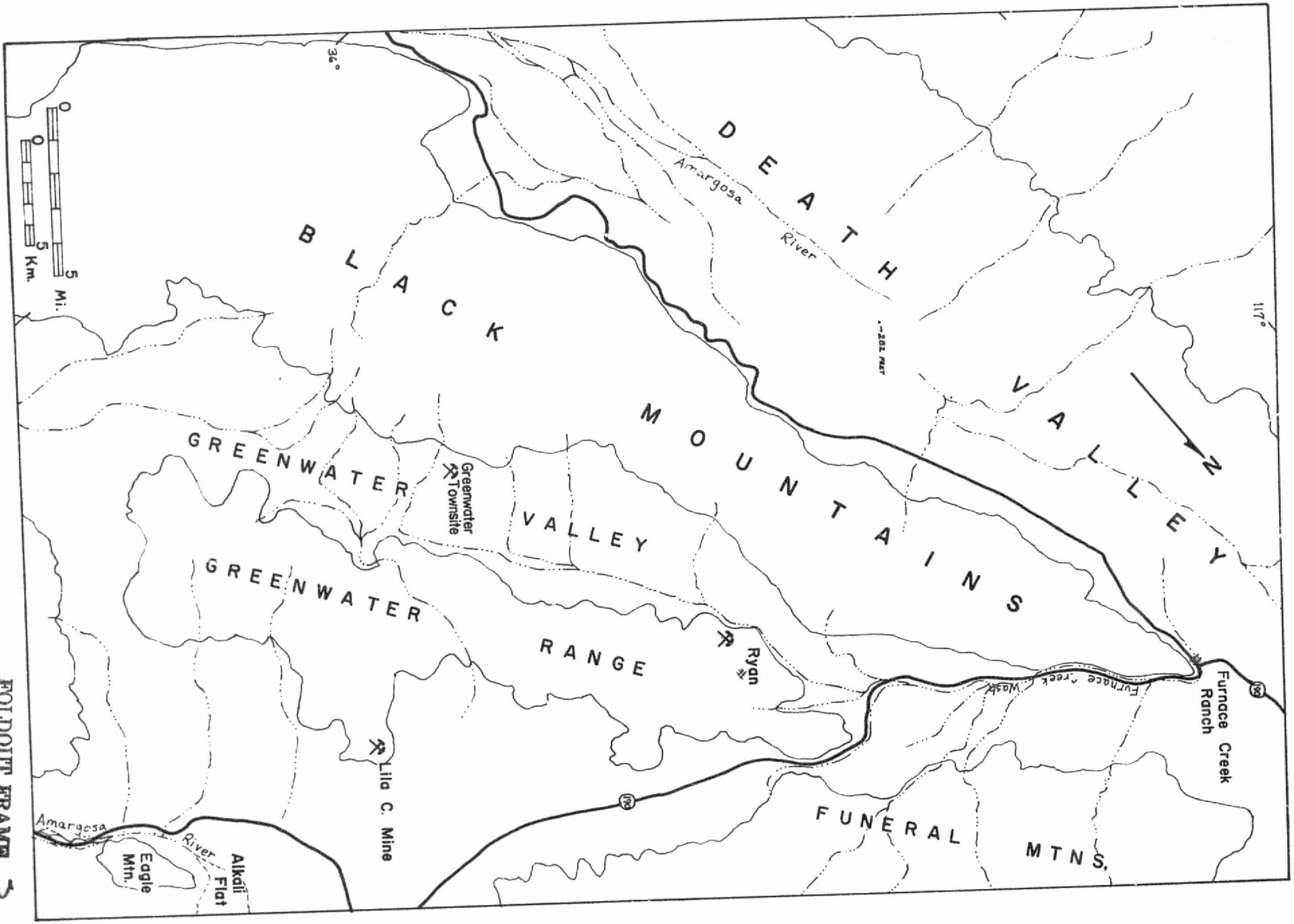


PLATE III Skylab S190B SL4-94-015
Approximate Scale 1:250,000

FOLDOUT FRAME /



FOLDOUT FRAME 2

I. Greenwater Valley

Potential Water Resource Area

Eastward tilting of the Black Mountains and Greenwater Range in response to movement on associated fault zones has produced a rectangular valley striking parallel to the mountains. The valley is bordered on the east by the fault bounding the Greenwater Range and on the west by the dip-slope of the Black Mountains (see Fig. 8). The fault bordering the valley is unnamed and not identified on most geologic maps of the area. However, the fault is apparent in Skylab imagery (Plate III) as a series of discontinuous scarps and elongate, narrow plateaus of dark-colored alluvium, identified in the field as desert pavement. The areas of desert pavement are topographically higher by a few feet than adjacent detritus, suggesting fault movement. An intermittent stream in the valley is apparently controlled by this fault.

A series of dark, reddish-brown linears cross the valley approximately perpendicular to its strike near the townsite of Greenwater in the Black Mountains. The linears correspond to conglomeratic deposits of the Funeral formation, which was once continuous across Greenwater Valley (Drewes, 1963).

Topographically this area is a "peak" in the elevation of the valley and divides it into south and north halves. Surface runoff to the north drains toward Ryan, into Furnace Creek; runoff to the south drains toward Shoshone. Thus the linears may indicate a topographic high in the basement of the valley, or a fault.

Linears were also detected at the north end of the valley. These linears are interpreted to be near-vertical faults that displace Tertiary volcanics. They may represent extensions of faults mapped in the Black Mountains, such as Dante's fault.

Thus, northern Greenwater Valley is effectively bounded on two sides by faults, on the third side by a dip slope, and on the fourth by a basement ridge. Gravity maps of the region (Mabey, 1963; Chapman and others, 1971) indicate a closed Bouguer gravity low that correlates with the bounded portion of Greenwater Valley. The gravity anomaly suggests that a substantial thickness of low density material has accumulated in the valley.

A potential water reservoir may exist in the alluvium of the valley, if the material can be demonstrated to have sufficient porosity and permeability to yield infiltrated runoff water to well pumps.

A large recharge area exists in the Black and Greenwater Mountains. Intermittent flow in Furnace Creek, which leaves the north end of the valley near Ryan, may not be sufficient to carry off rainfall of the area. Thus, a substantial amount of rain may infiltrate into Greenwater Valley and be trapped there, restricted from lateral movements by impermeable fault zones, a basement ridge, and a dip slope.

J. Black Mountains-Greenwater Range Imagery Analysis of Copper Deposits

An investigation of the Black Mountains-Greenwater Range area, east of Death Valley, was conducted using Skylab S190 photography to analyze the geologic environment of minor, known copper deposits and to suggest additional areas that may be favorable for exploration for copper mineralization (see Plate III and Fig. 8).

The northwest-trending Black and Greenwater Mountains which are separated by the narrow Greenwater Valley form a diamond-shaped structural block that has been squeezed and jostled between the Death Valley fault zone on the west and the Furnace Creek fault on the east. The block is approximately 92km long and 56km wide. Repeated movement on faults bordering the block has subjected the block to relative northeast-southwest horizontal shortening and northwest-southeast extension (Hill and Troxel, 1966). This strain system evidently has been active from Precambrian to Quaternary, as structures of this time span compatible with the sense of strain have been mapped in the rocks of the block.

Estimates of total lateral displacement on the Death Valley and Furnace Creek faults have been presented by several workers and range from as much as 80km to only a few kilometers. Sense of motion on the faults is described by vertical offset as well as a strike-slip component. Movement on the faults has produced complex folding and faulting within the block and subjected it to repeated uplifts during which the once thick Paleozoic section and some Cenozoic volcanics have been eroded.

The Black Mountains are composed of Precambrian metasediments that are exposed in northwest-trending anticlines (turtlebacks), Tertiary quartz monzonites, and Tertiary-Quaternary volcanics and sedimentary rocks. Paleozoic rocks occur only as chaotic structural blocks, although Paleozoic sections as thick as 6,000m are known in areas outside the Black Mountains block. The rocks

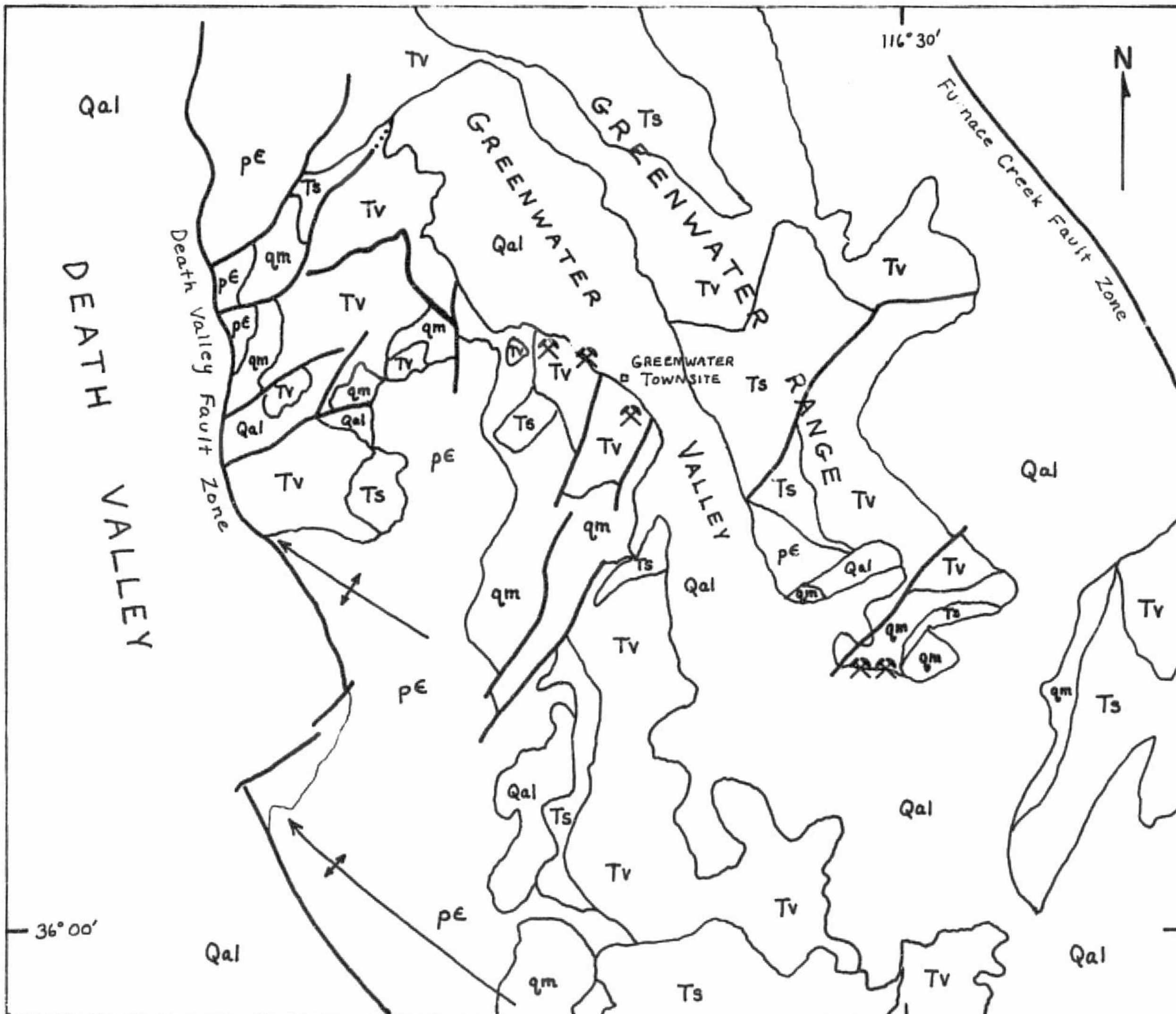


Fig. 8 Generalized Geologic Map of the Black Mountains-Greenwater Range Area

Explanation

Qal	Quaternary Alluvium		Fault
Tv	Tertiary Volcanic Rocks		Contact
Ts	Tertiary Sedimentary Rocks		Anticline
qm	Tertiary Quartz Monzonite	⚒	Copper Areas
pЄ	Precambrian Rocks		

Scale

5 0 5 Miles

5 0 5 Kilometers

exposed in the Greenwater Range are predominantly Tertiary-Quaternary volcanics and sediments. Most of these lithologies can be discerned and contacts traced in Skylab photography, especially S190B Ektachrome.

Analysis of the photography resulted in the identification of several areas in both the Black and Greenwater Mountains that display anomalously bright reflectances in Ektachrome films. These areas were interpreted to be alteration zones that are largely exposed in extrusive rhyolites and rhyodacites that form gray, tan, and red-colored slopes and knobs. The zones are linear, trending northwest, and are approximately parallel to each other and to the nearby contact of the volcanics with outcrops of quartz monzonite. Mining activity in the early 20th century was concentrated along these zones, and many shafts and pits were dug in the zones to locate copper deposits.

Further study of the more conspicuous parts of the alteration zones in the Black Mountains near the townsite of Greenwater revealed many linears striking northeast, approximately perpendicular to the trend of the alteration zones and the monzonite-volcanics contact. These linears are generally short (0.3-0.5km) and only rarely are continuous across lithological contacts. However, linears striking northeast are common, and can be observed on the crests of the turtlebacks and in the monzonite and the volcanics of the Blacks; they are less common in the volcanics of the Greenwater Range, but are abundant in the monzonite outcrops southeast of Greenwater townsite.

Some of the linears correspond to faults and to dikes that crop out on the crests of the Precambrian anticlines and near the contact of Tertiary monzonites with host metasediments (Drewes, 1963). The majority of the linears are not mapped as geologic structures by Drewes, but northeast-trending features are compatible with the strain system described above and correspond to a direction of tension fracturing (Hill and Troxel, 1966).

Field examination of several northeast linears at their intersection with the alteration zones near Greenwater townsite resulted in the identification of some of the linears as brecciated fault zones, approximately 45m wide, composed of volcanic rock fragments. More significantly, copper minerals -- silicates and carbonates -- were common as veins and fracture fillings in the breccia. Additional exploration in the rhyolites that were interpreted as altered in Skylab photography disclosed further deposits of copper minerals and veins of barite. As these mineralized rhyolites are near contacts with quartz monzonite, a genetic relationship between the monzonite and the copper deposits was suspected.

Further interpretation of imagery and comparison of locations of known copper deposits in other areas, northeast linears, alteration zones, and monzonite outcrops resulted in the observation of spatial relationships of all elements for each area examined.

A tectonic history utilizing interpretations derived from observations of Skylab imagery and from theories of Drewes (1963) and Hill and Troxel (1966) has been developed to explain the copper deposits of the Black Mountains and Greenwater Range. The initial pertinent geologic event was the passive emplacement of the Tertiary quartz monzonite into the Precambrian metasediments and Paleozoic rocks. The monzonite stock was elongated northwest-southeast which complied with directions of strain active at the time of emplacement and with dominant Precambrian structures. Primary copper sulfides were disseminated in the stock. Continued movement on the Death Valley and Furnace Creek faults caused uplift of the block and subsequent erosion of the Paleozoic section and exposure of the Precambrian and Tertiary rocks. Tension oriented northeast-southwest, caused by fault movement, resulted in fractures and faults which served to control volcanic extrusive and intrusive activity. Sulfides in the monzonite were remobilized in a late phase of the activity and localized by the northeast fractures. Secondary copper minerals were redeposited in the fault zones and fractures in adjacent volcanic rocks.

This model implies that a disseminated porphyry-type copper deposit may exist in the area if copper minerals have not been totally eroded from the monzonite. Additional exploration of quartz monzonite outcrops is warranted. Geophysical studies, particularly to determine depth of alluvial fill in Greenwater Valley, are needed to evaluate the possibilities of the area containing a major copper deposit.

K. Mono Lake-Long Valley Areas

Volcanism and Geothermal Activity as Viewed from Skylab

The Mono Lake region has long been known as an active volcanic and geothermal district, in general related to the extensional tectonism on the eastern edge of the Sierra Nevada fault block. Satellite imagery puts the locations of these thermal areas in geologic and geographic perspective; structural controls on, and surface manifestations of, geothermal systems become evident through study of the data at different scales, in different seasons, and with different spectral combinations.

Long Valley is a tremendous oval-shaped depression, rimmed by hills on the east and south, and bounded on the west by the Sierra Nevada faulted basement complex. Drainage into the basin, mostly from the west, loses velocity quickly near the central part before flowing into Crowley Lake. In the west and central areas, many of the streams appear bright white in imagery due to transport of large quantities of fine clays, in most part produced as alteration products from prolific hydrothermal activity. The most prominent white areas correspond with known hot springs deposits and streams frequently flow out from these, spreading into plume-like fans as they near the basin's interior. The sluggish sediment plumes appear mottled dark brown rather than white, probably due to an abundance of vegetation and old organic debris.

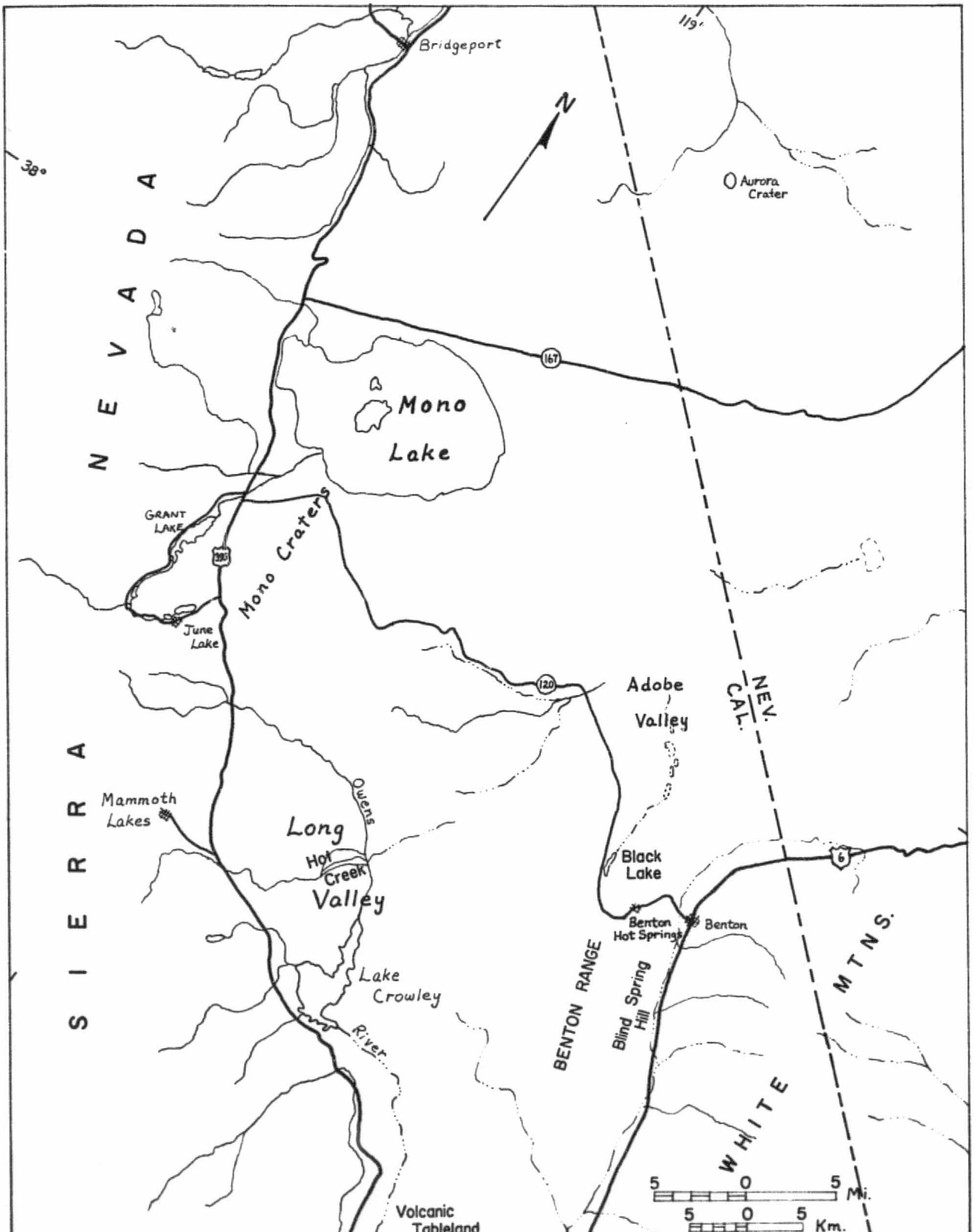
One prominent but narrow canyon observed in S190B imagery (SL3-88-007, Plate IV) is where Hot Creek flows directly eastward into the depression. A section of the stream valley about 1.6km long appears bright white. This area was visited briefly and consists of tremendous deposits of tufa and travertine, actively deposited at present by numerous steam vents, water spouts, and fumaroles along the valley floor and even hot upwellings within the creek itself. The canyon is narrow and steep-sided (about 15m deep) and the linearity observed in imagery strongly suggests fault or fracture control.

In general, altered zones appear to be restricted to the west and central areas of the Long Valley depression; outcrops of volcanic rocks as well as old cones are visible along the periphery in the northwest. The activity may be related to the apparent linearity of volcanism associated with the Mono Craters directly to the north. Numerous other linear features, probably fractures, should be carefully studied as potential conductors of geothermal fluids, particularly where they intersect the western area.

The Mono Craters extend from Mono Lake to the town of Mammoth Lakes, about 40km south, in a general north-south alignment (map accompanying Plate IV). The volcanic centers are evident in Skylab imagery as circular cones usually about 1-2km in diameter, amidst smoothly surfaced and vegetated volcanic terrane, presumably mainly basalt flows.

Vegetation in the Mono Craters area is readily visible in the high resolution S190B scene. Individual trees can be discerned especially in one area which was presumably thinned by logging operations in the past. Noticeable large spots barren of all vegetation correspond to the young craters and volcanic cones. Relatively bare spots also surround apparently older and eroded cones, evidently due to a rock type or local mineral chemistry

PLATE IV   Skylab S190B   SL3-88-007
Approximate Scale   1:500,000



FOLDOUT FRAME 2

producing an unfavorable growing medium. Kistler (1966a) maps part of this area as sand. The volcanic rocks associated with the aligned cones seem in general to produce fertile soil, whereas the surrounding area, including the basement rocks of the Sierra Nevada, exhibit sparse vegetation and desert climate at the same elevations. This vegetation "anomaly" is probably in part due to nutrients provided by breakdown of the basalts as well as water penetration. Similar application of vegetation changes demonstrates lithologic and geochemical differences; this utilization of remote sensing data is especially applicable to mineral exploration.

The cones and volcanic flows are easily mapped in the Mono Craters region. Analysis indicates that potential volcanism presents a threat to populated areas. June Lake, located in a circular valley directly below steep bluffs of the volcanic terrane, is a well-known populous resort area. The relatively active cones appear to be no more than 2 to 3km to the east and nearly 300m higher than the valley. From the appearance of the volcanic rocks of some of the cones and from published sources, much of the rock here is determined to be rhyolitic; silicic volcanism in this area could be devastating to the resort community.

Even though the more northerly rhyolitic cones appear younger and imagery indicates the southern centers are more eroded and vegetated, a chance of explosive volcanism seems a possibility, especially from one young rhyolite cone (Wilson Butte) only 3km east of June Lake. A mud flow, especially of the nuee ardente type, could totally demolish the area. An apparently very thick, large flow structure appears northeast of the area. Kistler (1966a) indicates this is a Quaternary obsidian flow because it appears to overlie glacial till and is over 3km long, covering at least 360m in relief. This feature may be an indication of the type of volcanic activity to be expected. Pleistocene glaciation has apparently removed most evidence of flows and effects of previous explosive volcanism.

L. Benton Range

Evidence of Geothermal and Mineral Occurrences

Hot springs in the region east of Mono Lake at the north end of Owens Valley are evident in imagery where white clays produce high reflectance. Very extensive basalt flows cover the area and numerous subparallel faults cut the volcanic field. In some places small basins have been formed containing white clays. Many of these correspond with springs according to topographic maps. Hot springs are manifested as usually more extensive white deposits, and the larger ones display abundant white clays carried in the discharging streams.

Numerous lineations observed in imagery, especially SL3-88-007 (Plate IV), in the vicinity of Benton Hot Springs are faults responsible in part for the geothermal activity; one major lineation can be seen to offset the stream which flows eastward through the Benton Range. Manifestations of Benton Hot Springs are identifiable as white areas occurring in the valley on the northwestern edge of Blind Spring Hill and in the northern Benton Range, probably controlled by elongated north-south faults. Major springs northeast and west of Benton Hot Springs, north of Black Lake, and in Adobe Valley lie directly adjacent to dark mottled areas apparently comprised of vegetation similar to that occurring near the Long Valley geothermal sites.

Other large areas covered by white clays conspicuous in imagery, particularly the deposits in Adobe Valley to the north-west, suggest the amount of alteration and geothermal activity is extensive and perhaps not restricted to Benton Hot Springs. Although active hot springs may not surface in the depressed area northwest of the Benton Range, it seems very plausible that drilling might disclose some high thermal gradients.

Adobe Valley, a closed alluvium-filled basin, may well be a volcano-tectonic depression such as Long Valley. Although it has no definite caldera-type rim, the valley is encircled almost entirely by basalt flows and tuffs. Faulted basalts form the northern boundary and are directly adjacent to the topographic low of the basin where the abundant white clays appear. The closed depression could be a water collection source, supplying the hydrologic needs of a geothermal system. These conditions also seem to fulfill requirements for deposition of borate minerals, especially considering the known profusion of thermal waters in the region. The possibility of boron occurring in the fine sediments of Adobe Valley is suggested for ratification by future exploration.

Tertiary structure is particularly evident in Skylab images and probably is directly related to much of the geothermal activity. Where the upper Benton Valley bends northward around the north end of the White Mountains, for example, marked tonal differences appear in the alluvium; one prominent lineament cutting across the valley with a northwesterly trend is particularly evident and may be part of the fault zone that bounds the White Mountains (Plate IV). This linear corresponds exactly with the fault mapped by Crowder and others (1972). Small white areas lying along the fault correspond with a series of springs. The recent alluvium from the fans of Montgomery Creek flowing out of the White Mountains has apparently covered the southern trace of the fault. The alluvium, in fact, appears a lighter tan, corresponding to the leucocratic adamellite which the stream carries down from elevations of nearly 4,000m.

To the south (off Plate IV), Tertiary volcanism and faulting is particularly evident throughout the Volcanic Tableland north of Bishop. The relatively flat and featureless plateau has been dissected by large numbers of parallel, north-south linears -- scarps mapped by Bateman (1965) as swarms of normal faults with small displacement. Fish Slough, 42km due south of Benton, is a small vegetated valley and one of the most prominent of these small grabens (visible on SL3-40-194; see inside front cover of Geothermal Energy article, Appendix A, p. 258).

Faults and altered areas in close association are found throughout the Benton Range expressed as linear trends and coloration anomalies on Skylab imagery. Jointing is readily visible in the granitic rocks, and swarms of northerly and northwesterly trending linears apparently are dikes cutting both Paleozoic and granitic rocks. Much mining activity has proceeded on these. Detailed study of the S190B scene (SL3-88-007) reveals relatively white linear features throughout the range, corresponding with the porphyritic rhyolite and aplite dikes mapped by Rinehart and Ross (1957). In addition, the various plutonic intrusives can be differentiated to a fairly accurate degree; the mapped diorite-gabbro and tactite bodies in particular are distinct dark masses. In the northern part of the range, igneous contacts are well exposed and easy distinction can be made between profusely jointed granite and more mafic granodiorite. According to Rinehart and Ross, the main ore deposits are of tungsten or schellite occurring in the thermal metamorphic zones near calcareous rocks, and of gold, silver, lead, and copper occurring in the north- to northwest-striking quartz veins.

M. Goldfield, Nevada

Image Analysis of Ore-Bearing Silicified Zone

A large, anomalous, color zone observed on Skylab S190A (SL3-28-057) and S190B (SL4-90-297) Ektachrome transparencies forms a prominent semi-elliptical pattern north and east of Goldfield, Nevada. The arcuate structure corresponds to that mapped as a ring fracture containing ore-bearing zones, the westernmost of which made Goldfield a famous gold-producing district in the early 1900's. The zone appears white to reddish in coloration, forms a curved outcrop at the west end (nearest Goldfield), and strikes due east in a linear trend for nearly 12km (Fig. 9). This zone has a maximum width of about 1.5km and averages over 0.8km wide. The brightest reflecting portions of the zone in the north and west form ridges with the same arcuate trend, and the east-trending swath strikes across hill terrain. The gray and brown interior of the arcuate structure appears relatively featureless and flat, except for small ridges and lineaments striking mostly northeast, and interpreted as compositionally similar to the outlying zone.

Most of the ridges and hilly terrain occupied by the anomalous coloration are interpreted generally as siliceous igneous rocks, in places containing considerable iron oxidation. The main swath has a kink in it near the Nye County-Esmeralda County boundary suggesting northward continuation and hence completion of the arcuate perimeter. Ridges to the northeast strike almost directly north-south, and trends of lineations imply continuity with the ridges on the northern edge of the arcuate structure. Hence, from distant viewing, the resistant rock outcrops of the Goldfield district appear to exhibit an annular distribution.

The entire structure was plotted, and boundaries placed on the zone as it appeared in S190B imagery (Fig. 9). Detailed plotting of the zone and major lineaments in the area was made possible by projection of the Skylab transparency to a map scale of 1:24,000. The imagery-derived features were then compared with available geochemical maps at the mapped scale showing

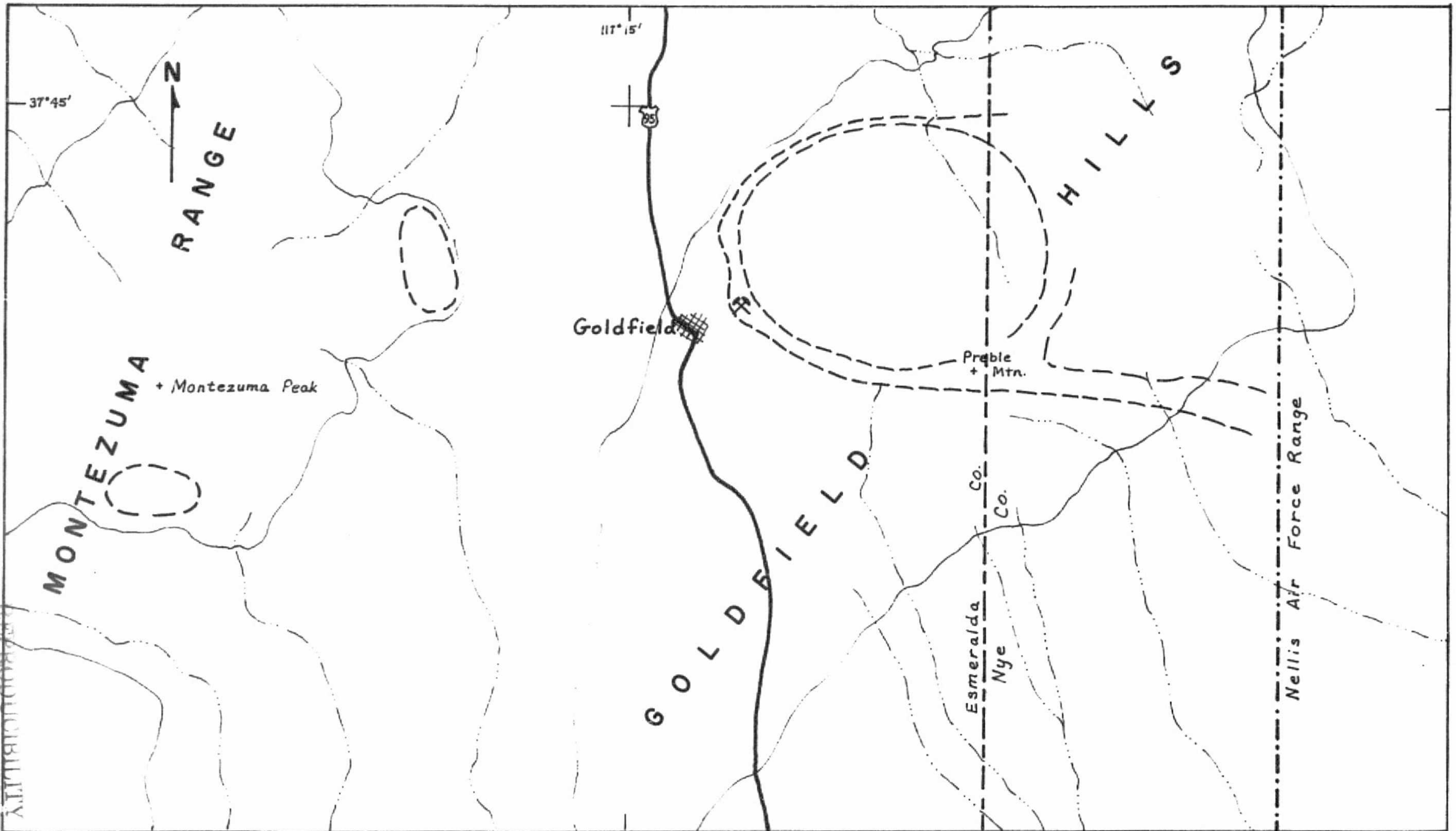


Fig. 9 Location Map of the Arcuate Silicified Ore-bearing Zone at Goldfield, Nevada

Imagery-Derived Silicified Zone
Bedrock Outcrops
Major Mining District

Scale: 1:125,000
1 ½ 0 1 2 3 4 Miles
1 0 1 2 3 4 Kilometers

NEVADA

occurrences of metallic elements (Ashley and Keith, 1973). Maximum error due to plotting and alignment with the map is estimated at 90 ground-meters.

Strong correlation is found between the plotted color zone, the silicified rocks, and highest concentrations of ore metals. As suspected, the brightest reflectance zones and most resistant ridges correspond to areas of much silicification. Elongate trends within the arcuate zone exhibiting relief or coloration differences correspond to siliceous zones. As indicated by the images and supported by the geochemical map, the zone is generally narrow and silicification is not as abundant northeast of Goldfield, whereas the major part of the east-west swath is wide, well silicified, and carries large concentrations of ore minerals. Additionally, this latter zone is observed to be much more complex structurally, and the areas of greatest intersection of lineations often seem to correspond with the major ore-bearing localities.

Individual areas of most promising economic potential are indicated by specific trends of lineaments mostly tangential, but also radial, to the general arcuate trend within the bright siliceous zone. The coloration changes delineate these zones and outcrops of more mafic volcanic phases especially evident on the interior of the south and western edges of the arcuate zone. The areas which seem to hold most promise are along the eastern edge of the arcuate zone high in the Goldfield hills and the region around Preble Mountain (Fig. 9). Additional economic deposits may occur north of the main original Goldfield workings and fault zones in the interior of the ring structure.

The arcuate feature described corresponds to that structure mapped as a ring fracture comprising considerably \ idespread silicified zones with ore deposits apparently produced by caldera collapse in mid-Tertiary time (Ashley, 1974). Later igneous intrusion, alteration, and ore deposition took place in fractures but was mainly concentrated in the ring fracture zone. Mined ore bodies have all been within the arcuate color zone and the major Goldfield district is restricted to the western end of the structure.

Other zones suggested for further exploration include portions of the arcuate zone especially in the southern region where rocks are abundantly fractured, the resistant ridges in the east, and much of the easternmost part of the prominent east-trending silicified zone. In addition, areas near Montezuma Peak to the west appear similar in coloration to the Goldfield rock outcrops in S190A, suggesting other possibly valuable ore deposits as extensions of the Goldfield district. Another arcuate feature is observed south of Montezuma Peak with concentric ridges, snow enhanced in SL4-90-297. Silicification again appears to accompany the structure, judging by the white outcrops.

The structure and color anomalies observed are not distinctly visible in ERTS imagery, appearing only as a cloudy region of generally gray color. The high resolution and color definition afforded by Skylab data, and especially S190B, produces a vivid image of the geometric outcrop as well as coloration zones identifiable as siliceous volcanic phases and fractures presumed to have controlled most of the ore deposition.

N. Crater Flat, Nevada

Image Study of Crater Flat Depression

Crater Flat is a gently sloping alluvium-filled depression more than 10km in diameter on the northeast edge of the Amargosa Desert, 20km southeast of Beatty, Nevada (Fig. 10). The area lies just outside the western edge of Nellis Air Force Range near Highway 95. Crater Flat appears in Skylab images (SL2-04-190, SL4-76-223, SL4-94-014) as a circular, alluvium-filled basin with streams draining south. It is bounded by Bare Mountain on the west, over 600m higher; by the lower Yucca Mountain Range on the east; and by ends of both ranges converging in the south, forming a roughly circular rim. The southernmost rim is eroded and a small pass has broken through allowing drainage to the lower Amargosa Desert flats.

The basin contains two prominent black volcanic cones, probably basalt, which obviously pierced and flowed out upon the alluvial floor. Other small cones cropping out across the basin in various places coupled with the lack of fresh exposures of basalt in the surrounding region suggest Crater Flat to be an area of anomalous volcanic activity, probably Quaternary in age. The circular configuration and almost complete closure of the basin suggest perhaps a caldera collapse and imply the strong possibility of an effective natural dam to create a sizeable underground water reservoir. Further, if the area is volcanically active as seems apparent, seepage into alluvium across the expanse of the basin appears sufficient to supply water to the igneous source to provide a geothermal system. Further detailed study, including

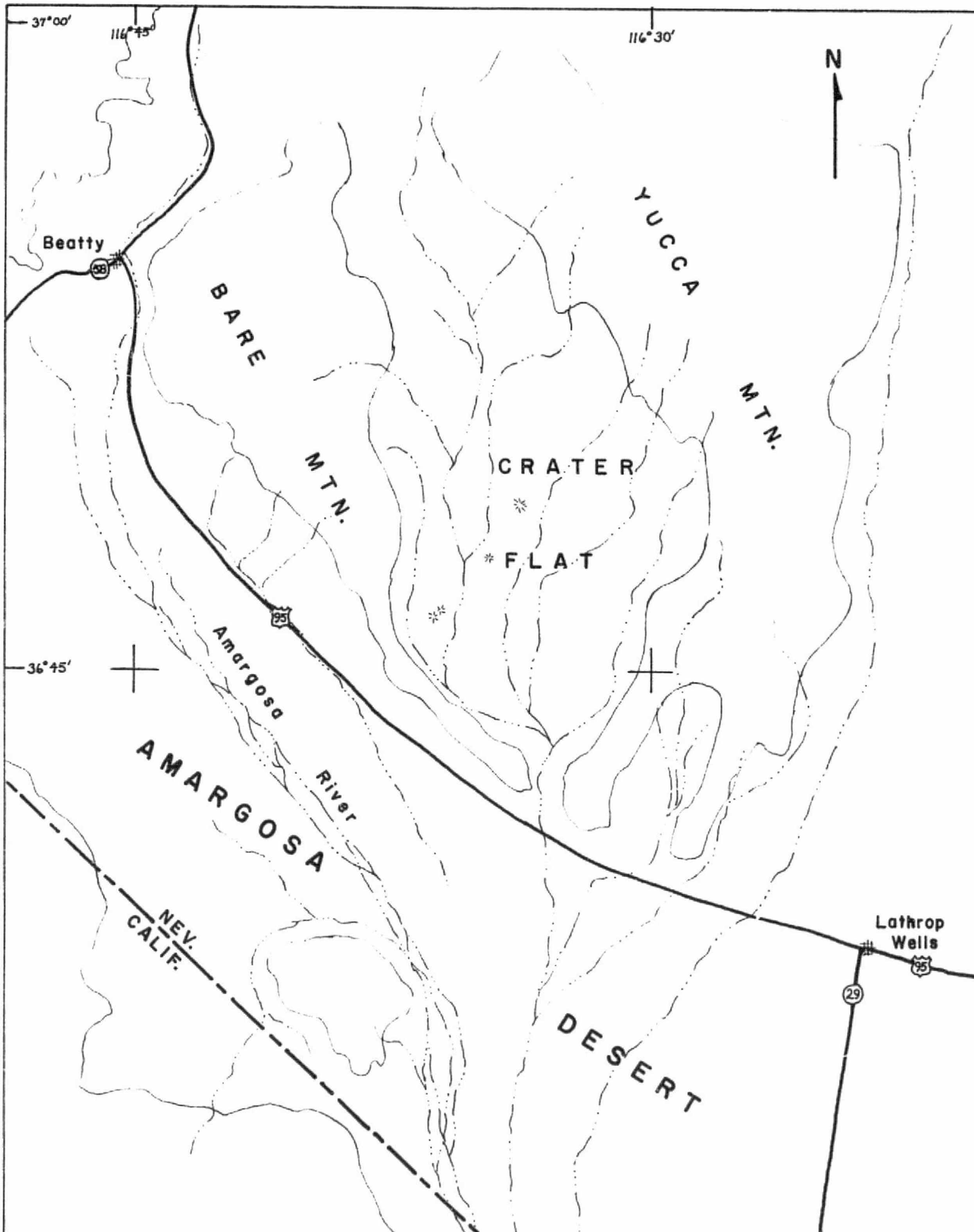


Fig. 10 Location Map of Crater Flat, Southwestern Nevada

Scale: 1:250,000

Basaltic Cones
Bedrock Outcrops
Intermittent Streams

5 0 5 Miles
5 0 5 Kilometers

NEVADA

determination of thermal sources and ground geophysics, may locate faults and fractures through which thermal waters might infiltrate.

Whether or not conditions are favorable for geothermal development, the south end of the basin is a likely spot for fresh water collection and extraction. Topographic maps show a narrow path of drainage through the hills in the south where the Bare Mountain block apparently plunges beneath the alluvium. Assuming bedrock lies near the south rim's surface, a depth of 50 to 100m of alluvium (probably mainly sand-sized particles judging by the light coloration and homogeneity) would produce a substantial water reservoir underlying much of the southern basin. The alluvial washes slope gently across much of the area allowing sufficient water percolation; whether the basement surface follows the same trend has yet to be determined.

According to the preliminary geologic map of Nevada at 1:500,000 scale, Crater Flat is bounded on the west by a fault, as suspected from image analysis, where Paleozoic rocks of Bare Mountain rise abruptly from the flat. The Yucca Mountains appear in Skylab scenes to be tilted sedimentary rocks, dipping east away from Crater Flat. These beds are mapped as Tertiary volcanics and are probably pyroclastics, judging by their apparent fine bedding, light coloration, and profuse dissection. They also appear to be step-faulted by north-south trending lineations (steep, straight, west-facing slopes), and the unit crops out highest along the west edge, comprising the rim of Crater Flat. These lithologic and structural occurrences support the idea of the basin being a caldera. In addition, the isolated cones are mapped as Quaternary volcanic rocks, indicating activity has proceeded within the circular rim and that it is still an active vent. If the damming effect is produced by Paleozoic rocks of the Bare Mountain Range, considerable water-holding and recharge capacity might be controlled by carbonate rocks.

Confirmation of image analysis of Crater Flat is provided by the following data from the geologic map of Cornwall and Kleinhampl (1961): 1) the alluvium is mainly sand and silt in the valley bottom and gravels on fans flanking the hills; 2) four basalt cones and numerous small outcrops of basalt occur on the floor of Crater Flat; 3) the entire west edge of the flat is faulted where Bare Mountain rises above the fans; 4) to the north and east are late Tertiary volcanic tuffs, in part welded, dipping gently (approximately 10° to 20°) east, except local variations nearest the cones; 5) basalts in Crater Flat are probably of recent age; 6) some areas of tuff are intensely silicified and opalized; and 7) presently active hot springs occur only 15km northwest of the central flat.

Image study reveals three small white areas in alluvium occurring along the south side of the low hills that act as a barrier to the southward stream flow. These areas possibly denote silicic alteration, plausibly by thermal waters conducted through permeable rocks; no published sources were found to indicate previous discovery of any such geothermal manifestations. Judging from the known occurrence of hot springs to the northwest, Crater Flat deserves further attention as a potential geothermal resource area.

O. Black-Cerbat Mountains, Arizona
Geologic Investigation Using Skylab Imagery

Analyses of Skylab S190A and B photography and S192 imagery over northwest Arizona resulted in the identification of large numbers of arcuate and linear features, many of which are spatially related to known economic mineral deposits. The area analyzed encompasses the Black and Cerbat Mountains which are tilted fault blocks characteristic of the Basin and Range physiographic province. Diverse rock types are exposed in the ranges including Precambrian schists and gneisses, Mesozoic "Laramide" quartz monzonite intrusives, and Cenozoic volcanics (Fig. 11). Known economic mineral deposits of the region have been classified as epithermal vein deposits (gold -- principally in the Black Mountains), mesothermal vein deposits (lead, silver -- principally in the Cerbat Mountains), and disseminated copper deposits.

Except for intense folding in the highly contorted Precambrian metamorphic rocks, normal faulting has been the dominant structural process in rock deformation. Large intermontane faults bound both ranges; small faults that trend at different angles to the large faults divide the ranges into segments. As indicated by Figure 11, the Cerbat Mountains are composed essentially of Precambrian metamorphics and Tertiary granitic intrusives, although Tertiary volcanics occur to the north and to the south at Kingman. The Black Mountains, conversely, are dominated by volcanics -- basalts, andesites, rhyolites -- but some Precambrian crops out on both flanks of the range. Volcanics in the Blacks usually rest on Precambrian basement (Dings, 1951); volcanics overlying occasional

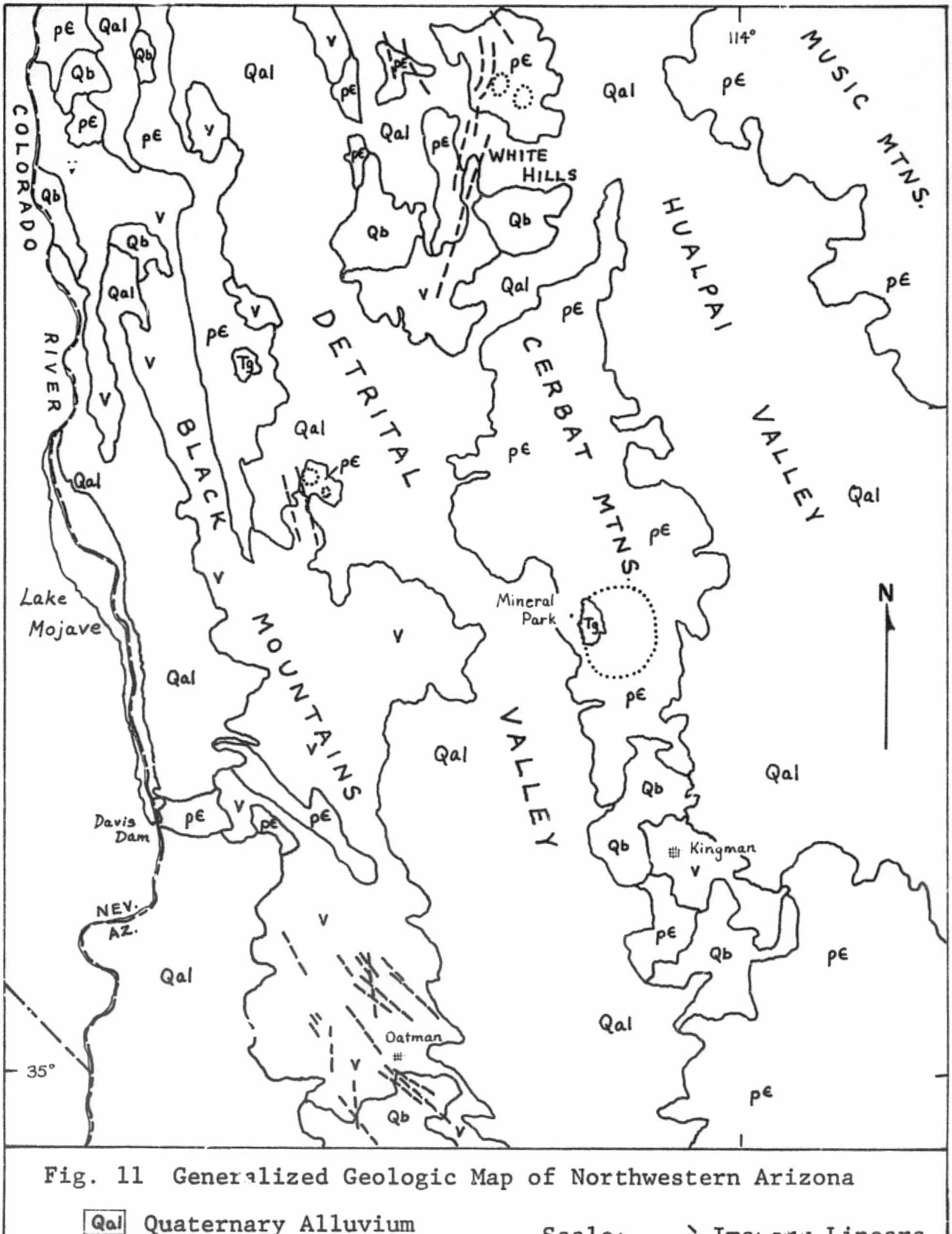


Fig. 11 Generalized Geologic Map of Northwestern Arizona

Qal	Quaternary Alluvium
Qb	Quaternary Basalt
Tg	Tertiary Granitic Rocks
V	Undifferentiated Volcanics
pЄ	Precambrian Rocks

Scale: 1:500,000

5 0 5 Miles

5 0 5 Kilometers

Imagery-Linears

Arcuate Anomaly

ARIZONA

limestone blocks have been noted in underground workings at Oatman (Lausen, 1931) indicating Paleozoic formations exposed extensively east and west of the study area were continuous.

The volcanics of the Black Mountains evidently were localized along a major north-south lineament that is visible in ERTS, Apollo, Skylab, and Nimbus imagery (see Lake Mead section, p. 106). This lineament is terminated to the north at the Las Vegas shear zone (Bechtold and others, 1972).

Linears derived from analyses of Skylab imagery (Plate V) of the Cerbat Canyon mining area (Wallapai mining district) have been correlated by literature and field studies to faults and shear zones that strike N40-65W in Precambrian rocks. At least one shear zone in the mining area is wide enough (45-60m) to be observed directly on S190A and B transparencies. This zone is high-angle, dipping 65NE. Many small ore shoots were evident within the zone in both the hanging and foot walls. Minerals sampled were galena, chalcopyrite, and argentite. Galena was particularly abundant. The gangue included iron-stained quartz, clays, and fragments of the host rocks -- schist, garnetiferous gneiss, and granite. Other faults displacing gneiss and schist were examined, but mineralization was not readily apparent.

Linears trending northwest have also been correlated with dikes of varied composition -- granite pegmatites, aplite, rhyolite, and granite. They are most commonly aligned parallel to northwest-trending faults and fractures and occasionally fill them. Although few dikes can be seen directly on S190B high-resolution photography, analysis of the imagery indicates the dikes are very abundant and discontinuous. At least one dike thought to be rhyolite in composition can be seen as a white band cutting the dark gneiss. Dings (1951) theorizes that all dikes are probably genetically related to the intrusion of the quartz monzonite exposed near Mineral Park.

Imagery studies also indicate that the linears interpreted to be faults or shear zones extend into areas that have not been heavily prospected, suggesting localities for additional exploration.

Linears trending approximately perpendicular to the faults and shear zones are related to the schistosity of the Precambrian rocks which trends N40-65E. Some northeast linears correspond to valleys and may represent transverse faulting that served to offset mineralized veins. Mineral-bearing fluids may have been localized at intersections of northeast and northwest fractures.

A large arcuate feature noted in S190A and S192 imagery over the main mass of the Mesozoic quartz monzonite near Mineral Park in the Cerbats apparently is an indicator of an alteration halo around the intrusive. The arcuate extends beyond the area mapped as intrusive, suggesting Mesozoic monzonite may lie at shallow depths beneath the Precambrian host rock. This may be significant as Duval Corporation currently mines disseminated copper and molybdenum from parts of the intrusive where it is exposed near Mineral Park. Tailings ponds and pits are clearly visible in Plate V.

An area across Detrital Valley from Mineral Park on the east flank of the Black Mountains displayed anomalous reflectances in

Ektachrome films that are characteristic of altered siliceous rocks. Comparison of the anomaly with published geologic maps and field work revealed that the rocks were altered Precambrian gneisses. If alteration was caused by the same Mesozoic intrusive cropping out in the Cerbats, the possibility of a major copper body existing beneath the alluvium is very real. Anomalous concentrations of desert vegetation, noted in S190A color infrared films, are also located in the valley near the altered gneiss.

Analysis of the Residual Aeromagnetic Map of Arizona (Sauck and Sumner, 1970) indicates a relative aeromagnetic low over the quartz monzonite where it crops out in the Cerbats. A comparable low value is apparent over the altered gneiss area in Detrital Valley suggesting, perhaps, a similar geologic cause.

Another region displaying aeromagnetic low values is the Gold Basin-White Hills area to the north of the main block of the Cerbat Mountains. The low values correlate to outcrops of Precambrian schist and gneiss, which is to be expected. However, a relatively high magnetic value occurs adjacent to the lows as a circular anomaly. The low and high values are separated by a steep aeromagnetic gradient (600 gammas). The high anomaly is similarly centered over Precambrian schists which indicates a substantial composition change in the schists or an intrusion of magnetic material at depth. Analysis of Skylab photography over the area reveals northwest linears which correspond to copper-bearing veins in the rock (Dings, 1951). It also reveals north-northeast linears that correlate approximately with the location of the aeromagnetic gradient (which may be displaced as much as 2.5km due to flight-line spacing).

Furthermore, rocks interpreted from Skylab data to be altered crop out in the schist near the location of the gradient, within the area covered by the aeromagnetic high. Dings (1951) reports north-trending veins, containing gold and silver mineralization, that may correspond to north-northeast image-linears in this area. The suspected intrusion may be responsible for fracturing and alteration of the schist and for the emplacement of mineral-bearing fluids.

Linears observed in imagery correlate very strongly with gold-producing veins exposed in faults and fissures in siliceous volcanics exposed at the southern end of the Black Mountains near Oatman. Linear trends range from N20W to N60W. This area has been extensively explored for gold and many millions of dollars in gold have been produced from the region. The gold values are in veins in rhyolites and andesites, overlain in part by non-mineralized basalts. In many cases, linears can be traced into areas covered by basalts indicating, perhaps, that faults extend beneath the basalt cover. The faults may be mineralized in this area as they are in surface exposures. This suggests that exploration for additional gold-bearing veins should be concentrated in the faulted rhyolites below the basalts.

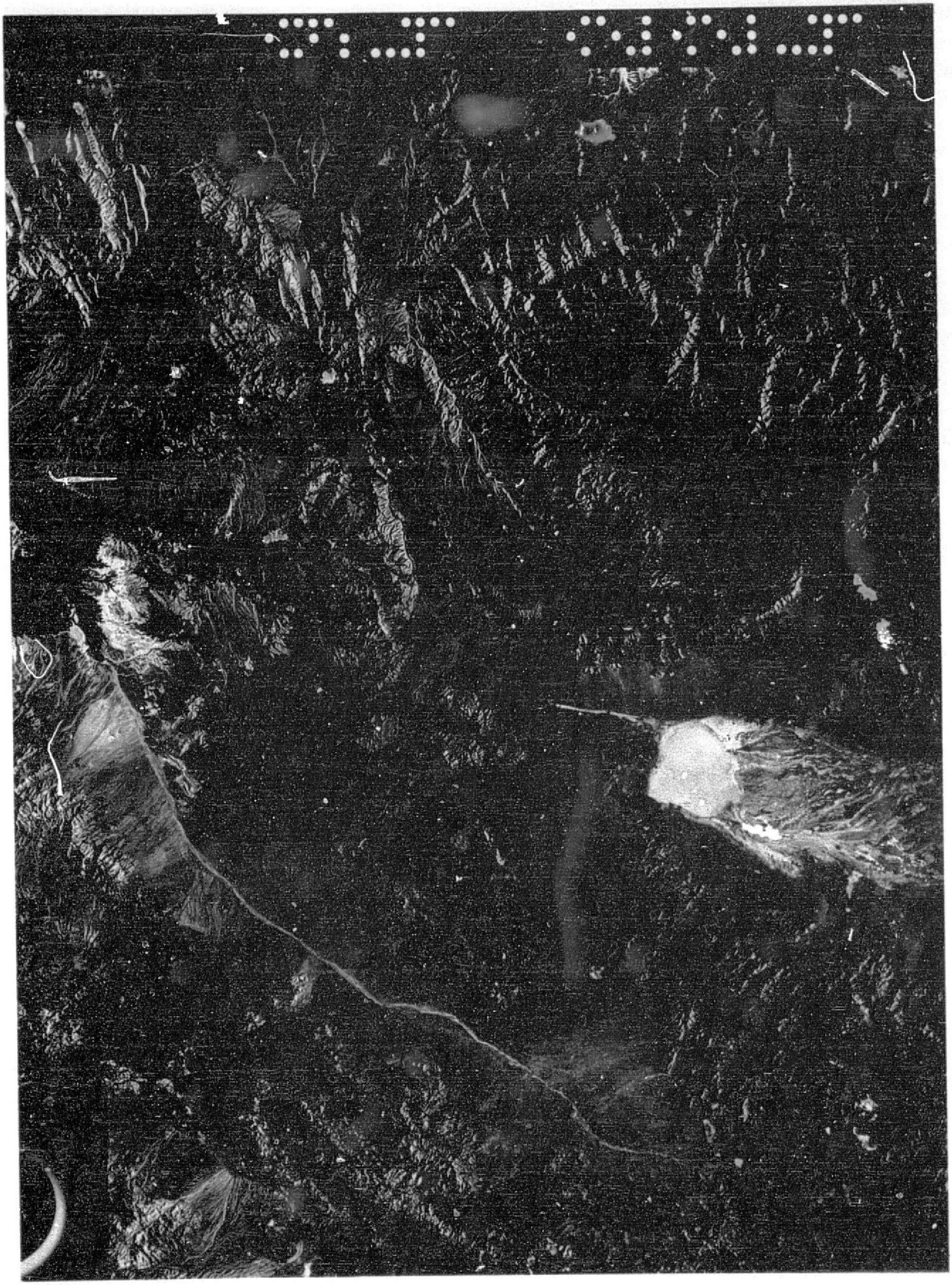
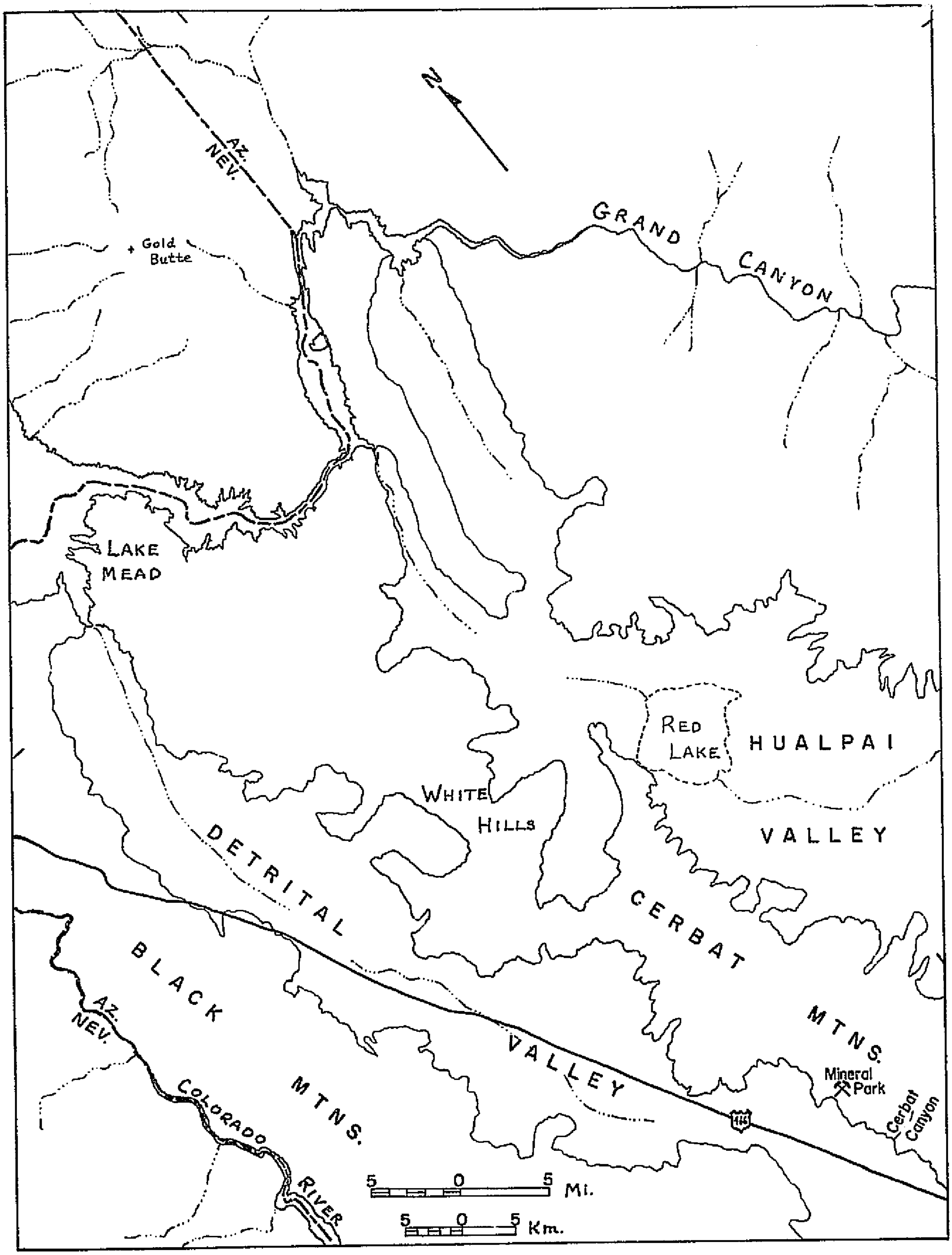


PLATE V Skylab S190B SL4-94-224
Approximate Scale 1:500,000



FOLDOUT FRAME 2

P. Gold Butte Region, Southeastern Nevada

Skylab photographic coverage of the study area in southeastern Nevada including Gold Butte, Bunkerville, Valley of Fire State Park, and the northern Black Mountains proved to be useful for geologic investigation and interpretation. Color and structural differences plotted from the images are interpreted as being important in relation to location of mineralized areas and to lithologic and structural features. Generally significant data obtained from the images includes recognition of mapped geologic units and structures (such as faults, schistosity and jointing). Furthermore, some structures and units are seen in the images that do not correlate with mapped geology. These items may represent geologic features which are as yet unmapped.

The Skylab imagery used in the study of the area includes: SL4-94-224 (Plate V), SL4-4B-029 (Plate VIII, p. 120), and SL3-28-059 color composite (Plate IX, p. 121). The image found most useful for detailed analysis is the Ektachrome S190B (SL4-94-224). This image was viewed by mounting it in a multi-spectral viewer and projecting to a scale of 1:48,000 to compare with the Gold Butte geologic map by A. Volborth (1962) at the same scale. Acetate overlays with anomalies as well as points of reference plotted were projected in a similar manner for comparison with Volborth's map. Other comparisons were made by directly overlaying the S190B 9-inch transparency (scale 1:500,000) on the Progress Geologic Map of Nevada (Webb and Wilson, 1962) at the same scale.

The overall area of this study covers approximately 3,000 square kilometers of southeastern Nevada, within Clark County in the vicinity of Lake Mead. The Lake Mead area is located on the boundary between the Basin and Range and the Colorado Plateaus physiographic provinces.

Trending approximately due north above Lake Mead is the Sevier orogenic belt which apparently is terminated just above the lake by right lateral movement on the Las Vegas shear zone, so that the southward extension of the belt has been moved as much as 70km to the west (Anderson, 1973).

The major portion of the study was centered around the Gold Butte area in the South Virgin Mountains. This area, bounded by the Overton Arm of Lake Mead on the west and Virgin Canyon and Gregg's Basin on the south, is roughly 850 square kilometers. Three areas of general consideration are located outside of Gold Butte: Bunkerville to the north and the Valley of Fire and northern Black Mountains to the west (Fig. 12). These areas are also referred to in the Lake Mead section (p. 106).

The Gold Butte area is topographically rugged and access is either by dirt roads from the north or by Lake Mead. The highest elevation within the area is 1,746m (Jumbo Peak), and maximum relief is 1,381m. Gold Butte itself has an elevation of 1,528m and is located at $36^{\circ}17'$N latitude and $114^{\circ}12'$W longitude.

Gold Butte is an elevated block bounded by the Gold Butte Fault (Anderson, 1973) on the north and west and a system of unnamed faults on the east. The block consists of several

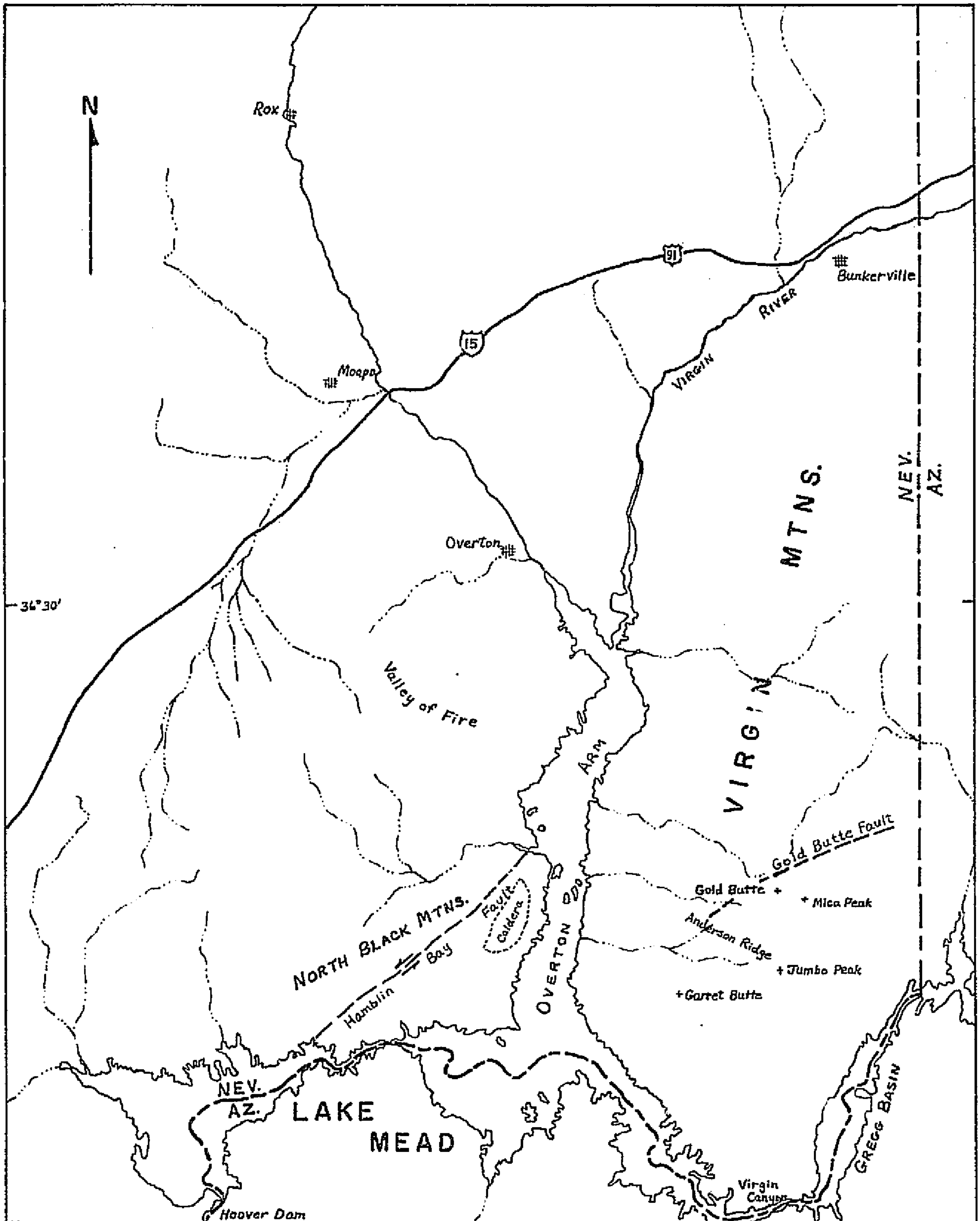
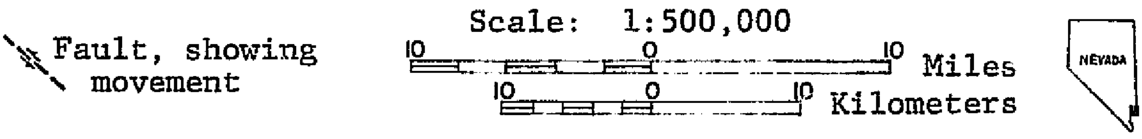


Fig. 12 General Location Map of Gold Butte Area, Nevada

Scale: 1:500,000



northwest-trending ranges which are composed of Precambrian granites, gneisses, and schists.

According to Volborth the Precambrian gneisses and schists served as host rocks for various granitic and ultramafic intrusions with the formation of ultramafics being accompanied by copper mineralization. This event was followed by the intrusion of aplite and pegmatite dikes into the metamorphic complex. The entire assemblage underwent extreme regional metamorphism and the various bodies adjusted themselves to the general northwest trend.

While metamorphism was continuing, a granitic pluton was emplaced, rising to higher levels in anticlinal structures within the metamorphic host rock. The structure of the host rock thus controlled the formation of the pluton so that it has also taken on a general northwest trend.

The emplacement of the pluton was followed by the intrusion of various types of dikes. The metamorphic rock acted as a roof over the intrusive bodies and mineralization took place along this contact. Most of the mineralization is due to hydrothermal solutions associated with the injected bodies, although some is attributed to meteoric solutions (Leighton, 1954). The main zones of mineralization are the pegmatites and the ultramafic bodies, while secondary copper mineralization took place along veins and joints as a result of the same hydrothermal fluids (Volborth, 1962). Subsequent erosion of the area has exposed many of these mineralized zones as well as the granitic body so that the Precambrian granites now exposed represent the roof of the pluton.

Initial features observed in the Skylab images show the Gold Butte area to be a dark-colored, rugged area surrounded by lighter-colored, eastward dipping beds on the north and east (Plate V). Within the Gold Butte area, several features were observed which include anomalous color and structural differences with correlation to areas of mineralization as well as to the general geology. The Bunkerville area north of Gold Butte also exhibits some anomalous relationships with possible correlation to mineralized zones. Anomalies observed within Skylab images of Gold Butte include lineaments as well as color differences.

Lineaments observed exhibit two distinct trends. The greatest number fall within a group with trends varying from north-south to N70W, the same as the general trend of the ranges in the area. The second group, not as large, trends N40E to N60E, or roughly perpendicular to the major trend. Upon comparison with mapped geology of the area (Volborth, 1962), the major group of lineaments correlates strongly with schistosity attitudes of the metamorphic rocks as well as some foliation and joint attitudes within the granite. The second group, opposed to the general trend, is not as strongly related to mapped features but it does correlate with the few joint attitudes mapped by Volborth. Because of the relative lack of joint attitudes, it is difficult to draw definite relationships to the linears, but it does appear from imagery that joint trends are present which may be borne out by more detailed mapping.

In addition to being related to rock structures, some of the lineaments correlate with pegmatite, aplite, and granite dikes in the immediate vicinity of Gold Butte and Mica Peak. A strong set of north-trending linears was observed in this area as well as numerous north-trending light-colored bands (the largest band is approximately 4km long and 200m wide). The lineaments are concentrated within a small area above and between Gold Butte and Mica Peak. Mapped geology (Volborth, 1962) indicates a concentration of dike structures in the same area with northerly strikes, so that the lineaments are interpreted to be indicative of these dikes as well as quartz veins (Longwell and others, 1965). The light-colored bands observed in Skylab images are similarly interpreted as dike structures or quartz veins larger in size, since individual structure can be discerned. Some of these dikes may be as narrow as 6m or less (since it is possible to see single lane dirt roads in the images) which probably indicates the maximum resolution of Skylab S190B photography. The largest band observed, already mentioned to be 4km long, correlates almost precisely with a pegmatite-aplite dike on the east slope of Mica Peak.

The lineaments, besides being closely related to the structure and lithology of the area, also appear to be significant with respect to mineralized zones. Many of the lineaments and bands were found to correspond with known dike structures, but there were also some which did not. These are probably unmapped bodies and have the potential for future mineral exploration.

Concentrations of linears indicate two main areas of potential mineralogical significance within 12km of Gold Butte. One is the Anderson Ridge area, roughly 4km southwest of Gold Butte; the other is the Garrett and Mineral Buttes area, 12km southwest of Gold Butte (Fig. 12). Both of these areas exhibit a roughly orthogonal pattern of linears with directions trending northwest and northeast as defined earlier. Volborth states that secondary copper mineralization took place along veins and joints, so it seems likely that the sets of linears may be indicators of mineralization along joints, or of dikes with possible mineralogical importance.

Both linears and color differences correlated with the general geology of the area. Linears plotted directly from the Skylab images corresponded with the mapped faults of the area. A few structural linears were also observed that do not correspond to mapped structures; these appear to be previously unnoticed faults.

The overall color of the Gold Butte pluton is a dull green-gray in the S190B Ektachrome image (SL4-94-224) with only a few anomalous white areas, other than the bands already mentioned (Plate V). Two of these light-colored bodies correspond with units of gneissoid granite as mapped by Volborth (1962). Recognition of other rock units on the basis of color is uncertain due to several factors: 1) in all of the scenes of this area, the sun angle is low so that large shadows interfere; 2) the major rock types are similar in color; and 3) the color resolution of the images is poor. Texture, however, may aid in rock-type discrimination.

The observed surface texture of the area exhibits noticeable differences within the Skylab images. In some areas the surface appears more rugged and dissected and exhibits greater relief, while in other areas the surface appears to be smoother and less rugged. These observed differences in topography correspond very closely with the Precambrian igneous and metamorphic rock units as mapped by Volborth. The granites weather into angular gravels which tends to subdue the granite outcrops, whereas the metamorphics are more resistant to erosion and thus create a rugged surface (Volborth, 1962).

Approximately 45km to the north of Gold Butte lies the Bunkerville mining area in the northern Virgin Mountains. This area is somewhat geologically similar to Gold Butte in that it is also an uplift of Precambrian rocks flanked by Paleozoic sediments. However, the Precambrian unit is composed of well-foliated metamorphic rock without the granite that is common to Gold Butte (Seager, 1966). In the Skylab S190A image of this area (SL3-28-059, Plate IX, p. 121), a well-pronounced linear was observed which trends northeast through the area. Other minor linears were also observed in close association with the larger linear. Comparison of the linears with mapped mining areas shows a strong correlation between alignment of the mineralized zones and the linears. Most of the economic minerals of the area (beryllium, cobalt, nickel, and various pegmatite minerals) are known to occur in pegmatites within the area (Nevada Bureau of Mines, 1964). The majority of these pegmatites are concordant with the general northeast trend of the foliation of the area (Holmes, 1964) as well as the image linears. There is an apparent correspondence between the linears and the pegmatite zone, but the resolution of S190A is so much less than S190B, that structures as small as the pegmatites seen at Gold Butte cannot be discerned at Bunkerville. Only S190A data was available for study of this area. If S190B data had been available, it seems likely that structures as small as the pegmatites would have been visible.

Just west of Gold Butte on the opposite side of Lake Mead lies an area of general interest to this report. This area, within the northern Black Mountains, is composed essentially of Tertiary volcanic rocks flanked by Paleozoic and Mesozoic sediments with a complex system of strike-slip and oblique slip faults dissecting the area (Anderson, 1973). The interesting aspect of this area is not economic mineralization, since it is limited to two known manganese deposits, but with the recognition of features in Skylab images which have apparent correlation to mapped geology.

Within the S190A (SL4-4B-029) image of the area, three distinct dark-colored units were observed which correspond with a volcanic outcrop -- termed the Hamblin-Cleopatra Volcano by Anderson (1973) -- which has been fragmented into three large blocks along the Hamblin Bay Fault system. If these three bodies were moved into their original positions, they would form a roughly circular unit. In the S190A image and especially S190B (SL4-94-224), linears are observed trending radially from the center of the northernmost volcanic unit. Minor linear patterns within the other two volcanic bodies were also noted. These linears correlate directly with basalt, dacite, and andesite dikes which range in thickness from less than 0.3m to 21m (Anderson, 1973) and thus appear to be good indicators of imagery ground resolution. In the S190A scene, the linears are not as easily distinguished; only larger dikes are visible, thus setting the S190A resolution at approximately 21m. The S190B has already been indicated as having a resolution of 6m or less and is therefore more useful for detecting small structures.

Still another area exhibiting anomalous features is located northwest of Gold Butte, within the Muddy Mountains, in an area known as the Valley of Fire. There is a large arcuate outcrop which is bright red with an anomalous white area roughly in the center. Within the arc, definite bedding planes which trend north to northwest are observed, but the white anomaly appears discordant to any of these planes, suggesting that it is an altered zone rather than a separate rock unit. The outcrop is Jurassic Aztec Sandstone which is characterized by a brick-red color. According to Longwell and others (1965), the original color has been altered in some areas to lavender, buff, and whitish gray due to leaching, especially near large faults. This would account for localized color changes, but the size and shape of the white anomaly suggest larger scale alteration, possibly of a hydrothermal nature. If this is the case, this area may be important as a potential geothermal resource.

In relation to the areas studied, the Skylab data proved very useful both geologically and mineralogically. As evidenced by a study of the Gold Butte area, Skylab imagery would contribute significantly to reconnaissance mapping. Because of the resolution differences, the S190B data is superior to S190A for many purposes. The smaller-scale S190A, however, is useful for detection of larger features. The two types of data are best used together as there are advantages to both.

Many anomalous features corresponded to areas of mineralogical significance which warrant further investigation by ground work as well as imagery analysis.

Q. Southwestern Utah Iron Deposits

The Iron Springs mining district is located approximately 15km west of Cedar City, Utah, within the transition area between the Colorado Plateaus and Basin and Range physiographic provinces on the southern edge of the Escalante Desert (Fig. 13). This study was centered around the mining district which is in southern Iron County in southwest Utah. The area is extensively faulted and intruded by plutonic rocks of probable mid-Tertiary age. Evidence of this age is implied by the monzonite intrusion deforming the Claron Formation which is of probable Eocene age (Granger, 1963). Much of the area is composed of large quantities of silicic volcanic rocks (especially ignimbrites) of middle to late Tertiary age which may be in part contemporaneous with emplacement of the monzonite.

This area is significant in that it has been, and will continue to be, a major source of iron ore for western steel industries. Present reserves are estimated to be more than 300 million tons (Engineering and Mining Journal, 1974). Southwestern Utah is also important as one of the largest undeveloped coal regions in the United States (Robison, 1963).

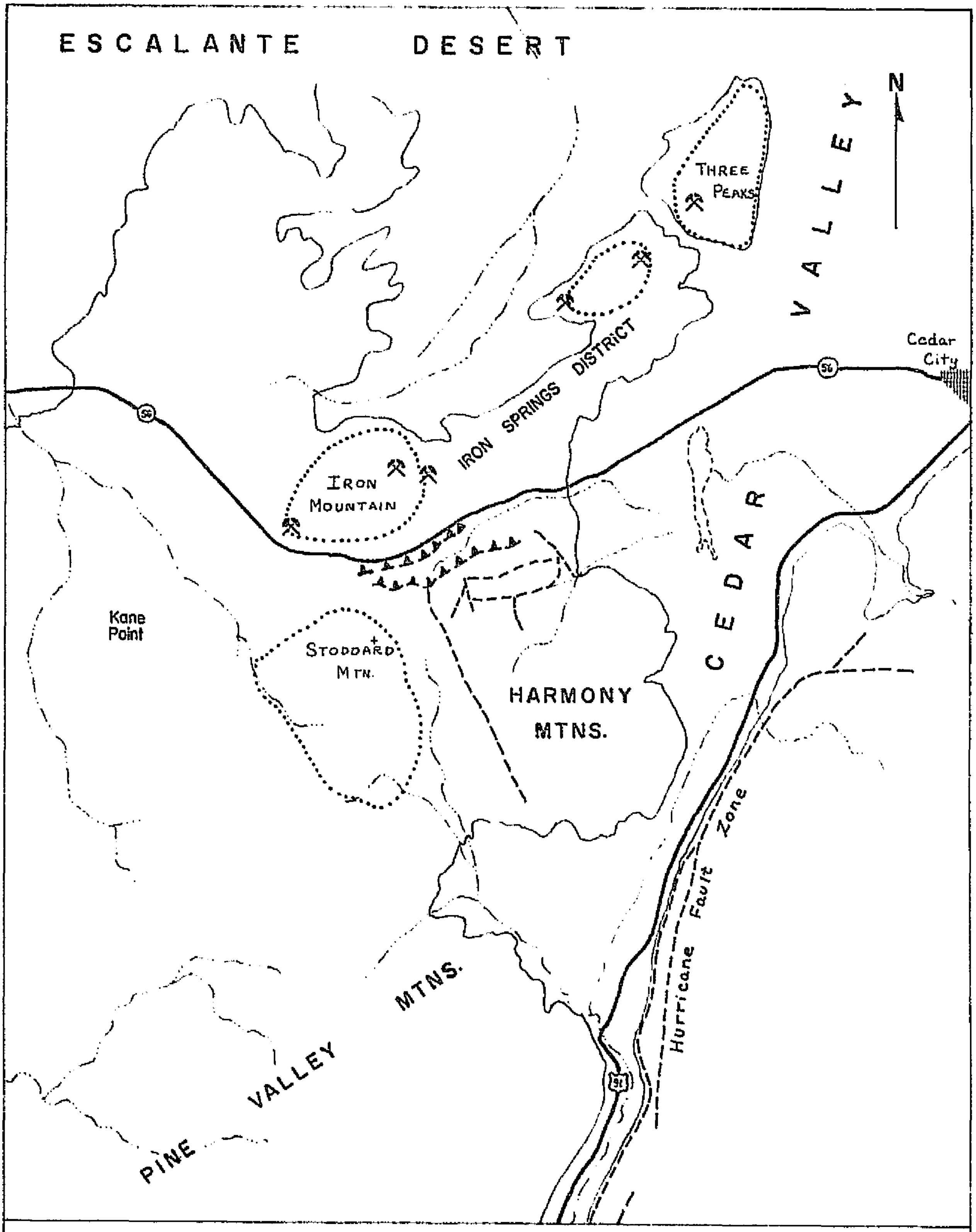


Fig. 13 Location Map of Iron-bearing Plutons, Iron Co., Utah

- Image-derived Pluton Margins
- Faults
- Thrust Faults
- Iron Mines

Scale: 1:250,000

5 0 5 Mi

5 0 5 Km.

Initial features observed in Skylab imagery (SL2-04-015) include four oval-shaped structures west of Cedar City, ranging in size from 3km to 10km in diameter. The three smaller bodies are aligned in a northeast direction (Fig. 13). Large open pit mines are observed on the edges of these bodies and are identified as the major iron mining areas. The arcuate features are found to correlate with porphyritic monzonite plutons intruding late Mesozoic sedimentary rocks (Granger, 1963).

According to Granger, iron ore occurrences within the area are of three types: 1) fissure veins of magnetite in the monzonite stocks, 2) replacement bodies mainly in limestones of the Jurassic Homestake Formation, and 3) alluvial iron-bearing gravels. Ore has been extracted from all three types of deposits. Economically, the most important types of deposits are the replacement bodies. These occur predominantly in limestones of the Homestake Formation at the margins of the intrusive bodies.

The monzonite stocks appear dark to light gray-green in Skylab Ektachrome images. They are surrounded by lighter, reddish beds. Around Iron Mountain's eastern and southern edges, these sedimentary beds conform to the shape of the pluton, thus giving rise to the circular appearance. On the northwest edge of Three Peaks, a white streak about as long as the intrusive body is observed. This white zone correlates with the limestone beds found encircling Iron Mountain, in which most of the replacement mineralization has taken place.

Stoddard Mountain, the fourth and largest monzonite stock is not directly aligned with the other three bodies and is lighter in color, exhibiting a speckled white appearance. A halo circumscribing its eastern boundary evidently correlates with mid-Tertiary sedimentary beds. Because of the similarity of the Stoddard Mountain stock to the other three, iron ore deposits may also be found in association with it. The known major deposits occur as replacement bodies within limestones of the Homestake Formation (Granger, 1963) where it is found in contact with the monzonite. Strata of slightly younger age than these beds are observed in contact with the Stoddard Mountain body on its south border, so that at depth the Homestake Formation is probably in contact with the monzonite and thus may yield iron ore.

Bright red beds apparent in Skylab Ektachrome images correlate with the Cretaceous Iron Springs Formation which occurs in the Iron Springs district as limestones, lenticular conglomerates, and sandstones. This formation is commonly adjacent to the plutonic stocks. The red coloration is due to possible high concentrations of iron. and the beds have been mined for economic minerals. The overlying early Tertiary Claron Formation also displays red coloration near the plutons and consists of limey clastic rocks and freshwater limestone. Limestone beds generally appear light gray to white, especially where exposed in the plateau area and on the south flank of the Pine Valley Mountains. Limestones occur infrequently in the Harmony Mountains and Iron Springs district, but where they do, they are probably often replaced with ore. Only the uppermost red beds outcrop near the plutons, indicating that assimilation of large amounts of iron-bearing Jurassic strata, characteristically thick and extensive in the nearby plateau region, may have been the source of the concentrated iron deposits.

The Stoddard Mountain monzonite body is terminated to the southwest along a northwest-southeast trending linear which appears to be a fault running from the Hurricane Cliffs (formed by Hurricane Fault zone) to the Escalante Desert. The stock is also bounded on the northwest by another linear which trends southwest-northeast between Iron and Stoddard Mountains. This linear terminates at the previously mentioned northwest-trending linear and appears to be offset approximately 5km to the northwest by it, then continues southwest below Kane Point. Although neither of these linears are mapped as faults, study of imagery suggests the likelihood of fracturing and possible offset.

Between Iron Mountain and the Harmony Mountains is an area of thrust faulting apparently due to emplacement of the Iron Mountain pluton. The thrusts cut Tertiary sedimentary beds of the Claron Formation and appear to be expressed in the images as linears. South of, and adjacent to, the thrusting is a peculiar oval-shaped feature, corresponding to a complex fault system.

Other minor bodies of monzonite occur southwest of Iron Mountain intruding Tertiary strata, according to the Geologic Map of Utah (Hintze, 1963). These seem to align in the same general northeast trend, suggesting considerable quantities of granitic rock probably underlie the south and eastern Escalante Desert region. Substantial ore deposits may yet remain buried in this region if the limestones have undergone contact metamorphism and replacement at the peripheries of the porphyritic monzonite stocks.

Further detailed analysis of satellite imagery for delineating possibly significant ore zones should be performed and supported by detailed geophysical work.

R. Lake Mead-Colorado River Region Imagery Evaluation and Comparison: Apollo; ERTS; Skylab S190A, S190B, S192; X-15; U-2

The general region surrounding Lake Mead including southeastern California, southern Nevada, western Arizona, and the channel of the Colorado River is known to be outstandingly interesting geologically and very complex in terms of ages of outcropping rocks spanning Precambrian to late Quaternary time. One notable lithologically and structurally complex area which has been imaged by sensors on almost all space platforms flown by NASA is the Lake Mead, Black Mountain, and Cerbat Mountain region. Since spectacular images have resulted from the many missions flown over this area, very meaningful comparisons can be drawn from a series starting with X-15 and ending with Skylab and ERTS. Two previous sections of this report (p. 84 and p. 91) include studies of portions of this region.

The most essential features observed in synoptic views from spacecraft are very long, broad, and deep fracture zones or "lineaments." We avoid the use of the word "fault" whenever offset cannot be demonstrated. These lineaments are of the greatest significance with respect to their intersections and contact with the deep crust and the upper mantle. The more important areas are those of multiple intersections; of equal importance are the "arcuate" structures which appear in great profusion throughout all imagery. These are believed to be the result of collapsed calderas, fossil craters, and of most importance, evidence of truncated or eroded intrusives of younger rocks into the older sequences of basement terranes. These intrusives are expected to have altered their host rocks producing the usual alteration products such as clays, barite, calcite, silica, and related secondary mineralization. Thus these arcuate structures indicate the potential locations of mineralized areas both of commercial and academic value. In particular, certain special relationships of "arcuates" and lineaments are good indicators of the presence of potentially valuable mineral deposits.

Images were selected from many different remote sensing missions over the Lake Mead region to allow a detailed comparison and relative evaluation of sensor capabilities and their applicability to geologic studies. This area was chosen for the most effective comparison since it has the most diverse coverage available, as well as a wide array of geologic environments. Ten images taken from platforms ranging in altitude from 20 to 920km, showing views of the Lake Mead-Colorado River region are represented in Plates VI through XV (see also Fig. 11, p. 85, and Fig. 12, p. 93). The Colorado River has deeply eroded the Colorado Plateau to produce the Grand Canyon which emerges from the plateau into the Basin and Range province. At this point, the transported sediment is dropped in the relatively still water of Lake Mead (see Plate XI). Hoover Dam, visible in Plate XIII, holds the water in Lake Mead at the point where the river begins its straight southward flow through typical Basin and Range terrain, continuing for the remainder of its course to the Gulf of California. Prior to the construction of the dam in 1933, the river channel was subjected to numerous floods, meanderings, and development of major river valley geomorphology as is strikingly exemplified in the photos used to illustrate this section. This direct southward course is thought to be structurally controlled, and in fact, many major lineament systems have been described in the region, apparently intersecting in the Lake Mead vicinity. The Las Vegas shear zone has been hypothesized to trend southeast through Las Vegas, controlling the deep east-west portion of the Lake Mead basin.

One linear feature of particular interest to this study is the Black Mountain lineament, a straight north-south aligned fracture zone which is the locus of the volcanics forming the Black Mountains immediately east of the Colorado River in westernmost Arizona. Not only is the entire range aligned, but even rock outcrops clearly exhibit the north-south elongated trend.

Another, though not so distinct, linear feature is the New York Mountain lineament striking approximately N30E and intersecting the Black Mountain lineament just south of Hoover Dam. The apparent intersection of these major lineations provides reasons for the structural complexity, active seismicity, recent volcanism, and morphology of the Lake Mead basin. Since the construction of Hoover Dam and filling of the lake, increased seismicity on the order of one magnitude has been recorded to the south and east of the lake basin (Jones, 1944; Carder, 1970). It is believed that a major cause for this activity might be lubrication of the three major fracture zones by water seepage, especially as lake levels rise and fall, injecting water into paths not previously so lubricated.

The scene taken from Apollo 9 (Plate VI) provides an excellent oblique view of the region looking northward between the entire Black Mountain and New York Mountain lineaments. Las Vegas, in the upper center, appears only as a hazy gray spot on the light-colored clays to the west of Lake Mead. Many rock types are not distinctive in this image, although the reddish areas correspond to outcrops of the brilliant Aztec sandstone which typically has a high iron oxide content. The most recent basaltic lava flows appear dark black and sedimentary rocks north of Las Vegas are readily discernible. Areas of vegetation are not as readily identifiable as in other types of film.

Plate VII is a standard ERTS false infrared color composite (scale 1:1,000,000) including Las Vegas, Lake Mead, and Lake Mojave. At the far east edge, the river and tributaries appear light blue due to reflectance of transported sediment which most clearly appears in band 4. The bright outcrops of Aztec sandstone exhibit definite yellow coloration. Detail is apparent in the City of Las Vegas, primarily due to the red reflectance of vegetation. In the folded beds north of Lake Mead, blue and pink colorations correspond to distinct sedimentary beds. The Black Mountains exhibit their linear trend, with some indication of different rock types occurring near Lake Mojave. Arcuate features appear in the Black Mountains, especially in the Lake Mojave region. Linear ranges and alignments parallel to the Colorado River appear throughout the region south of Lake Mead.

A more detailed view of the area is afforded by the Skylab S190A Ektachrome image (Plate VIII). In this scene, some of the major trends of lineations already noted are not so obvious, but the greater resolution allows discrimination of individual linears and the low sun angle casts longer shadows, enhancing the trends, especially those having north-south orientation. Numerous lineations are visible in the Gold Butte region and in the area north of Lake Mead allowing considerable detailed analyses of the structural features in this relatively inaccessible terrain.

Plate IX is a color composite of Skylab S190A black and white bands; the color filters are selected to again provide a false infrared picture. Vegetation (red) is particularly strong in this combination. Cameras numbered 2, 5, and 6 (rolls 26, 29, and 30) in the S190A package were selected and assigned red, green, and blue color filters, respectively. Registration of the bands was not possible over the entire scene at once; Las Vegas was registered, as well as mountains to the west, but detail is lost to the east. Where the scene is well registered, the resolution appears to be comparable to that of the S190A Ektachrome image. The tendency to overexpose the regions containing fine clays, producing an exceptionally high albedo, provides a means for locating clays such as the alteration products of mineralized zones. This is in reality a qualitative "ratioing" technique (Bechtold and Jahns, 1971). The subtle distribution of the iron-rich sedimentary rocks north of Lake Mead is particularly enhanced in this color rendition. The excellent possibilities for rock type discrimination by using various combinations and ratios of S190A films is outstandingly useful, and further study of all combinations and permutations of S190A films should be explored.

One of the most significant results of the entire study has been the evaluation and use of S192 data. The thirteen-channel multispectral scanner experiment provides the most varied potential for combinations of spectral data ever achieved in any single satellite imaging system flown to date. Compositing of various bands can produce very significant results and, we believe, even delineation of many different rock types, lithologic contacts, soil types, vegetation zones, and hydrologic provinces. The almost limitless possibilities of combinations and permutations of the thirteen channels are so great that further discussion would exceed the time limitations of this report.

In Plate X, three of the S192 bands of a scene over Lake Mojave and the Black Mountains have been composited. Band 3 (green region), band 6 (red to near-infrared), and band 11 (mid-infrared) were combined with blue, green, and red color filters, respectively. Of special interest to the compositor is the ease in registering the bands; ticks along the image edge and scan lines coincide precisely. Plate X is the result of enlargement from 70mm film; hence scan lines are easily visible and the image appears somewhat grainy. The resolution, although not sharp, is acceptable; exclusion of details and local noise may be advantageous for lithologic and thermal studies. The primary difficulty with S192 data is the residual conical scan line pattern; however, even in areas of considerable residue, exceptionally useful information can be extracted. More improvement in this scanning technique is highly recommended, and it is believed that the S192 experiment would become one of the outstanding developments of satellite instrumentation.

Sediment from alluvial channels entering Lake Mojave as detected by the short wavelength band 3 (but more obvious in band 2) is visible as a bluish tint in parts of the lake. This is apparently due to agitated water containing sediment-laden runoff from the surrounding alluvial slopes, imaged soon after a storm as checked with weather data (see p. 240).

Particularly significant to geologists is the wide range of color represented in the mountain ranges. The rock types in the Black Mountains are especially prominent and their north-south elongation is conspicuous. Some correlation of coloration with rock types has been discerned. The light browns generally correspond to Precambrian gneiss, the white outcrops (exclusive of clays in drainage basins) to silicic volcanic rocks (especially tuffs), blue-green to andesitic volcanics, and dark brown to Quaternary basalt. Sources of alluvium are indicated by the colors in washes and fan deposits (see also Appendix A, p. 238). This type of false color imaging also emphasizes the presence of clay minerals in basins, drainage channels, or altered zones around mineralized areas as is the case with near-infrared film (2443) or standard false color combinations of ERTS bands.

The image suggests much more lithologic complexity than is indicated by geologic maps (see Fig. 11, p. 85). One notable example is a linear outcrop mapped as Precambrian gneiss east of Lake Mojave; this area exhibits highly variable coloration rather than the expected brown, suggesting the rocks have been altered, though not recorded in detail by the cartographer. The abundance of igneous intrusions mapped nearby give support to this hypothesis.

Only one of many possible composite combinations of S192 can be pictured, hence only a fraction of the data obtainable from S192 imagery is represented. One other S192 scene studied in this project is a strip over the Death Valley region represented by the thermal infrared channel (13) (see "Application of Satellite Imagery to Geothermal Resources Exploration," Appendix A, p. 258). Unfortunately, only a small portion of all S192 data has been processed and the imagery for other areas is virtually unobtainable.

The Skylab imagery found most useful for emphasis of geologic and topographic detail has been the S190B data. Plate XI shows the frame that best covers the Lake Mead region. The detail in this high resolution scene is so great that single track dirt roads are easily visible. Hoover Dam, barely visible at the far left edge of the image (due to loss of resolution in printing), is easily discernible in detail in the original transparency. Details of lineations, alluvial washes, and canyons are exceptional. Even the rock colorations are good, despite the low sun illumination angle. Of greatest importance is the fine detail shown in bedding, jointing, foliation, and minor drainage control, all of which contribute greatly to structural analyses.

Plates XII through XV give examples of lower altitude imaging platforms. The X-15 spacecraft, a highly confidential craft in the 1960's, took a limited number of pictures of the California, Nevada, and Arizona desert region. Plate XII shows one of these unique scenes (utilizing 8443 near-infrared film), viewing Las Vegas and the Colorado River from the north. The linearity of the Black Mountains is again evident and appears to terminate at Lake Mead. The intersection of the New York Mountain lineament is also evident. Again, as is characteristic with near-infrared photography, the clay areas show very high reflectance, hence appear snow-white in this color rendition. Here again is a means for identifying certain clay types and using the spectral data to characterize these mineral zones (Bechtold and Jahns, 1971; Salisbury and Hunt, 1974). When this oblique view was taken, the altitude of the spacecraft was approximately 100km. This view was the first case in which the high reflectance characteristics and their correlation with the spectral response was noted (Hunt and Salisbury, 1970; Bechtold and Jahns, 1971). Also visible is the fine detail in bedding and jointing in the various outcrops. Further investigation should be made into the fact that rocks appearing a more natural brown or tan in the 8443 film previously used now appear blue-gray in the present 2443 film, and whether the former should be utilized for geological studies.

Plates XIII, XIV, and XV are prints enlarged from 70mm U-2 frames taken at altitudes of approximately 20,000m over selected portions of Lake Mead. Hoover Dam is visible in Plate XIII as are details of most roads. The northern Black Mountains appear at the upper edge, and lineations are apparent throughout the range. Trends orthogonal to the main north-south direction are also clearly visible; many of these can be seen in the S190B image but are not as obvious due to the scale difference and illumination angle. Fortification Hill is the conspicuous dark basalt mesa in the center of the U-2 image. Various linears intersect near this feature, some enhanced in the S190B, others more apparent in the U-2 scene.

Plate XIV shows the northern termination of the Black Mountain lineament and details of known fault zones. The Hamblin Bay Fault zone extends diagonally across almost the entire scene and has caused disruption of strata throughout the region. One especially interesting feature is the Hamblin-Cleopatra volcano (Anderson, 1973), a caldera which lies directly west of the Overton Arm of Lake Mead, visible in both Plates XIV and XV. This caldera, of which only one-half is evident, has been dissected and moved by strike-slip faulting (see description, p. 99, and Fig. 12, p. 93). Radial and concentric fractures and linears (often correlating with dikes) are apparent within the semi-arcuate caldera near Overton Arm. These are visible in the S190B as well as the U-2 imagery. The S190B scene particularly emphasizes the coloration differences within the caldera, apparently created by volcanic rocks of varying compositions.

This one volcanic structure permits the most effective comparison of resolution, scale, color balance, and image quality between different imaging platforms. The caldera is an indistinguishable dark mass in Apollo (Plate VI) and the ERTS image

(Plate VII) only gives an indication of the caldera outline. S190A imagery begins to provide resolution of the caldera interior and coloration distinction; S190B provides evidence of radial and tangential structures. Plate XV shows unmistakable lineations but still appears lacking in detail. The resolution of the S190B when magnified to the same scale is, in fact, favorably comparable. Faults evident in the alluvial fans east of the Overton Arm, readily obvious in the S190B, are partially lost in the U-2 amidst the highly reflecting sediments.

Other areas studied which can be compared in the images are the conspicuous outcrops of Aztec sandstone in the Valley of Fire region (p. 100) and the geology of the Gold Butte region (p. 91). By spectral comparison, one may locate small outcrops of this Aztec sandstone west of Las Vegas in the foothills of the Sheep Mountains.

Among the advantages of the Skylab imagery is the collection of clear, detailed frames obtained in winter months over the area. The low sun angle favorable for lineation enhancement is never found in the sun-synchronous ERTS coverage, even in winter months. Oblique views are limited in value, especially for cartographic purposes, and the U-2 scenes are tonally flat.

Each of the image types has its own merits, but the Skylab experiments offer such a diversity of climatic and seasonal conditions, film types, spectral ranges, and resolution that they are especially advantageous for use in geologic investigations. When utilized in their most diverse combinations, Skylab data reveal new and valuable concepts of geology, tectonics, hydrology, and other features, not obtainable from any other remote sensing platform. ERTS provides repetitive frames with good geodetic correlation and the advantage of compositing standard sets of spectral bands. If Skylab could be operated continuously, like ERTS, and the data rate realistically managed, much more essential information concerning the earth's crust would be available than has been acquired by any single mission flown to date.

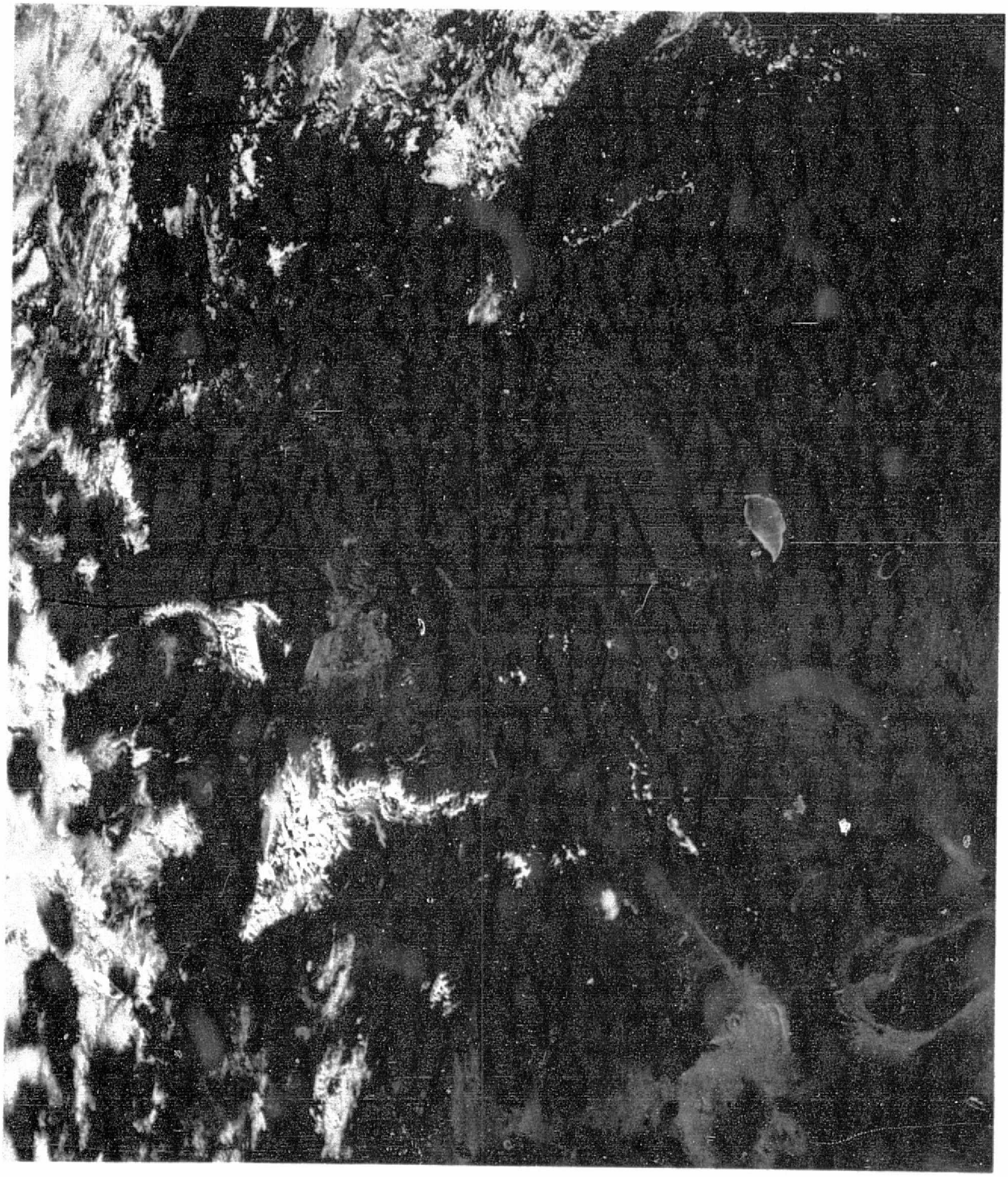


PLATE VI Apollo AS9-20-3135, March 12, 1969.
Oblique view of Lake Mead region.

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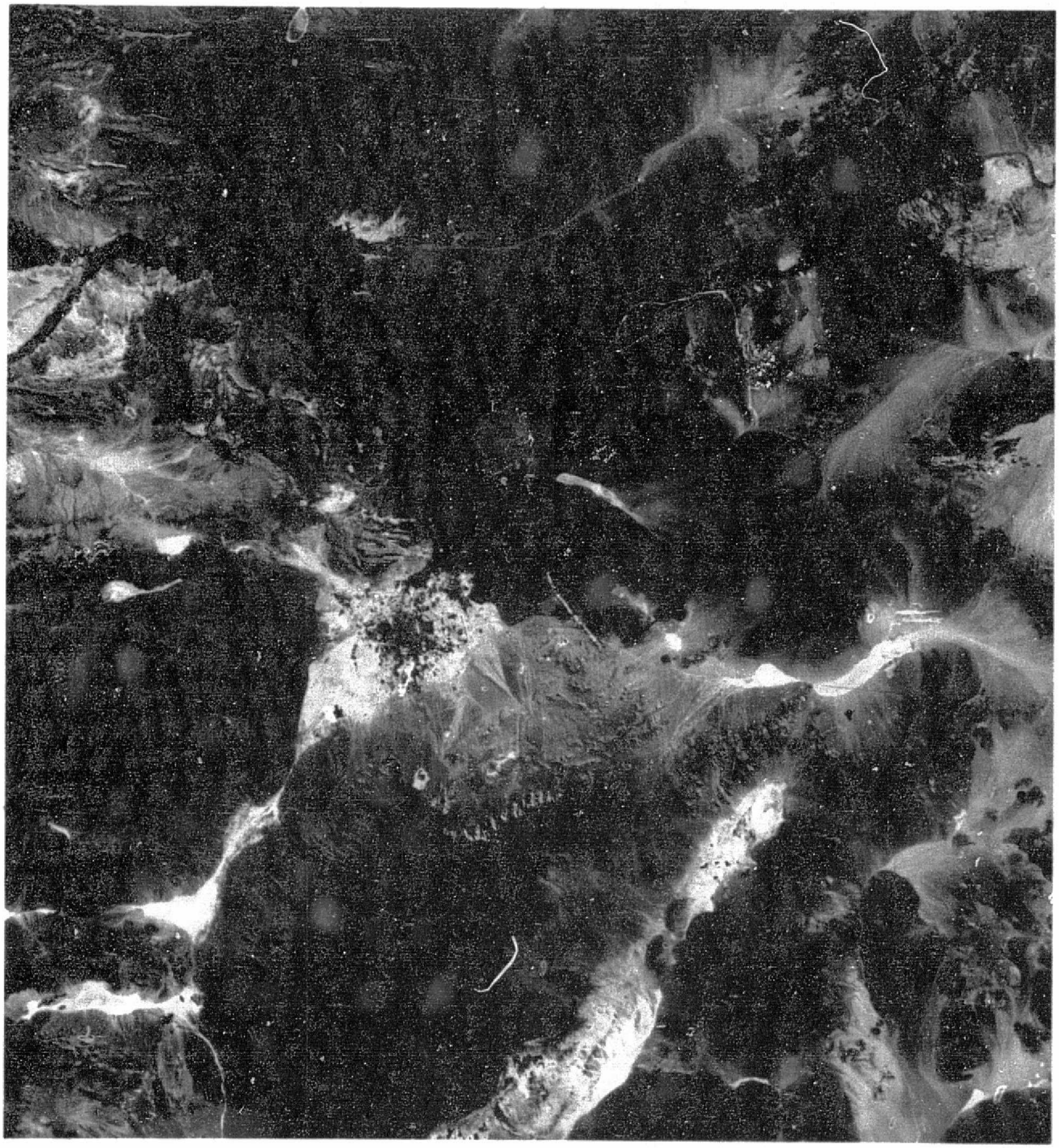

PLATE VII ERTS 1052-17490, September 13, 1972.
False infrared color composite. Band 4 (blue), Band 5 (green), Band 7 (red). Scale 1:1,000,000.

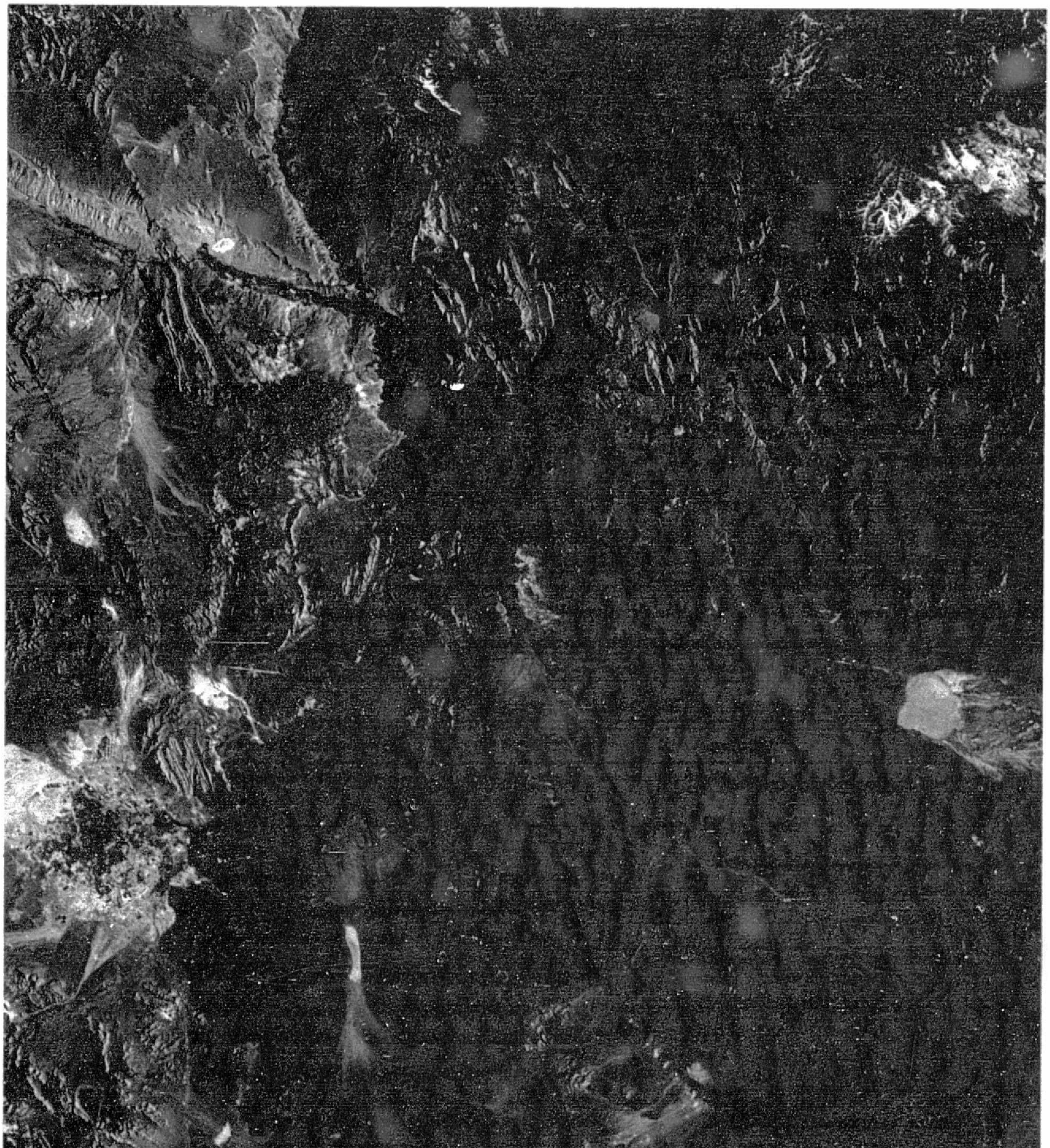

PLATE VIII Skylab SL4-4B-029, S190A Ektachrome, January 2, 1974. Approximate scale 1:800,000.

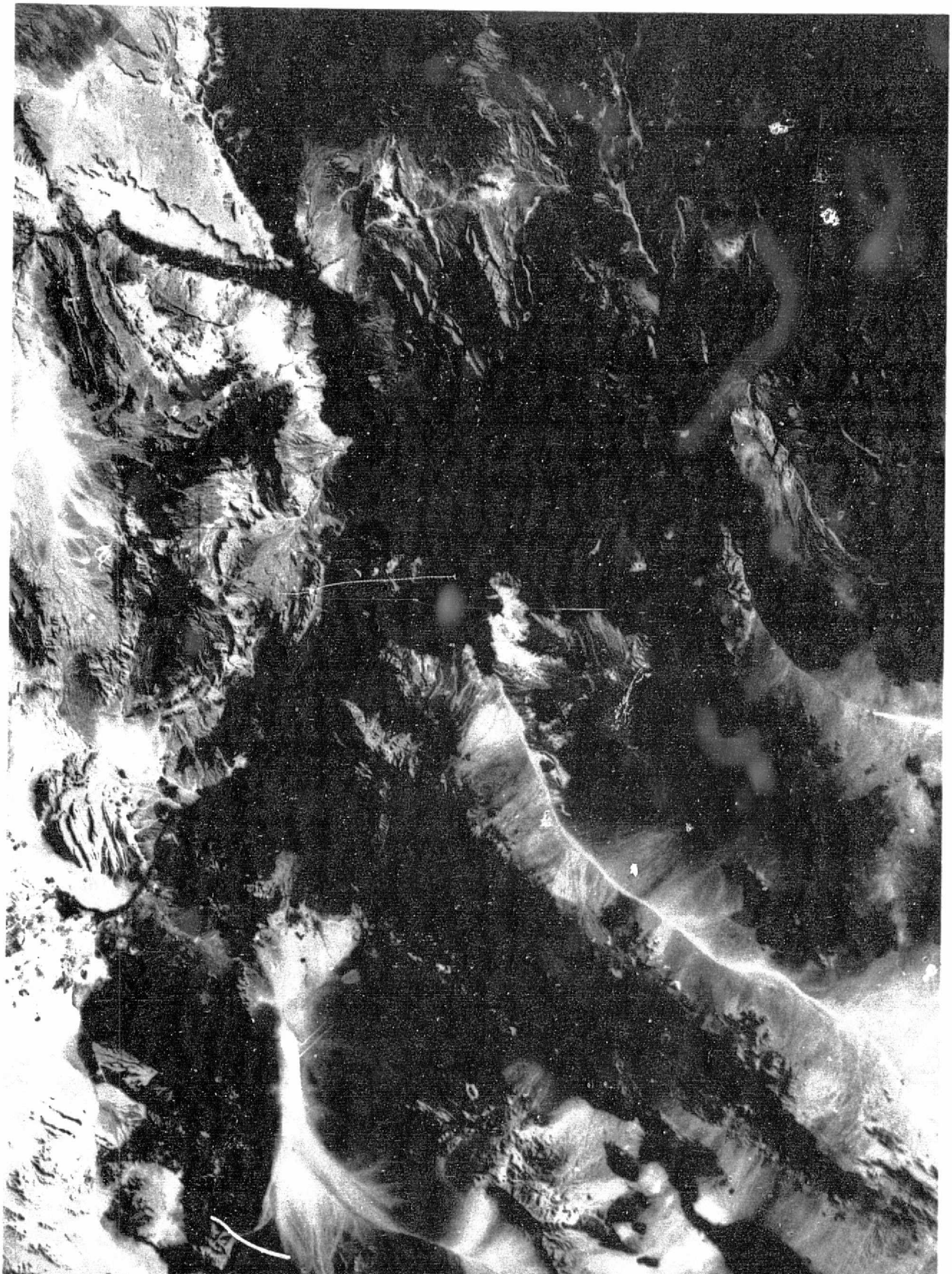

PLATE IX Skylab SL3-26/29/30-059, S190A false infrared color composite, November 8, 1973, Roll 26 (red), Roll 29 (green), Roll 30 (blue). Approximate scale 1:600,000.

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PLATE X Skylab S192 (SL2, orbit 3) multispectral scanner color composite over Lake Mojave, November 8, 1973. Band 3 (blue), Band 6 (green), Band 11 (red). Approximate scale 1:400,000.

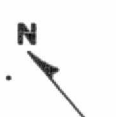

PLATE XI Skylab SL4-94-224, S190B Ektachrome, January 2, 1974. Approximate scale 1:600,000.

PLATE XII X-15 oblique, looking southeast from Las Vegas (frame 3143). Summer, 1965.

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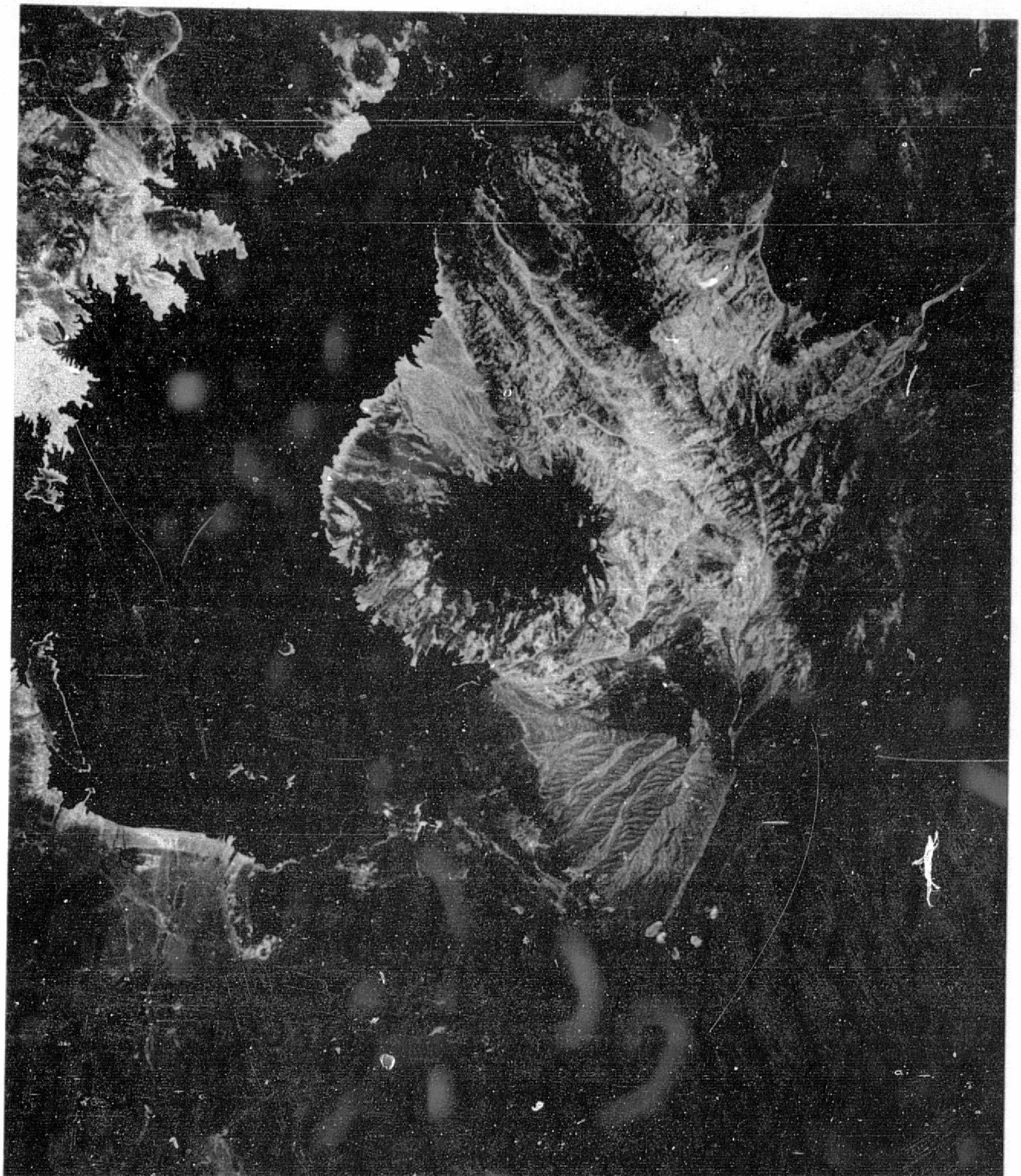

PLATE XIII U-2 infrared, flight 72-077, frame 104, May 12, 1972. Hoover Dam in lower center. Approximate scale 1:130,000.

PLATE XIV U-2 infrared, flight 72-077, frame 106, May 12, 1972. Northern Black Mountains and Overton Arm. Slightly oblique.

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PLATE XV   U-2 infrared, flight 72-098, frame 101, June 14, 1972. Overton Arm of Lake Mead. Approximate scale 1:130,000.

IV. APPLICATIONS OF SKYLAB IMAGERY TO RESOURCES EXPLORATION

This analysis of potential applications of Skylab imagery is based on investigations of individual test sites that have been discussed in previously submitted interim progress reports or in Section III. These investigations have been conducted in a variety of tectonic, geologic, and physiographic environments and results suggest that the methodology is applicable to resource exploration in most areas of the world.

This section represents a brief summary of ways in which Skylab imagery can be effectively utilized for resources exploration and evaluation. A more comprehensive discussion of applications is presented through the 18 examples of site investigations in Section III.

Geothermal Resources

Known geothermal reservoirs are directly related to recent and active volcanism, recent faulting, and geochemical and geophysical anomalies. Careful studies of Skylab imagery reveal that many of these geologic characteristics distinctly appear on imagery as do anomalous areas probably associated with, or directly caused by, geochemical and geophysical changes near a geothermal system. Arcuate anomalies, for instance, may represent buried intrusive granitic stocks or expressions of associated hydrothermal solutions. Other similar features, less obvious color anomalies, and reflective changes from rocks and soils often indicate rock products altered by thermal waters.

Since the most economical producing geothermal reservoirs are usually those that convey solutions with siliceous deposition characterized by relatively high temperatures, siliceous volcanism and hydrothermal activity present important targets for exploration. Skylab image analysis performs this significant step by presenting structural detail and providing for mapping of volcanic terrane. Distribution of volcanic rocks is reasonably well known in many areas, but there still remain regions that have been mapped only in a reconnaissance fashion. Volcanic rocks of many types can be discriminated by imagery study, and siliceous phases when either concentrated or widespread and disseminated can be discerned. Examples are the study areas of Saline Valley (p. 34), Coso Hot Springs (p. 43), Greenwater Range (p. 62), and Lava Mountains (p. 38).

Even without surface manifestations such as springs and fumaroles, image analysis supplies indirect evidence suggesting areas with high probability of geothermal potential. Fracture patterns related to intrusive bodies can be of major importance and are visible in bedrock, or may be manifested as anomalous vegetation zones, just as seepage of meteoric waters into fault zones creates a healthy, yet restricted, plant community.

Additionally, image studies indicate basement rock fracture patterns that are only subtly expressed at the surface through the overlying rocks and sediments. Such fractured rock might provide favorable hydrologic conditions for geothermal reservoirs, especially when in proximity to active or quiescent volcanism.

The above discussion was part of an article which appeared in the May, 1975, issue of Geothermal Energy magazine (see Appendix A, p. 258).

Petroleum Resources

Both the reconnaissance and detailed phases of petroleum exploration programs can be aided immeasurably by utilizing two principal aspects of Skylab imagery. Regional patterns of an exploration province can be studied through the synoptic qualities of the imagery and specific areas of interest can be examined using the high resolution characteristics of the imagery, particularly S190B.

Regional analysis of a potential hydrocarbon resource area includes studies of regional lithologic and structural relationships. During this phase, Skylab data can be used to: 1) map lithology, 2) delineate major structural features such as axes of large anticlines and extensive fracture systems, 3) describe the limits of basins, 4) examine trends and patterns of producing wells and fields, and 5) suggest specific areas of interest to explore in detail using conventional geology and geophysics as well as high-resolution remote-sensing techniques.

Once attention has been focused on a specific area of interest, information on small-scale structures -- minor anticlines and faults -- can be gathered from analysis of high-resolution imagery such as S190B. As exemplified by the San Joaquin Valley oil fields of central California, faults are frequently oil-field bounding features. Some of these faults can be accurately identified and located from space, providing a significant contribution to petroleum exploration. This type of study has been done using ERTS data, but little with Skylab in the test site due to limited coverage.

A principal use of high-resolution imagery is to extend known faults or axial traces of anticlines and suggest areas that may contain additonal petroleum accumulations. S190A imagery is excellent for this task as it has sufficient resolution to locate short, discontinuous fault traces accurately with respect to roads; yet it retains synoptic view which permits visualization of small-scale structural trends.

No S190B imagery was available over the only major oil fields in our test area, thus severely limiting study of their characteristics. However, from analysis of the data over other areas and evaluation of the geologic features than can be discerned on S190B imagery, it is expected that many structures and lithologies pertinent to exploration for hydrocarbons can be analyzed on S190B imagery.

The "hazy anomalies" reported by many investigators from analysis of ERTS imagery and suspected to be related to hydrocarbon accumulations were not noted in the one Skylab S190A image of the San Joaquin oil fields. Arcuate features were observed, however, apparently related to topographic effects. Hazy anomalies were evaluated from analysis of ERTS imagery of the area, because the seasonal vegetative cover and the higher resolution of Skylab do not permit visualization of the anomalies.

Water Resources

Evidence for potential water resources that can be discerned from analysis of Skylab imagery is indirect. Although the high-resolution S190B data can permit direct observations of some features, such as vegetation concentrations near springs in arid lands, determination of basin geometry is a principal contribution of Skylab imagery analysis. Large and small-scale structures such as faults, grabens, and depressions can be noted in the imagery (see Crater Flat section, p. 91). General rock and soil types can be discriminated (aided by field checks) and aquifers such as sandstones, carbonates, and coarse-grained alluvium can be recognized and distributions mapped. Drainage patterns can be delineated very accurately; thus the groundwater cycle can be modeled from the watershed area to movement of water on the surface to potential reservoirs and traps.

In the arid areas of the southwest United States, concentrations of vegetation are unusual and indicate locations of water, either surface or subsurface. Vegetation can be detected in Skylab imagery, particularly color infrared films and false-color composites (S190A). Travertine deposits indicative of percolating mineralized waters can be detected in Skylab imagery as anomalously high reflectances, especially in the Death Valley region where

Grapevine Springs and others appear distinct (also see section on Saline Valley, p. 34).

Structural control of water resources can be analyzed using imagery. Faults that act as conduits or as impermeable zones to limit horizontal fluid migration can be described (Greenwater Valley, p. 61). In alluvial areas, for example, faults that have created hydrological traps are apparent because the soils differ in spectral response across the fault. Linear vegetation patterns suggest faults that are acting as conduits for subterranean accumulations of water (see p. 74).

Mineral Resources

Almost every aspect of the geologic or tectonic environment that can be evaluated from analyses of Skylab S190A, S190B, and S192 imagery is applicable to exploration for mineral deposits since economic minerals occur in a wide variety of conditions.

As with petroleum, mineral resource exploration is guided by imagery during both the regional and detailed phases. The expressions of a variety of geologic and structural features at Skylab's synoptic scale is valuable, as features not apparent or efficiently studied at the scale of conventional ground-based mapping can be evaluated for significance to potential mineral deposits. Skylab data can provide the explorationist a basis for selecting from a large area, a series of anomalies or features that can be economically explored by ground geology and geophysics. Examples are the reports presented in section III: Inyo Mountains

(p. 19), Hunter Mountain (p. 27), Argus Range (p. 30), Greenwater Mountains (p. 62), Benton Range (p. 72), Goldfield (p. 75), Black-Cerbat Mountains (p. 84), and Southwest Utah (p. 101).

Indirect evidence for mineral deposits supplied by Skylab imagery analyses includes: 1) structural control of ore deposits -- faults, fractures, shear zones, joints, schistosity, etc.,; 2) rock or soil color anomalies that may represent alteration products, a buried intrusive body, or the presence of characteristic minerals; 3) topographic expressions of alteration or mineralization such as resistant dikes, eroded areas, or arcuate plutons; 4) lithologic mineral associations; and 5) regional or near-regional trends of known mineral deposits.

V. CONCLUSIONS AND RECOMMENDATIONS

A great number of significant contributions to resource exploration programs can be produced from careful analyses of Skylab S190A, S190B, and S192 imagery. The data can be effectively utilized for all phases of exploration activities from regional evaluations and reconnaissance-type work to detailed ground geologic studies. Contributions of the data include: 1) regional analysis of structural and lithologic trends and patterns, 2) delineation of critical areas or anomalies within the region that are determined to be of interest and worthy of subsequent detailed work, and 3) examination of geologic features and lithology within the delineated specific areas.

Analysis of Skylab imagery can assist in the mapping of rock and soil types, structural features, and vegetation and drainage patterns which are important to every type of geologic investigation.

Skylab imagery represents a significant advance for remote sensing methodology. The combination of synoptic view, high resolution, color acuity, and varied spectral bands cannot be duplicated by any other single orbital remote sensing package. Furthermore, many of the qualities such as resolution of the imagery are comparable to qualities exhibited by high-altitude aircraft imagery.

One disadvantage of S190A imagery is the unconventional scales of the products supplied by NASA. More conventional scales, such as 1:500,000 (similar to S190B 2X enlargements) or 1:1,000,000 (ERTS) are recommended.

Analyses of Skylab imagery over a wide variety of terrane has resulted in the recognition of color, linear, and arcuate anomalies that have been interpreted to be geologic in origin, and spatially and genetically related to known mineral, geothermal, water, and petroleum resources. Many anomalies that have been detected in the imagery have not been investigated as to significance to resources because of lack of time. Numerous areas that have been analyzed with Skylab and supportive data and suspected to contain economic resources should be investigated more thoroughly. Sufficient time -- particularly field time -- has not been available to completely evaluate the potential of these significant areas. We recommend that additional investigations be initiated to accomplish this work. Areas of primary importance include:

Hunter Mountain, California: possible copper mineralization

Greenwater Range-Black Mountains, California: possible copper porphyry

Lava Mountains, California: potential geothermal resource

Coso Hot Springs, California: extension of KGRA located

Black-Cerbat Mountains, Arizona: extensions of gold/lead deposits

Goldfield, Nevada: extension of gold ore bearing zone

Additional Skylab EREP-type sensor platforms and packages are recommended for continued, detailed investigations of crustal structure related to resources. Areas not covered by Skylab 2, 3, or 4 tracks should be imaged. Repetitive coverage of many areas of high priority should be achieved. Stereoscopic coverage should be accomplished for all areas. We strongly recommend S192 data be processed and distributed to the user community, since its value to industry and research is undoubtedly great.

One of the most significant advantages of remote sensing from Skylab is the greatly decreased costs in manpower and time, especially in the initial exploration phases as well as in field work. These benefits could mean a real and dramatic change for industry, which is still utilizing older, more orthodox exploration methods.

To summarize: Skylab EREP imagery is valuable for investigations of undiscovered resources such as mineral, geothermal, water, and petroleum. Analysis of the imagery and supporting data can contribute immeasurably to the success of exploration programs.

VI. PROGRAM SUMMARY

Summary of Significant Results

Many significant results have been achieved during this investigation. A substantial number of important findings have been mentioned in interim progress reports previously submitted to NASA. A brief listing of some results determined to be significant by BESTEC investigators is included below. More comprehensive discussions can be found in other sections of this final report or in interim reports compiled in Appendix A.

Imagery -- Methods of Enhancement, Analysis, Interpretation

Film positives (70mm) from all six S190A multispectral photographic camera stations for any one scene can be registered and analyzed in a color additive viewer.

Similarly, film chips (70mm) from all thirteen channels of the S192 multispectral camera can be registered and analyzed in a viewer.

70mm contact negative films can be composited with contact positive films of the same, or different, bands in a viewer to produce an image especially useful for detection and analyses of major, long-length linears.

Using a multispectral viewer, S190A and B films can be projected directly onto published geologic and topographic maps at scales as large as 1:62,500 (using S190A 4X enlargements) and 1:24,000 (using S190B 2X enlargements) without significant loss of detail. Accurate location of observed anomalies is insured and accessibility of anomalies via roads can be ascertained, thus reducing time necessary for field reconnaissance surveys.

High quality color prints produced from S190A and S190B Ektachrome and color infrared films are frequently as useful as transparencies for geologic investigations, particularly during field work. Studies of S190B films projected to 1:24,000 indicate prints at that scale will retain excellent color quality and resolution.

The capability of certain S190A and B frames to be viewed stereoscopically is an important advantage over other space imagery. A number of fault scarps not identified during monoscopic viewing have been detected in northwestern Arizona using a stereoscope to analyze S190A imagery.

S190B films and prints permit the detection of faults, fractures, and other linear features not visible in any other space imagery.

S190A films and prints permit more subtle color variations to be detected than is possible with any other space imagery.

Linear features as narrow as 4m (12 feet) have been delineated in situations of high contrast using S190B films.

The scale (1:500,000) of 2X S190B enlargements is especially valuable for reconnaissance-type studies as many published reference maps -- geology, geophysics, topography -- are available at that scale, as are ERTS frames projected in a conventional color additive viewer.

Successful enhancement of imagery has been achieved using contact duplicating films. A very simple and inexpensive technique using a standard office copier to produce machine copies of imagery has been employed.

Applications of Imagery to Geologic Investigations

Skylab S190A and S190B imagery can be utilized effectively for all phases and types of geologic investigations. Preliminary geologic reconnaissance of an area can be advanced significantly by using Skylab imagery to supplement and correct existing geologic and topographic maps and to decrease the number of areas requiring detailed geologic studies. Imagery, particularly S190B, can also be valuable during field work as a map base and as an analytical tool.

Studies have indicated that most features important to geologic investigation can be discerned on Skylab 190A or B imagery. Furthermore, the synoptic view of Skylab imagery permits local geologic features to be studied in relation to regional trends or patterns.

S192 MSS imagery may be useful for rock-type discrimination studies and delineation of linear patterns and arcuate anomalies. Sediment distribution in Lake Mojave has been detected in S192 films using channels in the violet-blue part of the spectrum (see Plate X, p. 122).

The majority of arcuate, linear, and color anomalies noted in Skylab imagery correlate with geologic features that have been interpreted to be spatially or genetically related to known resources for many sites in the test area. Most correlations were made from studies of existing maps and reports, but a significant number have been established from field reconnaissance work. Thus, anomalies noted in imagery can be located on the ground and interpreted.

The geologic environments of most known resource sites in the test area can be evaluated from analysis of space imagery. For many sites, areas to explore for extensions of present resources can be suggested.

A study of S190A and B images of the northern Panamint Range, California, revealed a prominent arcuate structure 8 to 10km in diameter. This structure exhibits topographic, vegetative, and color anomalies having high correlation with mineralized zones, copper deposits in particular. Field reconnaissance has confirmed this interpretation (Hunter Mountain report, p. 27).

Near the abandoned townsite of Greenwater, Death Valley area, field examination of color anomalies and linears interpreted to be alteration zones and fractures, respectively, has resulted in the conclusion that copper deposits are localized at intersections of the two features.

Anomalous color reflectances and arcuate color patterns in the Lava Mountains area, California, were interpreted to be andesitic volcanic rocks altered by hydrothermal fluids. The area may represent a potential geothermal resource.

Large numbers of arcuate and linear features have been noted in Skylab imagery of northwestern Arizona and are spatially related to known mineral deposits. Areas likely to contain additional deposits have been suggested from imagery studies.

Examination of the Coso Hot Springs, California, KGRA in space imagery has suggested numerous areas of anomalous geothermal activity that should be explored for possible additional geothermal resources.

Accomplishments

Interim Progress Reports

Fourteen progress reports entitled "An Evaluation of Skylab (EREP) Remote Sensing Techniques Applied to Investigations of

Crustal Structure" have been submitted in accordance with specifications of NASA Contract NAS9-14235 (see Appendix A).

Monthly Reports, BESTEC Nos.:

101-M1-1/75:	1-31 July 1974
101-M2-1/75:	1-31 August 1974
101-M3-2/75:	1-31 October 1974
101-M4-3/75:	1-30 November 1974
101-M5-6/75:	1-31 January 1975
101-M6-6/75:	1-28 February 1975
101-M7-8/75:	1-30 April 1975
101-M8-8/75:	1-31 May 1975
101-M9-8/75:	1-30 June 1975
101-M10-8/75:	1-31 July 1975

Quarterly Reports, BESTEC Nos.:

101-Q1-2/75:	1 July - 30 September 1974
101-Q2-8/75:	1 January - 31 March 1975

Semiannual Report, BESTEC No.:

101-SA-6/75: 1 July - 31 December 1974

Milestone Report, BESTEC No.:

101-S-2/75: 1 July 1974 - 30 June 1975

Publications

Reynolds, J. T., and Wagner, C. G., 1975, Application of satellite imagery to geothermal resources: Geothermal Energy, v. 3, no. 5, p. 45-54.

Bechtold, I. C., Reynolds, J. T., and Wagner, C. G., 1975, Application of Skylab imagery to resource exploration in the Death Valley region: NASA Earth Resources Survey Symposium, Houston, Texas; Proceedings, NASA TM X-58168, JSC-09930, v. 1B, p. 665.

Bechtold, I. C., Wagner, C. G., and Reynolds, J. T., 1975, Implications of Skylab (EREP) imagery for resources exploration in Arizona: (Abs.) EOS/American Geophysical Union, June 1975.

Bechtold, I. C., Wagner, C. G., and Reynolds, J. T., 1975, Utilization of Skylab S192 satellite imagery for geological investigations: (Abs.) Abstracts with Programs for 1975 Annual Meeting of the Geological Society of America, v. 7, no. 7, p. 993.

Presentations

Wagner, C. G., April 1975, Applications of space imagery to earth resources exploration: Geography Dept., California State University at Fullerton.

Bechtold, I. C., April 1975, Remote sensing, including space imagery, applied to earth resources: Graduate School, Earth Sciences Dept., Stanford University.

Bechtold, I. C., April 1975, The use of space imagery for geologic interpretation, an overview: Society of Experimental Paleontologists and Mineralogists (SEPM), 50th Annual Meeting of the Pacific Sections of AAPG, SEG, and SEPM, Long Beach.

Bechtold, I. C., May 1975, Earth resources observed from space satellites: San Clemente Kiwanis Club.

Bechtold, I. C. (Presenter), Reynolds, J. T., and Wagner, C. G., June 1975, Application of Skylab imagery to resource exploration in the Death Valley region: NASA Earth Resources Survey Symposium, Houston.

Bechtold, I. C. (Presenter), Wagner, C. G., and Reynolds, J. T., June 1975, Implications of Skylab (EREP) imagery for resource exploration in Arizona: 56th Annual Meeting of the American Geophysical Union, Washington, D. C.

Bechtold, I. C., July 1975, Satellite communications and imagery -- a new dimension in resource and energy exploration: The "50" Club of California, Inc., Los Angeles.

Bechtold, I. C., August 1975, Space imagery -- a reconnaissance tool for resource exploration: South Coast Geological Society, Tustin.

Bechtold, I. C. (Presenter), Wagner, C. G., and Reynolds, J. T., October 1975, Utilization of Skylab S192 satellite imagery for geological investigations: Annual Meeting of the Geological Society of America, Salt Lake City.

Field Reconnaissances

September	1974, Mojave Desert, Granite Mountains, California
November	1974, Death Valley region, Mojave Desert, California
February	1975, Castle Mountains, Mojave Desert, California
March	1975, Inyo Mountains, California
April	1975, Death Valley-Mojave Desert, California
April	1975, Black-Cerbat Mountains, Arizona
May	1975, Lava Mountains, California

Meetings - Conferences

July 1974, Skylab EREP Principal Investigators' Data Meeting: Houston, Texas.

August 1974, State of California Geothermal Resources Board: Santa Rosa and Geysers Geothermal Field, California.

September 1974, NSF Conference on Research for the Development of Geothermal Energy Resources: Pasadena, California.

March 1975, 41st Annual Meeting of the American Society of Photogrammetry: Washington, D. C.

March 1975, 71st Annual Meeting of the Cordilleran Section of the Geological Society of America: Los Angeles, California.

May 1975, Second United Nations Symposium on the Development and Use of Geothermal Resources: San Francisco, California.

June 1975, NASA Earth Resources Survey Symposium: Houston, Texas.

June 1975, 56th Annual Meeting of the American Geophysical Union: Washington, D. C.

July 1975, State of California Geothermal Resources Board: Sacramento, California.

Data Distribution

Dissemination of a substantial amount of imagery, information, and technology pertaining to the Skylab Earth Resources program has been accomplished through discussions, cooperative investigations, and presentations with individuals and organizations. A partial list includes:

Arizona Bureau of Mines
Bureau of Reclamation, Davis Dam Field Division
California Division of Mines and Geology
California Earth Science Corporation
California Academy of Sciences
University of California, Berkeley
University of Utah
NASA, Ames Research Center
Eastman Kodak Company

Nevada Bureau of Mines
University of Minnesota
U. S. Bureau of Mines
U. S. Geological Survey
Whittier College
American University, Washington, D.C.
West German Geological Survey, Hannover, Germany

Personnel

The following personnel have been members of the research staff assigned to execute Contract NAS9-14235.

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VII. REFERENCES

Anderson, D.N., and Hall, B.A., eds., 1973, Geothermal exploration in the first quarter century: Geothermal Resources Council Special Report No. 3, p. 117-144.

Anderson, R.E., 1973, Large-magnitude late Tertiary strike-slip faulting north of Lake Mead, Nevada: U.S. Geol. Survey Prof. Paper 794, 18p.

Andreasen, G.E., and Petrafeso, F.A., 1963, Aeromagnetic map of the east-central part of the Death Valley National Monument, Inyo County, California: U.S. Geol. Survey Map GP-428.

Arizona Bureau of Mines, 1969, Mineral and water resources of Arizona: Bull. 180, 638p.

Ashley, R.P., and Keith, W.J., 1973a, Geochemical map showing distribution and abundance of copper in silicified rocks, Goldfield mining district, Esmeralda and Nye Counties, Nevada: U.S. Geol. Survey Map MF-474.

Ashley, R.P., and Keith, W.J., 1973b, Geochemical map showing distribution and abundance of gold in silicified rocks, Goldfield mining district, Esmeralda and Nye Counties, Nevada: U.S. Geol. Survey Map MF-475.

Ashley, R.P., and Keith, W.J., 1973c, Geochemical map showing distribution and abundance of lead in silicified rocks, Goldfield mining district, Esmeralda and Nye Counties, Nevada: U.S. Geol. Survey Map MF-476.

Ashley, R.P., and Keith, W.J., 1973d, Geochemical map showing distribution and abundance of mercury in silicified rocks, Goldfield mining district, Esmeralda and Nye Counties, Nevada: U.S. Geol. Survey Map MF-477.

Ashley, R.P., and Keith, W.J., 1973e, Geochemical map showing distribution and abundance of silver in silicified rocks, Goldfield mining district, Esmeralda and Nye Counties, Nevada: U.S. Geol. Survey Map MF-479.

Ashley, R.P., 1974, Goldfield mining district: Nevada Bur. Mines and Geology Report 19, p. 49-66.

Atomic Energy Commission and U.S. Geological Survey, 1970, Preliminary reconnaissance for uranium in Mohave County, Arizona, 1952 to 1956: U.S. Atomic Energy Commission Division of Raw Materials, RME-158, 173p.

Austin, C.F., Austin, W.H., Jr., and Leonard, G.W., 1971, Geothermal science and technology a national program -- Coso thermal area: Naval Weapons Center, China Lake, California, 95p.

Averitt, P., and Threet, R.L., 1973, Geologic map of the Cedar City quadrangle, Iron County, Utah: U.S. Geol. Survey Map GQ-1120.

Bailey, E.H., 1962, Mercury in the United States: U.S. Geol. Survey Mineral Investigations Resource Map MR-30.

Bateman, P.C., Pakiser, L.C., and Kane, M.F., 1965, Geology and tungsten mineralization of the Bishop district, California: U.S. Geol. Survey Prof. Paper 470, 208p.

Beal, L.H., 1963, Investigation of titanium occurrences in Nevada: Nevada Bur. Mines Report 3.

Bechtold, I.C., Liggett, M.A., and Childs, J.C., 1972, Structurally controlled dike swarms along the Colorado River, northwest Arizona and southern Nevada (Abs.): NASA-CR-128290, E72-10192.

Bechtold, I.C., Liggett, M.A., and Childs, J.C., 1973a, Regional tectonic control of Tertiary mineralization and Recent faulting in the southern Basin-Range province -- an application of ERTS-1 data: ERTS-1 Symposium presentation, Goddard Space Flight Center, Greenbelt, Md., March.

Bechtold, I.C., Liggett, M.A., and Childs, J.C., 1973b, Remote sensing reconnaissance of faulting in alluvium, Lake Mead to Lake Havasu, California, Nevada and Arizona -- an application of ERTS-1 imagery: Assoc. Engin. Geologists, Special Publication, October, 5p.

Bingler, E.C., and Bonham, H.F., Jr., 1973, Reconnaissance geologic map of the McCullough Range and adjacent areas of Clark County, Nevada: Nevada Bur. Mines and Geology, Map 45.

Bishop, C.C., compiler, 1963, Geologic map of California, Needles sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Burchfiel, B.C., 1969, Geology of the Dry Mountain quadrangle, Inyo County, California: Calif. Div. Mines and Geol. Special Report 99, 19p.

California Division of Mines and Geology, 1966, Mineral resources of California: Calif. Div. Mines and Geol. Bull. 191.

Carlisle, D., and Cleveland, G.B., 1958, Plants as a guide to mineralization: Calif. Div. Mines and Geol. Special Report 50, 31p.

Carlson, J.E., and Willden, R., 1968, Transcontinental geophysical survey (35°-39°N) geologic map from 112°W longitude to the coast of California: U.S. Geol. Survey Misc. Geologic Investigations Map I-532-C.

Chapman, R.H., Healey, D.L., and Troxel, B.W., compilers, 1971, Bouguer gravity map of California, Death Valley sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Clark. M.M., 1973, Map showing recently active breaks along the Garlock and associated faults, California: U.S. Geol. Survey Misc. Geologic Investigations Map I-741.

Clark, W.B., 1970, Gold districts of California: Calif. Div. Mines and Geol. Bull. 193.

Clarke, F.W., 1924, The data of geochemistry : U.S. Geol. Survey Bull. 770, 841p.

Clements, T., 1973, Geological story of Death Valley: Death Valley '49ers, Inc., publication No. 1, 62p.

Cornwall, H.R., and Kleinhampl, F.J., 1961, Geology of the Bare Mountain quadrangle, Nevada: U.S. Geol. Survey Map GQ-157.

Crowder, D.F., Robinson, P.F., and Harris, D.L., 1972, Geologic map of the Benton quadrangle, Mono County, California and Esmeralda and Mineral Counties, Nevada: U.S. Geol. Survey Map GQ-1013.

Crowder, D.F., and Ross, D.C., 1973, Petrography of some granitic bodies in the northern White Mountains, California-Nevada: U.S. Geol. Survey Prof. Paper 775, 28p.

Davis, G.A., 1973, Relations between the Keystone and Red Spring thrust faults, eastern Spring Mountains, Nevada: Geol. Soc. Am. Bull., v. 84, p. 3709-3716.

Davis, G.A., and Burchfiel, B.C., 1973, Garlock Fault: an intra-continental transform structure, southern California: Geol. Soc. Am. Bull., v. 84, p. 1407-1422.

DeDecker, M., 1966, Mines of the eastern Sierra: Glendale, Calif., La Siesta Press, 72p.

Dibblee, T.W., Jr., 1967, Areal geology of the western Mojave Desert, California: U.S. Geol. Survey Prof. Paper 522, 153p.

Dings, M.G., 1951, The Wallapai mining district, Cerbat Mountains, Mohave County, Arizona: U.S. Geol. Survey Bull. 978-E, p. 123-163.

Donath, F.A., Stehli, F.G., Wetherill, G.W., et al., eds., 1974, Annual review of earth and planetary sciences, v. 2, Palo Alto, Calif.: Annual Reviews Inc., p. 213, 403.

Drewes, H., 1963, Geology of the Funeral Peak quadrangle, Calif., on the east flank of Death Valley: U.S. Geol. Survey Prof. Paper 413, 78p.

Duffield, W.A., 1975, Late Cenozoic ring faulting and volcanism in the Coso Range area of California: Geology, v. 3, no. 6, p. 335-338.

Dutcher, L.C., and Moyle, W.R., Jr., 1973, Geologic and hydrologic features of Indian Wells Valley, Calif.: U.S. Geol. Survey Water-Supply Paper 2007, 30p.

Eagleman, J.R., 1974, Moisture detection from Skylab: Ninth International Symposium on Remote Sensing of Environment, Proceedings, v. 1, p. 701-705.

Engineering and Mining Journal (E/MJ), 1974, Utah's Iron Springs district is a major western resource: E/MJ, Nov., p. 152.

Erwin, J.W., 1967, Gravity map of Battle Mountain and adjacent areas, Lander, Pershing, and Humboldt Counties, Nevada: Nevada Bur. of Mines, Map 31.

Evernden, J.F., and Kistler, R.W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geol. Survey Prof. Paper 623, 42p.

Furgerson, R.B., 1973, Progress report on electrical resistivity studies, Coso Geothermal Area, Inyo County, California: Naval Weapons Center, China Lake, California.

Garfunkel, Z., 1974, Model for the late Cenozoic tectonic history of the Mojave Desert, Calif., and for its relation to adjacent regions: Geol. Soc. Am. Bull., v. 85, p. 1931-1944.

Gillespie, J.B., and Bentley, C.B., 1971, Geohydrology of Hualapai and Sacramento Valleys, Mohave County, Arizona: U.S. Geol. Survey Water-Supply Paper 1899-H, 37p.

Goetz, A.F.H., Billingsley, F.C., et al., 1975, Application of ERTS images and image processing to regional geologic problems and geologic mapping in northern Arizona: Jet Propulsion Laboratory (CIT), Technical Report 32-1597.

Goodwin, J.G., 1957, Lead and zinc in California: Calif. Jour. Mines and Geol., v. 53, p. 353-724.

Granger, A.E., 1963, The iron province of southwestern Utah: Guidebook to the Geology of Southwestern Utah, Intermountain Assoc. Petrol. Geologists Twelfth Annual Field Conference, Salt Lake City, p. 146-150.

Greensfelder, R.W., 1972, A map of maximum expected bedrock acceleration from earthquakes in California: Calif. Div. Mines and Geol. Preliminary Map.

Hall, W.E., 1971, Geology of Panamint Butte quadrangle, Inyo County, California: U.S. Geol. Survey Bull. 1299, 67p.

Hall, W.E., and Mackevett, E.M., 1958, Economic geology of the Darwin quadrangle, Inyo County, California: Calif. Div. Mines and Geol. Special Report 51, 73p.

Hall, W.E., and Stephens, H.G., 1963, Economic geology of the Panamint Butte quadrangle and Modoc district, Inyo County, California: Calif. Div. Mines and Geol. Special Report 73, 39p.

Haskell, B.S., 1959, The geology of a portion of the New York Mountains and Lanfair Valley: M.A. thesis, Univ. of Southern California, 95p.

Healey, D.L., compiler, 1973, Bouguer gravity map of California, Kingman sheet: Calif. Div. of Mines and Geol., scale 1:250,000.

Heinrich, E.W., 1960, Some rare-earth mineral deposits in Mohave County, Arizona: Arizona Bur. Mines Bull. 167, 22p.

Henderson, J.R., White, B.L., et al., 1963, Aeromagnetic map of Long Valley and northern Owens Valley, California: U.S. Geol. Survey Map GP-329.

Heylmun, E.B., ed., 1963, Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petrol. Geologists Twelfth Annual Field Conference, Salt Lake City.

Hill, M.L., and Troxel, B.W., 1966, Tectonics of Death Valley region, California: Geol. Soc. Am. Bull., v. 77, p. 435-438.

Hintze, L.F., compiler, 1963, Geologic map of southwest Utah: Utah State Land Board, scale 1:250,000.

Holmes, G.H., Jr., 1964, Investigation of beryllium deposits in the northern Virgin Mountains of Clark County, Nevada, and Mohave County, Arizona: U.S. Bur. Mines, Report of Investigations 6572.

Hubbard, P.B., Bray, D., and Pipkin, G., 1972, Ballarat, 1897-1917, Facts and folklore: Lancaster, Calif., Hubbard Publishers, 98p.

Jahns, R.H., 1954, Geology of southern California: Calif. Div. Mines Bull. 170, v. 1.

Jenkins, O.P., et al., 1948, Copper in California: Calif. Div. Mines Bull. 144, 429p.

Jennings, C.W., compiler, 1958, Geologic map of California, Death Valley sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Jennings, C.W., compiler, 1961, Geologic map of California, Kingman sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Jennings, C.W., compiler, 1973, State of California preliminary fault and geologic map: Calif. Div. Mines and Geol. Preliminary Report 13.

Jennings, C.W., Burnett, J.L., and Troxel, B.W., compilers, 1962, Geologic map of California, Trona sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Johnson, R.N., 1973, California-Nevada ghost town atlas: Susanville, Calif., Cy Johnson & Son, 48p.

King, P.B., and Beikman, H.M., 1974, Explanatory text to accompany the geologic map of the United States: U.S. Geol. Survey Prof. Paper 901.

Kinkle, A.R., Jr., and Peterson, N.P., 1962, Copper in the United States: U.S. Geol. Survey Mineral Investigations Resource Map MR-13.

Kistler, R.W., 1966a, Geologic map of the Mono Craters quadrangle, Mono and Tuolumne Counties, California: U.S. Geol. Survey Map GQ-462.

Kistler, R.W., 1966b, Structure and metamorphism in Mono Craters quadrangle, Sierra Nevada, California: U.S. Geol. Survey Bull. 1221-E, 53p.

Kramsky, M., Allison, R.G., et al., 1964, Crustal strain and fault movement investigation -- faults and earthquake epicenters in California: Calif. Dept. Water Resources Bull. No. 116-2.

Langenheim, R.L., Jr., and Larson, E.R., 1973, Correlation of Great Basin stratigraphic units: Nevada Bur. Mines and Geol. Bull. 72.

Lanphere, M.A., Dalrymple, G.B., and Smith, R.L., 1975, K-Ar ages of Pleistocene rhyolitic volcanism in the Coso Range, California: Geology, v. 3, no. 6, p. 339-341.

Lausen, C., 1931, Geology and ore deposits of the Oatman and Katherine districts, Arizona: Arizona Bur. Mines, Geol. Series No. 6, Bull. 131, 126p.

Leighton, F.B., 1954, Origin of vermiculite deposits, southern Virgin Mountains, Nevada (Abs.): Geol. Soc. Am. Bull., v. 65, p. 1277.

Liggett, M.A., and staff, 1974, A reconnaissance space sensing investigation of crustal structure for a strip from the eastern Sierra Nevada to the Colorado Plateau: Type III Final Report of Investigation, Argus Exploration Company, Los Angeles, California.

Longwell, C.R., 1936, Geology of the Boulder Reservoir floor, Arizona-Nevada: Geol. Soc. Am. Bull., v. 47, p. 1393-1476.

Longwell, C.R., 1949, Structure of the northern Muddy Mountain area, Nevada: Geol. Soc. Am. Bull., v. 60, p. 923-968.

Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bur. Mines Bull. 62.

Lovering, T.G., 1972, Jasperoid in the United States -- its characteristics, origin, and economic significance: U.S. Geol. Survey Prof. Paper 710, 164p.

Mabey, D.R., 1963, Complete Bouguer anomaly map of the Death Valley region, California: U.S. Geol. Survey Map GP-305.

Marvin, R.F., 1968, Transcontinental geophysical survey (35°-39°N) radiometric age determinations of rocks: U.S. Geol. Survey Misc. Geologic Investigations Map I-537.

Matthews, R.A., and Burnett, J.L., compilers, 1965, Geologic map of California, Fresno sheet: Calif. Div. Mines and Geol., scale 1:250,000.

McAllister, J.F., 1955, Geology of the mineral deposits in the Ubehebe Peak quadrangle, Inyo County, California: Calif. Div. Mines and Geol. Special Report 42, 63p.

McAllister, J.F., 1970, Geology of the Furance Creek borate area, Death Valley, Inyo County, California: Calif. Div. Mines and Geol. Map Sheet 14.

McAllister, J.F., 1973, Geologic map and sections of the Amargosa Valley borate area -- southeast continuation of the Furnace Creek area -- Inyo County, California: U.S. Geol. Survey Map I-782.

McAllister, J.F., 1974, Silurian, Devonian, and Mississippian formations of the Funeral Mountains in the Ryan quadrangle, Death Valley region, California: U.S. Geol. Survey Bull. 1386, 35p.

Merriam, C.W., 1963, Geology of the Cerro Gordo mining district, Inyo County, California: U.S. Geol. Survey Prof. Paper 408, 83p.

Michael, E.D., 1966, Large lateral displacement on Garlock Fault, California, as measured from offset fault system: Geol. Soc. Am. Bull., v. 77, p. 111-114.

Moore, J.G., 1963, Geology of the Mount Pinchot quadrangle, southern Sierra Nevada, California: U.S. Geol. Survey Bull. 1130, 152p.

Moore, R.T., 1972, Geology of the Virgin and Beaverdam Mountains, Arizona: Arizona Bur. Mines Bull. 186.

Mundorff, J.C., 1970, Major thermal springs of Utah: Utah Geol. and Mineral. Survey & Univ. of Utah Water Resources Bull. 13.

Murdoch, J., and Webb, R.W., with sections by Campbell, I., and Learned, E.M., 1966, Minerals of California, centennial volume (1866-1966): Calif. Div. Mines Bull. 189, 559p.

Naff, R.L., Maxey, G.B., and Kaufmann, R.F., 1974, Interbasin ground-water flow in southern Nevada: Nevada Bur. Mines and Geol. Report 20, p. 1-26.

Nelson, C.A., 1966a, Geologic map of the Blanco Mountain quadrangle, Inyo and Mono Counties, California: U.S. Geol. Survey Map GQ-529.

Nelson, C.A., 1966b, Geologic map of the Waucoba Mountain quadrangle, Inyo County, California: U.S. Geol. Survey Map GQ-528.

Nelson, C.A., 1971, Geologic map of the Waucoba Spring quadrangle, Inyo County, California: U.S. Geol. Survey Map GQ-921.

Nevada Bureau of Mines, 1964, Mineral and water resources of Nevada: Bull. 65.

Noble, D.C., and Christiansen, R.L., 1974, Black Mountain volcanic center: Nevada Bur. Mines and Geol. Report 19, p. 27-34.

Noble, L.F., 1926a, Borate deposits in the Kramer district, Kern County, California: U.S. Geol. Survey Bull. 785, p. 45-61.

Noble, L.F., 1926b, Note on a colemanite deposit near Shoshone, California, with a sketch of the geology of a part of Amargosa Valley: U.S. Geol. Survey Bull. 785, p. 63-73.

Norman, L.A., Jr., and Stewart, R.M., 1951, Mines and mineral resources of Inyo County: Calif. Jour. Mines and Geol., v. 47, p. 17-223.

Palmer, L.A., 1916, The Oatman district, Arizona: Engineering and Mining Journal (E/MJ), v. 101, p. 895-900.

Park, C. F., Jr., 1955, The zonal theory of ore deposits: Econ. Geol., 50th Anniversary Vol., p. 226-248.

Ransome, F.L., 1923, Geology of the Oatman gold district, Arizona: A preliminary report: U.S. Geol. Survey Bull. 743, 58p.

Rinehart, C.D., and Ross, D.C., 1957, Geology of the Casa Diablo Mountain quadrangle, California: U.S. Geol. Survey Map GQ-99.

Ritter, E.A., 1916, Oatman and the Tom Reed-Gold Road mining district, Arizona: Mining and Eng. World, v. 44, p. 645-648.

Robison, R.A., 1963, Coal resources of southwestern Utah: Guidebook to the Geology of Southwestern Utah, Intermountain Assoc. Petrol. Geologists Twelfth Annual Field Conference, Salt Lake City, p. 151-156.

Rogers, T.H., compiler, 1967, Geologic map of California, San Bernardino sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Ross, D.C., 1965, Geology of the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Bull. 1181-O, p. 1-64.

Ross, D.C., 1966, Stratigraphy of some Paleozoic formations in the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Prof. Paper 396, 64p.

Ross, D.C., 1967a, Generalized geologic map of the Inyo Mountains region, California: U.S. Geol. Survey Map I-506.

Ross, D.C., 1967b, Geologic map of the Waucoba Wash quadrangle, Inyo County, California: U.S. Geol. Survey Map GQ-612.

Ross, D.C., 1969, Descriptive petrography of three large granitic bodies in the Inyo Mountains, California: U.S. Geol. Survey Prof. Paper 601, 46p.

Rowan, L.C., Wetlaufer, P.H., Goetz, A.F.H., et al., 1974, Discrimination of rock types and detection of hydrothermally altered areas in south-central Nevada by the use of computer-enhanced ERTS images: U.S. Geol. Survey Prof. Paper 883, 35p.

Sauck, W.A., and Sumner, J.S., 1970, Residual aeromagnetic map of Arizona: Dept. of Geosciences, Univ. of Arizona, Tucson.

Schaller, W.T., 1930, Borate minerals from the Kramer district, Mohave Desert, California: U.S. Geol. Survey Prof. Paper 158-I, p. 137-170.

Schilling, J.H., 1969, Metal mining districts of Nevada: Nevada Bur. Mines Map 37, 2nd ed.

Scholz, C.H., Barazangi, M., and Sbar, M.L., 1971, Late Cenozoic evolution of the Great Basin, western United States, as an ensialic interarc basin: Geol. Soc. Am. Bull., v. 82, p. 2979-2990.

Schrader, F.C., 1917, Geology and ore deposits of Mohave County, Arizona: Trans. Am. Inst. Mining Eng., v. 56, p. 195-236.

Seager, W.R., 1966, Geology of the Bunkerville section of the Virgin Mountains, Nevada and Arizona: Dissert. Abs., Science and Eng., v. 27, no. 5, p. 1519B, sec. B.

Seager, W.R., 1970, Low-angle gravity glide structures in the northern Virgin Mountains, Nevada and Arizona: Geol. Soc. Am. Bull., v. 81, no. 5, p. 1517-1538.

Silberman, M.L., and McKee, E.H., 1974, Ages of Tertiary volcanic rocks and hydrothermal precious-metal deposits in central and western Nevada: Nevada Bur. Mines and Geol. Report 19, p. 67-72.

Smith, A.R., 1964, Geologic map of California, Bakersfield sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Smith, G.I., 1962, Large lateral displacement on Garlock fault, California, as measured from offset dike swarm: Am. Assoc. Petrol. Geol. Bull., v. 46, p. 85-104.

Smith, G.I., 1964, Geology and volcanic petrology of the Lava Mountains, San Bernardino County, California: U.S. Geol. Survey Prof. Paper 457, 97p.

Smith, G.I., Troxel, B.W., Gray, C.H., Jr., and von Huene, R., 1968, Slate Range, San Bernardino and Inyo Counties, California: Calif. Div. Mines and Geol. Special Report 96, 33p.

Smith, R.S.U., 1975, Guide to selected examples of Quaternary tectonism in Panamint Valley, California: Calif. Geology, v. 28, no. 5, p. 112-115.

Smith, W.C., 1962, Borates in the United States: U.S. Geol. Survey Mineral Investigations Resource Map MR-14.

Strand, R.G., compiler, 1967, Geologic map of California, Mariposa sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Titley, S.R., and Hicks, C.L., eds., 1966, Geology of the porphyry copper deposits, southwestern North America: Tucson, Univ. of Arizona Press, 287p.

Troxel, B.W., and Morton, P.K., 1962, Mines and mineral resources of Kern County, California: Calif. Div. Mines and Geol., County Report 1.

U.S. Air Force Aeronautical Chart and Information Center, 1968, Transcontinental geophysical survey (35°- 39°N) Bouguer gravity map from 112°W longitude to the coast of California: U.S. Geol. Survey Misc. Geologic Investigations Map I-532-B.

U.S. Geological Survey, 1971, Aeromagnetic map of parts of the Goldfield, Mariposa, and Death Valley 1° by 2° quadrangles, Nevada-California: Map GP-753.

U.S. Geological Survey, 1972, Aeromagnetic map of the Gold Butte-Chloride area, Arizona and Nevada: Map GP-757.

Volborth, A., 1962, Rapakivi-type granites in the Precambrian complex of Gold Butte, Clark County, Nevada: Geol. Soc. Am. Bull., v. 73, p. 813-832.

Vuich, J.S., 1974, Strata-bound sulfide deposits and suggestions for exploration in Arizona: Arizona Bur. Mines Circ. 16.

Waring, G.A., 1965, Thermal springs of the United States and other countries of the world -- a summary (revised by Blankenship, R.R., and Bentall, R.): U.S. Geol. Survey Prof. Paper 492, p. 9-43.

Webb, B., and Wilson, R.V., 1962, Progress geologic map of Nevada: Nevada Bur. Mines Map 16.

Weight, H.O., 1970, Lost mines of Death Valley: Twentynine Palms, California, The Calico Press, 86p.

West, R.E., 1972, A regional Bouguer gravity anomaly map of Arizona: Dissertation, Univ. of Arizona, Tucson.

West, R.E., and Sumner, J.S., 1973, Bouguer gravity anomaly map of Arizona: U.S. Geol. Survey Lab. of Geophysics, Dept. of Geosciences, Univ. of Arizona, Tucson.

Wilson, E.D., Cunningham, J.B., and Butler, G.M., 1967, Arizona lode gold mines and gold mining: Arizona Bur. Mines Bull. 137, 254p.

Wilson, E.D., and Moore, R.T., 1959, Geologic map of Mohave County, Arizona: Arizona Bur. Mines, Univ. of Arizona, Tucson.

Wilson, R.V., and Paul, R.R., 1965, Map of intrusive rocks in Nevada: Nevada Bur. Mines Map 30.

Wright, L.A., Steward, R.M., Gay, T.E., Jr., and Hazenbush, G.C., 1953, Mines and mineral deposits of San Bernardino County, California: Calif. Jour. Mines and Geol., v. 49, nos. 1 & 2, p. 49-192.

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. Am. Bull., v. 78, p. 933-950.

Zietz, I., and Kirby, J.R., 1968, Transcontinental geophysical survey (35°-39°N) magnetic map from 112°W longitude to the coast of California: U.S. Geol. Survey Misc. Geologic Investigations Map I-532-A.

ADDITIONAL REFERENCES

Bechtold, I.C., and Jahns, R.H., 1971, Remote sensing by photogeology applied to ground current paths in an HVDC system: Seventh International Symposium on Remote Sensing of Environment, Proceedings, p. 951-971.

Carder, D.S., 1970, Reservoir loading and local earthquakes: Engineering Seismology: The Works of Man, Geol. Soc. Am. Engineering Geology Case Histories, no. 8, p. 51-61.

Hunt, G.R., and Salisbury, J.W., 1970, Visible and near-infrared spectra of minerals and rocks: I. Silicate minerals: Modern Geology, v. 1, p. 283-300.

Hunt, G.R., and Salisbury, J.W., 1971, Visible and near-infrared spectra of minerals and rocks: II. Carbonates: Modern Geology, v. 2, p. 23-30.

Jones, A.E., 1944, Earthquake magnitudes, efficiency of stations, and perceptibility of local earthquakes in the Lake Mead area: Seis. Soc. Am. Bull., v. 34, p. 161-173.

Salisbury, J.W., and Hunt, G.R., 1974, Remote sensing of rock type in the visible and near-infrared: Ninth International Symposium on Remote Sensing of Environment, Proceedings, v. III, p. 1953-1958.

VIII. A P P E N D I X A

Interim Reports

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 July 1974 - 31 July 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M1-1/75

Contract Monitor:

Martin Miller, Code TF6
Earth Observations Div sion
NASA - Lyndon B. Johnson S e Center
Houston, Texas 770

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6. Performing Organization Code none

7. Author(s) Ira C. Bechtold

8. Performing Organization Report No. BESTEC 101-M1-1/75

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Houston, Texas 77058

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14. Sponsoring Agency Code BB62

15. Supplementary Notes

16. Abstract

Preliminary phases of the EREP investigation including development of image indexing, filing, and retrieval systems and library reference system have been initiated. Office procedures for the investigation have been established and literature pertinent to the test area has been compiled. Preliminary analysis of Skylab data indicate usefulness of S190A and S190B imagery for identification and exploration of potential geothermal resources. In particular, very accurate mapping of structural features related to geothermal activity is possible with S190B photography.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Geology Basin & Range Skylab data Geothermal Exploration	Martin Miller/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I Contract Objectives:

A Analysis, interpretation, and evaluation of EREP data for application to a study of regional crustal structure as applied to mineral, petroleum, geothermal, and water resources exploration, and to evaluations of geologic hazards.

B Comparison and evaluation of selected available remote sensing techniques, including Apollo 9, X-15, U-2, and conventional aircraft photography, ERTS-1 imagery, as well as EREP data.

C Field investigations to confirm interpretation studies and to evaluate significance and practical applications of geologic phenomena visible in Skylab imagery and other EREP data.

II Summary of Work Performed:

A Establishment and general organization of Bechtold Satellite Technology corporate office facilities to execute the EREP Contract NAS9-14235 and development of office procedures to achieve objectives of investigation.

B Transfer of research material pertinent to EREP study area from the office of Ira C. Bechtold, Consultant; development of cross-reference library system at BESTEC. Assembly of interim and special reports written for ERTS-A Contract NAS5-21809 entitled "A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra Nevada to the Colorado Plateau" by Argus Exploration Company.

C Development of film handling procedures for ERTS and EREP data capable of organizing nine-inch prints and transparencies, 70mm negative and positive transparencies for indexing and quick retrieval; training of personnel in all aspects of system.

D Receipt of ERTS imagery, Skylab S190A and S190B imagery, and other EREP data products. Filing and cataloging of all imagery. Preliminary examination of imagery for degraded or unusable products and for appraisal of quality. Familiarization of personnel with EREP products. Determination of completeness of ERTS and EREP imagery coverage over test area.

E Filing and cataloging of available supporting imagery -- Apollo, Gemini, Nimbus, U-2, X-15, and SLAR.

F Research of geologic and geophysic data relating to EREP study area. Gathering of ERTS Principal Investigators' reports pertinent to BESTEC investigation. Contact with Federal and State geology offices, as well as earth science departments of universities, colleges, and private companies in Nevada, California, Utah, and Arizona.

G Study of the general tectonics of the test area. Comparison of S190B, S190A, and ERTS imagery over specified sites for usefulness in identifying potential geothermal resources. Selection of several sites for more detailed study using EREP data such as S192 imagery.

III Analysis of Research Progress:

The initial stages of the EREP investigation are proceeding satisfactorily. The library reference system and the imagery filing, indexing, and retrieval system are operating and are facilitating investigations of the test area. A compilation of references on the geology of the test area that was initiated during this reporting period is proving to be invaluable for investigations and for acquainting personnel with the complexities of the geologic and tectonic environments in the EREP test area.

Preliminary analysis of S190B photography over geothermal areas in California and Arizona has substantiated previous workers' interpretations of tectonic control of the activity. Furthermore, the high resolution S190B photography has enabled us to locate structural features more precisely than was possible with previous spacecraft imagery. Studies of S190A imagery support the conclusions of Bechtold and Jahns (1971) that alteration areas can be readily identified in infrared film.

IV Scientific Staff and Backup Personnel:

The following personnel are presently assigned to the EREP investigation:

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Assistant Geologist
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant

V Work Planned for Next Reporting Period:

A Development of enhancement techniques for ERTS and Skylab S190A 70mm film positives. Interpretation of enhanced films on International Imaging Systems Mini-Addcol color additive viewer.

B Examination of EREP S191, S192, S193, and S194 experiments and evaluation of potential application of the data to investigations of crustal structure. Study of S192 screening film.

C Continued development of BESTEC's physical facilities to index, file, and locate imagery, maps, and references.

VI References Cited:

Bechtold, Ira C. and Jahns, Richard H. 1971. Remote Sensing by Photogeology Applied to Ground Current Paths in an HVDC System: Proceedings of the Seventh International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor. pp951-956.

VII Acknowledgments:

The assistance of Gregory Wagner in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

NOTE: The acronym BESTEC has been adopted to use as an alternative to the full name of Bechtold Satellite Technology Corporation

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 August 1974 - 31 August 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M2-1/75

Contract Monitor:

Martin Miller, Code TF6
Earth Observations Division
NASA - Lyndon B. Johnson Space Center
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15. Supplementary Notes

16. Abstract

Projection of ERTS and EREP imagery to large scales by using a color additive viewer has greatly increased the quality and completeness of interpretation of the imagery. Procedures to enhance 70mm format imagery have been initiated and are expected to further increase the capabilities of the interpretor. Imagery selection and retrieval systems are operating. S190A Ektachrome can be used to discriminate more rock types than was possible with ERTS imagery.

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Multispectral Skylab Data Geothermal Exploration Enhancement Mineral Exploration	Martin Miller/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058		
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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I Contract Objectives:

A. Analysis, interpretation, and evaluation of EREP data for application to a study of regional crustal structure as applied to mineral, petroleum, geothermal, and water resources exploration, and to evaluation of geologic hazards.

B. Comparison and evaluation of selected available remote sensing techniques, including Apollo 9, X-15, U-2, and conventional aircraft photography, ERTS-1 imagery, as well as EREP data.

C. Field investigations to confirm interpretation studies and to evaluate significance and practical applications of geologic phenomena visible in Skylab imagery and other EREP data.

II Summary of Work Performed:

A. Continued improvement of BESTEC procedures, filing and reference systems to facilitate research procedures and analysis of imagery by personnel.

B. Continued receipt of ERTS imagery and EREP data and imagery. Filing and cataloging of all imagery. Preliminary examination of imagery for degraded or unusable products and for appraisal of quality. Determination of completeness of ERTS and EREP coverage received by BESTEC and comparison of S190A and S190B coverage with NASA photo index compilations. Ordering of S190A and S190B photography pertinent to study area but not supplied by NASA.

C. Continued compilation of geologic reports pertinent to study areas and collection of EREP and ERTS Principal Investigators' reports concerning interpretation techniques for Skylab and ERTS data.

D. Initiated interpretation procedures for 70mm film chips mounted in an International Imaging Systems Mini-Addcol viewer. Trained personnel in use of machine and benefits of color additive viewing. Compared resolution of ERTS and S190A film chips projected in viewer to larger scales. I^2S Model 6040PT Viewer, with front viewing magnification of 3.37X and rear projection capabilities up to 20X, was purchased by BESTEC for image interpretation. Viewer was received 15 August.

E. Discussion of enhancement of 70mm black and white films with Dr. Floyd Sabins and his staff at Chevron Oil Field Research, La Habra. Dr. Sabins instructed BESTEC personnel in methods of increasing contrast by using duplicating films in contact with originals, sandwiched in mylar to eliminate the need for a vacuum frame and lessen the chances of Newton's rings occurring.

F. Examined EREP S192 screening film (bands 7 and 13) to select areas of interest for further processing of S192 data by NASA.

G. Revised list of study areas within the general test area boundaries on the basis of S190A and S190B coverage received to date or expected in the near future. Also, analysis of EREP photography revealed several anomalies of different types -- structural, topographic, color -- located in areas not previously identified as sites of interest.

H. Examined structural features discernible in EREP photography (including handheld 35mm and 70mm) around areas of known mineralization in the Mojave Desert.

III Analysis of Research Progress:

The preliminary phases of the investigation that were initiated in July, 1974, are completed to the point that work can now be concentrated on analysis of EREP data and its applicability to resource exploration. Filing, cataloging, and indexing of imagery is still proceeding, and is proving to require more time and effort than anticipated. However, it is necessary that a reliable and efficient imagery selection and retrieval system be operational prior to examination of a specific site. This system will require constant attention to maintain its effectiveness.

Projecting ERTS and EREP 70mm films to a large scale by using the I^2S Viewer has greatly increased the usefulness and aided interpretation of the data. Different combinations of color filters and light intensities on the various film bands emphasize different geologic and cultural features. The large scale projection (ERTS 1:500,000; S190A approximately 1:420,000) facilitates accurate location of observed geologic features onto published maps for comparison and analysis. Registering of up to 4 bands of S190A has presented no problems. It is anticipated that increasing the contrast of black and white 70mm chips will increase the value of color additive viewing.

We have found that S190A Ektachrome permits discrimination of more rock types than was possible with ERTS imagery and that S190B color photography is very useful for mapping color anomalies and lineaments in alluvium.

IV Work Planned for Next Reporting Period:

A. Addition of personnel to aid in clerical duties and in analysis of EREP data.

B. Development of standardized procedures for enhancement of 70mm format imagery by commercial photographers in the Los Angeles area.

C. Attendance at National Science Foundation sponsored conference on geothermal energy.

D. Study of applicability of S192 imagery to remote sensing of geothermal anomalies.

E. Interpretation of EREP data over specific sites in Death Valley and the Mojave Desert.

V Acknowledgments:

The assistance of Gregory Wagner in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

<u>NOTE</u>: The acronym BESTEC has been adopted to use as an alternative to the full name of Bechtold Satellite Technology Corporation.

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MILESTONE REPORT

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-S-2/75

Contract Monitor:

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Earth Observations Division
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15. Supplementary Notes

16. Abstract

Eight major tasks that will be accomplished by BESTEC in order to comply with the terms of EREP Contract NAS9-14235 range from administration to development of new interpretation techniques to geological investigation and interpretation of specific anomalies noted in EREP imagery. A schedule of the duration of each of the tasks, which is presented in the Milestone Chart, is subject to revision as time requirements for each task are more fully recognized.

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES

APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I Contract Objectives:

A. Analysis, interpretation, and evaluation of EREP data for application to a study of regional crustal structure as applied to mineral, petroleum, geothermal, and water resources exploration, and to evaluations of geologic hazards.

B. Comparison and evaluation of selected available remote sensing techniques, including Apollo 9, X-15, U-2, and conventional aircraft photography, ERTS-1 imagery, as well as EREP data.

C. Field investigations to confirm interpretation studies and to evaluate significance and practical applications of geologic phenomena visible in Skylab imagery and other EREP data.

II Milestone Report:

This Milestone Report presents a description of the major tasks that will be accomplished by BESTEC in order to comply with the terms of EREP Contract NAS9-14235 and the approximate duration of each task over the period of the contract which is 1 July 1974 to 30 June 1975. Each of the tasks listed on the accompanying Milestone Chart is discussed below in detail to explain phases, or sub-tasks, that are included within each major task.

Modifications to the overall schedule are expected to occur. These changes will be noted in the monthly reports and the Milestone Chart will be updated and resubmitted.

III Discussion of Tasks:

A. Administration and Reports:

This task includes the preparation and submittal of monthly reports, both financial and technical. It also includes all administrative and clerical duties that are necessary for the execution and completion of the contract. Special reports on specific investigations, discussions of new technology developed by BESTEC, and presentations by BESTEC personnel are sub-tasks within this major task.

B. Imagery Catalog, Index, and Retrieval System:

Prior to the formal initiation of the EREP contract, it was decided that an efficient, effective index catalog and retrieval system for imagery was necessary for a competent investigation. The system is to be developed during the first month of the contract, and we expect it to be operating throughout the duration of the contract. The system will require constant updating and revising to handle new data and new formats. We have designed the system to handle imagery in all forms and from all spacecraft, aircraft, and from ground investigations.

C. Data Receipt:

Delivery of NASA-supplied data to be used in the analysis of potential resources in our test area is expected for the first months of the contract period. However, due to reordering from NASA of degraded, damaged, or missing products, and special processing of imagery for interpretation, this task is expected to continue for the duration of the contract. S192 MSS film is not expected until 1975.

D. Library System:

A comprehensive library of references on the geology of our test area is available from the private library of Ira C. Bechtold. Many college and university libraries in the Los Angeles area are allowing us to use their facilities for the EREP investigation. We also intend to supplement references in available libraries by gathering complete sets of topographic, geologic, and geophysical maps of the test area. Other reports, pertinent to geology of the test area, or concerned with techniques of interpretation of space imagery will be compiled, and copies placed in BESTEC reference files. Sources will include ERTS and EREP PI reports available from NTIS, Federal and State agencies, and private industry.

E. Interpretation Techniques:

BESTEC has available an International Imaging Systems Mini-Addcol viewer, model 6040PT, which will be operational in August, 1974. We will then initiate interpretation of imagery available in 35mm or 70mm film positive format. We will utilize front projection (6.7X) which displays the image on a screen suitable for tracing image detail and rear projection, which is capable of enlargement up to 20X onto a vertical viewing screen. All activities relating to enhancement of NASA-supplied data, including discussions with professional photographers and ERTS and EREP investigators, in this task are included. We expect that procedures for routine enhancement of black and white 70mm will be developed early and other, more sophisticated, forms of image enhancement will be used later, as the advantages of different forms of enhancement are analyzed.

F. Evaluation of EREP Data:

This task is a general analysis of all EREP data, its usefulness, and its applications to resources exploration. Included in this task are evaluations of the quality and resolution of S190A, S190B, and S192 imagery and assessments of relative usefulness of the various film formats -- 70mm, 5 inch, and 9 inch. We also plan to photographically enlarge S190A and S190B imagery to determine resolution and detail at large scales, such as 1:250,000. Other EREP experiments -- S191, S193, S194 -- will be studied and utilized for resources investigations if their usefulness to geologic studies can be demonstrated.

G. Specific Site Analysis:

This major task is the actual application of EREP data to investigations of resources. There are three phases to an investigation of a specific site: 1) selection of the site, by discovering anomalies or geologic features visible in EREP imagery that may be related to resources; 2) comprehensive study of the site, first using EREP data, then substantiating interpretations with other spacecraft, aircraft, and reference material; 3) field reconnaissance of the site and evaluation of imagery-derived interpretations of the cause of the anomaly and its significance.

In accordance with the proposal "An Evaluation of Skylab (EREP) Remote Sensing Techniques Applied to Investigation of Crustal Structure," NASA Control Nos. Y-05-420-002 and SR541, a large portion of the background for the work to be accomplished in this project would have already been completed, reported, and data delivered to BESTEC from Argus Exploration Company's investigation "A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra Nevada to the Colorado Plateau," ERTS Contract NAS5-21809.

Not all anomalies noted in EREP data will require the complete investigative sequence. Many anomalies will have been found and interpreted by Argus Exploration Company during their analysis of ERTS imagery over the same test area as ours, and reported by them in monthly, special, or final reports, or in field notes. Therefore, our investigations are contingent upon our receiving all Argus notes, as we do not want to duplicate their investigations of anomalies. Furthermore, we intend to use Argus' results to aid in our interpretations and reduce the amount of field work needed to check our results. Any delay in our receipt of this critical data will correspondingly delay our investigations. Also, if Argus' field notes should prove to be inadequate or incomplete, more field checking than is here noted on our Milestone Chart will be required.

H. Final Report:

A Final Report of investigations is due in rough form June 1, 1975, and preparation of that report will commence early enough to insure that BESTEC meets that deadline. The final report will consist of summaries of our studies of the application of EREP data to resources exploration as well as reports on specific site investigations.

IV Acknowledgments:

The assistance of Martha N. Wadsworth and C. Gregory Wagner in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

NOTE: The acronym BESTEC has been adopted to use as an alternative to the full name of Bechtold Satellite Technology Corporation.

BESTEC — Contract No. NAS9-14235 — 2/10/75

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

MILESTONE CHART

TASK	July 1974	Aug	Sept	Oct	Nov	Dec 1974	Jan 1975	Feb	Mar	Apr	May	June	July
Administration and Reports	---	---	---	---	---	---	---	---	---	---	---	---	
Imagery Catalog Index and Retrieval System	---	---	---	---	---	---	---	---	---	---	---	---	
Data Receipt	---	---	---	---	---	---	---	---					
Library System	---	---	---	---	---	---	---	---	---	---	---	---	
Interpretation Techniques		---	---	---	---	---	---	---	---	---	---		
Evaluation of EREP Data	---	---	---	---	---	---	---						
Specific Site Analysis		---	---	---	---	---	---	---	---	---	---		
(Field Reconn.)		---	---		---			---	---	---			
FINAL REPORT										---	---	---	---

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

QUARTERLY REPORT
1 July 1974 - 30 September 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-Q1-2/75

Contract Monitor:

Martin Miller, Code TF6
Earth Observations Division
NASA - Lyndon B. Johnson Space Center
Houston, Texas 77058

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle QUARTERLY REPT: 1 July - 30-Sept 74. An Evaluation of Skylab (EREP) Remote Sensing Techniques Applied to Investigations of Crustal Structure		5. Report Date 6. Performing Organization Code none
7. Author(s) Ira C. Bechtold, EREP PI 541		8. Performing Organization Report No. BESTEC 101-Q1-2/75
9. Performing Organization Name and Address Bechtold Satellite Technology Corporation 17137 East Gale Avenue City of Industry, California 91745		10. Work Unit No. none 11. Contract or Grant No. NAS9-14235 13. Type of Report and Period Covered Quarterly Progress 1 July - 30 Sept 74
12. Sponsoring Agency Name and Address NASA - Lyndon B. Johnson Space Center Technical Support Procurement Branch Houston, Texas 77058		14. Sponsoring Agency Code BB62
15. Supplementary Notes		

16. Abstract

Four major tasks were emphasized during the first quarter including development of supportive reference systems, preliminary analysis of EREP data, selection of sites for more detailed study, and examination of anomalies noted in EREP data over several geothermal areas. Structural control of geothermal areas was analyzed using S190A and S190B. Results correlated well with studies done by other workers. Several anomalies suspected to be caused by geothermal activity are being studied. 70mm S190A and 5" S190B imagery have excellent resolution and are very useful for detailed geologic studies. S190A films can be enlarged at least 19X and still be very useful for geologic mapping. S190A black and white films can be color-composited so as to duplicate natural rock colors.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Geothermal Exploration Skylab data Geology Basin and Range	Martin Miller/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

PROGRAM SUMMARY

The purpose of this study is to analyze, evaluate, and interpret EREP data for application to studies of crustal structure as applied to resources exploration and to compare the usefulness of EREP data for geological investigations to other remote sensing techniques, such as aircraft, Apollo, Gemini, and ERTS imagery.

During this first quarter, major effort focused on four tasks: (1) the development of reference and filing systems to support geological investigations; (2) the receipt and preliminary analysis of Skylab imagery; (3) the initial selection of specific sites for detailed study; and (4) study of EREP imagery over known and potential geothermal resources. In addition, studies of the regional geology and geophysics of the entire test area were undertaken to permit BESTEC investigators to correlate field observations with space imagery and to provide the basis for selecting specific potential resources sites.

Significant results during this quarter include identification of structural control of several geothermal areas in the Basin and Range geologic province using EREP data, compositing of S190A black and white films in a multispectral viewer to obtain natural rock color, and determination that S190A films are excellent for geologic interpretation at 18X-19X magnification.

EREP IMAGERY

During the first quarter we analyzed S190A 70mm film positives enlarged to approximately 1:420,000 in an International Imaging Systems viewer. Resolution at this scale is very good; we found that resolution of S190A at 18X-19X enlargement is useful for geologic interpretation and still greater enlargements should be possible within the limits of S190A photography.

S190B data has thus far been available for use only in the 5" film positive format, and we have not yet enlarged any S190B. The 5" film image has very good resolution and is useful for detailed geological mapping. In general, quality of S190A and S190B received from NASA thus far is good, with only a very few frames degraded by scratches. In contrast, we have found that ERTS 70mm chips received for this investigation require tone enhancement by photographic processes to effectively utilize the imagery in a multispectral viewer.

Both S190A and S190B Ektachrome imagery are superior to ERTS color-composited imagery for rock type discrimination. Color closely resembling natural rock colors can be obtained by using black and white S190A film and combinations of color filters and light intensities in an I^2S Model 6040PT color additive viewer. Other combinations produce "false color" effects, which also permit rock type discrimination. (It is possible to make corrections or additions to published geological maps once the signature of a particular rock type is established by reference to the map.)

Maps showing S190A and S190B coverage over our test area have been prepared at a 1:5,000,000 scale and are reproduced in this report as Figure 1 (S190A) and Figure 2 (S190B). In general, only a small fraction of the test area is not covered by either S190A or S190B. Some imagery was not supplied to us by NASA as the imagery exhibited greater than 30% cloud cover. We are requesting this data if there were no other EREP passes over the same area. Several cycles of ERTS data over the entire test area havebeen supplied by NASA.

We have received S192 screening film as well as some data from S191, S193, and S194 experiments for each of the three manned Skylab missions. The S192 film was analyzed during this reporting period (see page 6 of this report) and data from the other experiments will be viewed and analyzed in future months.

DISCUSSION OF ACTIVITES

Geothermal Exploration:

During this period, preliminary analysis of S190A and S190B photography over known geothermal areas has indicated that structural control of the activity can be readily identified and mapped. Preliminary analysis of S190A data over the Colorado River south of Lake Mead has revealed dikes and faults previously identified in ERTS imagery by Bechtold et al. (1973) in close proximity to the hot springs near Willow Beach, Arizona. Several arcuate features, related to granitic plutons or Tertiary volcanics have also been noted, but their significance and relation to geothermal activity has not yet been ascertained.

Known strike-slip and near-vertical faults that occur near the Coso (California) geothermal area have been identified in EREP hand-held photography, although the sense of movement on the faults cannot be determined. When S190A and S190B photography over Coso is received, we anticipate being able to map lithologic units, alteration zones, and structural features that may indicate potential geothermal activity outside of the Coso KGRA and outside the U.S. Naval Weapons Center test station boundaries.

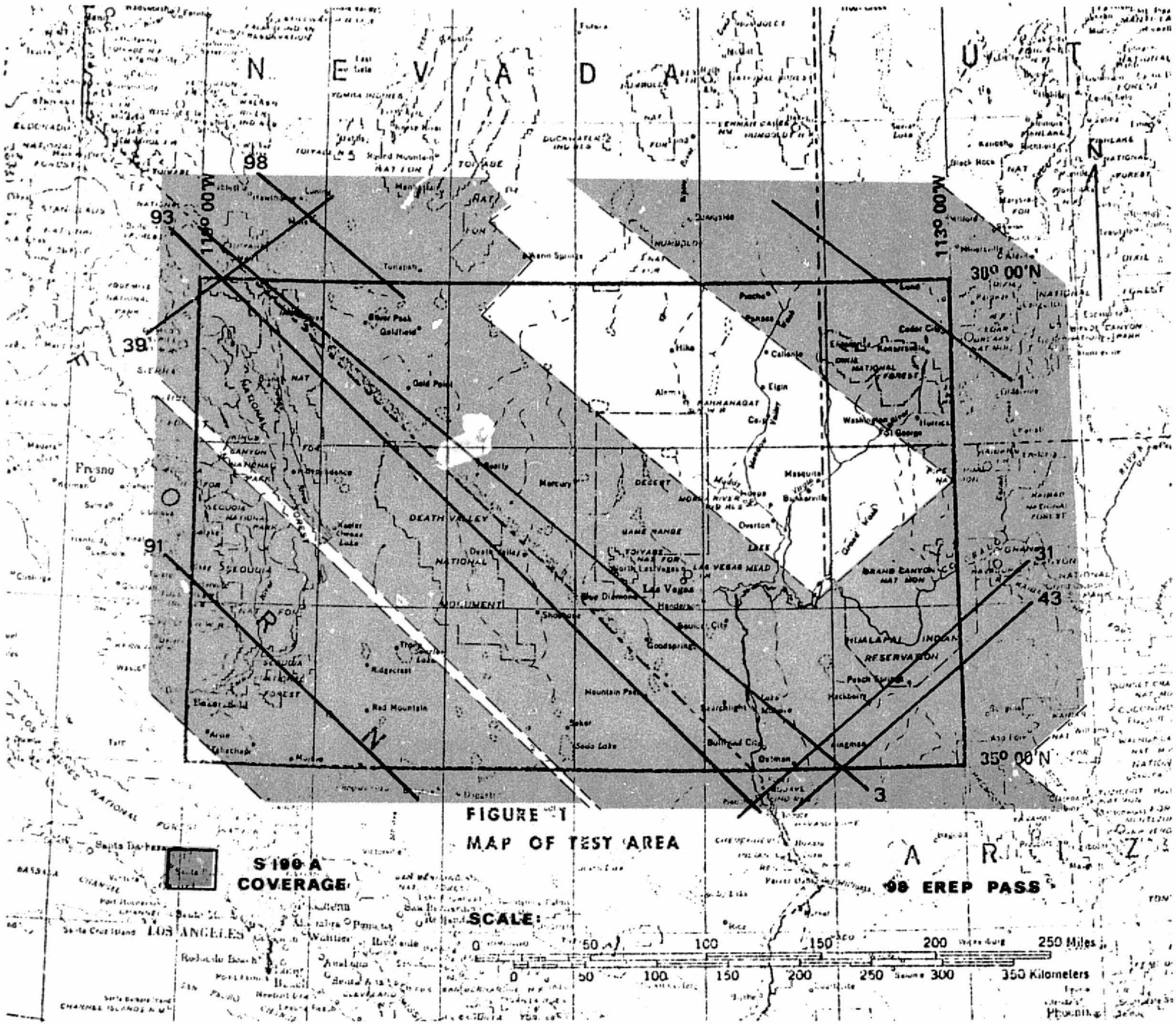

FIGURE 1
MAP OF TEST AREA

ORIGINAL PAGE IS OF POOR QUALITY

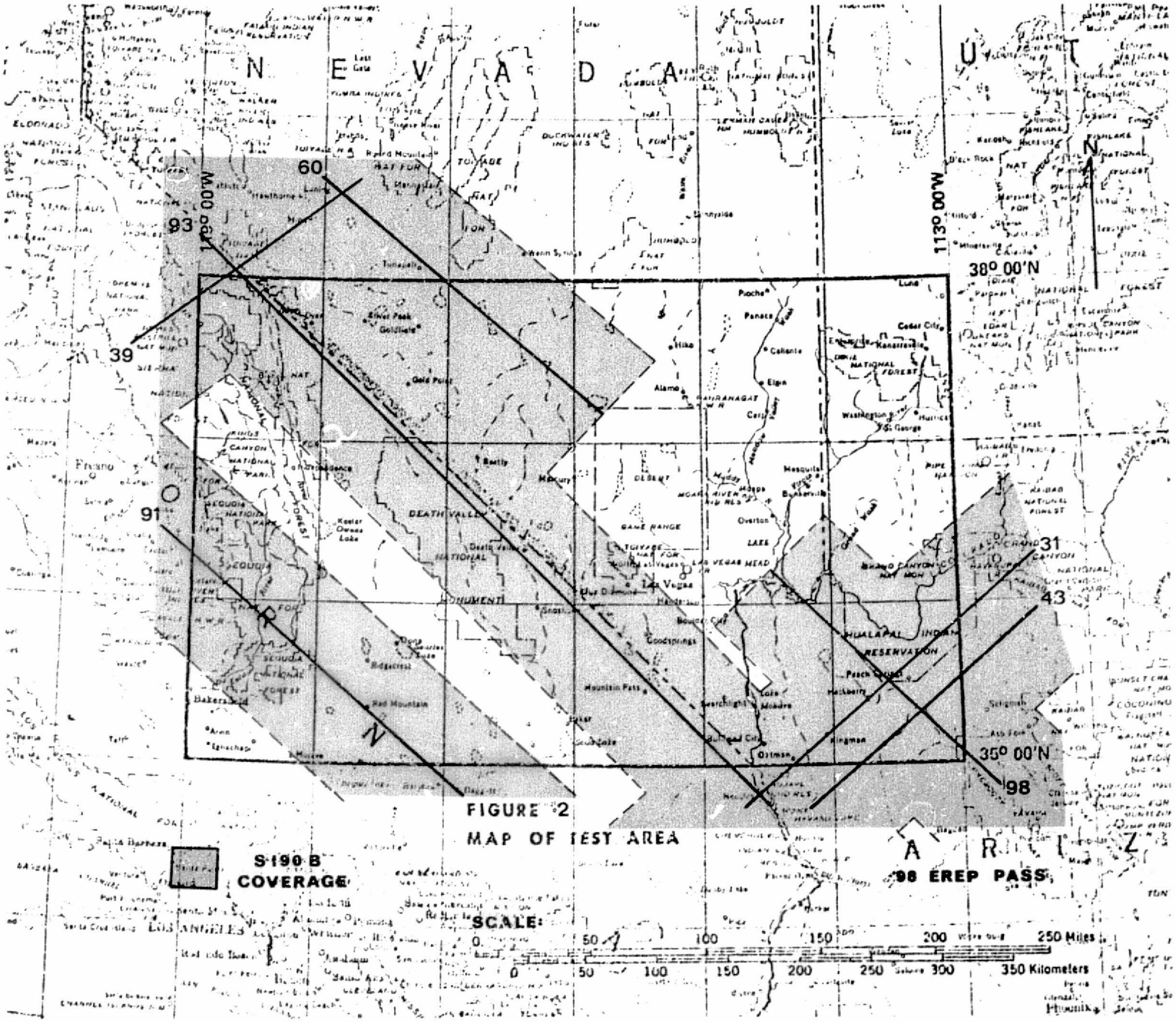

FIGURE 2
MAP OF TEST AREA

Other anomalies noted in S190A photography over Nevada and eastern California are thought to be related to geothermal activity; a detailed examination of these anomalies is under way.

S192 data over these potential geothermal areas has been requested from NASA.

Skylab Weather Data:

Prior to the flight of Skylab 2 and 3, the Principal Investigator established a weather communications net through volunteer amateur radio operators throughout the test area. Reports on ground-observable weather conditions were sent by these operators to the PI via amateur radio frequencies. The compilation of weather data is a sizable report on cloud formations, winds, and ground moisture conditions over Tracks #6, 16, 20, 45, 59, and 60 of Skylab 2 and 3. The reports and audio tapes of the actual radio transmissions, which have been forwarded to NASA for inspection, are providing invaluable information for our investigation.

Imagery Enhancement:

A simple, inexpensive method of enhancing imagery prints is being used at BESTEC. The method requires only a standard office copying machine. The procedure is simply to reproduce the print, varying the tone control for lighter or darker copies. We have found that certain features or anomalies not readily apparent in the original print can be accentuated. This method is especially useful for preliminary phases of imagery analysis and emphasizing features to persons not experienced in image interpretation. A separate, more complete, report is being prepared to be submitted as new technology.

Field Investigations:

An area in the Mojave Desert near Kelso, California, was visited by the Principal Investigator in order to sample rock outcrops and field check structural features interpreted from Skylab imagery. Hand lens analysis of samples confirmed rock-type interpretations made on the basis of color anomalies noted in S190A. Imagery studies of anomalies in this area perhaps related to mineral deposits showed promise during this period and are continuing, and results will be reported at a later date.

Conferences:

NSF Conference on Research for the Development of Geothermal Energy Resources: September 23-25, 1974: Pasadena, California. Organized by JPL/CIT.

Three BESTEC investigators attended this conference which provided a background on many aspects of geothermal resources including legalities, drilling and production technology, and exploration. Exploration techniques discussed were primarily standard geophysical tools and geology. Few workers commented on remote sensing applications to exploration for geothermal energy, and no one mentioned the use of EREP data for exploration. Discussions with NSF personnel indicated a significant interest in projects which would use EREP data in exploration for geothermal resources. BESTEC is considering submitting an unsolicited proposal to carry out such a study.

Skylab EREP Principal Investigators Data Meeting: July 16-18, 1974; Houston, Texas.

This meeting, held at Lyndon B. Johnson Space Center, was attended by Ira C. Bechtold. Numerous discussions on the status of EREP data processing at Johnson Space Center and the uses of EREP data by PI's were held. Much useful information on problems associated with EREP data and the uses of EREP data to various scientific disciplines was gathered. One result of this meeting was better understanding of the applicability of EREP data to our investigative field-resources exploration and geologic hazards evaluation.

ADDITIONAL ACCOMPLISHMENTS DURING SEPTEMBER

A. Viewing of S192 screening films and selection of segments to be processed by NASA into line-straightened 70mm format. Chosen segments were described by GMT.

B. Receipt and subsequent preliminary analysis of pre-ERTS Investigator Support (PEIS) imagery. Some of the U-2 imagery was received in a 9" film format and some in a 70mm format. Plotting of this data and determination of completeness of coverage was initiated.

C. Receipt of Final Report of Investigation for ERTS Contract NAS5-21809, A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra Nevada to the Colorado Plateau, by Argus Exploration Company.

Analysis of the report and its usefulness and significance to an investigation was initiated. Argus Exploration Company field maps and field notes, critical to our own field investigations, were not included with the Final Report and have not been received.

PERSONNEL

The following scientific and back-up personnel are presently assigned to the EREP investigation:

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant

REFERENCES CITED

Bechtold, Ira C., M. A. Liggett and J. F. Childs (1973) Structurally controlled dike swarms along the Colorado River, Northwestern Arizona and Southern Nevada (Abst.): NASA-CR-128290, E72-10192.

ACKNOWLEDGMENTS

The assistance of Martha Wadsworth, John Reynolds and Greg Wagner in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 October 1974 - 31 October 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M3-2/75

Contract Monitor:

Martin Miller, Code TF6
Earth Observations Division
NASA - Lyndon B. Johnson Space Center
Houston, Texas 77058

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4. Title and Subtitle MONTHLY PROGRESS REPORT 1 Oct-31 Oct 74: An Evaluation of Skylab (EREP) Remote Sensing Techniques Applied to Investigation of Crustal Structure		5. Report Date
		6. Performing Organization Code none
7. Author(s) Ira C. Bechtold, EREP PI 541		8. Performing Organization Report No. BESTEC 101-M3-2/75
9. Performing Organization Name and Address Bechtold Satellite Technology Corp. 17137 East Gale Avenue City of Industry, California 91745		10. Work Unit No. none
		11. Contract or Grant No. NAS9-14235
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12. Sponsoring Agency Name and Address NASA - Lyndon B. Johnson Space Center Technical Support Procurement Branch Houston, Texas 77058		14. Sponsoring Agency Code BB62

15. Supplementary Notes

16. Abstract

Geologic maps made from interpretations of Skylab imagery agree well with geologic maps (scale 1:62,500) made from ground geology studies. Analyses of S190A and S190B imagery over our test area reveal many features that may represent alteration zones. The "zones" correlate well with mining areas when plotted on the same map. Our investigations of two of these features indicate the zones extend beyond areas that are mapped as having mining activity. The extensions may represent areas of unexploited economic mineral deposits.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Alteration zones Mineral exploration Skylab imagery	Martin Miller/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I Summary of Work Performed:

A. Continued operation of supportive reference and filing systems. Addition of part-time personnel to manage system and assist in research.

B. Discussions with commercial photographers on tone enhancement of ERTS and Skylab black and white positive films by contact duplication and production of high-quality prints from negatives. Discussions on use of the Diazo process for duplicating, enhancing, and compositing imagery. Contact with Mr. Wally MacGalliard of MacGalliard Colorprints, Hollywood, regarding enhancement of Skylab color imagery.

C. Preliminary study of applications of EREP S191 infrared spectrometer data and S194 L-band radiometer data to resources exploration. Plotting of S194 antenna temperature versus distance across part of test area for part of EREP pass 68.

D. Continued study of arcuate features and color anomalies noted in S190A and S190B imagery which are suspected to be related to geothermal activity. Overlays of structural features and lithologies mapped from the imagery at 1:500,000 scale are being transferred to large scale maps (1:62,500) to compare imagery-derived interpretation with detailed ground geological mapping. Also, detailed studies are being conducted of anomalies noted in S190A and S190B imagery that are thought to be related to mineral deposits.

II Analysis of Research Progress:

Routine procedures for tone enhancement of black and white imagery have not yet been established. Commercial photographers contacted by us seem to be reluctant to do enhancement work on a regular basis. We are continuing our efforts to locate suitable photographic facilities and competent technicians.

Except for this problem, we are adhering to the schedule detailed in the Milestone Chart (BESTEC Report 101-S-1/75) and no significant changes to that chart are to be reported at this time.

We have made satisfactory progress toward the identification of the causes of anomalies thought to be related to geothermal activity in California and Nevada. Preliminary comparison of geologic maps made from imagery interpretation studies with geologic maps made by conventional ground mapping indicate that location of most lithologic contacts and structural features noted in imagery agree well with locations on the ground geological map.

Many interesting features visible in S190A and S190B transparencies seem to be related to mineral deposits. We are investigating two particularly interesting anomalies in the Death Valley, California, area both of which exhibit color anomalies indicative of alteration zones. Plotting of these zones on maps shows good correlation with mine localities. However, the zones extend beyond the mines; this may indicate areas of potentially economic mineral deposits. We intend to complete our analysis of the anomalies, field check our results, and prepare reports to be submitted to NASA on our findings.

III Work Planned for NextReporting Period:

A. Field reconnaissance to confirm interpretation from imagery of alteration zones and areas of potentially economic mineral deposits.

B. Trip to Edwards AFB to view imagery taken by X-15 aircraft over our test area.

C. Continued efforts to establish tone enhancement procedures for imagery with commercial photographers in the area.

IV Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

V Acknowledgments:

The assistance of BESTEC personnel assigned to the EREP project in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 November 1974 - 30 November 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M4-3/75

Contract Monitor:

David Amsbury, Code TF6
Team Leader, Geology
Earth Observations Division
NASA - Lyndon B. Johnson Space Center
Houston, Texas 77058

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5. Report Date:

6. Performing Organization Code: none

7. Author(s): Ira C. Bechtold, EREP PI 541

8. Performing Organization Report No.: BESTEC 101-M4-3/75

9. Performing Organization Name and Address:
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17137 East Gale Avenue
City of Industry, California 91745

10. Work Unit No.: none

11. Contract or Grant No.: NAS9-14235

12. Sponsoring Agency Name and Address:
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Technical Support Procurement Branch
Houston, Texas 77058

13. Type of Report and Period Covered: Monthly Progress 1 Nov-30 Nov 1974

14. Sponsoring Agency Code: BB62

15. Supplementary Notes:

16. Abstract

A strong correlation between anomalous features noted in Skylab (EREP) photography and occurrences of known mineral deposits has been established for several areas in our test site. Field reconnaissance of an arcuate anomaly expressed in the Hunter Mountain quartz monzonite confirmed correlation of mineralized zones with edges of the anomaly. Highly reflective alteration areas intersected by short linears in the Black Mountains near Death Valley correlate on the ground with copper mineralized breccia zones.

17. Key Words (Selected by Author(s)):
Geology
Mineral exploration
Skylab (EREP) photography
Alteration zones

18. Distribution Statement:
Martin Miller/TF6
Earth Observations Division
NASA - LBJ Space Center
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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I SUMMARY OF WORK PERFORMED

A. Discussions regarding tone enhancements of ERTS and EREP black and white films by contact duplication processes with technical representatives from Eastman Kodak Company. Specific film types recommended by them for optimizing data are being ordered and tone enhancement of imagery will be attempted. Results will be reported.

B. Discussions on state-of-the-art computer manipulation of ERTS imagery on CCT's with scientific personnel from Electromagnetics Systems Laboratories (ESL), Sunnyvale, California. Reviewed specific computer programs developed by ESL for geological interpretations of ERTS imagery. Observed computerized Image Selection System for Earth Resources Aircraft Project (ERAP) designed and operated by ESL at Ames Research Center, Moffett Field. System provides a listing of ERAP imagery that is available over a geographic area specified by the user as well as depicts the limits of ERAP coverage on a CRT screen for that same geographic area. System greatly facilitates selection of high altitude aircraft data pertinent to EREP investigations.

C. Screening of X-15 photography at Edwards AFB. Discussions with Mr. Clint Johnson and Mr. Mike Groen on the applicability of X-15 data to resources exploration.

D. Complete study of two anomalies noted in EREP imagery and suspected to be related to mineralized zones. Anomalies were initially noted in S190A and S190B photography and subsequent study of the anomalies with other imagery and published data corroborated interpretations. Conclusions were field checked during a reconnaissance to the areas. Summaries of findings are included in this report.

E. Continued operation and updating of reference systems, imagery indexes, and retrieval systems.

II FIELD INVESTIGATIONS

A field reconnaissance to two areas near Death Valley and one near Baker, California, was conducted by three BESTEC investigators in order to sample rock outcrops and check structural features, alteration zones, and arcuate anomalies interpreted from Skylab imagery. On Hunter Mountain (36°33'N, 117°30'W), a circular anomaly was correlated with geologic and vegetative features observed on the ground.

Altered areas and mineral occurrences noted in outcrops were plotted on large-scale maps, and rock samples and ground photographs were taken to correlate with imagery-interpreted anomalies. Near Greenwater (36°10'N, 116°40'W), several linears noted in Skylab imagery and interpreted to be fractures and faults were examined on the ground and their relationship to mineralized zones assessed.

III SIGNIFICANT RESULTS

The following summaries outline significant results of our investigations. More complete reports are being prepared.

A. Application of Skylab Imagery to Resource Exploration in the Death Valley Region.

A study of Skylab satellite images of the northern Panamint Range, California, reveals a prominent arcuate structure, almost perfectly circular, five to six miles in diameter. This structure exhibits topographic, vegetative, and color anomalies having high correlation with mineralized zones, in particular, copper deposits.

The feature expressed within the Hunter Mountain quartz monzonite intrusive body of probable Cretaceous age is bounded in part by remnants of metamorphosed Paleozoic marine sediments. The linear contact of the massive quartz monzonite body with the Paleozoic rocks occurs along the northern edge of the structure and extends to the southeast, but the arcuate anomaly departs southward from this contact. Published geologic maps indicate this contact is located only approximately, and the region is relatively unexplored. Analysis of space imagery provides interpretation of previously unrecognized structural and lithological detail.

Along its southern and eastern margins, the anomaly is expressed within the plutonic rock, and hence may represent a later igneous intrusion of similar composition or a zone of contrasting grain sizes. The Paleozoic metasedimentary rocks bound the anomaly along the western and northern margins and exhibit high reflectance in the images.

A major fault system strikes approximately N60W from Saline Valley to Panamint Valley, tangential to the southwestern edge of the anomaly in Grapevine Canyon. Other mapped faults extend approximately N10E along the western edge toward Racetrack Valley in the north. Fractures easily visible in satellite imagery generally parallel these two sets throughout the plutonic and metamorphic rock bodies. Other less distinct fractures appear to trend nearly E-W and N30E.

Skylab S190A and S190B Ektachrome images show the arcuate feature with a light snow cover, enhancing the relief and margins considerably; in another scene without snow, the boundaries cannot be easily determined, especially in the south and east where igneous rocks of similar composition occur. The Paleozoic rocks exhibit high reflectance in all scenes, including S190A Ektachrome, near-infrared, and composited multispectral frames, easily defining the northern and eastern margins. The S190B Ektachrome earth terrain camera offers good detail and indicates that the margins of the anomaly are topographically steep, dissected by deep canyons, while the interior region is relatively flat and featureless. Vegetation occurs predominantly in the south and east region, but is extremely sparse in the northern half within the anomaly and along the margins. Additionally, subtle color differences delineate various rock types and potential mineralized zones. ERTS imagery also supports these observations and confirms the fracture pattern.

Field reconnaissance indicates the bordering, highly-reflecting Paleozoic rocks have been thermally metamorphosed and enriched by metasomatic processes. A wide calc-silicate zone comprises the northern margin, accompanied by skarn-bearing disseminated copper oxides and minor sulfides. Copper mineralization appears to be closely associated with the regions of bright reflectance. A strong geographic control of indigenous evergreen trees and shrubs is readily discernible.

Further field study should indicate a relation of copper with the anomaly; we expect contacts of the Hunter Mountain quartz monzonite outside of the anomalous arcuate structure may reveal little or no copper mineralization. Detailed mapping and sampling of the vegetation and analysis for metallic ion concentrations would likely show a correlation of decreased density of plant population toward the margins with increased mineralization.

B. Geologic Investigations in the Black Mountains-Greenwater Range, California, Using Skylab (EREP) Photography

The northwest trending Black Mountains and Greenwater Range, which are separated by the Greenwater Valley, form a diamond-shaped structural block that has been squeezed between the Death Valley fault on the west and the Furnace Creek fault on the east. This squeezing has produced complex folding and faulting within the block and has subjected the block to repeated uplifts during which the once thick Paleozoic section was eroded. The Black Mountains are composed of Precambrian metasediments that are exposed in northwest trending anticlines, Tertiary granitics, and Cenozoic volcanics. The exposed rocks in the Greenwater Range are predominantly volcanics. These lithologies can be easily discerned and contacts traced in Skylab photography, especially S190B Ektachrome.

An investigation of this area was conducted using Skylab S190A and S190B photography to analyze the geologic environment of known copper deposits and to suggest additional areas that may be favorable for copper mineralization.

Analysis of the photography resulted in the identification of several areas displaying anomalously high reflectance in Ektachrome films. These areas were interpreted to be alteration zones that are largely exposed in extrusive rhyolites and rhyodacites that form buff-colored slopes. The zones are linear and are approximately parallel to each other and to the nearby contact of the volcanics with Tertiary monzonitic rocks. Mining activity in the early 20th century was concentrated along these zones, and many shafts and pits are dug in the zones to locate copper deposits.

Further study of the more conspicuous parts of the alteration zones revealed many linears striking approximately perpendicular to the trend of the zones and the monzonite-volcanics contacts. These linears are generally short (1/3 - 1/4 mile) and are not continuous across lithological contacts. However, the pattern of linears form a band that extends from the northwest trending anticlines near the Death Valley fault across the Black Mountains, across the Greenwater Valley, and possibly into the volcanics of the Greenwater Range.

Field examination of the alteration zones and fractures near the townsite of Greenwater has resulted in the conclusion that copper deposits are localized at intersections of the two features. Some of the linears were identified as brecciated zones, approximately 50 yards wide, that contain many outcrops of copper silicates and carbonates and some barite. The copper mineralization appeared to be confined to the volcanic rocks. No copper sulfides were found.

Several alteration zone fracture intersections that were not field-checked coincide with mapped prospects and shafts. Other intersections in the Black Mountains and southern end of the Greenwater Range suggest areas that have a strong potential for copper mineralization. All of the areas displaying alteration and fractures are spatially related to monzonitic rocks which suggests that primary copper minerals might have been derived from the monzonite by fluids associated with the extrusion of the volcanic rocks or with the breccia zones.

IV ANALYSIS OF RESEARCH PROGRESS

Investigations of our test area are proceeding satisfactorily as we now have S190A and S190B imagery over most of our selected study sites. We are analyzing S190A in 70mm format projected to approximately 1:420,000 as discussed in previous reports. However, we are experimenting with projecting S190A imagery directly onto published topographic and geologic maps and evaluating loss of resolution and color at high magnification (up to 20X). We are also comparing interpretations done at the lower magnification (6X) to those done at the higher magnification.

Thus far, we can analyze S190B imagery only in 4.5 or 9-inch film format, but we are attempting to devise a method by which we can enlarge the 4.5 films approximately 20 times in our 6040PT I^2S viewer.

Several areas displaying unusual or anomalous features in Skylab imagery have been investigated thoroughly and, for all of the areas, a correlation between the anomalous features and occurrences of known mineral deposits or geothermal springs has been established. This correlation is based exclusively on published geologic maps and reports. However, for two of the areas, our field investigations confirm our imagery-based conclusions and support our theories concerning the detection and evaluation of resources from orbiting platforms.

More anomalous features are being "discovered" in EREP imagery than can be evaluated as to their significance and relationship to resources. Anomalies have been noted in nearly every rock type and alluvium. We suspect the geologic causes of the anomalies are many and diverse, and we are attempting to establish criteria by which anomalies not related to potential resources can be evaluated and eliminated.

We are adhering to the schedule detailed in the Milestone Chart (BESTEC Report 101-S-1/75) and no significant changes to that chart are to be reported at this time.

V WORK PLANNED FOR NEXT REPORTING PERIOD

A. Production of map of known mineral occurrences in the Eastern California region.

B. Visual-hand lens-analysis of rock samples and analysis of ground photography from November field investigations and preparation of detailed reports of findings.

C. Discussions regarding enhancement and enlargements of S190A and S190B color photography with Wally MacGalliard, MacGalliard Colorprints, Hollywood.

D. Receipt and analysis of S192 MSS imagery over pre-selected areas.

E. Analysis of a potential water resources area noted in EREP photography.

VI PERSONNEL

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

VII ACKNOWLEDGMENTS

The assistance of C. Gregory Wagner, John T. Reynolds, and Martha N. Wadsworth in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

SEMIANNUAL REPORT
1 July - 31 December 1974

Submitted by:

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15. Supplementary Notes

16. Abstract

Skylab S190A and S190B imagery over a 70,000 square mile test area has been received and evaluated for usefulness to resources exploration. The high resolution of 190B films permits accurate location of anomalies and identification of linear ground features as small as twelve feet wide. Advantages of 190A films include availability in different spectral bands, end lap (stereo viewing), and color contrast superior to ERTS. Arcuate anomalies, linears and color variations detectable in Skylab films are often related to mineral, geothermal, or petroleum deposits.

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Technical Report Standard Title Page

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. PROGRAM SUMMARY

Introduction:

The purposes of this study are to analyze, interpret, and evaluate data and imagery from the Skylab (EREP) earth-looking sensors and apply these results to mineral, petroleum, geothermal, and water resources exploration. Additionally, Skylab products are to be compared to other space-orbiting and aerial remote sensing techniques, such as ERTS imagery, X-15, Apollo spacecraft, and high-altitude aircraft photography for an evaluation of usefulness to geological investigations. Interpretations made from remote sensing data are to be confirmed and extended by studies of published geological and geophysical reports and maps, as well as on-site field reconnaissance surveys.

Test Area:

The area chosen for the study is a 70,000 square mile rectangle encompassing parts of Arizona, California, Nevada, and Utah (see Figure 1). Most of the area is a part of the Basin and Range physiographic province and is characterized by elongate, partially-buried fault blocks of variable structure and rock type separated by broad, alluvial-filled basins. Parts of the Colorado Plateaus, a region of relatively unfaulted, flat-lying, Paleozoic sedimentary rocks, and the granitic Sierra Nevada massif are also included in the test area. Thus, investigations of remote sensing data and imagery are being conducted over a variety of geologic environments.

The mineral wealth of the area is exemplified by the large deposits currently being mined, such as the Duval copper porphyry deposit in northwestern Arizona, the iron deposits of southwestern Utah, the Goldfield-Tonopah and Pioche areas in Nevada, and the borax deposits in California. Numerous mining districts, currently inactive, produced millions of dollars in mineral deposits. Many small mines are active in the test area and abandoned shafts, pits, and tunnels signify that the area has been extensively explored for mineral deposits.

Description of Facilities:

Facilities committed to the NASA investigation by BESTEC include an International Imaging Systems (I^2S) color additive viewer, Model 6040PT. This viewer, designed to accept 70mm film chips,

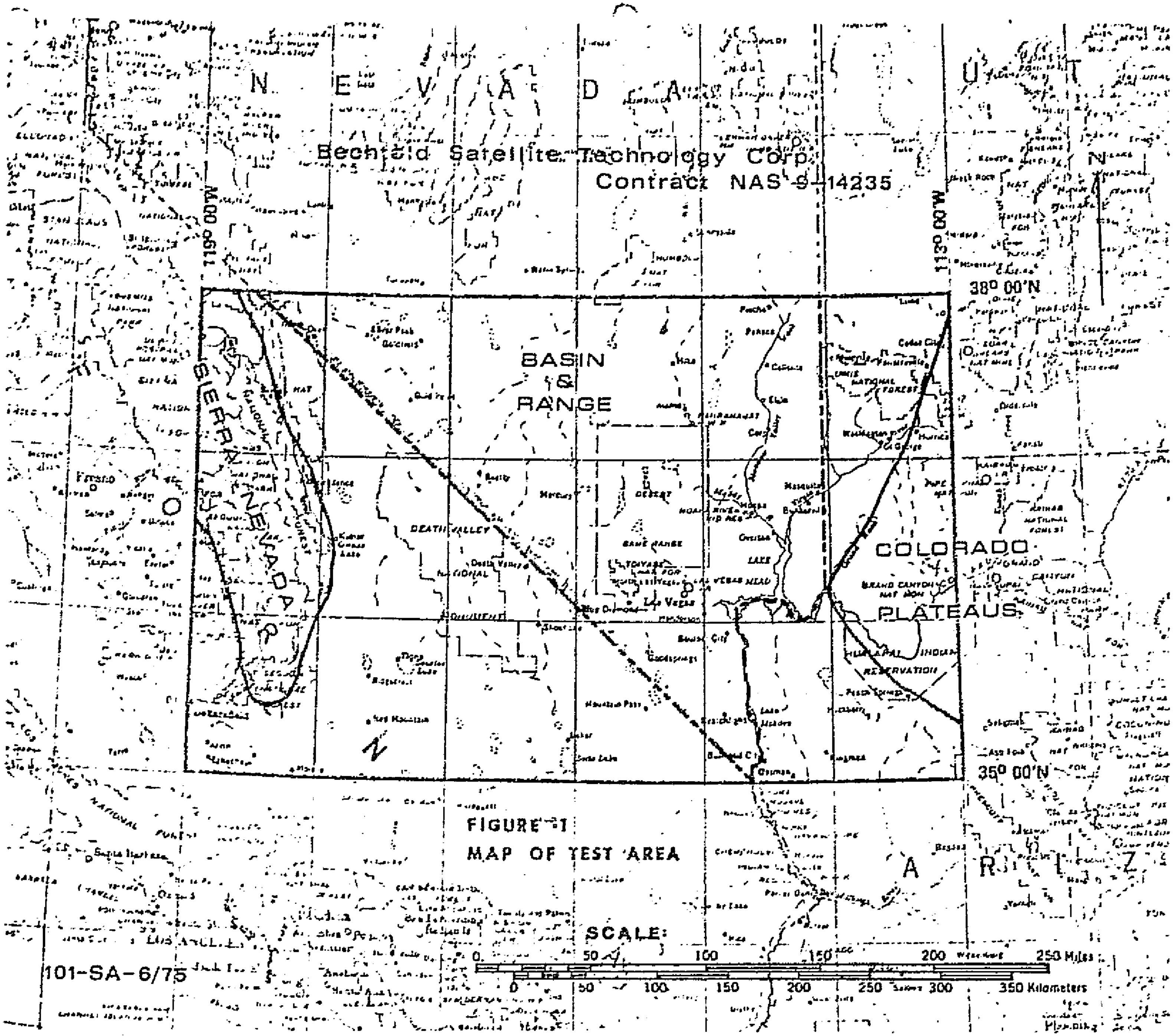

FIGURE 1
MAP OF TEST AREA

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displays the image on a Polacoat viewing screen suitable for tracing image detail at an enlargement factor of 6.7. It also projects images at magnification up to 20X from the rear of the machine onto a vertical, opaque screen. Any image available in 35mm or 70mm film chips such as ERTS MSS and RBV, Skylab S190A and handheld, U-2, and RB-57 can be analyzed in the I^2S viewer.

Other standard image viewing instruments such as microfilm readers, light tables, stereoscopes, monoscopes, reducing lenses, and magnifying glasses are also available for the study.

An extensive library of literature and maps (geological, geophysical, topographical) pertaining to the test area has been compiled to complement imagery studies. Much of the material has been transferred from the private collections of Mr. Ira C. Bechtold; other references have been received from federal and state government agencies, universities, and industry.

A reliable and efficient filing, cataloging, and indexing system for imagery has been developed for the investigation. The system contains approximately 400 scenes of ERTS and Skylab imagery supplied by NASA under the Skylab contract, in addition to many hundreds of frames of Skylab, ERTS, Gemini, Apollo, X-15, Nimbus, and U-2 imagery already in BESTEC's or Mr. Bechtold's files. All imagery has been indexed by place names and filed according to NASA identification numbers.

Other equipment supplied by BESTEC for the investigation includes a GMC 4-wheel drive truck, specially equipped for geologic field work, and a portable proton magnetometer that will be available for field use later in the study.

<u>Accomplishments</u>:

During the six-month period discussed in this report, major effort proceeded in three main phases:

1. organization
2. inspection
3. investigation

The organizational phase included the establishment of office facilities to execute the Skylab investigation, the development of office procedures, and the familiarization of BESTEC personnel with the requirements of the NASA contract and the specifics of the EREP program. During this phase, a process for handling imagery was designed and initiated. The process involved preliminary evaluation of the quality of NASA supplied imagery and filing of all products (70mm positive and negative films, 5- and 9-inch positives, negatives, and prints) for each scene in one readily-accessible location. Each image was cross-referenced with place names. The process was much more complex and time-consuming than originally anticipated due to the large volumes of imagery received from NASA. The value of the comprehensive imagery files has been frequently demonstrated in investigations, however.

The inspection phase was essentially an intermediate stage, providing the transition from organization of the investigation to active interpretation of EREP data and field work. During this phase, Skylab imagery was visually inspected on light tables to determine:

1. how completely the test area was imaged by the S190A multispectral photographic and S190B earth terrain cameras by each of the three manned missions;

2. the presence of scratches and fogging in the film;

3. characteristics of each magazine (color, contrast, resolution, scale) and cloud cover of each frame;

4. percent end lap per frame for each 190A and 190B magazine; and

5. relative usefulness of different Skylab products (70mm films, 5- and 9-inch films) and of different film types for geologic investigations.

In addition, the imagery was analyzed to determine if ground sites, predetermined to be of interest to this investigation, were imaged by EREP sensors. A listing of other areas noted in Skylab imagery that displayed unusual or anomalous color, textural, linear, or arcuate features was compiled; all imagery over these areas was analyzed to ascertain if the anomaly was real (related to the cultural or geological environment) or a product of film processing.

S192 screening films were viewed and specific fragments of data were selected by BESTEC investigators and reported to NASA for processing of all channels into 70mm, line-straightened imagery. Selection was based on determination of geologically significant anomalies possibly related to mineral deposits as noted during analyses of 190A and B transparencies.

The third phase of the investigation encompasses detailed imagery studies and interpretation of anomalies. There are three steps in a comprehensive study of an anomaly:

1. analyses of imagery, first using EREP data, then substantiating interpretations with imagery from other spacecraft and aircraft;

2. corroborating results with reference material; and

3. confirming interpretations with on-site field reconnaissance surveys and evaluating their significance to mineral exploration in the area of the anomaly.

Included in the third phase is the preparation of monthly progress reports, special reports, publications, and oral presentations.

During the first six months of this investigation, approximately twelve sites or anomalies were examined in detail using EREP data as the primary tool. Two short field reconnaissances were conducted to check ground geology in areas of interest. Two areas of particular interest were reported in the November monthly report -- Hunter Mountain and Greenwater Valley-Black Mountains, both in California.

Significant Results:

The following significant results have been previously reported:

Studies of S190A imagery support the conclusions of Bechtold and Jahns (1971) that altered rocks can be easily identified in color infrared films.

High resolution S190B photography permits the location of structural features that control geothermal activity more accurately than is possible with other spacecraft data.

Films from all six S190A multispectral photographic camera stations (for any one scene) can be registered and analyzed in a color additive viewer (four films at a time).

S190A and B films are excellent for geologic interpretation at 18X-19X magnification.

A study of 190A and 190B images of the northern Panamint Range, California, reveals a prominent arcuate structure five to six miles in diameter. This structure exhibits topographic, vegetative, and color anomalies having high correlation with mineralized zones, copper deposits in particular. Field reconnaissance confirms this interpretation. (Summary of this study was reported in November monthly report; full length report is in preparation.)

Near the abandoned townsite of Greenwater, Death Valley, field examination of color anomalies and linears interpreted to be alteration zones and fractures, respectively, has resulted in the conclusion that copper deposits are localized at intersections of the two features. (Summary of this study was reported in November monthly report; full length report is in preparation.)

Anomalous colorations determined to be alteration zones correlate with many mapped mining areas in Nevada and California. Extension of the zones beyond the known areas suggest areas of additional mineralization.

Another significant result not previously reported is a study of Greenwater Valley which indicates that the valley is bounded on the north and east by faults, on the south by a basement high, and on the west by the dip slope of the Black Mountains. Movement of groundwater from the valley is thus restricted, indicating the valley is a potential water reservoir.

II. DISCUSSION OF IMAGERY

S190A Multispectral Camera Photography:

Over 70% of the 70,000 square mile test area was photographed at least once by the S190A cameras. Five Skylab tracks traversed the test area, three descending (63,20,6) and two ascending (16, 59). There were 14 different S190A data-gathering EREP passes over those tracks; NASA supplied BESTEC with photography from eight of the 14 passes (42 frames).

As specified in the data requirements section of BESTEC's Skylab contract, NASA supplied only that imagery exhibiting less than 30% cloud cover. On several occasions, however, we requested copies of S190A frames over sites of particular interest even though catalogs and reference maps indicated cloud cover of the frame was greater than 30%. Cloud-covered frames were requested only if no other Skylab data was available over the site of interest. Fortunately, windows in the clouds were located over the sites in some of the requested frames.

A few areas were photographed on more than one EREP pass, which permitted evaluations under different climatic conditions and different sun angles. For example, photography for the Lake Mead region is available from S190A magazines 04 (SL2 - June 1973), 28 (SL3 - September 1973), and 4B (SL4 - February 1974).

S190A photography was received in sleeved 70mm film positives and, just recently, in 9-inch (4X) film positives and negatives (for black and white films only).

The quality of the films is generally excellent regarding fogging, spots, and scratches due to processing. The small scale of the film chips (1:2,850,000) makes geological analysis impossible, but it is adequate for an evaluation of quality, cloud cover, and geographic area covered by the frame as well as an appraisal of the resolution and color contrast. The chips are interpreted in an I^2S multispectral viewer which enlarges them 6.67X to a scale approximately 1:425,000.

The projection results in some loss of detail, especially in the Ektachrome films, but this is attributed mostly to the Polacoat screen and optical degradation inherent in the viewer.

70mm chips have been composited (four at a time) with no registration problems. No single configuration of light intensities, color filters, and spectral bands has proven best for investigations of all magazines.

The black and white IR exhibits poor resolution (graininess) and generally detracts from the composited image. Ektachrome chips are perhaps overall the most useful; but the black and white band 5 usually has the best resolution.

Projecting S190A chips through the rear of the I^2S viewer permits enlargements of 20X from the 70mm size. In this way, S190A can be registered directly onto published maps of conventional scales: 1:250,000 and 1:62,500. The image is still very useful if viewed in a darkened room where incident light cannot detract from the image. Obviously, some resolution and color contrast is lost at enlargements of this magnitude; we interpret the frame at 6.67X before the larger projection.

Photographic enhancement of 190A films has not yet been attempted. It is anticipated that the same procedure used to enhance ERTS will be successful for the black and white 70mm films. Currently we are processing some 190A Ektachromes into prints, enhancing the interneg by varying exposure times.

Stereo-viewing capabilities of S190A have not been fully investigated but appear to be very useful. Magazine 4B over the Lake Mead area and into northwest Arizona has been examined using a stereoscope. Several short linears observed are interpreted to be normal faults. They were not noted during conventional monoscopic analysis.

Several features of the S190A multispectral camera photography are especially useful to geological investigations:

1. availability in several spectra bands
2. capability of false-color compositing in a multispectral viewer
3. resolution (better than ERTS)
4. endlap: stereo viewing capabilities
5. Ektachrome films: more subtle color variatio s can be detected than is possible with ERTS; many tin s, the

color contrast is as good as that of the Apollo 6 photography which exhibits excellent color contrast due to a low sun angle.

S190B Earth Terrain Camera Photography:

The very high resolution of 190B photography makes it the most useful of Skylab EREP products, although it does not have the multispectral capabilities of S190A or S192 imagery. Approximately 60% of our test site was photographed with the 190B camera; the largest expanse of territory not photographed is in southwestern Utah - eastern Nevada. Frames supplied by NASA in 5- and 9-inch film positives number 34. To date, all 5-inch films and a small number of 9-inch films have been processed into our storage system and analyzed.

The resolution of 5-inch 190B is excellent. Linear features as narrow as 12 feet can be delineated in situations of high contrast, such as dirt roads cutting alluvial fans in a desert environment. The black and white films (e.g., magazine 85) appear to have the best optical resolution, but it is easier to identify small features in the Ektachrome films. Color infrared films have the poorest resolution of 190B film types but resolution is still very good; we have identified features in an urban environment approximately 50 feet square (magazine 87).

A principal advantage of 190B high resolution is that it permits identification of man-made features such as roads and stock tanks that aid in the registration of projected films directly onto published topographic or geologic maps. Thus, items of geologic interest -- color anomalies or linears -- can be accurately located on the map, which makes field reconnaissance less time-consuming and more apt to be successful.

To this point we have been analyzing 190B in 5-inch format (scale 1:950,000) only, on light tables with monoscopic viewing devices. Although our I^2S multispectral viewer is designed to accept film chips no larger than 70mm, we are attempting to utilize the enlargement capabilities of the viewer on the 5-inch films. The technique we devised is simple: tape the 5-inch film to the underside of the platen, such that the area of interest appears in the opening where a 70mm chip is normally mounted. In this way, the 5-inch film is enlarged to approximately 1:142,000 using the 6.67X front projection facility, and to as large as 1:47,500 using the rear projection facility. S190B films supplied at 2X enlargements will project correspondingly larger.

S190B films are generally excellent in quality; very few processing flaws have been noted in frames analyzed. Parts of some magazines (e.g., 94) are overexposed -- color contrast is minimal. Because overexposure is more apparent in 2X 190B films, we suspect the problem is in processing, and the original was not overexposed. We are attempting to bring out colors on certain frames by enhancing internegs made from NASA transparencies.

S190B photography complements S190A very well, as anomalous features noted in 190A composited multispectral products can usually be located on 190B films and analyzed as to geologic significance using the better resolution films.

From a geologic standpoint, 190B resolution makes it possible to discern faults, fractures, and other linear features not visible in 190A, ERTS, Apollo, or Gemini imagery. Low sun angles seem to be especially useful in 190B frames to enhance linear features, particularly short-length faults that cut Holocene deposits of uniform color. Lithologic contacts can frequently be resolved and accurately mapped using Ektachrome films.

S192 Multispectral Scanner Imagery:

S192 screening films were viewed on light tables, and data fragments over previously-determined sites of interest were requested from NASA in a 70mm, line-straightened format. Approximately 83 seconds of data from seven different EREP passes were ordered. To date, no processed data has been received.

S191 Infrared Spectrometer; S193 Microwave Radiometer, Scatterometer, and Altimeter; S194 L-Band Radiometer:

No work of any significance has been performed on any of these experiments. Some S194 data was plotted for orbit 68 over the Sierra Nevada and the Mojave Desert as antenna temperature versus position of spacecraft. No definite conclusions have been formulated as to significance of results.

It is anticipated that research into the usefulness of S191 data will result in the conclusion that resolution is insufficient for geologic investigations.

ERTS Imagery:

Over 300 frames from many different ERTS cycles over the test area have been received to complement the Skylab data. Nine-inch prints, positive transparencies, and 70mm negative and positive films were delivered to BESTEC and filed. All of the area was imaged at least once by ERTS sensors under optimum conditions, yielding high-contrast, cloud-free imagery.

Prints are generally poor-quality reproductions, useful only for quick scanning for indexing and coverage purposes. Nine-inch transparencies are good quality and useful at the scale of 1:1,000,000. The 70mm negatives are of little use, and we find it necessary to enhance 70mm positives photographically to increase contrast for use in the multispectral viewer.

The common map scales (1:1,000,000) at which ERTS 9-inch products are reproduced is a particular advantage of ERTS. In addition, the I^2S multispectral viewer was designed to enlarge ERTS 70mm chips to 1:500,000, a convenient scale, as many geological and geophysical maps of the same resolution are published at that scale; e.g., the geology, Bouguer gravity, and residual aeromagnetic map series of Arizona. The 1:500,000 scale is especially valuable as 2X enlargements of S190B photography are also at 1:500,000, which will allow a ready comparison of the products as well as evaluation of features noted in ERTS at the higher resolution of 190B.

The synoptic view afforded by ERTS imagery remains a principal advantage, especially regarding identification of lineaments. Compositing four ERTS spectral bands in a multispectral viewer is another advantage. The repetitive coverage of ERTS, which allows temporal evaluations of features of interest, is a third distinct advantage over Skylab photography.

Enhancement of Imagery:

Several forms of enhancing imagery are being tried with the intent of producing enhanced prints or films at the best cost-effective rate. Computer processing was not attempted as we wanted a procedure that could be done routinely at low cost by non-technical personnel.

A very simple procedure for enhancing black and white Skylab or ERTS 70mm positives has been established using Kodak duplicating films. The positives are placed in contact with the duplicating films in a vacuum frame which minimizes the occurrences of Newton's rings. The films are duplicated at several different exposure times which serves to enhance different parts of the image. The process is performed by a local printing company. The process is also effective for producing enhanced negatives from which high-quality prints are made.

Another inexpensive method of enhancing prints requires only a standard office copying machine. The procedure is simply to reproduce the print, varying the tone control for lighter or darker copies. We have found that certain features or anomalies not readily apparent in the original print can be accentuated. This method is especially useful for preliminary phases of analysis and emphasizing features to persons not familiar with image interpretation.

A third enhancement method in use involves photographing an image as it is projected onto the front screen of the I^2S multispectral viewer. The 35mm camera is mounted above the screen, and several pictures are taken of the image at different exposure times. The resulting slides are then analyzed using a conventional 35mm slide projector or the I^2S viewer. Slides taken in this manner are good records of false color composites made in the multispectral viewer and are also excellent for use in lecture presentations. The slides do not have the resolution of the original that was photographed, but this frequently has proved to be an advantage.

III. DISCUSSION OF ACTIVITIES

Geothermal Exploration:

Geothermal reservoirs are manifested at ground surface by several different geological signatures that can be detected using Skylab imagery. Arcuate anomalies may represent buried intrusive granitic stocks that create hydrothermal solutions or collapsed and buried calderas. Color anomalies and subtle tone variations may indicate rock products altered by thermal waters. Volcanic terranes, of the diverse types associated with many KGRA's, may be detected and mapped using Skylab photography. Structural features -- faults and fractures -- that control movements of hydrothermal fluids can be discerned and mapped very accurately using 190B photography.

Two geothermal areas were examined to ascertain which geologic signatures pertinent to exploration for geothermal activity would be most important when using Skylab photography as an exploration tool.

Analyses of S190A and B photography over the Colorado River south of Lake Mead has revealed dikes and faults in close proximity to the host springs at Willow Beach, Arizona. Several large arcuate features noted in the imagery were determined to quite likely be expressions of the extrusive Tertiary volcanic activity in the area, although there is a possibility the arcuates are related to Mesozoic granitic bodies that are common east of the river.

An anomalous light-colored zone east of the beach is interpreted to be Precambrian gneiss altered by thermal fluids possibly associated with the nearby hot springs. A series of north-trending faults observable on both sides of the river may control the extent of the geothermal activity. If so, high temperature waters may be found at shallow depths at sites other than the springs at Willow Beach. The location of faults and the light-colored anomaly has been pinpointed using high-resolution 190B films. The coloration anomaly is most easily identified in S190A color infrared films. Field reconnaissance of the area is planned for April.

The structural environment of the Coso (California) KGRA has been analyzed using ERTS imagery preparatory to receiving specially-requested Skylab photography of the area. The KGRA is underlain by Mesozoic granitic rocks with Cenozoic basalts and rhyolites outcropping in flows and domes.

Many arcuates of varying dimensions that can be mapped from ERTS imagery may represent surface expressions of the granitic batholith such as fractures, faults, collapse features, or alteration zones. Smaller arcuates evident are probably stocks from the batholith and may be directly responsible for the numerous hot springs and other manifestations of geothermal activity in the area. Known activity apparently is bounded on the south by the Wilson Canyon fault, a left-lateral fault extending from Searles Lake across the Argus Range, Indian Wells Valley, and into the Sierra Nevada. The Airport Lake playa is aligned along the fault. Many northerly-striking faults that can be observed in the imagery appear to terminate against the Wilson Canyon fault. Volcanic domes and hot springs within the Coso area are aligned along the northerly-striking faults.

Coloration anomalies detected in ERTS false-color composites are interpreted to be hydrothermally altered granites.

Arcuate features extend over a larger area than that which currently exhibits geothermal activity. Thus, potential geothermal reservoirs may exist outside of the present KGRA. Detailed analysis of Coso will be delayed until Skylab films are received.

Water Resources Exploration:

Investigative efforts have centered on identifying alluvium-filled grabens or structural depressions bounded by faults that might limit horizontal migration of water, thus creating a closed basin. Recharge water would be confined in the subsurface to the basin and a reservoir would be created.

One graben previously mentioned is the Greenwater Valley, Death Valley region, where the valley is bounded on two sides by vertical faults, on the third side by the dip slope of the Black Mountains, and on the fourth by a basement ridge. Gravity maps indicate a substantial thickness of low-density material has accumulated in the valley. Run-off from the Black Mountains and the Greenwater Range into the valley may be effectively sealed from vertical or horizontal movement, creating a water resource.

Mineral Exploration:

For two cases, analyses of Skylab photography have resulted in the identification of anomalies proved by field reconnaissance to be associated with occurrences of mineral deposits. Both the Hunter Mountain and the Black Mountain-Greenwater anomalies were studied extensively with Skylab data in conjunction with published maps and reports previous to field work.

Many other anomalies -- arcuate, coloration, linear -- have been observed in Skylab photos, mapped, and correlated with mining districts but have not yet been field checked.

Petroleum Exploration:

In the extreme southwestern part of the 70,000 square mile test area are the oil and gas fields of the eastern San Joaquin Valley where oil (with associated wet gas) and dry gas are obtained from reservoir rocks which range in age from Eocene to Pleistocene. Sandstones and conglomerates are the principal reservoir rocks, but production has been obtained from fractured shales and from fractured and weathered schist.

The accumulations of oil and gas are contained in structural and stratigraphic traps. The structural traps are anticlines and faults which are superimposed on a regional syncline whose axis lies to the west, outside of the test area. These structural features are strongly aligned in a northwesterly direction parallel to the axis of the basin. The structural trends are reflected by topographic features. Many of the fields in the test area are the result of oil having been trapped against normal faults.

Preliminary examination of 190A films of the eastern San Joaquin reveal that linear trends interpreted to be faults and anticlinal axes can be detected and located. The potential contributions of 190A to petroleum exploration in the area are great, if the linears can be confirmed to be oil field-bounding faults by studying them in high resolution 190B or U-2 photography.

Detailed analysis of the San Joaquin fields will be delayed until additional Skylab data is received. The data will be examined for linears and for the so-called "hazy anomalies" suspected to be related to hydrocarbon accumulations.

IV. ADHERENCE TO SCHEDULE

In general, we are adhering to the schedule detailed in the Milestone Chart (BESTEC Report 101-S-1/75) and no significant changes to that chart are to be reported at this time.

However, two items that are necessary for the successful completion of our investigation have not yet been received: Argus Exploration Company's field notes and S192 imagery. If this data is not received in the near future our own investigations may be delayed.

V. WORK PLANNED FOR NEXT REPORTING PERIOD

Several additional sites in the Death Valley area are to be examined in detail using Skylab data as well as U-2 photography. Another field reconnaissance to Death Valley is planned for April to re-evaluate geological interpretations made from imagery studies.

In order that more sites in the test area can be analyzed in detail, a part-time geologist will be hired to supplement existing staff.

VI. PERSONNEL

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

VII. REFERENCES CITED

Bechtold, Ira C., and Jahns, Richard H., 1971, Remote sensing by photogeology applied to ground current paths in an HVDC system: Proceedings of the Seventh International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, p. 951-956.

VIII. ACKNOWLEDGMENTS

The original contributions of C. Gregory Wagner and John T. Reynolds to methods of imagery enhancement, analysis, and interpretation are gratefully acknowledged. Their contributions to field work are also to be recognized. Martha N. Wadsworth reviewed, edited, and typed this report.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 January 1975 - 31 January 1975

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M5-6/75

Contract Monitor:

David Amsbury, Code TF6
Earth Observations Division
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Houston, Texas 77058

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7. Author(s) Ira C. Bechtold

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17137 East Gale Avenue
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Technical Support Procurement Branch
Houston, Texas 77058

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Monthly progress
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14. Sponsoring Agency Code BB62

15. Supplementary Notes

16. Abstract

High quality color prints have been produced from S190A and 190B positive transparencies that are useful for field geologic investigations. S190B films enlarged and printed at 1:250,000 scale have excellent color and resolution. Compilation of known economic mineral deposits in the test area has been initiated to provide an evaluation of regional zoning of minerals.

17. Key Words (Selected by Author(s))
Geology
Skylab photography
Mineral zoning

18. Distribution Statement
Dr. David L. Amsbury/TF6
Earth Observations Division
NASA - LBJ Space Center
Houston, Texas 77058

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Technical Report Standard Title Page

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

Procedures were established with Mr. Wally MacGalliard, MacGalliard Colorprints, Hollywood, to produce color prints of different sizes from S190A and B positive transparencies. The 70mm and 4.5-inch films were used to make internegatives, rather than the 2X or 4X enlargements, to insure the highest quality possible in the print. Generally, full frames are printed on 8 x 10 inch paper. A part of one S190B frame was enlarged to 8 x 10 inches and has been very useful during field investigations. We plan to produce prints of parts of S190B frames at 1:62,500 scale to allow ready comparison with 15' topographic maps while in the field.

One S190B frame, SL4-94-015, which covers the Black Mountains-Greenwater Valley area, California, was enlarged to 1:250,000 to correspond to geological and geophysical maps published at the same scale. The quality, color, and resolution of the print is very good and the print is comparable to 2X enlarged films supplied by NASA when used for geologic investigations. In addition, we have found that color prints are excellent for displaying arcuate anomalies and linear patterns to personnel not familiar with space imagery interpretation.

A compilation of all known economic mineral deposits in the test area was initiated. Information on the deposits, such as location, ore type, and quantity produced was gathered from published references and maps. Each deposit was plotted on a 1:500,000 scale base map with a symbol denoting the type of deposit. The purpose of the compilation is twofold:

1. to allow quick, comprehensive analyses of known mineral deposits in the vicinity of anomalies noted in Skylab photography.

2. to permit an evaluation of mineralization zoning patterns using Skylab data.

Thus far only the compilation for eastern California has progressed to any degree of usefulness.

A series of linears and coloration anomalies have been noted in Skylab photography of the Furnace Creek area, California. The features are being examined for correlation with borate mineralization in the area. Field reconnaissance to the site is planned for April.

II. Work Planned for Next Reporting Period:

Field reconnaissance of the Castle Mountains, eastern Mojave Desert, is planned to examine coloration anomalies noted in Skylab photography and relationship to known gold-ore producing mines.

III. Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

IV. Acknowledgments:

The assistance of C. Gregory Wagner, John T. Reynolds, and Martha N. Wadsworth in preparation of this report is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 February 1975 - 28 February 1975

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M6-6/75

Contract Monitor:

David Amsbury, Code TF6
Earth Observations Division
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Houston, Texas 77058

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7. Author(s) Ira C. Bechtold

8. Performing Organization Report No. BESTEC 101-M6-6/75

9. Performing Organization Name and Address
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15. Supplementary Notes

16. Abstract

70mm contact negatives are being composited with 70mm positives in a multispectral viewer to produce images useful for detecting major lineaments. Projection of S190B 2X films onto 1:62,500-scale maps, using the MSV facilitates interpretation of observed anomalies and insures their accurate location on the map. Studies of drainage patterns of the Garlock Fault area indicate some evidence exists to extend the fault several kilometers beyond its presently-accepted terminus near the Avawatz Mountains. A north-south lineament is interpreted to be responsible for the emplacement of gold-bearing fluids into volcanic rocks of the Castle Mountains, California.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Interpretation techniques Garlock Fault Castle Mountains Geology	David Amsbury/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES

APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

In addition to the usual contact positives produced during a routine black and white film enhancement process, 70mm contact negatives are also being produced. Prints are made from the negatives, but the negatives are also being used in conjunction with 70mm positives in the multispectral viewer. A very useful image is generated when negatives are composited with positives of the same or different bands. In particular, major lineaments are emphasized. A wide variety of false-color images is possible, increasing the likelihood of identifying anomalies on the image.

S190B 2X enlarged films (1:500,000 scale) are being projected directly onto published geologic and topographic maps at scales as large as 1:62,500. The procedure facilitates accurate location of linears, arcuate and color anomalies, and cultural detail. Analysis of plotted features is made much easier by the direct comparison with published data. In some cases, structural detail, such as fault traces and joints has been added to geologic maps. Registration of image onto map does reveal significant geometric differences, especially over large areas, which must be taken into account.

II. Geologic Investigations:

Garlock Fault Extension

The seemingly abrupt termination of the Garlock Fault at the Avawatz Mountains presents a unique geologic problem. Skylab imagery over the area has been studied to determine if evidence can be discovered to indicate the Garlock Fault extends beyond the Avawatz Mountains.

On many geologic and tectonic maps the Garlock is shown as curving around the east side of the Avawatz Mountains, changing strike from essentially east-west to north-south. Imagery studies indicate that the apparent curvature is a result of pieces of the Avawatz Mountains that have been distorted along splays of the Garlock and Death Valley faults.

Other workers have presented theories to show the Garlock terminates at the Avawatz Mountains. Davis and Burchfiel (1973) state the Garlock is an intracontinental transform fault that originates a few kilometers east of the Avawatz Mountains in Kingston Wash.

Skylab imagery studies indicate the Garlock may be extended beyond the terminus suggested by Davis and Burchfiel. The drainage pattern of the Silurian Hills area is similar to that of the eastern side of the Avawatz Mountains, which has been influenced by the Garlock Fault. That similar structures exist to the east seems to indicate the same structural constraint, the Garlock Fault, has been imposed on this drainage pattern.

Additional studies are needed to confirm this conclusion.

Castle Mountains, California

A one-day field reconnaissance was conducted in the vicinity of Castle Mountains, San Bernardino County, California, to examine structural features and coloration anomalies detected in Skylab transparencies. The object of the field work was to sample rocks in an elongate zone of light coloration that was initially observed in 190A photographs (SL4-76-226) and interpreted to be Tertiary siliceous volcanic rocks altered by hydrothermal activities to clays. A second objective was to locate intersections of linears that were plotted on 1:62,500 topographic maps from analyses of Skylab and U-2 photography and determine if any evidence existed to indicate mineralization was concentrated at these intersections.

The area of investigation is located 19km southwest of Searchlight, Nevada, in the eastern Mojave Desert. Tertiary volcanic activity was widespread in the area around Castle Mountains. Comparison of the location of the coloration anomaly with a mineral occurrences map revealed that gold-ore had been mined from the southern end and western edge of the north-south elongate anomalous zone from rhyolite flows and tuffs. Published reports indicate the ore deposits consist of breccia zones along which the wall rock is silicified. In general, gold-ore veins trend N35E. The deposits are epithermal-type deposits, which extend over much of the Mojave into Arizona at Oatman.

Examination of the Castle Mountains and surrounding area in 190B and U-2 photography indicated three directions of linears: N30-40E, N20-40W, and north-south. The first two sets are also prominent in Piute Mountains, a Tertiary volcanic range that borders the Castles on the east. Since no gold or other metallic minerals have been mined from the Piutes and the range does not appear to be hydrothermally altered, it is concluded that the north-south direction of linears was responsible for the emplacement of thermal fluids into the rhyolites of the Castles that altered the rocks and deposited gold-bearing minerals.

Evidently an episode of volcanism later than the Piute volcanics was extruded along the north-south linear and ore-bearing fluids were associated with this activity. Vertical migration of fluids was structurally controlled by fractures (NE and NW linear sets) that already existed in the rocks of the Castle Mountains. Imagery studies indicate that all three sets of linears had been altered and therefore may contain some mineral values. The likelihood of ore-bearing fluids being concentrated at fracture intersections is great, however, and intersections were priority targets for field work.

Results of the field work are inconclusive as much of the area that we determined to be of interest was private property, and therefore inaccessible. No linear intersections were examined. We did confirm that much of the bright reflectance areas as seen in Skylab imagery was rhyolite altered to clays, especially montmorillonite. Field work near the P.S. Hart Clay Mine showed that layered rhyolites that underlie the mountains contain extensive zones of hydrothermal alteration. The most intense alteration followed vertical fractures. Additional fieldwork in the area is recommended to examine linear intersections in the Castle Mountains and to formulate a viable tectonic model for the area.

III. Work Planned for Next Reporting Period:

Field reconnaissance of the Inyo Mountains is planned to examine arcuate structures noted in Skylab photography.

IV. Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

- Ira C. Bechtold, Principal Investigator
- C. Gregory Wagner, Field Geologist
- John T. Reynolds, Assistant Geologist
- Steven T. Cerri, Junior Geologist (part-time)
- Martha N. Wadsworth, Secretary
- Paul C. Linam, Accountant
- Maurene B. Gray, Clerical Assistant

V. References Cited:

Davis, G.A., and Burchfiel, B.C., 1973, Garlock Fault: an intracontinental transform structure, southern California: Geol. Soc. Am. Bull., v. 84, pp. 1407-1422.

VI. Acknowledgments:

1. Special recognition is given to C. Gregory Wagner and John T. Reynolds for innovative contributions to methods of enhancement of S190A and S190B images.

2. C. Gregory Wagner, John T. Reynolds and Steven T. Cerri showed commendable ingenuity in arriving at very important indications with respect to the Garlock Fault extension with a minimum of field work.

3. C. Gregory Wagner has been responsible for important conclusions from S190A and S190B images as to the origin of, and possible extension of, gold and nonmetallic mineralization in the Castle and Piute Mountains. This was accomplished with a minimum amount of field work owing to a thorough and productive study, in the office, of images and other data.

4. All personnel have contributed significantly to the usefulness of Skylab imagery.

5. Martha N. Wadsworth was responsible for editing and secretarial work throughout this period. Her thoroughness and helpful suggestions have been significant for arriving at conclusions quickly and efficiently.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

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17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-Q2-8/75

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15. Supplementary Notes		

16. Abstract

Investigative efforts during the third quarter emphasized photographic enhancement and special processing of EREP imagery and applications of the imagery to resources exploration. Prints produced from enhanced internegatives are useful in the field and office to supplement studies of films. S192 70 mm film chips are easily registered in a multispectral viewer. Indications are that the data will be useful for rock-type discrimination. Six test sites investigated in detail include four mineral resource areas, one possible geothermal area, and one fault extension. Brief field studies to the Castle and Inyo Mountains, California, confirmed interpretations from imagery analysis of hydrothermally altered rocks. Imagery studies of other sites reveal arcuate and linear patterns spatially related to known mineralized zones.

17. Key Words (Selected by Author(s)) Mineral exploration Geothermal exploration Interpretation techniques Geology	18. Distribution Statement David Amsbury/TF6 Earth Observations Division NASA - LBJ Space Center Houston, Texas 77058

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

PROGRAM SUMMARY

Efforts during the third quarter of this investigation were concentrated on two major areas: (1) photographic enhancement and special processing of EREP photography; and (2) applications of S190A and S190B data to geologic investigations of individual test sites. Significant accomplishments have been achieved in both areas.

Both color and black and white film positives were processed by commercial photographers into prints to allow an evaluation of the usefulness of this format of Skylab photography to geologic investigations. Generally, black and white prints were contact printed from internegatives made from nine-inch positive transparencies. Color prints, conversely, were produced from enlarged internegatives made from 70 mm films (S190A Ektachrome and color infrared films) or five-inch films (S190B Ektachrome and color infrared films). All internegatives were enhanced before prints were produced.

Prints have obvious and distinct advantages over transparencies during field work, even though some of the resolution and quality of the transparencies is necessarily lost during processing to prints. When possible during a field reconnaissance, studies of 2X (S190B) or 4X (S190A) enlarged transparencies using a portable light table have proved to be very useful, however. Portions of S190B frames enlarged to 1:250,000 are particularly valuable for reconnaissance-type field investigations. Although no S190B prints have yet been produced at the scale 1:62,500, studies of S190B films projected to that scale indicate resolution is good, and prints will be useful during field mapping.

An advantage of Skylab prints not anticipated is that prints are superior to transparencies for describing arcuate anomalies and linear patterns to personnel not familiar with space imagery interpretation.

70 mm contact negative films, produced from enhanced 70 mm film positives, are being composited with the positives of the same or different bands in the multispectral viewer. The image produced is especially useful for analyses of major lineaments. Registration of images is more difficult with film negatives, and spurious lineaments are frequently generated if images are misregistered.

S192 line-straightened 70 mm film positives were finally received and are currently being processed for use in the multispectral viewer. Preliminary indications are that the data

are easily registered in the viewer, and false-color images produced will be useful for geologic investigations, especially rock type discrimination. With 13 channels of data, the number of permutations possible is large, and some effort will have to be expended to determine the most useful combinations of channels.

The three other EREP sensor packages--S191, S193, S194--have not been examined in detail for application to resources exploration.

Several anomalies or structural features noted in Skylab photography and suspected to be significant to mineral deposits or geothermal resources have been investigated in detail during the third quarter. Procedures to analyze features of particular interest include compilation and examination of all available data--pertinent imagery from all sensor platforms, maps, reports, and when possible, original geologic field work. ERTS imagery is particularly valuable during site analysis due to its multispectral and temporal capabilities, but Apollo and X-15 photography (especially X-15 8443 color IR film) are quite useful.

Six individual sites were investigated during the third quarter in detail, and for two of the six, brief field reconnaissances were conducted. The six sites include: Gold Butte and Crater Flat, Nevada; Inyo Mountains, Castle Mountains, Halloran Hills, and Garlock Fault, California. Brief discussions of each of these sites are included below.

In addition to site examinations, a compilation of all known economic mineral deposits in the test area was initiated during the quarter. Most of the deposits in the part of California in the test site have been plotted on a 1:500,000 scale map. Compilation of deposits in northwestern Arizona is nearing completion.

SIGNIFICANT RESULTS

Significant results accomplished during the third quarter include:

1. compositing of 70 mm film negatives with 70 mm positives which yields an image that emphasizes major linements;

2. projection of 2X S190B film positives directly onto 1:62,500-scale maps facilitates interpretation of observed anomalies and insures their accurate location on the map;

3. imagery studies of drainage patterns of the Garlock Fault area indicate some evidence exists to extend the fault several kilometers beyond its presently-

accepted terminus;

4. a north-south lineament identified in Skylab photographs is interpreted to be responsible for emplacement of gold-bearing fluids into volcanic rocks of the Castle Mountains, California.

DISCUSSION OF ACTIVITIES

Geothermal Exploration:

Preparation of a full-length journal article on the application of space imagery to geothermal resources exploration has been initiated. The report, which will summarize results of geothermal exploration-centered investigations conducted under Contract NAS9-14235, has been requested by Mr. San Dermingian, editor of Geothermal Energy magazine. The report will be published in the May 1975 issue of the magazine which will be available at the Second United Nations Symposium on the Development and Use of Geothermal Resources, to be held in San Francisco, May 20-29, 1975. Mr. A.V. Mazade, Lockheed Electronics Company, Aerospace Division, NASA Contractors at JSC, is providing a specially-processed, false-color image from the thermal infrared channel (13) of the S192 multispectral scanner for display on the cover of the magazine and discussion therein.

Investigation of an arcuate topographic feature at Crater Flat, Nevada suggests the area is a collapsed caldera. Evidence has been discerned to substantiate ideas that the area may represent a potential geothermal system. The area will be more completely analyzed and reported at a later date.

Mineral Exploration:

Color and structural differences have been noted in Skylab imagery and interpreted to be pertinent to mineral exploration in the Gold Butte, Nevada area. Significant data obtained from the images includes recognition of geologic structures, such as faults, schistosity, and jointing. Extension of ore deposit-controlling structures beyond mapping limits suggests areas for additional exploration. Additional studies are being done on this area and will be reported later.

A large number of arcuate structures have been identified from analysis of Skylab and ERTS data in the Halloran Hills, California region. Investigations indicate the arcuates are the results of Mesozoic granitic plutons that have intrudded Paleozoic and Precambrian rocks. Especially significant are arcuates that apparently delineate contacts between igneous intrusions and limestones. In addition, many lineament intersections have been detected that may have served to localized ore-bearing solutions.

Geologic Field Investigations:

Reconnaissance field investigations have been conducted for two sites during the third quarter. The brief field check of the Castle Mountains, California, anomaly was reported in the February progress report (BESTEC 101-M6-6/75) and will not be repeated. A more complete report on the Castle Mountains investigation is being prepared and will be submitted later.

The second field reconnaissance was to the Inyo Mountains, California, where three prominent arcuate zones interpreted from Skylab and ERTS imagery to be plutonic bodies were investigated. Geologic field study of selected anomalously-colored zones on the peripheries of the arcuate structures revealed limestones that were thermally metamorphosed and sometimes altered by ore-bearing hydrothermal solutions, associated with adjacent monzonite or diorite bodies.

Regular geometric configurations observed in Skylab photography correlated with the Papoose Flat pluton, northeast of Independence and the Birch Creek pluton, north of Deep Springs Valley and Owens Valley. Three plutons were examined in the field: the Marble Canyon pluton northeast of Big Pine; the Joshua Flat pluton, slightly north and east of Deep Springs Valley; and the Santa Rita Flat pluton, east of Independence. These intrusives are apparently Jurassic to Cretaceous in age, and of intermediate granitic composition.

Marble Canyon is a very long, narrow gorge and mine shafts are located along the majority of its length, presumably dug in search of placer gold. Evidence of mineralization is indicated by occurrences of sulfides in fractures near a contact of monzonite and bedded limestone.

A bright white zone noted in Skylab imagery on the edge of the Joshua Flat pluton was determined to be limestones, which contained occasional sulfides near the granitic contact. An area which appeared from imagery studies to be more favorable for mineral exploration was not examined due to time restrictions.

The Santa Rita Flat pluton was found to be the most promising in terms of easily accessible ore (e.g. copper) occurrences along Mazourka Canyon, which is the arcuate border zone of the pluton. The area has been mined on a small scale, and the alluvium in the canyon was once worked for placer gold. Abundant faulting and alteration was especially evident in one area within the contact zone of the pluton with limestones.

The brief field study of the areas identified from imagery indicates mineralized zones can be found from synthesis of the varied data conveyed in the images. A more detailed report of the investigation is being completed.

Abstracts of Investigations:

Two abstracts detailing Skylab investigations were submitted this month in accordance with requests from NASA:

1. Application of Skylab Imagery to Resource Exploration in the Death Valley Region; submitted to NASA to be considered for presentation at the Earth Resources Survey Symposium, in Houston, June 1975.

2. Implications of Skylab (EREP) Imagery for Resource Exploration in Arizona; submitted to the American Geophysical Union to be considered for presentation at the 56th Annual Meeting, in Washington, June 1975.

Copies of the Abstracts are attached.

Conferences:

The Principal Investigator attended the 41st Annual Meeting of the American Society of Photogrammetry, in Washington, D.C., March 9-14, 1975.

The Principal Investigator and two geologists assigned to the EREP investigation attended various sessions of the 71st Annual Cordilleran Section of the Geologic Society of America meeting, in Los Angeles, March 25-27, 1975.

WORK PLANNED FOR NEXT REPORTING PERIOD

Dr. David Amsbury, Contract Technical Monitor, will visit BESTEC offices to be familiarized with investigative procedures and updated on results of investigations.

Two field reconnaissance trips are planned: one to the Death Valley--Mojave Desert area with Mr. Richard Underwood of NASA, and one to the Black and Cerbat Mountains of northwestern Arizona.

At least three oral presentations demonstrating the types and uses of space imagery will be given to various groups by BESTEC investigators.

PERSONNEL

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)

Robert Archer, Research Assistant (part-time)
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

ACKNOWLEDGMENTS

1. Credit must be given to all personnel for excellent work done in image enhancement and analysis. Through this careful work a minimum of field studies has been required to arrive at the ground-based correlations required.

2. Recognition is given to C. Gregory Wagner and John T. Reynolds for significant contributions to two special reports being prepared for oral presentation at future professional society meetings. Abstracts are attached hereto.

3. C. Gregory Wagner and John T. Reynolds exhibited an unusual degree of ingenuity in interpretation of arcuate structures as being the result of mineralizing pluton intrusives in the Inyo Mountains, these later being confirmed by field studies which revealed mineralization where it was expected and of the type predicted.

4. Mr. Robert Archer is credited with having accomplished a high degree of expertise in interpreting anomalies in the imagery of the Gold Butte area. The correlative data thus secured will shorten field work by very important amounts of time and effort.

Ira C. Bechtold, President
EREP PI 541

APPLICATION OF SKYLAB IMAGERY TO RESOURCE EXPLORATION IN THE DEATH VALLEY REGION

By:
Ira C. Bechtold, John T. Reynolds, C. Gregory Wagner

A study of Skylab satellite images of the northern Panamint Range, California, reveals a prominent arcuate structure, almost perfectly circular, five to six miles in diameter. This structure exhibits topographic, vegetative, and color anomalies having high correlation with mineralized zones, in particular, copper deposits.

The feature expressed within the Hunter Mountain quartz monzonite intrusive body of probable Cretaceous age is bounded in part by remnants of metamorphosed Paleozoic marine sediments. The linear contact of the massive quartz monzonite body with the Paleozoic rocks occurs along the northern edge of the structure and extends to the southeast, but the arcuate anomaly departs southward from this contact. Published geologic maps indicate this contact is located only approximately, and the region is relatively unexplored. Analysis of space imagery provides interpretation of previously unrecognized structural and lithological detail.

Along its southern and eastern margins, the anomaly is expressed within the plutonic rock, and hence may represent a later igneous intrusion of similar composition or a zone of contrasting grain sizes. The Paleozoic metasedimentary rocks bound the anomaly along the western and northern margins and exhibit high reflectance in the images.

A major fault system strikes approximately N60W from Saline Valley to Panamint Valley, tangential to the southwestern edge of the anomaly in Grapevine Canyon. Other mapped faults extend approximately N10E along the western edge toward Racetrack Valley in the north. Fractures easily visible in satellite imagery generally parallel these two sets throughout the plutonic and metamorphic rock bodies. Other less distinct fractures appear to trend nearly E-W and N30E.

Skylab S190A and S190B Ektachrome images show the arcuate feature with a light snow cover, enhancing the relief and margins considerably; in another scene without snow, the boundaries cannot be easily determined, especially in the south and east where igneous rocks of similar composition occur. The Paleozoic rocks exhibit high reflectance in all scenes, including S190A Ektachrome, near-infrared, and composited multispectral frames, easily defining the northern and western margins. The S190B Ektachrome earth terrain camera offers good detail and indicates that the margins of the anomaly are topographically steep, dissected by deep canyons, while the interior region is relatively flat and featureless. Vegetation occurs predominantly in the south and east region, but is extremely sparse in the northern half within the anomaly and along the margins. Additionally, subtle color differences delineate various rock types and potential mineralized zones. ERTS imagery also supports these observations and confirms the fracture pattern.

Field reconnaissance indicates the bordering, highly-reflecting Paleozoic rocks have been thermally metamorphosed and enriched by metasomatic processes. A wide calc-silicate zone comprises the northern margin, accompanied by skarn-bearing disseminated copper oxides and minor sulfides. Copper mineralization appears to be closely associated with the regions of bright reflectance. A strong geographic control of indigenous evergreen trees and shrubs is readily discernible.

Further field study should indicate a relation of copper with the anomaly; we expect contacts of the Hunter Mountain quartz monzonite outside of the anomalous arcuate structure may reveal little or no copper mineralization. Detailed mapping and sampling of the vegetation and analysis for metallic ion concentrations would likely show a correlation of decreased density of plant population toward the margins with increased mineralization.

IMPLICATIONS OF SKYLAB (EREP) IMAGERY FOR RESOURCE EXPLORATION IN ARIZONA

By

Ira C. Bechtold, C. Gregory Wagner, John T. Reynolds

Interpretation of Skylab (EREP) photography has enhanced understanding of local structural control of known mineral deposits in the Black and Cerbat Mountains in northwestern Arizona. North-trending mountains are characterized by extensive exposures of Precambrian schists and gneisses that have been intruded along a major fracture zone by Cretaceous volcanics, Cretaceous-Tertiary felsic dikes and plugs, Laramide granitics, and Quaternary basalts. Many dikes and plutons are elongated N-S. Faults strike approximately north. Plutonism and volcanism represent a structurally controlled volcanogenic province which ends abruptly at an extension of the Las Vegas Shear zone. Regional tectonic control of mineralization has been described from geologic studies and analyses of Apollo and ERTS imagery and is genetically related to crustal extension. Arcuate features noted in Skylab films and false-color composites as anomalous areas are related to known mineralized zones. These arcuates exhibit radial fracture patterns along their margins; one arcuate is centered over the Oatman district which has produced gold from quartz veins in Tertiary volcanics. Another arcuate is related to a disseminated copper deposit in a Laramide quartz monzonite.. Other arcuate and linear anomalies, not related to known mineral deposits and located in outcrops and alluvium, represent favorable areas for potential economic mineral deposits. Also, Skylab imagery studies of mapped fractures that control mineralization have revealed previously unknown extensions of fractures that suggest continuation of mineral deposits.

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 April 1975 - 30 April 1975

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
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BESTEC Report 101-M7-8/75

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16. Abstract

Analysis of S192 data over northwestern Arizona has indicated the imagery can contribute significantly to geologic investigations, including rock-type discrimination and linears-arcuates observations. Light-colored reflectances noted in Lake Mojave may represent recent sediment plumes or possibly sediments on the bottom of the lake. Imagery linears correspond to mineralized shear zones and faults in the Black and Cerbat Mountains. Arcuates in the Halloran Hills area correlate with edges of Mesozoic plutons where they contact Precambrian and Paleozoic host rocks.

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES

APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

Two separate field reconnaissances were planned and executed during April to check several different sites within the 70,000 square mile test area. The trips were designed to examine a maximum number of imagery-observed anomalies in a minimum amount of time and travel. Consequently, careful office study of the anomalies--relative importance, accessibility, location--was an extremely important part of the field investigations of the individual test sites. One office procedure that has proved especially valuable for efficient field operations is projection of S190A and S190B film positives directly onto 7½- and 15-minute topographic maps. Accurate location of observed anomalies is insured, accessibility of anomalies via roads can be readily ascertained, and, occasionally, cultural causes for anomalies--cleared land, roads, etc.--can be determined, thus eliminating some anomalies from consideration of importance to geologic investigations.

Field work was emphasized during April as it is generally the last month before high temperatures (>100°F) are common during the day over much of the test area.

Mr. Richard Underwood, Photographic Technology Division, NASA-JSC, accompanied investigators during a field reconnaissance of the Death Valley-Mojave Desert region. Mr. Underwood's knowledge of the geography of the area contributed immeasurably to the success of the reconnaissance. In addition, his contributions to geologic interpretations of imagery-observed anomalies in the Ubehebe Craters area were significant and are hereby acknowledged.

Dr. David Amsbury, technical monitor for our contract, visited BESTEC offices, and was acquainted with our investigative procedures. Results of field investigations from Hunter Mountain, Greenwater Valley-Black Mountains, and Inyo Mountains (all California) including imagery interpretations, ground-based photography, and rock samples were examined by Dr. Amsbury. Current status of our entire investigation was discussed.

A cooperative effort to utilize Skylab photography to investigate geologic structures in the Clark Mountains area, California, was initiated between BESTEC and the Department of Geology, Pomona College, Claremont, California. Actual study of imagery will be done by Ms. Cynthia Rebeck, a senior level geology student, under the supervision of Dr. A.K. Baird, Pomona College, and Mr. Ira Bechtold. Support on investigative techniques and methods of imagery analysis will be supplied by BESTEC geologists. Progress and final results of Ms. Rebeck's study will be reported.

Several presentations pertaining to the use of space imagery as a tool for geologic interpretation and resources exploration were given by BESTEC investigators. Visual aids for the talks included 35 mm and 70 mm slides from Apollo, Gemini, ERTS, and Skylab earth-looking sensors.

1. April 15: "Applications of Space Imagery to Earth Resources Exploration;" presented to geography/geology classes at California State University at Fullerton, by C. Gregory Wagner.

2. April 22: "Remote Sensing, including Space Imagery, Applied to Earth Resources;" presented to the Graduate School, Earth Sciences Department, Stanford University by Ira C. Bechtold.

3. April 24: "The Use of Space Imagery for Geologic Interpretation, an Overview;" presented at the Society of Experimental Paleontologists and Mineralogists. (SEPM), banquet meeting, by Ira C. Bechtold at the Fiftieth Annual Meeting of the Pacific Sections of AAPG, SEG, and SEPM, Long Beach, California.

II. Significant Results:

1. Analysis of S192 imagery can contribute significantly to geologic investigations, including rock-type discriminations and linear-arcuate observations.

2. Field investigation of linear and arcuate features noted in Skylab imagery over the Black-Cerbat Mountains has resulted in the confirmation of the significance of the features to location of known mineral deposits and in the suggestion of areas that sould be explored for additional deposits.

3. Analysis of S192 imagery revealed light-colored reflectances in Lake Mojave related to sediment distribution.

III. Geologic Investigations:

A. Analysis of S192 Imagery over Northwestern Arizona

A preliminary analysis of one segment of S192 imagery over northwestern Arizona has yielded several important conclusions on the utilization of S192 thirteen-channel MSS data to geologic investigations. The Skylab 2 imagery, in line-straightened, 70 mm film chip format, was analyzed in a multispectral viewer, using false-color compositing techniques developed for ERTS MSS and Skylab S190A films.

As reported in March, the registration of films of different channels of the S192 scene presents no problems. Various combinations of two, three and four different channels, when viewed through different colors of filters with varying light intensities, produce many different false-color composites. Different composites have proved useful for investigating different aspects of the geologic environment, for example: channels in the visible part of the spectrum, when viewed in combination, emphasize drainage patterns and texture in alluvium areas; conversely, composites produced from channels eight through twelve emphasize outcrops and structural features within the mountain blocks because the valleys exhibit abnormally high reflectances that mask detail. These observations are generalized and may not apply to all S192 scenes.

Resolution limits of the S192 were very difficult to ascertain, as few recognizable landmarks exist in the area. Two-lane dirt roads, even in areas of high contrast, could not be located in any of the channels. The tailings pond from Duval's open pit copper mine at Mineral Park was the only man-made feature identifiable with any confidence in the S192 imagery. It should be noted that the roads are not readily identifiable in ERTS imagery of the same area, though they can be located after being pin-pointed on a map. As was expected, resolution varied considerably throughout the 13 channels; channel 7 appeared to have the best over-all resolution.

The area covered by the S192 segment includes the Black and Cerbat Mountains, and Lake Mojave on the Colorado River. The segment was taken June 3, 1973. This particular segment was analyzed because S190B, S190A and ERTS imagery of the area had been previously inspected and interpreted in terms of geologic structures suspected to be related to known mineral deposits. Also, a field reconnaissance to the area was already planned, during which anomalies detected in the S192 image could be examined.

Analysis of many false-color composites of the S192 data resulted in the identification of numerous linears and arcuate features in the ranges and the intervening valleys. Particularly noticeable were the arcuates centered over the volcanic outcrops in the Black Mountains and near "Laramide-age" (72 m.y.) quartz monzonite intrusives in the Cerbats. The low resolution of the S192 image probably permitted observation of the arcuates because they were not noted in higher-resolution S190A or S190B imagery. Plots of linears made from the three different Skylab images compared very well, however. Many of the linears corresponded to fracture zones and geologic contacts.

Altered rhyolites in the Black Mountains can be discriminated from associated basalts and Precambrian gneisses in most channels. In channel 11, linear gneiss outcrops can be differentiated from nearby schists and granites, due to textural contrasts rather than color reflectance.

Drainage patterns in the alluvium-filled valleys between the mountains can be discerned and mapped accurately, particularly using channel 3, while drainage from the west side of the Black Mountains into the Colorado River is more easily recognized in channels 8, 9, and 10. Many coloration zones within the interior valley alluvium are noticeable in the blue to yellow channels. Some of these zones can be interpreted as being sediments and fragments from a specific rock type; others, not so easily explained, may be due to anomalous concentrations of vegetation.

Light-colored reflectances in Lake Mojave are observed in channels 1, 2, and 3, but not in any other channels analyzed (13 and 4 were not received and 5 is degraded). The reflectances are most intense in channel 2, particularly in the part of the lake immediately above Davis Dam. As seen in channel 3, the reflectances exhibit diverse shapes--linear and arcuate--and many times appear to be extensions of drainage patterns observed on the adjacent mountain slopes. For this reason, one explanation of the anomalous reflectances is that they are sediment plumes recently introduced into the lake by stream transport. Supporting evidence was supplied by Paul Burgess, Chief, Davis Dam Field Division, whose weather data indicated there were isolated thundershowers in the days prior to the imaging of the area by the S192 scanner (Paul R. Burgess, personal comment, 1975).

It is interesting to note that the washes above the lake are apparent in channels 8, 9, 10, but the sediment plumes that are evidently composed of detritus from the washes are not. An alternate explanation for the anomalous reflectances in the lake is that sediment on the bottom of the lake is being observed. Data on the configuration of the bottom surface of Lake Mojave is needed before this explanation can be evaluated.

B. Black-Cerbat Mountains Field Investigation

Analyses of Skylab S190A and B photography and S192 imagery over northwest Arizona resulted in the identification of large numbers of arcuate and linear features, many of which are spatially related to known mineral deposits. The area analyzed encompasses the Black and Cerbat Mountains, which are tilted fault blocks characteristic of the Basin and Range physiographic province. Diverse rock types are exposed in the ranges, including Precambrian schists and gneisses, Mesozoic "Laramide" quartz monzonite intrusives, and Cenozoic volcanics. Known economic mineral deposits of the region have been classified as epithermal vein deposits (gold--principally in the Black Mountains) and mesothermal vein deposits (lead, silver--principally in the Cerbat Mountains) and disseminated deposits.

Careful plotting of linears and arcuates onto 15-minute topographic maps permitted the selection of the most easily accessible features to be examined during a two-day field reconnaissance to the area. Investigation of four separate sites displaying anomalies thought to be related to mineral deposits was planned. Each of the areas was located in a different part of the region under study to allow a representative evaluation of the significance of the linears and arcuates.

Imagery-derived linears plotted on the Cerbat and Stockton Hill 7½-minute quadrangles in the Cerbat Mountains corresponded in the field to faults and shear zones that strike N40-65W. At least one shear zone is wide enough (45-60 meters) to be observed directly on S190A and B transparencies. The zone is high-angle, dipping 65NE. Many small ore shoots were evident within the zone, in both the hanging and foot walls. Minerals sampled were galena, chaleopyrite, and argentite. Galena was particularly abundant. The gangue included iron-stained quartz, clays, and fragments of the host rocks--schist, garnetiferous gneiss, and granite. Granite pegmatite dikes were noted outside of the shear zone but parallel to it. Other faults displacing gneiss and schist were examined but mineralization was not apparent. Water production from shallow wells in the area is controlled by the faults, however, as they are conduits in the otherwise impermeable crystalline rock. Imagery studies indicated that the linears extend beyond the area examined in the field, suggesting areas for additional geologic field work and prospecting. Linears trending approximately perpendicular to the faults and shear zones were determined to be related to the schistosity of the rocks, which trends N40-65E. Some northeast linears corresponded to valleys, and may represent traverse faulting that served to localize mineral-bearing fluids at intersections of NE and NW fractures or to offset mineralized veins.

A prominent knob-like outcrop of porphyritic granite that appeared to be aligned with similar-appearing outcrops to the northwest was examined. The outcrop is weathered black, due to alteration of finely-disseminated pyrite. Examination of the other outcrops near Chloride revealed similar composition; the rocks are probably Mesozoic granitic intrusions. The outcrops are sheared, and emplacement was probably controlled by a northwest-trending fracture.

Inspection of part of the main mass of the Mesozoic granitics in the Cerbats revealed that the intrusion of the rock so completely altered the host Precambrian rocks (gneiss, granite, schist) that a contact zone between the two cannot be located. An arcuate feature noted in 190A and 192 imagery apparently is an indicator of an alteration halo around the granitic intrusive. The arcuate extends beyond the area mapped as intrusive, suggesting Mesozoic granitics may lie at shallow depths beneath the Precambrian host. This may be significant as Duval Corporation currently mines disseminated copper from parts of the intrusive, where it is exposed near Mineral Park.

Investigation of an area, on the east side of the Black

Mountains across the Detrital valley from the Cerbats, that exhibited reflectances characteristic of altered siliceous rocks revealed that the rocks of the area were altered gneiss, presumably Precambrian. If the alteration was caused by the same Mesozoic intrusive cropping out in the Cerbats, the possibility of a major copper body existing beneath the alluvium is very real. Anomalous concentrations of desert vegetation, noted in imagery, are also located in the valley near the altered gneiss.

Rocks exposed in the southern end of the Black Mountains, near Oatman, are Tertiary rhyolites and andesites, overlain in part by basalts. Linears observed in imagery correlated very strongly with gold-producing veins exposed in faults and fissures in the siliceous volcanics. Linear trends ranged from N20W to N60W. In many cases, linears could be traced into areas covered by basalts, indicating, perhaps, that faults extend beneath the basalt cover. The faults may be mineralized in this area as they are where exposed, thus suggesting exploration for additional gold-bearing veins should be concentrated in the faulted rhyolites below the basalts.

C. Halloran Hills Field Study

A brief field study of a part of the Halloran Hills, northeast of Baker, California, was made following image analysis and identification of particularly interesting structural patterns. Numerous large arcuate features found in Skylab imagery correlated with edges of plutonic bodies where they contacted Precambrian or Paleozoic host rock. Anomalous color regions observed in imagery were examined in the field to determine any potential economic mineralization associated with the regions.

Many of the light-colored regions corresponded with outcrops of talc in contact zones scattered widely across the low hills. Reddish-colored areas were found to indicate iron staining at the margins of intrusive bodies. Some sulfide mineralization apparently occurred near the pluton margins, and field work was performed with the intention of locating potential ore occurrences as hinted by the anomalous colorations in proximity to lineations and arcuate structures. The most striking arcuate zone was expressed by a curved stream course following a contact between Precambrian schist and less-resistant Mesozoic granite. This contact appeared clean and lacking in mineralization, but investigation of the opposite border of the pluton (north side) which exhibited local bright white reflectance in the imagery, revealed substantial siliceous alteration of the granitic rock. The site was located high on a ridge, and examination of the altered rocks disclosed the presence of calcite and copper sulfide minerals in cavities amongst crystalline quartz. Turquoise Mine, also located on this resistant ridge, was not visited, but apparently has yielded significant amounts of copper oxides. Evidently, hydrothermal alteration produced the mineralization near the contact of the pluton with Paleozoic limestones, since the limestones outcrop sporadically to the northeast of the arcuate pluton.

Another anomalously white area noted in Skylab imagery correlated with Squaw Mountain. This small ridge, comprised almost entirely of crystalline limestone, rises abruptly above well-eroded granitic terrane. It forms a curved outcrop, apparently between large masses of granitic rock, and in general seems to define a large annular structure. Part of this ridge was visited, and pyrite was found within limestone near a contact with a mafic igneous phase extending into the limestone. Linear trends are abundant but complex, and their relation to the arcuate structures and mineralization has not been determined.

IV. Work Planned for Next Reporting Period:

Two BESTEC investigators will attend sessions of the United Nations geothermal conference in San Francisco.

Field reconnaissance of the Randsburg-Lava Mountains-Garlock Fault area, California, is planned to examine features noted in imagery studies.

Imagery studies of many areas, including the Gold Butte, Nevada; Black Mountains, Arizona; and Goldfield, Nevada will continue.

V. Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)
Robert Archer, Research Assistant (part-time)
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Mauren B. Gray, Clerical Assistant

VI. Acknowledgements:

1. The staff has continued to contribute outstanding developments in image enhancement and analyses which shorten the time required for field work to a remarkable degree.

2. C. Gregory Wagner and John Reynolds are credited with very special ingenuity in applying space imagery to

the lithology, structure and location of potential ore deposits in the Black and Cerbat Mountains of northwestern Arizona.

3. The presence of Mr. Richard Underwood during one field trip was appreciated and of great advantage in discussing and interpreting Skylab imagery.

4. The assistance of Martha Wadsworth in compiling data, editing and typing reports is gratefully acknowledged.

Ira C. Bechtold, President
EREP PI 541

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 May 1975 through 31 May 1975

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M8-8/75

Contract Monitor:

David Amsbury, Code TF6
Earth Observations Division
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15. Supplementary Notes

16. Abstract

Anomalous color patterns and reflectances observed in the Lava Mountains are caused by hydrothermal alteration of andesites. Reports of high temperatures in shallow wells near the altered rocks suggest a potential geothermal reservoir. Two major reports of investigations were prepared. The anomalous features observed on Hunter Mountain that correlate strongly with mineralized areas are discussed. The second paper summarizes results of studies examining the applications of space imagery to geothermal resource exploration.

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Skylab
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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

Two major reports of investigation were prepared this month by BESTEC geologists:

1. Application of Skylab Imagery to Resource Exploration in the Death Valley Region, by Bechtold, Reynolds, and Wagner.

2. Application of Satellite Imagery to Geothermal Resources Exploration, by Reynolds and Wagner.

The Death Valley paper details the investigation of anomalous topographic, vegetative, color, and structural features observed in Skylab imagery of the Hunter Mountain Plateau, northern Panamint Range, California. The paper is to be presented in June at the NASA Earth Resources Survey Symposium by Ira C. Bechtold, and published in the Proceedings of the Symposium. Preliminary results of the Hunter Mountain investigation were reported in the November 1974 Monthly Progress Report and an abstract submitted to NASA was included in the March 1974 Quarterly Progress Report.

The geothermal paper is a summary of BESTEC investigations using Skylab and ERTS imagery for exploration of geothermal resources. The paper was published in the May 1975 issue of Geothermal Energy. Copies of both of these papers accompany this report.

An oral presentation was made by Mr. Bechtold to the San Clemente Kiwanis Club on May 14. The presentation, entitled Earth Resources Observed from Space Satellites, utilized 35 mm and 70 mm slides of Apollo, Gemini, ERTS, and Skylab imagery to demonstrate the applicability of space imagery to geologic investigations.

Mr. Bechtold and Mr. C. G. Wagner attended the first four days of technical sessions of the Second United Nations Symposium on the Development and Use of Geothermal Resources, May 20-29. Topics discussed at the sessions included geological, geophysical, and geochemical techniques for exploration of geothermal reservoirs. The majority of the papers that were presented related specific case histories, many aspects of which are pertinent to exploration programs for resources in other geographic areas. Studies of specific geophysical exploration techniques were also presented, such as magneto-tellurics, electromagnetics, and teleseismic P-wave delay. Remote sensing techniques, such as imagery analysis, were mentioned briefly by a few workers. Space imagery, including the S192 MSS thermal infrared channel, was not discussed.

II. Geologic Investigations:

Anomalous color reflectances and arcuate color patterns observed in Skylab photography of the Lava Mountains area, California, were interpreted after careful analysis to be andesitic volcanic rocks altered by hydrothermal fluids. The color pattern noted--gray, blue, purple, reddish purple--was interpreted to represent a composition zoning in the andesites, probably as a result of varying intensities of hydrothermal activity. The area, which is 8 km northeast of Johannesburg in the Mojave Desert, was briefly visited by a BESTEC geologist in order to evaluate the interpretations. Substantial amounts of siliceous, hydrothermally altered rock were noted, thus confirming imagery-derived interpretations.

Additional reference work on the area resulted in the discovery that drilling in the area in the 1920's, presumably in search of ore minerals, found anomalously high temperature rock at shallow depths. Indeed, steam wells were once planned for the area, but never completed. This fact, coupled with imagery observations, has resulted in the conclusion that the Lava Mountains area may represent a potential geothermal resource.

III. Work Planned for Next Reporting Period:

Two investigators will attend various sessions of the NASA Earth Resources Survey Symposium in Houston, Ju 8-13, 1975. Mr. Ira Bechtold will present Application of Skylab Imagery to Resource Exploration in the Death Valley Region during the Energy and Mineral Resources Exploration session of the geology segment of the Symposium.

Mr. Bechtold will present Implications of Skylab (EREP) Imagery for Resource Exploration in Arizona to a Special Union Session on Skylab Results at the 56th Annual Meeting of the American Geophysical Union, in Washington, D.C., June 19.

Imagery analysis of linear and arcuate anomalies and coloration patterns that are suspected to be indicative of potential mineral and geothermal resources will continue.

IV. Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Field Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)
Robert Archer, Research Assistant (part-time)

Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Maurene B. Gray, Clerical Assistant

V. Acknowledgments:

The staff is to be commended on the large amount of information which was extracted from imagery related to geothermal sites. Very little field work was required to delineate these areas on the ground.

Ira C. Bechtold, President
EREP PI 541

APPLICATION OF SKYLAB IMAGERY TO RESOURCE EXPLORATION IN THE DEATH VALLEY REGION

By Ira C. Bechtold, John T. Reynolds, C. Gregory Wagner
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ABSTRACT

The Hunter Mountain plateau in the northern Panamint Range, California, exhibits anomalous topographic, vegetative, color and structural features in Skylab and ERTS satellite images which have strong correlation with mineralized areas and should prove significant for future exploration. Data observed to date has been studied with reference to published geology and is interpreted in terms of greatest probability of ore mineralization. Further study in conjunction with space imagery analysis is recommended for location of potential mineral zones.

INTRODUCTION

Skylab photographic products have been found useful for all types of geologic investigations, and in many instances provide observations of previously unrecognized features. Such observations have been made specifically in a region on the western boundary of Death Valley National Monument in the northern Panamint Mountain Range, California. Regional as well as local structural, color, and reflectance differences have been plotted directly from satellite images and interpreted as highly significant in terms of mineral resource exploration. The correlations of identified photographic features with specific mineralized areas is tentative, as ground work has been very limited to date, and the study has not passed the reconnaissance stage of exploration. Satellite data has, however, exhibited the following valuable utilizations in this study:

1. Wide synoptic coverage assisting visualization of regional geologic structure and rock type relations.

2. Identification of abundant detail of culture and geography for location.

3. Ease of projecting transparencies to mappable scale for data transfer.

4. Location of subtle anomalies, especially those having high potential for mineralization.

5. Interpretation of some rock reflectance signatures as correlatable to mapped geologic units or zones of alteration.

6. Identification of regions probably not mapped accurately or in sufficient detail and of sites recommended for further investigation.

LOCATION

The study encompasses an area of approximately 500 square kilometers (200 square miles) in the northern Panamint Range, 50 km. (30 miles) due east of Lone Pine, California. Centered within the study area is Hunter Mountain, a high plateau between two major downfaulted valleys, Saline Valley to the northwest and Panamint Valley to the south (Figure 1). Death Valley lies beyond the mountains 30 km. to the east (Stovepipe Wells). The region is accessible almost solely by gravel road 30 km. north from California Highway 190 and from Ubehebe Crater at the northern end of Death Valley.

The Hunter Mountain plateau is approximately 1800 meters (6000 feet) in elevation, having steep canyons on all sides, with relief of as much as 900 meters (3000 feet) above the surrounding basin floors. All drainage is internal, principally into the three major valleys, thereby categorizing the region as part of the western edge of the Basin and Range province.

Hunter Mountain and the surrounding region is composed of large masses of granitic bodies in contact with older, deformed remnants of Paleozoic marine sedimentary rocks. The area is geographically near major mining areas, the Cerro Gordo mining district 25 km. due west, the Darwin mining district 30 km. due south. Additional activity has occurred throughout the Panamint Range to the southeast, and various operations are located to the north within the area studied. Geologic work done in the area is sparse, and virtually the only mapping done in the Ubehebe Peak quadrangle was by J. F. McAllister in 1956. Many of the surrounding quadrangles have been mapped more recently, but the Marble Canyon quadrangle, containing the eastern portion of Hunter Mountain, has remained virtually unmapped, primarily due to remoteness and rugged terrain.

PROCEDURE

Both ERTS and Skylab satellite imagery is available over the studied area; two scenes of Skylab were most important in the project, one S190B high resolution Ektachrome camera scene (SL4-94-013, Feb. 1974), and an S190A Ektachrome scene (SL2-04-189, June 1973). Additional useful scenes were SL4-76-222, ERTS 1287-17555, 1054-18001, 1090-18010. S190A data was projected in a viewer to a 1:250,000 scale, as were ERTS 70mm positive film chips. These were viewed as color composites utilizing various combinations of color filters in the spectral bands. The S190B data was viewed by mounting the film transparency so that the desired area appeared in the window originally made for 70mm frames and projecting to a scale of 1:62,500, the scale of a 15 minute topographic quadrangle. The data observed was compared to the geologic quadrangle mapped by J. F. McAllister (1956). Data transferred to the 1:250,000 scale was compared to the mapped geology on the Death Valley sheet of the Geologic Map of California series.

Data was gathered solely by visual means, and was transferred manually by acetate overlay to map scales. Interpretation primarily involved first hand observation of images, but also correlation with maps and geologic literature.

ANALYSIS AND INTERPRETATION

The initial feature observed is a large, nearly perfectly circular structure which appears strongly in the S190B high resolution camera image. The Hunter Mountain plateau is covered by a light snowfall, which evidently made possible the observation of the entire feature. In other images, this arcuate pattern is barely visible in the south and east, probably due to a subtle change in relief that appears only when enhanced by snow cover. The arc encompasses most of the topographic high named Hunter Mountain on the Ubehebe Peak quadrangle, over 8 km. in diameter, and is bounded on the southwest by a deep gorge, Grapevine Canyon (Figure 1). Northerly trending linears, interpreted as faults, form the western edge, along with light colored rock outcrops. Other numerous linears appear to strike tangentially to the arcuate edges. The entire arcuate structure lies within plutonic rock designated by McAllister (1955) as the Hunter Mountain quartz monzonite. The northern and northeastern edges are approximately at the contact of this igneous body and undifferentiated Paleozoic rocks (Death Valley sheet, Geologic Map of California), but the eastern and southern boundaries lie in a region of subdued topography within the mapped body which extends eastward to Death Valley.

Rock reflectances from the entire region are variable yet most of the gray-green and blue hues correspond to the Paleozoic sedimentary rocks, while the regions of mapped plutonic rock appear dark gray-green and brown in the S190A Ektachrome scene. Bright white regions occur immediately outside of the western, northern, and to a lesser extent, the northeastern margins of the arcuate structure. These areas correlate strongly with areas of exposed Paleozoic metasedimentary rocks, and apparently indicate the contact with the plutonic rock where deformation accompanied the intrusion. Anomalously bright reflectance is believed caused by fine clay materials, alteration likely by hydrothermal activity and by thermal metamorphism of the dominantly limestone and dolomite-bearing rocks. In the S190A Ektachrome image, an apparent color zoning appears east of the arcuate structure along the mapped contact of granitic and Paleozoic rocks. In this area, a brown zone parallels the contact for nearly 20 km. while a lighter gray-green reflecting zone appears to the south, toward the interior of the granitic body. This color zoning probably reflects rock type changes as yet unmapped in the Marble Canyon quadrangle; furthermore, lithology appears different from that within the arcuate area. The arcuate region appears much darker and appears to truncate the zoned region in the east, perhaps indicating it was a later intrusive phase.

McAllister (1955) describes the Hunter Mountain plutonic body as quartz monzonite intruding Paleozoic marine sedimentary rocks, with the majority of the mass light colored and containing less than 5% mafic minerals, but having various mafic border facies. In the adjoining region to the south, Hall (1971) indicates that biotite-hornblende quartz monzonite occurs as an extension of the Hunter Mountain body, and that centers of intrusive masses are predominantly more silicic quartz monzonite grading to quartz-poor monzonite or syenodiorite near the borders. McAllister's data agrees as he mapped the western portion of the Hunter Mountain body as a complex of mafic facies in contact with Paleozoic limestones, and he attributed the occurrence to mixing with the wallrock. He indicates pegmatite and aplite masses occur abundantly around Hunter Mountain, but did not consider them worthy of mapping. In the Darwin quadrangle, such small bodies are observed commonly at borders of quartz monzonite bodies and as thin dikes (Hall and MacKevett, 1958). Also he reports inclusions to be abundant in finer grained rock in places especially on the southern part of Hunter Mountain. Knowledge of these minor intrusive facies could contribute greatly to the understanding of the histories and conditions of intrusive emplacement, definition of border zones, and relations of mineral deposits.

The intrusive events apparently took place after deposition of at least 4600 meters (15,000 feet) of Paleozoic marine sediments, and probably after the middle Mesozoic since similar intrusives are known to cut Triassic rocks in the Inyo Range to the west (Ross, 1969). Nearly all authors describing the surrounding regions consider the masses of quartz monzonite to have intruded generally in Jurassic to Cretaceous time. Very few age determinations have been made near Hunter Mountain; Ross (1969) reports an age of 190 million years on a zircon from the area and assigns the intrusive event to early Jurassic. Hall and MacKevett (1958) reported a zircon dated at 99 million years from the southeast part of Ubehebe Peak quadrangle. The accuracy of these dates is tenuous, but they may have been obtained from widely different ages of intrusives. More reliable ages of similar rocks yield a middle Jurassic age in the Argus Range to the south and a late Jurassic to early Cretaceous age in the Panamint Range to the north (Burchfiel, 1969). Various similar ages have been obtained in the Inyo Range to the west, indicating a range of intrusive dates. The Hunter Mountain body may be Jurassic in age or possibly younger, and appears younger than the neighboring granitic body in the east.

The fracture pattern and lineament trends observed in satellite images are complex. Linears have been plotted which lie tangential to most of the perimeter of the arc, especially from the S190B scene. The greatest concentrations of lineaments appear to be at the west and southwest boundaries, and on the northern margin. Additional lineaments strike through the structure, trending mainly N 70 W and N 30 E. This pair of trends occurs throughout the region and may represent an orthogonal joint set. Other minor trends occur throughout the region, and may prove important to interpretation of mineralized zones. A major mapped fault zone, Grapevine Canyon, strikes about N 60 W along the arcuate's southwest boundary, linking Saline Valley with Panamint Valley; this fault appears to be a relatively recent feature, and has probably been responsible for much of the later fracturing.

Fault control of mineralization in the region has long been recognized as important. The Ubehebe Mine to the far north exhibits N-S faults, and associated N 15 E trending faults are particularly characterized by mineralization. This small district which has produced lead, zinc, and silver, occurs very close to a syenite facies of a stock of the same Hunter Mountain quartz monzonite and within shattered dolomitic rocks The altered and mineralized zone is readily apparent in satellite images as is that adjacent to two stocks nearer the Hunter Mountain body. The Lippincott Mine area which is located on the edge of the stock immediately northwest of Hunter Mountain produced lead and silver and some copper and tungsten from metamorphosed dolomite. The main controlling structures are apparently N 10 to 15 E and N 50 W. These trends are usually visible in detailed imagery, and in the Hunter Mountain region, the lineaments have been plotted and found to have a high correlation to known mineralized areas.

Small mine workings and prospects have been active around the margins of the Hunter Mountain body. Massive thermal metamorphism occurs along most of the northern and western margins, as is evident from the bright reflectances observed, and in many places metasomatic processes have enriched the zone with local tactite and ore deposits. Mineralized areas having previous mining activity seem to have a correlation with the arcuate anomaly, and the structural, lithologic, and vegetative differences appear to be interrelated. Mining of ore deposits has occurred primarily in the Paleozoic rocks where closely adjacent to the intrusive bodies, and control by faults and fractures has been important acocrding to many authors. To the west near Big Dodd Spring, copper, lead, and tungsten are the principal economical materials occurring in small bodies in fault zones. Here are seen abundant north-northeast trending lineaments as well as minor, discontinuous fractures at nearly 90 degrees. Old prospects were worked mainly for copper minerals in marble and calc-silicate rock in this area as well as to the northeast and to the south, following the western border of the arc. Near the southern edge of Hunter Mountain occur additional claims with copper silicates filling fractures and pegmatite trending N 70 W. This same trend is observed to be strong in the satellite images, particularly in this southerly area, and intersections with lesser northeast trending lineaments. In each of the mineralized areas, intersections of approximately N 70 W and N 30 E lineaments are observed. To the extreme north on the steep northern face below the plateau rim occurs a copper claim in a well-brecciated contact metamorphic zone where white marble contacts a mafic border facies of the Hunter Mountain quartz monzonite. In this region is observed a complex of lineaments which probably helped give rise to the large, bright altered zone visible, and the heavy mineral deposition.

In general, the faults which apparently help to control mineralization are more or less tangential to the plutonic contacts. This fact is of major significance to the location of new mineralized areas around the anomaly, especially with respect to copper which occurs mainly in deposits near the pluton margin. The well-known rich mining districts of Darwin and Cerro Gordo nearby to the south and west, exhibit many of the same relations of mafic border facies of quartz monzonite intrusives near limestone or dolomite contacts, in conjunction with complex control by faults and fractures.

The southern portion of the arcuate area appears darkest in the S190A Ektachrome frame. Compositing of the spectral bands into a false infrared color combination reveals this area to be one of the few densely vegetated regions in the scene. The vegetation appears isolated, however, and diminishes considerably to the north in the high plateau region. The primary explanation seems to be that the vegetation is restricted to areas of greatest water retention: the higher elevations and northern slopes. But, the entire northern portion and surrounding areas appear almost totally bareen despite comparable elevations and abundant north-facing slopes. ERTS color compositing of enhanced 70mm frames also reveals relatively dense vegetation only in the southern region and virtually none in the adjacent plateau region, but immediately outside the arcuate appears widespread, fairly homogeneous vegetation. For these reasons, the arcuate region has been identified as containing a vegetation anomaly, as well as structural and coloration anomalies. These characteristics have been observed in Skylab imagery, and are supported by ERTS color composite scenes.

FIELD OBSERVATIONS

A reconnaissance field trip was made to briefly study the region where the arcuate structure was seen, and to visualize what was actually being observed in the images. As soon as the area of the southern arcuate boundary was reached, it was evident that abrupt changes in the vegetation existed, all within the plutonic rock terranes. Juniper and pinyon pines occur above 1500 meters (5000 feet) elevation. Part of the northern border was also studied where a mafic border facies of the quartz monzonite contacted Paleozoic limestones, forming a wide zone of calc-silicate metamorphic rock with an associated tactite zone containing several percent of copper oxides. Pyrite and bornite occur disseminated in marble in the zone. Even from cursory examination, it was readily apparent that the large, bright-white area in the images corresponded with this thermally metamorphosed and mineralized zone. The dark region immediately adjacent to it apparently represents the mafic facies, and the contact appears linear, probably due to a fault, trending northeast. The local area appears in images to be complexly fractured, and this condition most likely provided the desired relations giving rise to mineralizing solutions near the contact.

FURTHER WORK RECOMMENDED

Beyond a more detailed study of lithologic and structural relations from satellite imagery, further work is suggested to support and complement the remote sensing investigation. Future study should include: sampling consistently across the arcuate structure to determine changes in lithology and minor mineral constituents, a geobotanical survey identifying any geochemical zoning, age dating of the plutonic bodies, investigation of color anomalies and determination of any possible remnants of Paleozoic rocks in the mass or near the arcuate edges, study of image lineaments and actual faults, joints and fractures and correlating them to mineralization, and a comprehensive mapping program in conjunction with imagery analysis. Few of the lineaments and subtle lithologic differences observed have been previously mapped, but the likely important associations of these with mineralized areas warrants detailed investigation of all features. We suspect that further work will indicate the arcuate region to be an intrusive sequence of slightly different composition and age, likely responsible for mineralizing the area.

CONCLUSION

Image analysis of the Hunter Mountain region has shown many interesting patterns deserving much more investigation on both regional and detailed scales. Mineralization of economic grade is known to occur throughout the region and has been mined for years. If attention is paid to the interrelationships of subtle lithologic differences, fracture patterns, vegetation anomalies and known mineralized areas, tremendous information about distribution of mineral resources could be gained, in particular utilizing all the methods and interpretations available with satellite remote sensing data. These various factors occurring in combination should continue to help delineate potentially valuable mineralized areas of Hunter Mountain and surrounding areas. Synthesis of previous data and present and future data applications will undoubtedly indicate recognizable patterns relating to mineralization in specific regions, and remote sensing techniques will be found invaluable as reliable and integrative tools for resource exploration.

BIBLIOGRAPHY

Burchfiel, B. C., 1969, Geology of the Dry Mountain Quadrangle, Inyo County, California: California Div. Mines and Geology Spec. Report 99.

Hall, Wayne E., 1971, Geology of the Panamint Butte Quadrangle, Inyo County, California: U.S. Geol. Survey Bull. 1299.

Hall, Wayne E. and MacKevett, E. M., 1959, Economic Geology of the Darwin Quadrangle, Inyo County, California: California Div. Mines and Geology Spec. Report 51.

Hall, Wayne E. and Stephens, Hal G., 1963, Economic Geology of the Panamint Butte Quadrangle and Modoc District, Inyo County, California: California Div. Mines and Geology Spec. Report 73.

Jennings, Charles W., 1959, Geologic Map of California, Death Valley Sheet: California Div. Mines and Geology, Scale 1:250,000.

McAllister, James F., 1952, Rocks and Structure of the Quartz Spring Area, Northern Panamint Range, California: California Div. Mines and Geology Spec. Report 25.

_______, 1955, Geology of Mineral Deposits in the Ubehebe Peak Quadrangle, Inyo County, California: California Div. Mines and Geology Spec. Report 42.

_______, 1956, Geology of the Ubehebe Peak Quadrangle: U.S. Geol. Survey Quadrangle Map GQ-95.

Merriam, C. W., 1963, Geology of the Cerro Gordo Mining District, Inyo County, California: U.S. Geol. Survey Prof. Paper 408.

NASA, 1972, EREP Investigator's Data Handbook: Manned Spacecraft Center, Houston, Texas.

Ross, Donald C., 1967, Generalized Geologic Map of the Inyo Mountains Region, California: U.S. Geol. Survey Misc. Geol. Investigations Map I-506.

_______, 1967, Geologic Map of Waucoba Wash Quadrangle, Inyo County, California: U.S. Geol. Survey Geologic Quadrangle Map GQ-612.

_______, 1969, Descriptive Petrography of Three Large Granitic Bodies in the Inyo Mountains, California: U.S. Geol. Survey Prof. Paper 601.

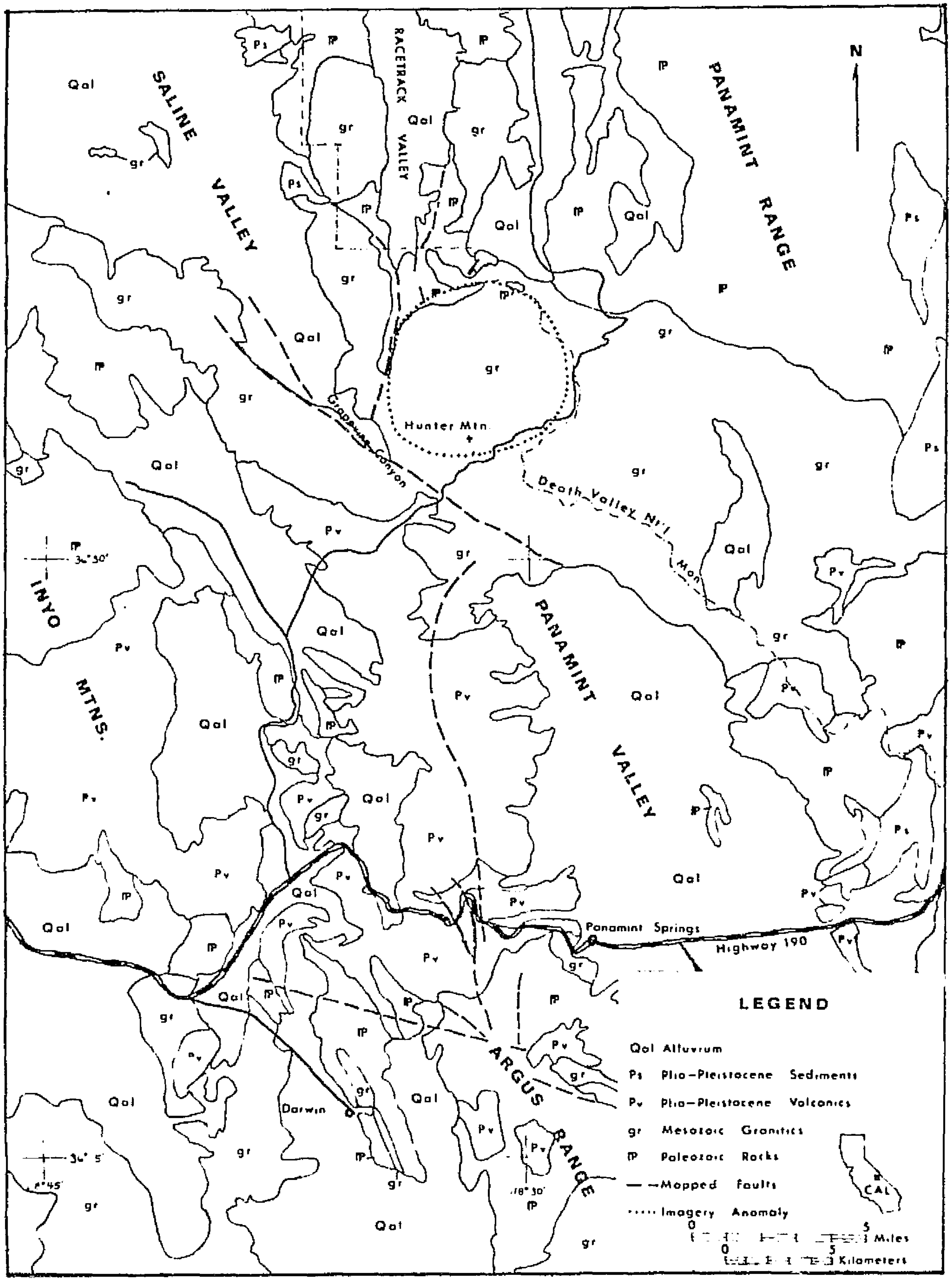

Figure 1 Location map and generalized geology of the Hunter Mountain region, California. Scale 1:250,000.

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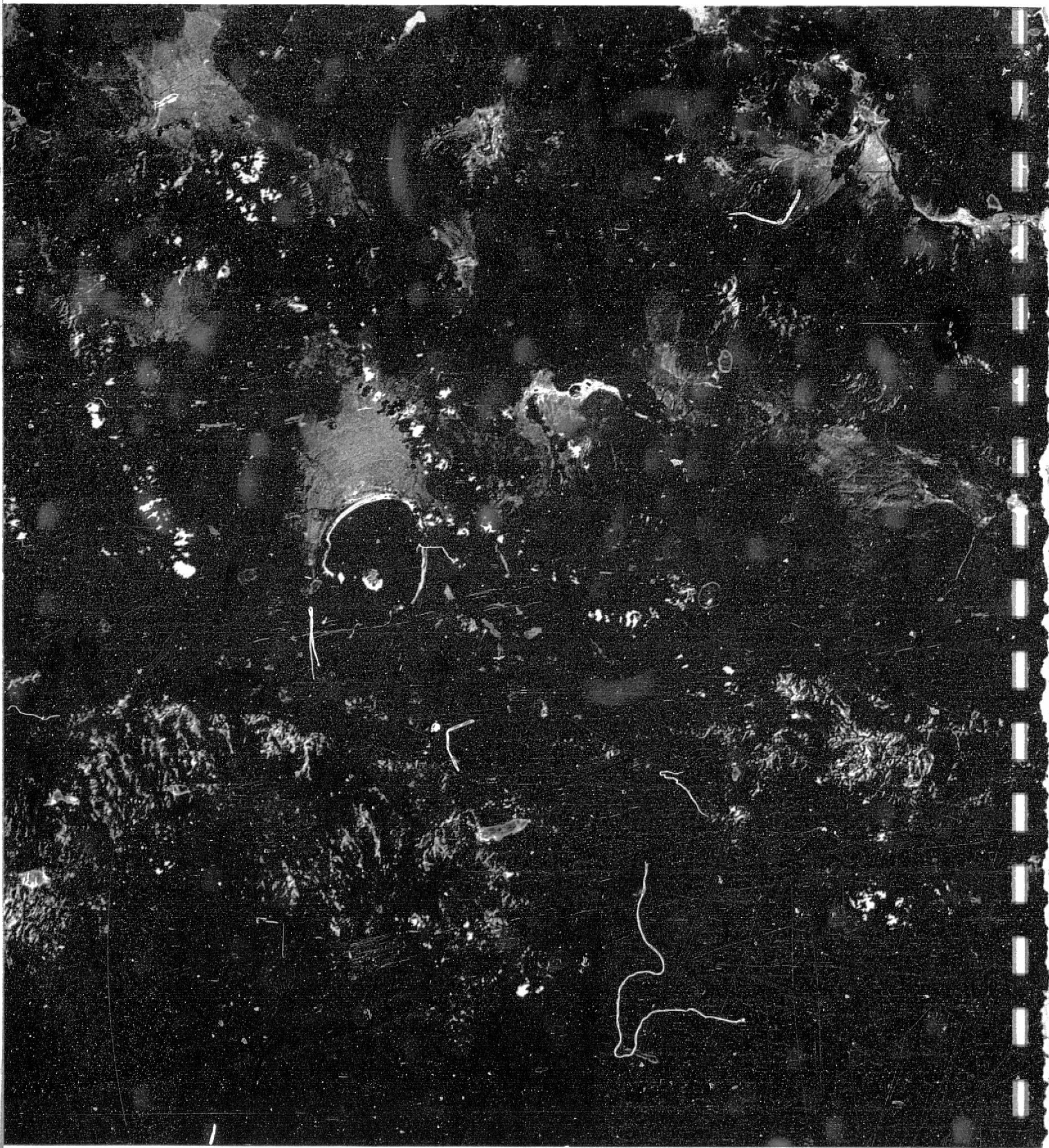

SKYLAB high resolution Ektachrome image of Mono Lake, California, taken Sept. 13, 1973, with S198A multispectral camera. (NASA SL3-40-194)

APPLICATION OF SATELLITE IMAGERY TO GEOTHERMAL RESOURCES EXPLORATION:
Geothermal Energy, v. 3, no. 5, pp45-55, May, 1975.

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Figure 1A, p.47

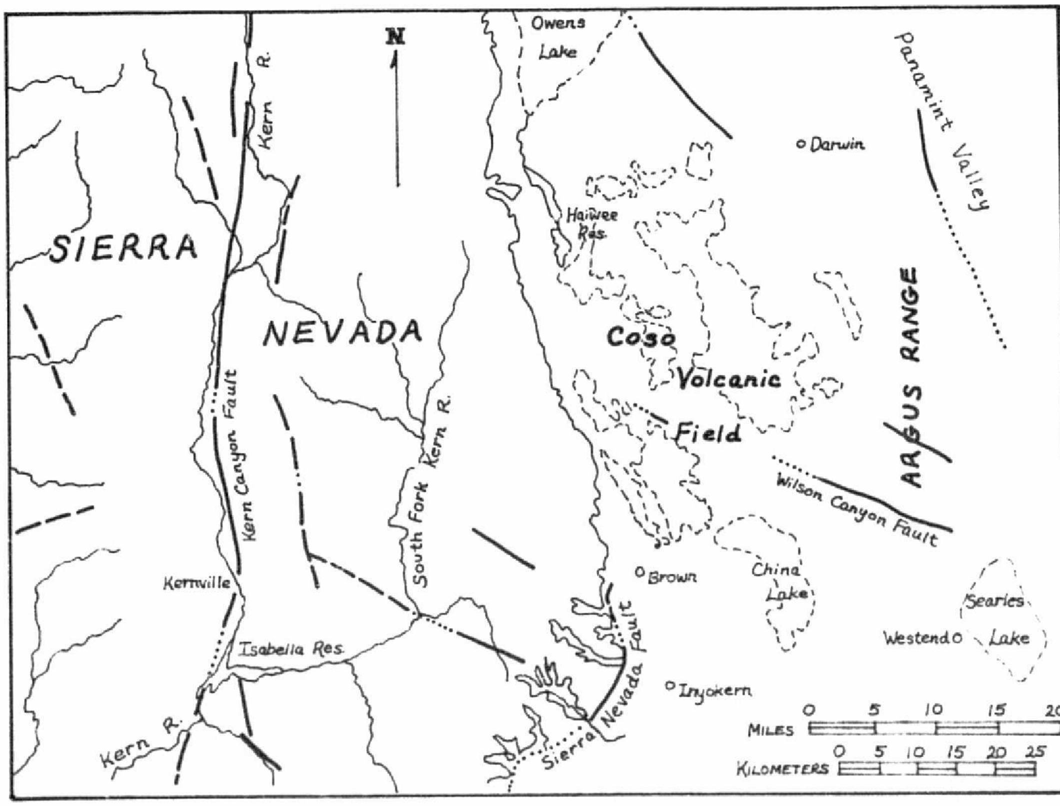

Figure 1B, p.47

Page	Paragraph	Line	Corrections
Inside front cover	Caption	3	S190A Multispectral camera
48	Table 4	8	0.90 - 1.08 micrometers
51			Units on scale:
		1	miles
		2	kilometers
53	4	1	...pictured on the inside front cover
53	6	3	...on the inside back cover
53	11	1	In Figure 1A...
53	13	Heading	SKYLAB image SL3-85-001

IMAGE REVERSED: ORIENTATION CORRECT IN ORIGINAL PRINTING

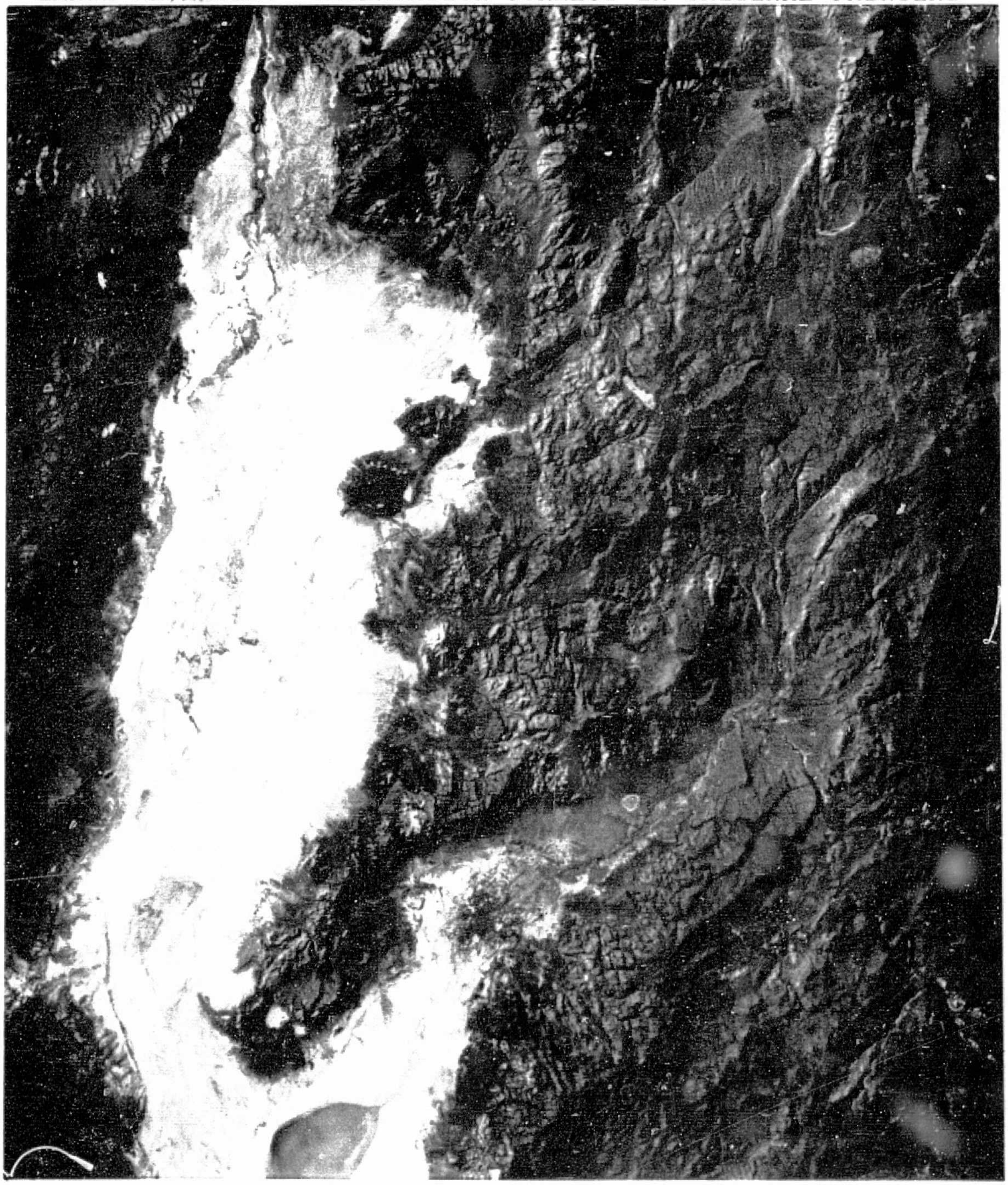

Figure 2A, p.50

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Application Of SATELLITE IMAGERY TO GEOTHERMAL RESOURCES EXPLORATION

JOHN T. REYNOLDS
AND C. GREGORY WAGNER

INTRODUCTION

Satellite imagery studies have proved to be valuable supplementary tools for the mineral and petroleum industries. Analyses of satellite imagery have been conducted to evaluate regional aspects of mineral deposits as well as to map structural and lithologic detail. Data derived from these studies have been used to facilitate the planning of ground geologic surveys, geophysical field explorations, and drilling programs. Much of the methodology and manv of the techniques developed for interpreting space imagery for mineral exploration are applicable to geothermal resources exploration using satellite data.

The main characteristic and principal advantage of satellite imagery is the synoptic coverage of large areas. This overview, obtained with uniform lighting conditions, sacrifices some ground resolution, but synoptic coverage allows regional structural-tectonic relationships and their significance to potential resources to be evaluated on a single image. Furthermore, synoptic coverage allows areas of similar and contrasting color or texture to be identified, providing an excellent reconnaissance mapping tool.

A second characterisitic of satellite imagery is the extreme high altitude of the orbiting sensor platform. As has been noted by other interpreters of space imagery, the advantages of high altitude are the elimination of cultural details which can confuse or obscure the surface geological picture and an accentuation of subtle surface anomalies that may be significant to potential geothermal resources.

Because of these two characteristics, satellite imagery can be used by the geothermal explorationist for regional structural studies, detection of favorable lithologies and soil and vegetation anomalies, as well as for an excellent geographic reference.

A third characteristic restricted to the camera facilities on board *Skylab* is excellent ground resolution at the scales of 1:62,500 and probably larger. This permits lithologic and structural mapping in great detail, and can serve in evaluations of individual geothermal areas.

Clearly, different types of satellite imagery are suitable for different exploration tasks. The term "satellite imagery" signifies data that is obtained from orbiting sensor platforms; two of these, *Skylab* and LANDSAT, are especially significant to geothermal exploration. Imagery can be either lens-camera products (photography), in the form of transparencies or paper prints, or line-scan images, the products of optical-electromechanical devices, which are initially recorded in digital form on magnetic tape.

This paper describes the types of space imagery available for geothermal exploration and discusses aspects of geothermal resources that can be analyzed and evaluated by interpreting space imagery. Examples from LANDSAT and *Skylab* are also presented and discussed.

LANDSAT PROGRAM*

Meteorological satellites have been used since the beginning of the space program. These satellites were equipped with visible and infrared sensors which produced video pictures that were processed to enhance cloud formations. Nevertheless, many pictures, particularly those from Nimbus, proved suitable for interpretation of major structural features present in the large area (hundreds of kilometers on a side) covered in the pictures.

LANDSAT-1, launched July 23, 1973, was the first space platform designed specifically to observe the earth repetitively with sensors that produce high resolution, multiband imagery, and digital data. LANDSAT orbits

**LANDSAT is the name now given to the former ERTS program by NASA.*

the earth at an average altitude of 950 kilometers in a sun-synchronous polar orbit, such that each part of the earth is imaged at approximately the same time every eighteenth day. LANDSAT provides an essentially planimetric, vertical view of the earth's surface which covers very large areas (185 kilometers square per scene).

Imaging sensors on LANDSAT include a multispectral scanner (MSS) and a return beam vidicon (RBV); an early electrical system malfunction on LANDSAT-1 (ERTS-1) caused premature shutdown of the RBV. MSS is a line-scanner system that generates individual scenes, with each scene scanned to produce four images simultaneously.

Figure 1A shows one of these bands. Each of the four images (bands) corresponds to a different segment of the visible and near-infrared spectrum (see Table 1). The system is designed to permit registration of all bands. The resolution of the system permits identification of high contrast, linear targets as narrow as 40 meters.

TABLE I

LANDSAT MSS Specifications

Spectral Band	Wavelength Ranges (micrometers)
4	0.5 - 0.6
5	0.6 - 0.7
6	0.7 - 0.8
7	0.8 - 1.1

MSS imagery is commonly processed from digital data on magnetic computer tapes into 70 mm black and white film transparencies. These transparencies (film positives) allow registration of all four bands either mechanically or optically in a projector. Various combinations of the four bands and color filters can be utilized to produce false color images of the earth's surface. MSS imagery can also be manipulated on computer-compatible magnetic tapes in digital form, and specialized processing such as optical enhancement techniques, density mapping, computerized feature recognition and classification, and interactive computer-graphics display can be utilized.

SKYLAB PROGRAM

NASA's manned spacecraft programs have included a number of platforms for supporting earth-sensing programs. Handheld 35 mm and 70 mm cameras were used by astronauts aboard Mercury, Gemini, and early Apollo missions, and a large number of geologically useful color photographs of the earth's surface were obtained. Apollo 9 was outfitted with a multispectral terrain photography experiment which provided a successful simulation of the later LANDSAT. The *Skylab* space station, which evolved from studies regarding the use of spent rocket stages as earth-sensing platforms, contained a sophisticated Earth Resources Experiment Package (EREP).

EREP, a six-instrument assortment of sensors that covers a wide range of the electromagnetic spectrum, was designed to provide imagery and other forms of data describing the earth's surface. The package consisted of two camera systems (S190A, S190B), one infrared spectrometer yielding data in five frequencies (S191), a multispectral scanner (S192), and two complementary microwave systems (S193, S194). Handheld 35 mm and 70 mm cameras were also on board the spacecraft.

MULTISPECTRAL PHOTOGRAPHIC CAMERA (S190A)

The S190A camera cluster was a boresighted, multiband, six camera station system designed to obtain precision, high ground resolution, multispectral photography in the visual and near-visual range. Four of the cameras (Stations 1, 2, 5, 6) containing black and white film were equipped with filters such that each camera recorded different wavelengths of radiation in the 0.5-0.9 micrometer range.

The images for each scene from these cameras can be composited in the same manner as LANDSAT MSS to produce false color combinations for interpretation. Station 3 camera contained color infrared film and Station 4 contained high resolution color film (inside front cover). Images from these two cameras can be composited with the black and white images to provide many more false color combinations.

TABLE 2

SPECIFICATIONS FOR S190A MULTISPECTRAL CAMERA SYSTEM

Station	Filter Bandpass (micrometers)	Film Type (Eastman Kodak)	Approximate Ground Resolution (meters)
1	0.7 - 0.8	B+W IR; EK2424	75
2	0.8 - 0.9	B+W IR; EK2424	75
3	0.5 - 0.88	Color IR; EK2443	75
4	0.4 - 0.7	High Resolution Color SO-356	45
5	0.6 - 0.7	B+W: PANATOMIC-X	35
6	0.5 - 0.6	B+W: PANATOMIC-X	45

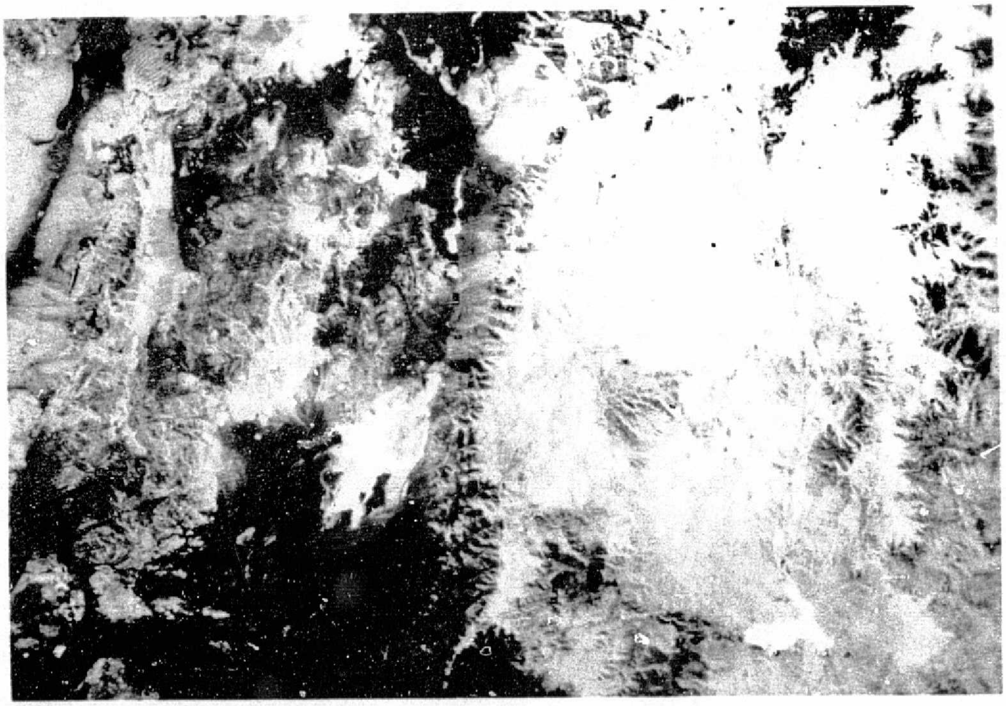


Figure 1A. Landsat-1 Multispectral scanner image 1324-18011, Band 7, June 12, 1973. Scale 1:1,000,000.

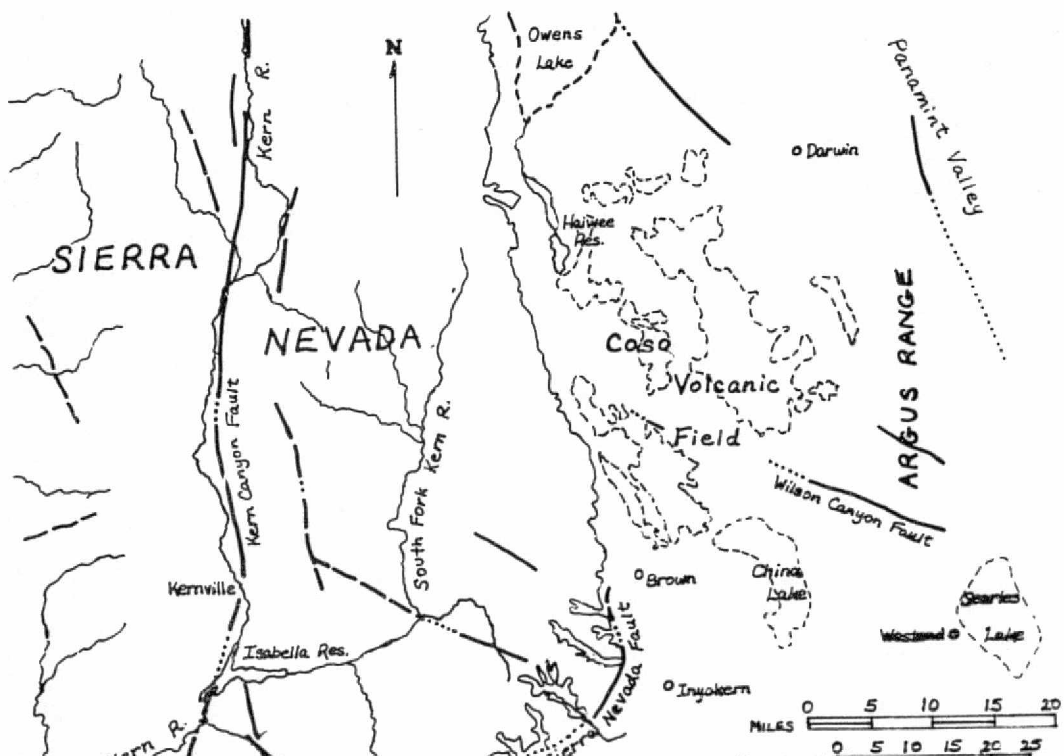


Figure 1B. Location map for area in Figure 1A, showing major mapped faults, and the Coso area in east central California. Scale 1:1,000,000.

The ground coverage of S190A imagery is 163 kilometers square, at a nominal spacecraft altitude of 440 kilometers. The rate of frame exposures was varied so that some successive S190A images have approximately 60 percent (or more) overlap to provide for stereoscopic viewing. The camera system is summarized in Table 2.

EARTH TERRAIN CAMERA (S190B)

The S190B earth terrain camera was a high resolution single-lens camera designed to obtain photographs in the field of view of the S190A cameras. It was equipped with 5-inch film, which for different film magazines was color, color infrared (inside back cover), or black and white (Figure 2A). S190B had a 455 mm focal length and provided ground coverage of 109 kilometers square.

The ground resolution is twice as fine as that of comparable S190A images, thus allowing very detailed mapping and analysis of relatively small features. S190B can be obtained in 9-inch format, offering an approximate 1:500,000 scale suitable for mapping and comparison with known features. The camera's specifications are listed in Table 3.

MULTISPECTRAL SCANNER (S192)

The S192 system was similar to LANDSAT MSS in that it was an optical-electromechanical scanner rather than a camera. Data from S192 MSS can be utilized in the same way as the LANDSAT MSS but has greater potential since line-scan images were obtained in thirteen different wavelength bands (Table 4). Each of these bands is more restricted than the LANDSAT MSS bands and together, the thirteen S192 bands extend over the visible part of the spectrum, the near-infrared, and includes a band in the thermal infrared.

S192 data, initially recorded digitally on magnetic tapes, can be processed into black and white imagery which can be composited into false color combinations. With thirteen different bands available, the number of combinations is vast.

TABLE 4
S192 MULTISPECTRAL SCANNER

Band Number	Wavelength Range *(micrometers)*
1	0.41 - 0.45
2	0.44 - 0.52
3	0.49 - 0.56
4	0.53 - 0.61
5	0.59 - 0.67
6	0.64 - 0.76
7	0.75 - 0.90
8	9.90 - 1.08
9	1.00 - 1.24
10	1.10 - 1.35
11	1.48 - 1.85
12	2.00 - 2.43
13	10.20 - 12.50

The S192 image on the outside cover of this magazine is a false color radiance slice of Band 13, the thermal infrared band. Colors have been assigned such that each color represents a narrow range of ground temperatures (Table 5). This image is discussed below in more detail.

SKYLAB SYSTEMS (S191, S193, S194)

The contributions of the three other Skylab systems for evaluating earth resources have not yet been assessed; Thus the systems will not be discussed in detail. The infrared spectrometer (S191) was designed to provide spectral data on the earth's surface in the 0.4-2.4 and 6.2-15.5 micrometer region.

Evaluations of S191 data indicate resolution of the system is probably inadequate for geological purposes. The microwave radiometer/scatterometer and altimeter (S193) provided simultaneous measurement of microwave reflectivity and emissivity of land and ocean areas at 13.9 GHz (approximately 2cm wavelength), and obtained altimetry data over ocean areas for sea state studies. The L-band radiometer (S194), supplemental to

TABLE 3
SPECIFICATIONS FOR S190B EARTH TERRAIN CAMERA

Filter Bandpass (micrometers)	Film Type (Eastman Kodak)	Approximate Ground Resolution (meters)
0.4 - 0.7	High Resolution Color SO-242	21
0.5 - 0.7	High Definition B+W EK3414	17
0.5 - 0.88	Color IR EK3443	30
0.5 - 0.88	High Resolution Color IR SO-131	23

S193, was designed to map brightness temperature of the earth's surface at 1.42 GHz frequency (approximately 21cm wavelength).

IMAGERY ANALYSIS FOR GEOTHERMAL EXPLORATION

Known geothermal reservoirs are directly related to recent and active volcanism, recent faulting, and geochemical and geophysical anomalies. Careful studies of space imagery reveal that many of these geologic characteristics distinctly appear on imagery as do anomalous areas probably associated with, or directly caused by, geochemical and geophysical changes near a geothermal system. Arcuate anomalies, for instance, may represent buried intrusive granitic stocks or expressions of associated hydrothermal solutions. Other similar features, less obvious color anomalies, and reflective changes from rocks and soils often indicate rock products altered by thermal waters.

Since the most economical producing geothermal reservoirs are usually those that convey solutions with siliceous deposition characterized by relatively high temperatures, siliceous volcanism and hydrothermal activity present important targets for exploration. Satellite image analysis performs this significant step by presenting structural detail and providing for mapping of volcanic terrane. Distribution of volcanic rocks is reasonably well known in many areas, but there still remain regions that have been mapped only in a reconnaissance fashion. Volcanic rocks of many types can be discriminated by imagery study, and siliceous phases when either concentrated or widespread and disseminated can be discerned.

Even without surface manifestations such as springs and fumaroles, image analysis supplies indirect evidence suggesting areas with high probability of geothermal potential. Fracture patterns related to intrusive bodies can be of major importance and are visible in bedrock, or may be manifested as anomalous vegetation zones, just as seepage of meteoric waters into fault zones creates a healthy, yet restricted, plant community.

Additionally, image studies indicate basement rock fracture patterns that are only subtly expressed at the surface through the overlying rocks and sediments. Such fractured rock might provide favorable hydrologic conditions for geothermal reservoirs, especially when in proximity to active or quiescent volcanism.

Other indirect methods are used for determination of heat flow in geothermal areas, including snow melt and plant stress. Williams (1974) of the U.S.G.S. shows that a 25 square kilometer geothermal field in Iceland has been detected on LANDSAT-1 images. Although the field itself has no direct characteristics recorded on MSS images, retarded formation of ice on an adjacent lake due to the influx of geothermally heated water is reflected on the image.

Light snow falls have also been observed by the authors to greatly enhance subtle geologic structure and areas of diminished snow cover may indicate areas of high heat flow. The response of plant growth to anomalously high heat flow is not well defined, but it is clear that plants are useful indicators (Dawson and Dickinson, 1970). Detection of general vegetation patterns is possible in false color infrared composites of multispectral scanner products, and more detailed analysis can be made using the high resolution cameras.

All types of imagery are useful in applications for remote sensing, yet each type has its own drawbacks and advantages. Used in combination, the data are augmented and strengthened. Particularly valuable have been the multispectral scanner images which allow for many combinations of visualization of any one scene. Interpretation and exploration is vastly improved by analysis of all imagery available over a target, thus providing study under different climatic conditions, varying solar illumination angles, and from different altitudes of sensing platforms.

The occurrences of geothermal systems in various host rocks exemplifies the need for diverse data; the Geysers field produces in fractured graywacke and siltstones, the Lardarello field in carbonate rocks, the Wairakei field in volcanic rocks and the Imperial Valley and Cerro Prieto fields in alluvial and deltaic sediments. These varied lithologic occurrences necessitate broad application of imagery exploration techniques and treatment of new localities as unique associations with differently manifested characteristics.

DESCRIPTIONS OF IMAGES

MULTISPECTRAL SCANNER THERMAL INFRARED IMAGE (magazine cover)

The image on the outside cover of this magazine is a false color representation of the thermal infrared channel (Channel 13) of the S192 multispectral scanner. The image was initially processed digitally into 64 shades, or radiance slices, which were analyzed statistically for frequency. Each slice represents a scene temperature. Colors of the spectrum were assigned to each slice such that the scene temperatures could be depicted in a false color

TABLE 5
COORDINATION OF COLORS WITH TEMPERATURES FOR S192 IMAGE

Color	*Scene Temperatures* °C
Black	-16
Blue	-16 to -11
Bluegreen	-10 to - 7
Green	- 6 to - 1
Greenish Yellow	0 to + 3
Yellow	+ 4 to + 9
Yellow Red	+10 to +13
Red	+14 to +19
Red Violet	+20 to +23
Violet	+24 to +29
White	+29

Figure 2A. Skylab S190 B earth terrain camera image SL3-85-001, taken on August 12, 1973, in the early morning. EREP Pass 20, Track 20, at altitude over 430 kilometers (270 statute miles). Region of bright white reflectance represents playa deposits of the Black Rock Desert in northwestern Nevada. Scale is approximately 1:500,000.

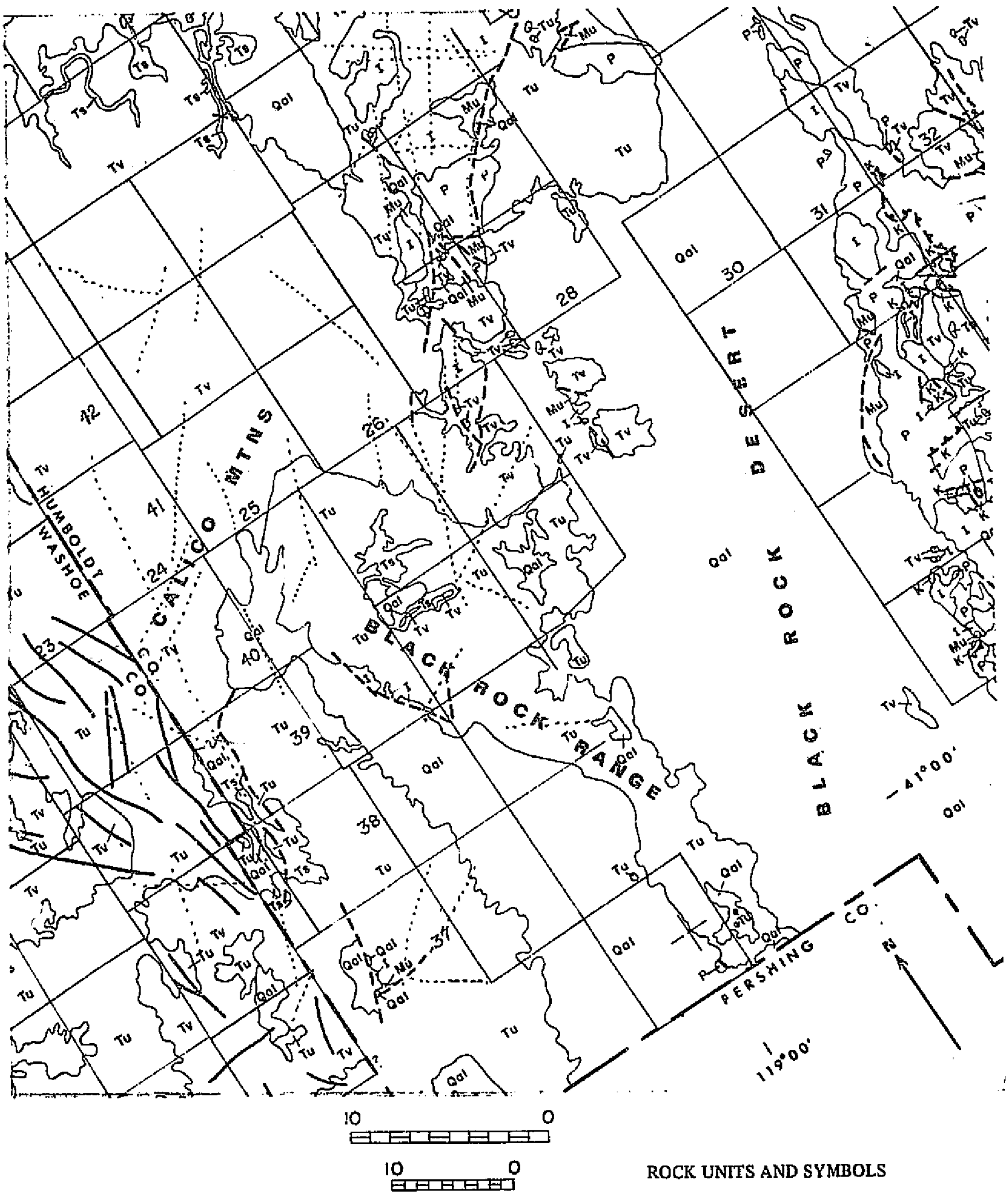


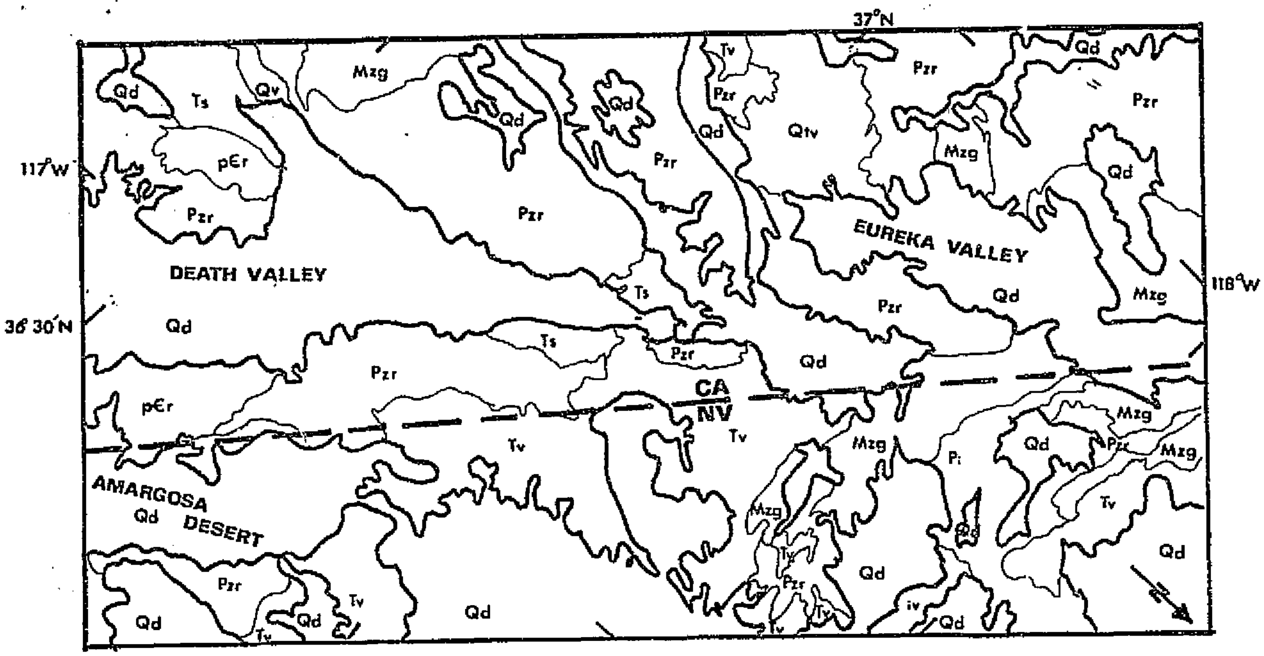
Figure 2B.

NORTHEAST OF GERLACH NEVADA, GENERAL GEOLOGIC MAP WITH TOWNSHIP LINES FOR AREA IN FIGURE 2A (FACING PAGE) FROM NEVADA BUREAU OF MINES MAP 16.

SCALE 1:500,000.

ROCK UNITS AND SYMBOLS

Qal	- QUATERNARY ALLUVIUM
Ts	- TERTIARY SEDIMENTARY ROCKS
Tu	- TERTIARY UNDIFFERENTIATED
Mu	- MESOZOIC UNDIFFERENTIATED
K	- CRETACEOUS
P	- PERMIAN
Tv	- TERTIARY VOLCANIC ROCKS
I	- INTRUSIVE ROCKS
——	MAPPED FAULTS
. . .	OBSERVED IMAGE LINEARS



EXPLANATION

Qd	QUATERNARY DEPOSITS
Qv	QUATERNARY VOLCANIC ROCKS
Qtv	QUATERNARY– TERTIARY VOLCANIC ROCKS
Ts	TERTIARY SEDIMENTARY ROCKS
Tv	TERTIARY VOLCANIC ROCKS
Mzg	MESOZOIC GRANITIC ROCKS
Pzr	PALEOZOIC ROCKS
pЄr	PRECAMBRIAN ROCKS

——— CONTACT

SCALE 1:1 000 000

25 km 0 25 km

Figure 3. Generalized geologic map showing area covered by S192 image on magazine cover. North is toward the lower right of the map.

image. The range of temperatures for the S192 image on the cover is from -16°C to +29°C. The temperature range that individual colors represent is shown in Table 5.

The S192 image covers an area approximately 80 kilometers wide by 160 kilometers long. Figure 3 depicts the area covered by the image. The image was obtained January 27, 1974, by Skylab 4 astronauts (Carr, Gibson, Pogue). Death Valley appears as the large swath of red and violet spanning most of the length of the cover, and Eureka Valley is the isolated dark red patch.

Small, individual thermal anomalies cannot be detected at the resolution of the S192 scanner, but large areas exhibiting elevated temperatures are discernible. The large, white region near the center of the image is the Ubehebe Crater volcanic region which lies at the junction of two major faults, both of which are apparent as linear features in the image.

The Furnace Creek fault zone is particularly evident, spanning nearly the entire length of the image along the eastern edge of Death Valley. A relatively cold spot appears in the midst of Death Valley just west of Stovepipe Wells and perhaps represents cool springs, a water body, or water-saturated soil. Numerous thermal regions occur within many of the basin areas as in the southern Eureka Valley and near the Keane Wonder fault in the Funeral Mountains near the southwestern edge of the scene.

SKYLAB IMAGE SL3-40-194

The *Skylab* S190A image pictured on the inside right cover is oriented with north to the upper left corner. The scene shows Mono Lake in a circular basin just left of center and Walker Lake, Nevada, in the upper left corner. Bishop, California, is pictured at right center, south of the Owens River flowing through Owens Valley. The east scarp of the Sierra Nevada (bottom of image) exhibits strong arcuate and linear structural features directly related to emplacement of granitic stocks and uplift of the large fault block.

Additional fault and fracture patterns bound and intersect arcuate structures; for example, the famous Long Valley depression seen just right of the image center, south of Mono Lake. The relatively active volcanic Mono Craters area appears as a linear zone of bare circular exposures between the Mono Lake and Long Valley depressions. Within Long Valley, brightly reflecting altered rock products indicate the intensity of geothermal activity in the area. Other known hot springs areas are visible, such as Benton Hot Springs, and additional prospective areas can be located by further study of numerous fault and fracture patterns, structural relations, and altered zones.

SKYLAB IMAGE SL3-87-112

An example of *Skylab* (EREP) S190B earth terrain camera photography utilizing color infrared film is presented on the inside left and right cover (north is to lower right). The image depicts the Salton Trough, suspected to be a landward extension of the Gulf of California rift zone, bounded by mountain blocks of various compositions.

The area contains much geothermal activity, some of which has no surface expression other than high thermal gradients. Much geologic detail is obscured by the patchwork of agriculture near the Niland geothermal area, but several arcuate features thought to be related to the activity can be observed.

In this image, bright red reflectance signifies healthy vegetation. Intensive study, including temporal data, may relate the stress condition of the vegetation to heat flow and mineralization and therefore provide a tool to aid in the identification of potential geothermal areas.

The ground resolution of this image which was taken from an altitude of 435 kilometers is approximately 30 meters. This image was enlarged from the original 5-inch film format; the scale is 1:500,000. The resolution and quality of S190B films permit enlargement to at least 18 times the original film size, still retaining valuable and useful geological information.

LANDSAT IMAGE 1324-18011

The value of the synoptic view provided by LANDSAT MSS is demonstrated in this image of the Coso KGRA. Even though only 50 percent of one scene is presented in Figure 1A, the tectonic and structural environment of the Coso area can be analyzed and evaluated fully. The Coso KGRA is located in Owens Valley between the upfaulted block of the southern Sierra Nevada and the Argus Range.

In Figures 1A, the hot springs and volcanic centers that characterize the Coso geothermal activity are located to the north of the dark basalt mass in the center of the valley. The principal source of heat in the Coso KGRA is a granitic intrusion of batholithic proportions. Several large arcuate features that are discernible in the image may represent surface expressions of the batholith such as fractures, faults, collapse features, or alteration zones. Smaller arcuates evident are probably stocks from the batholith and may be directly responsible for the numerous hot springs and other surface manifestations of geothermal activity in the area (Austin et al., 1971).

The geothermal activity is bounded on the south by the Wilson Canyon fault, a left-lateral fault extending from Searles Lake, across the basalt mass in the valley's center, and into the Sierra Nevada. The Airport Lake playa (a white linear feature to the east of the basaltic flows) is aligned along the fault as are several volcanic cones. Many northerly striking faults that have been mapped on the ground (Furgerson, 1973) appear in the image to terminate against the Wilson Canyon fault. Volcanic domes and hot springs within the Coso area are concentrated along these faults.

SKYLAB IMAGE S13-85-001

Another *Skylab* S190B high resolution image (Figure 2A) pictures the Black Rock Desert in northwestern

Nevada in high definition black and white film. This scene exhibits complex and intersecting fracture patterns, extensional block faults, and volcanic rock types, some of which have not been mapped (Figure 2B). A few of those fractures most prominent in the image are shown as dotted lines on the map. This entire region is relatively active, having thermal waters surfacing in many areas.

The hot springs, especially those near active faults, are likely only superficial manifestations of more extensive geothermal plumbing systems. One area of surficial thermal springs can be seen as small white areas in alluvium in the northernmost end of the small basin pictured near the left center of the image.

CONCLUSION

All types of satellite imagery are useful for analysis with respect to exploration for geothermal energy sources. Different formats of data provide different advantages depending on which aspects of the geothermal system are being studied. When interpretations are made from different data, the interpretations can be either reinforced by observed features occurring repetitively, or eliminated as being artifacts of handling and film processing.

Multispectral scanner systems have been found particularly valuable in the initial stages of many aspects of exploration, including rock type discriminations, thermal interpretations, and studies of vegetation occurrences and structural relations.

By synthesizing observed data from different images in various formats, sites can be chosen that offer the greatest potential for geothermal development from considerations of accessibility, development feasibility, coincidence of faults and fractures, and occurrences of favorable lithologic types, rock permeabilities, regional and local drainage conditions, high thermal areas, alteration zones and other color anomalies, and structural features.

Geothermal exploration by workers trained and experienced in utilizing remote sensing data of various types should be useful and valuable not only for initial exploration of a given area, but for detailed geologic mapping and interpretation and extension of known geothermal sites to other prospective areas with delineation of potentially highly productive areas. Image analysis can be applied to a wide array of interrelated disciplines comprehensively and economically, reliably conveying large amounts of data, much of which could be obtained in no other way.

Remote sensing techniques for exploration of geothermal and other resources are being developed and utilized at many different levels and will undoubtedly continue to offer many possibilities for application in all phases of research, exploration, and development.

ACKNOWLEDGMENTS

Much of the work summarized in this paper was accomplished under NASA EREP Contract NAS9-14235. The authors appreciate the cooperation and assistance of the technical monitors for the contract, Dr. David Amsbury and Mr. Martin Miller. Permission to publish Skylab and ERTS imagery was granted by NASA.

The authors also appreciate the personal cooperation and consultation of A. V. Mazade in matters concerning thermal false color processing and statistical interpretation of the S192 scene displayed on the outside cover. Mr. Mazade is employed by Lockheed Electronics Company, Aerospace Division, and accomplished the processing of the S192 scene for the NASA Principal Investigators Office under Contract NAS9-12200.

Finally, the authors acknowledge the contributions of Mr. Ira C. Bechtold, who not only reviewed the manuscript, but developed many of the concepts and techniques of imagery interpretation that were utilized in this remote sensing study of geothermal resources. Mrs. Martha N. Wadsworth typed and edited the manuscript; her efforts are most sincerely appreciated.

REFERENCES

Austin, C. F., Austin, W. H., and Leonard, G. W., 1971, Geothermal science and technology–a national program: Naval Weapons Center, China Lake, California.

Boeckel, J. H., 1974, ERTS-1 system performance overview, *in* Third Earth Resources Technology Satellite-1 Symposium, Vol. I–Technical Presentations, Section A: NASA Scientific and Technical Information Office, Washington, D.C., p.1-12.

Combs, J., and Muffler, L. J. P., 1973, Exploration for geothermal resources, *in* Kruger, P., and Otte, C., eds., Geothermal Energy: Stanford University Press, Stanford, California, p.95-128.

Dawson, G. B., and Dickinson, D. J., 1970, Heat flow studies in thermal areas of the North Island of New Zealand: *in* U.N. Symposium on Development and Utilization of Geothermal Resources, Pisa, Italy, p.466-473.

Furgerson, R. B., 1973, Progress report on electrical resistivity studies, Coso geothermal area, Inyo County, California: Naval Weapons Center, China Lake, California.

Keller, G. V., Grose, T. L., and Crewdson, R. A., 1974, The Colorado School of Mines Nevada geothermal study: *in* Proceedings of the Conference on Research for the Development of Geothermal Energy Resources, Pasadena, California, p.73-83.

NASA, 1972, Skylab EREP investigators' data book: Principal Investigator Management Office, Manned Spacecraft Center, Houston, Texas.

NASA, 1974, Skylab earth resources data catalog: U.S. Government Printing Office, Washington, D.C.

Williams, R. S., Jr., 1974, Satellite geological and geophysical remote sensing of Iceland: NASA Type II Progress Report, 1 Sept. 73–28 Feb. 74, CR-136868, E74-10467.

FAULT LOCATION

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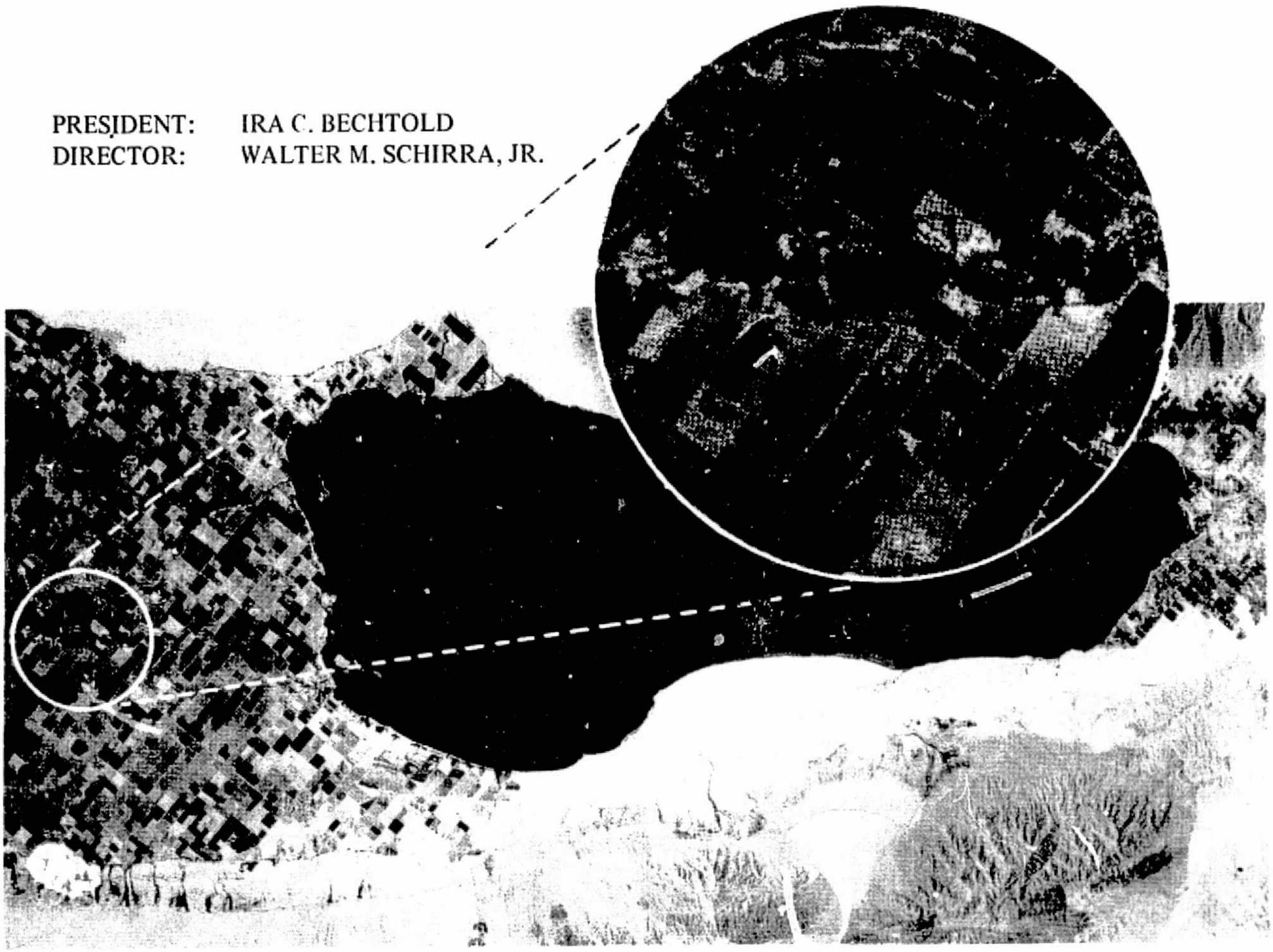

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SKYLAB Color IR image of Salton Sea (California) taken Sept. 15, 1973, with 450 mm. focal length S190B earth terrain camera. (NASA SL3-87-112)

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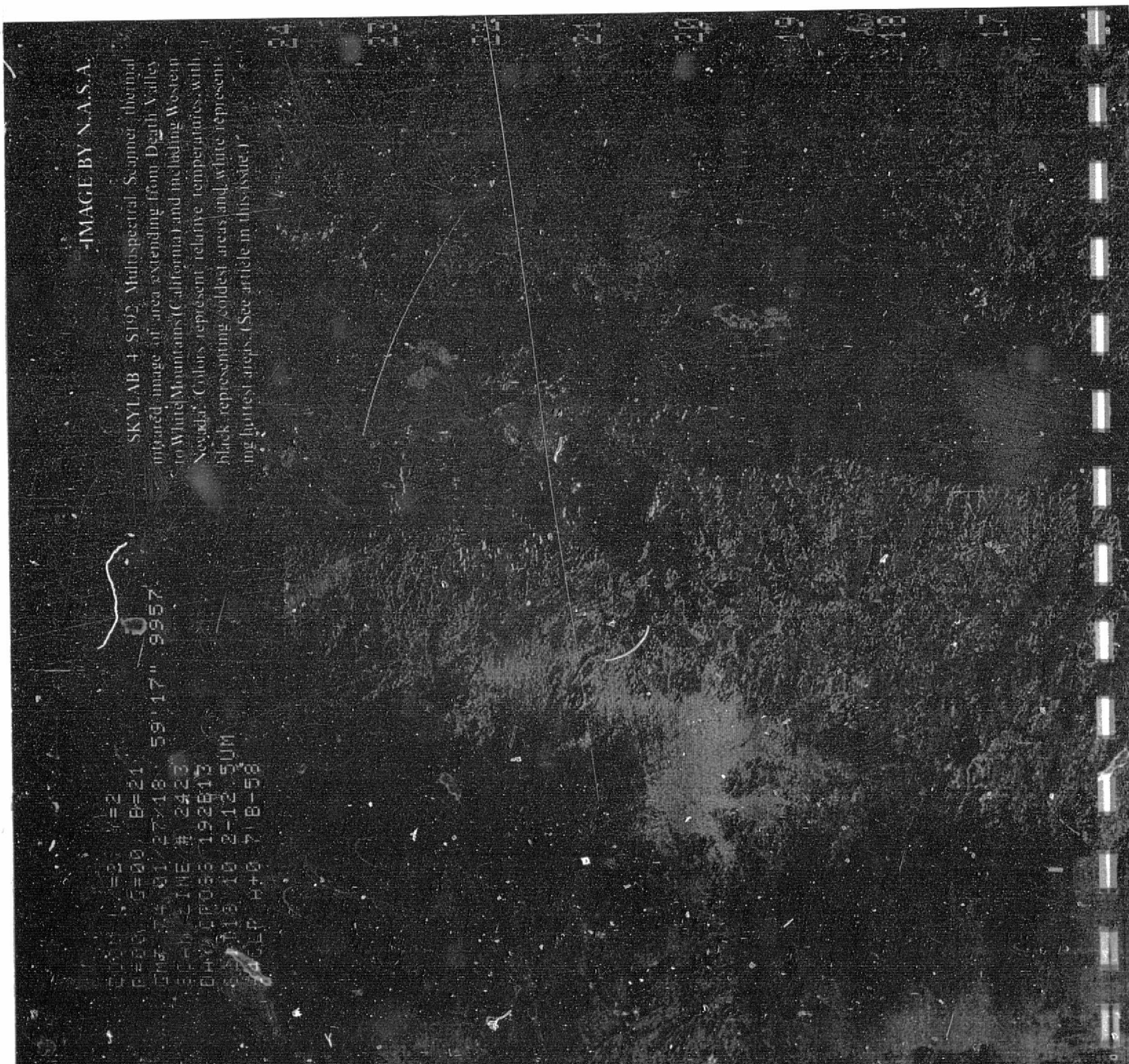

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 June 1975 through 30 June 1975

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION
17137 East Gale Avenue
City of Industry, California 91745

BESTEC Report 101-M9-8/75

Contract Monitor:

David Amsbury, Code TF6
Earth Observations Division
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16. Abstract

Two papers were presented on results of Skylab imagery analyses and subsequent applications to mineral exploration in California and Arizona. Two additional abstracts of results were prepared. In one, indications of the potential value of S192 MSS imagery to geologic investigations are discussed. In the other, geomorphological and geological features noted in imagery that suggest an ancestral San Andreas fault zone are outlined. Imagery studies continued, including an image analysis of the Goldfield, Nevada, area, which disclosed an elliptical coloration pattern corresponding to a silicified, ore-bearing zone.

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Technical Report Standard Title Page

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES

APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

Analysis and interpretation of Skylab S190A and B imagery and preparation of reports of investigation was emphasized during the month of June. Many sites in the test area that have been observed in Skylab imagery to display unusual or anomalous spectral signatures or linear patterns were examined for evidences of mineralization, geothermal activity, or water resources.

Primary methodology employed was visual analysis of 2X (S190B) and 4X (S190A) enlarged film positives on light tables and optical projection to topographic map scales (1:62,500; 1:24,000). One aspect of 2X S190B films is particularly useful--the near-exact 1:500,000 scale. It is especially valuable for studies in northwestern Arizona where Bouguer gravity, residual aeromagnetic, geologic, and topographic maps have been published at the same scale. Topographic and reconnaissance geologic maps at 1:500,000 are similarly available for Nevada. Also, false-color composites of ERTS (Landsat) imagery are readily available for comparison because our I^2S Model 6040PT multispectral viewer projects ERTS 70 mm chips to the scale 1:500,000. A series of acetate or mylar overlays made from analyses of space imagery and geophysical maps registered together on a geology sheet is a convenient method of interpreting linear and arcuate anomalies.

Several areas other than northwestern Arizona have been studied in detail this month, including Goldfield, Nevada, and southwestern Utah.

Mr. Ira Bechtold and Mr. C. G. Wagner attended the NASA Earth Resource Survey Symposium, June 8-14. Mr. Bechtold presented a paper, Application of Skylab Imagery to Resource Exploration in the Death Valley Region, to the Energy and Mineral Exploration session of the geology segment of the Symposium. Few new ideas were presented during the geology sessions, but many valuable informal discussions were held between participants. The Symposium was successful, as it achieved its purpose of providing a means for communication between workers in different disciplines. Especially helpful was the opportunity to discuss aspects and uses of remote sensing data--notably Skylab and ERTS--with personnel from private industry, state and local governments, universities, and NASA. Displays and exhibits effectively served to familiarize workers with new interpretation techniques, new data, and future remote sensing tools.

Mr. Bechtold also attended the 56th Annual Meeting of the American Geophysical Union, where he presented Implications of Skylab (EREP) Imagery for Resource Exploration in Arizona to the Special

Union session on Skylab results.

Two abstracts detailing space imagery investigations were submitted this month in accordance with requests from NASA:

1. Space Imagery, Geomorphology, and Seismicity Studies Indicate Ancestral Trace of the San Andreas Fault.

2. Utilization of Skylab S192 Satellite Imagery for Geologic Investigations.

Both of these abstracts were submitted to Dr. Mead LeRoy Jensen to be considered for presentation at the 1975 Annual Meeting of the Geological Society of America, in Salt Lake City, October 1975. Copies of the abstracts accompany this report.

II. Geologic Investigations:

Image analysis of part of west central Nevada disclosed a prominent elliptical coloration pattern which was found to correspond to the area directly east of Goldfield, Nevada. The structure appears white in relation to the surrounding brown and gray-colored rock outcrops. Published geologic reports consulted indicate the observed anomalous color zone is the expression of a large silicified, ore-bearing zone, portions of which have been mined for rich gold deposits. The elliptical shape is apparently due to silicification of a large ring fracture formed by caldera collapse. Detailed study of the structure shows fractures concentric with and emanating from the zone and reveals a good correlation between imagery-identified silicified zones of greatest probable interest to mapped siliceous zones containing relatively high concentrations of heavy metals.

III. Adherence to Schedule:

A modification of NASA Contract NAS9-14235 has been granted to BESTEC. The purpose of the two-month, no-cost, extension is to allow detailed examination, analyses, and reporting of more potential resource areas as indicated by Skylab imagery studies than would have been possible under the former contract time constraints.

As a consequence of the modification, several changes are to be reported in our Milestone Chart:

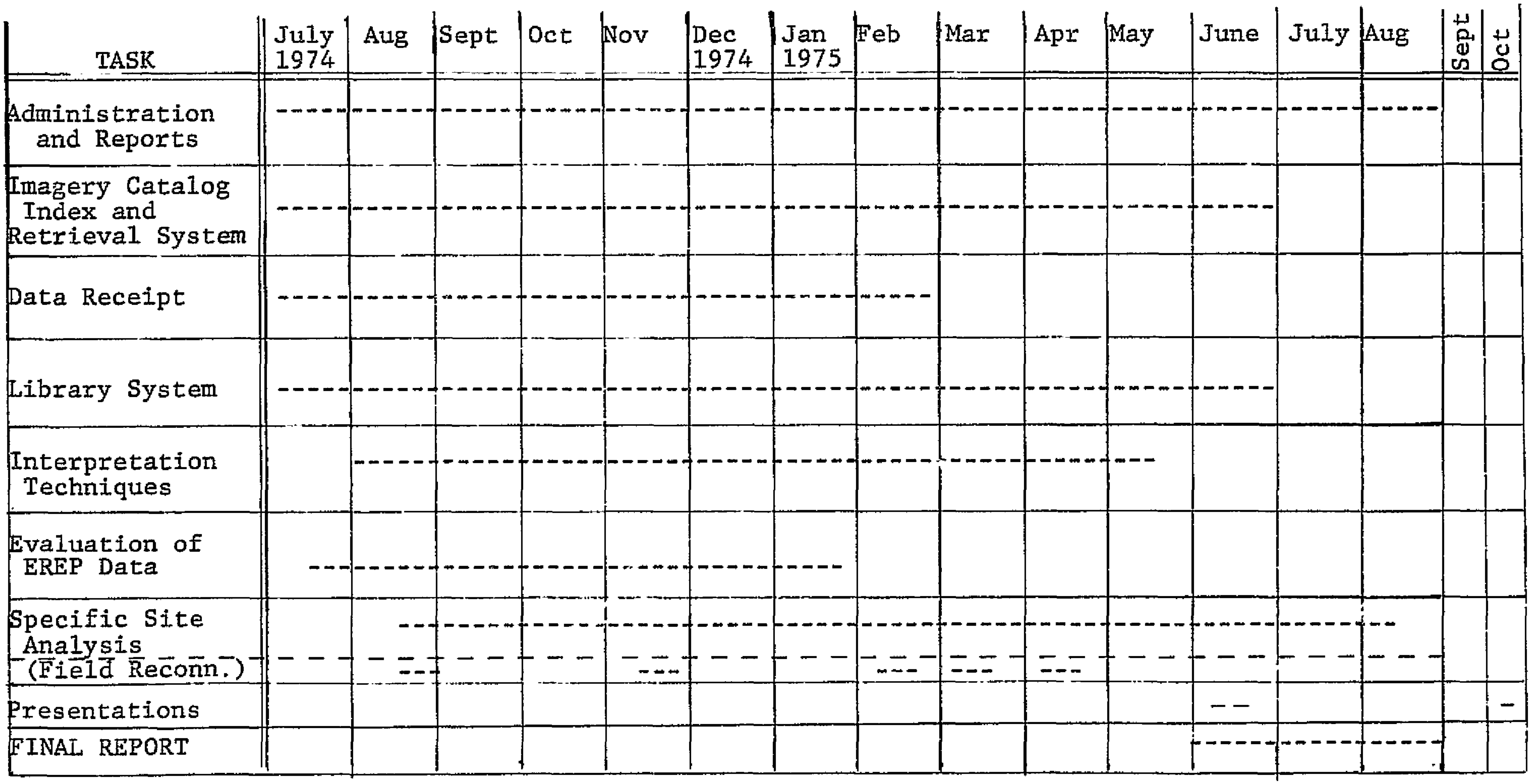
1. The specific site analyses phase will be extended.

2. The final report of investigation will be submitted August 31, instead of June 30, 1975.

BESTEC Contract No. NAS9-14235 8/19/75

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

REVISED MILESTONE CHART



3. Financial and progress monthly reports for June and July will be prepared and submitted.

These changes are incorporated in the Revised Milestone Chart.

IV. Work Planned for Next Reporting Period:

1. Continued analysis of selected test sites that display linear patterns or anomalous signatures in imagery suspected to be related to mineral or geothermal resources. Test sites that will be examined include Halloran Hills, Argus Range, Mono Craters, and others.

2. Preparation of the final report of investigation will be initiated. We anticipate final report will be completed on schedule, August 31, 1975.

V. Personnel:

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Project Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)
Robert Archer, Research Assistant (part-time)
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Pat L. Wineland, Secretary

VI. Acknowledgements:

1. The opportunities to attend the NASA Earth Resources Survey Symposium as well as the AGU meeting in Washington, D.C., and the recognition given by the presentation of papers is gratefully acknowledged by the staff.

2. The contributions of C. Gregory Wagner and John T. Reynolds as co-authors of papers presented during this period are acknowledged and their capable presentation of the data is recognized.

3. Very special ingenuity was displayed by John T. Reynolds Robert Archer in recognizing the significance and meaning of the color and topography anomalies in the imagery of the Goldfield, Nevada area.

4. During this period there was an unusual amount of editing and typing of papers and reports. The able assistance

of Martha Wadsworth is appreciated.

Ira C. Bechtold, President
EREP PI 541

SPACE IMAGERY, GEOMORPHOLOGY, AND SEISMICITY STUDIES INDICATE ANCESTRAL TRACE OF THE SAN ANDREAS FAULT

By:
Ira C. Bechtold, C. Gregory Wagner, John T. Reynolds

Study of satellite imagery over southern California, Arizona, and northern Mexico indicates alignment of mountain ranges, drainage basins and intrusive igneous rock terrane associated with strong lineaments on a regional scale. The synoptic views of the earth afforded by Skylab and ERTS satellite images as well as previous space missions allow visualization of probable large-scale geomorphic changes. Abrupt bends in the Colorado River flowing southeast and the Gila River flowing northwest near their confluence appears in the images to be controlled by major lineaments. The San Andreas fault zone appears as a straight, deep linear feature in the San Bernardino Mountains, and fractures now sealed by volcanics in the Chocolate Mountains to the southeast align with and continue this trend. The altered river channels and the southeasterly trending Gila and Mohawk Mountains appear to coincide with the same trend extrapolated into Mexico. Furthermore, the Cerro Pinacate volcanic field of late Pleistocene activity lies on the lineament trace on the eastern edge of the Gulf of California. Evidence of seismic activity in the area between the Cerro Pinacate region and the Gila River supports the belief that this lineament represents a major, and previously unrecognized fault zone which may represent the ancestral trace of the fracture zone from which developed the southern San Andreas fault system.

UTILIZATION OF SKYLAB S192 SATELLITE IMAGERY

FOR GEOLOGICAL INVESTIGATIONS

By:
Ira C. Bechtold, C. Gregory Wagner, John T. Reynolds

Examination of two different scenes from the thirteen-channel multispectral scanner (MSS) emphasizes the significance of S192 imagery to geological investigations. A correlation between thermal reflectances and moisture conditions is established for alluvium and bedrock in the Death Valley region from studies of a color-coded thermal infrared image (10.20-12.50μm) obtained during daylight hours. Pools or near-surface occurrences of water are detected as relative cold spots. Drainage patterns, faults, and fracture systems are delineated on the image by contrasting color patterns. Anomalous spectral response of the Ubehebe Craters area indicates high reflectances possibly accompanied by emissivity attributable to high heat flow. Different rock types have been discriminated and mapped in northwestern Arizona from analyses of false-color composites of S192 imagery. Coloration anomalies noted in the imagery correlate with ground observed vegetation and soil composition changes, and with areas of hydrothermal alteration. Light colored patterns observed in Lake Mojave from images in the 0.41-0.56μm. region may represent sediments on the bottom of the lake or recent sediment plumes. S192 imagery is especially useful when used in conjunction with LANDSAT MSS and high resolution Skylab photography. The thirteen channels permit a larger number of false-color combinations to be analyzed than is possible with LANDSAT imagery, offering a corresponding increase in potential applications of the data.

AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235
Task/Site No. 222198

Prepared by:

Ira C. Bechtold
Principal Investigator
ID 541

MONTHLY PROGRESS REPORT
1 July 1975 through 31 July 1975

Submitted by:

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16. Abstract
Analysis of the same S190B scene by a geologist experienced in imagery interpretation and an untrained secretary yielded results strikingly similar. Major differences in interpretation are attributable to the geologist's prior knowledge of the area covered in the image. Imagery analysis of the eastern Halloran Hills area, California, revealed complex linear patterns assumed to represent fractures or joints that served to localize turquoise deposits.

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES

APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. Summary of Work Performed:

Activity during the July reporting period was focused on the completion of imagery analyses and reports of investigations. Accordingly, studies of many sites within our test area were finalized in preparation for inclusion in the final report.

A brief study was undertaken to compare two workers' interpretations of the same S190B frame. One worker, a geologist experienced in image interpretation, was familiar with the geology of the area covered in the scene and had previously analyzed ERTS, Apollo, and U-2 imagery of the area. The other worker was a secretary, totally untrained in space imagery interpretation. Results were surprisingly similar. Major lineaments, arcuate structures, and anomalous color zones were identified on both interpretations; the geologist tended to extend linears farther, and the secretary delineated more color anomalies in alluvium-covered areas. The most appreciable difference in the interpretations was that the geologist identified many more subtle, short, linears than did the secretary. This difference is attributable to the geologist's training and to his examination of other imagery previous to analysis of the Skylab frame. Comparison of both workers' interpretations with geologic maps indicated that most imagery-derived linears, arcuates, and color zones are associated with geologic phenomena, such as dikes, fractures, faults, rock unit contacts, intrusive bodies, and volcanic centers. The area of the study included the Black and Cerbat Mountains of northwestern Arizona.

Preparation of outlines and drafts of the final report of investigation has been initiated. The report will include general discussions on Skylab and correlative imagery (ERTS, Apollo, U-2, etc.), methods of imagery analysis, and utilization of the imagery for resources exploration. Detailed reports on at least fifteen sites for which information significant to resource exploration has been extracted from Skylab imagery will be included in the final report.

II. Geologic Investigations:

Imagery study of the Halloran Hills region, 20 km northeast of Baker, California, revealed an abundance of complex linear and arcuate patterns that appear to be related to known copper mineralization. A small area northwest of Yucca Grove in the eastern Halloran Hills was observed in Skylab imagery to be highly dissected by two sets of linears, one striking N50-60W, the other striking generally northeast. The most prominent lineament found in this area is only about 2 km in length, but many mines and prospects lie approximately on it; of those that do not, most lie on linears cross-cutting the major lineament. The linears most probably represent fractures or joints in the granitic rock that provided conduits for hydrothermal fluids. Primary goal of the mining activity was turquoise, found in "veinlets, smears, and dissemination zones in granitic rock" (Wright et. al., 1953, p. 149). Therefore, the linears may represent structural control of turquoise deposits. More detailed investigations should be carried out to locate copper resources in the area and concentrations of turquoise in veins and fractures as indicated by imagery linears.

Reference Cited:

Wright, L. A.; Steward, R.M.; Gay, T.E., Jr.; Hazenbush, G.C.; 1953, Mines and Mineral Deposits of San Bernardino County, California: in California Journal of Mines and Geology, v. 49, Nos. 1 and 2, p. 49-192.

V. Personnel:

The following scientific and support personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator
C. Gregory Wagner, Project Geologist
John T. Reynolds, Assistant Geologist
Steven T. Cerri, Junior Geologist (part-time)
Robert Archer, Research Assistant (part-time)
Martha N. Wadsworth, Secretary
Paul C. Linam, Accountant
Pat L. Wineland, Secretary

VI. Acknowledgements:

1. Again in July staff personnel have shown unusual skill in deriving mineral deposit information directly from lineaments, which correlates very well with the field experience of the principal investigator and also with information in the literature. Interpretors in the laboratory had not been in the field in these particular localities.

2. Special recognition is given to Martha Wadsworth for her ingenuity and talent in accomplishing image interpretation of a high order of expertise without previous training.

3. Although her name will not appear on the personnel list until August we wish to acknowledge with sincere

gratitude the skillful and dedicated work of Elsie M. Creighton as secretary and editor of several monthly reports as well as work done on the final report.

4. Miss Pat G. Wineland has contributed much special skill to assisting with the indexing, filing, and study of imagery and other data. Her contributions to preparation of reports is gratefully acknowledged.

5. Steven T. Cerri and Robert Archer have very quickly acquired expert skill in processing, displaying and interpreting imagery with special emphasis on the correlation of image-derived geology with maps and field work in the Halloran Mountain area.

Ira C. Bechtold, President
EREP PI 541

IX. A P P E N D I X B

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In the course of this project and the preparation of its reports, many individuals and organizations have been notably generous in their contributions to the general progress of the work and the excellence of performance which has been evident throughout the term of the contract.

It is not possible to recognize each and every person, but an attempt will be made to mention those whose efforts and assistance were noted in the record. If anyone deserving credit is omitted, such omission is assuredly inadvertent.

BESTEC

The staff of BESTEC has performed admirably in accomplishing the basic concepts, their administration, implementation, and application to the problems at hand. Many original and ingenious techniques have resulted from their efforts. The pragmatic culmination of these efforts, in terms of one of the principal objectives of the proposal and Statement of Work of the contract, has been the identification of potential natural resource sites including mineral (20), petroleum (1), geothermal (8), and water (3). Three geologically hazardous areas and relationships to tectonic phenomena have also been identified.

In particular, the following individuals are recognized:

Capt. Walter M. Schirra, Director of BESTEC, whose assistance in management, guidance as to concepts and techniques, and general support and encouragement has been outstandingly valuable and helpful.

Mrs. Gladys E. Bechtold, Secretary-Treasurer of BESTEC, who has assisted with the details of the performance of the work and has provided very helpful assistance in managing the literature and data contributions made to BESTEC from the personal collections of Ira Bechtold, P.I.

Mr. C. Gregory Wagner, first employee of BESTEC and co-author of this report. His knowledge and skill in many disciplines, especially geology and geophysics, have been the source of much original work. His thoroughness in image interpretation, mapping, and correlation of geophysical data have been responsible for very significant savings in time and expense in field work. His expertise in the field was a great asset to the project. His resignation was accepted November, 1975.

Mr. John T. Reynolds whose knowledge of geology and persistence in image interpretation and field work has been outstanding. His contributions as co-author have been numerous and significant in accomplishing the objectives set forth in this report. The foregoing merited promotion to project geologist.

Mrs. Martha N. Wadsworth, as secretary and technical assistant to the geologists has given notable service and devotion to the work of the laboratory. Without previous experience with space imagery, she has become adept at analysis, correlation, indexing, and filing of all Skylab data. She also edited and typed a major portion of this report.

Mr. Steven T. Cerri, part-time employee of BESTEC and student at the University of Southern California, contributed to the study of imagery, correlation of related data, mapping, and field work within the test site.

Mr. Robert L. Archer has been a part-time employee while studying geology at California Polytechnic Institute at Pomona. The rapidity with which he achieved expertise in imagery interpretation and other data application is a notable example of successful application of Skylab and other data. He was particularly instrumental in applying data to the Gold Butte area. He also accomplished much of the drafting involved in this report.

Miss Pat L. Wineland, secretary and assistant to the staff, was most faithful and effective in accomplishing the objectives of the project, even though she was employed during only a portion of the work.

Mr. Paul C. Linam, accountant, has faithfully, expertly, and accurately kept the financial records, submitted monthly statements on schedule, consulted with the auditors, and assisted with cost estimates of the proposal. His contributions which, in effect, included those of a comptroller have been far more extensive than necessary by usual standards.

Mrs. L. Elsie Creighton, secretary, commenced work at the start of preparation of the final report and contributed expert knowledge and remarkable insight into the subject matter as she edited and typed parts of this report.

Mr. Robert Mellon, consulting CPA, who expertly monitored our compliance with the contract, audited the records, and cooperated admirably with the NASA-DOD auditors.

Mr. George Baffa, attorney with the firm of Hahn and Hahn, whose expert knowledge of this type of contract and able advice assisted the PI in readily complying with the terms of the proposal and the contract.

Ira C. Bechtold's Personal Office and Library

Mrs. Jean Lambert, secretary of long standing, was most gracious and helpful in applying her knowledge of the records, data, maps, references and other source material to assist the BESTEC staff.

MacGalliard Colorprints

Mr. Walter MacGalliard, a long time associate of the PI, accomplished remarkable results in color printing from NASA transparencies and assisted the staff in very useful fashion, beyond his obligations, in successfully utilizing the photography provided by NASA.

NASA

Throughout the entire history of this project, NASA personnel in Headquarters, JSC, Edwards NFRC, and GSFC were extremely helpful, gracious, and personally dedicated to the objectives of NASA and BESTEC from the concept of the proposal to the conclusion of the work. Recognition of their part in the success of this project is sincere and includes BESTEC's thanks and appreciation.

Department of Defense

BESTEC kindly acknowledges the efficient and expert assistance of the personnel at the Pasadena office, and their contributions to compliance with the terms of the contract.

USGS

The continued assistance of many persons at the U. S. Geological Survey at Reston, Los Angeles, and Menlo Park is sincerely appreciated. We are especially indebted to the personnel at EROS Data Center for their excellent service and help in imagery acquisition procedures and problems.

National Science Foundation

To all at NSF, BESTEC extends its thanks for suggestions and constructive criticism for this project and for advice in matters related to our geothermal studies.

Other Organizations and Individuals

Professor A. K. Baird of Pomona College has served as critic and advisor and has been very helpful in acquiring data and reference material from his excellent laboratory and library. An interesting and unusual contribution was his suggestion that one of his students, Miss Cindy Rebeck, be permitted to conduct a study at BESTEC using NASA imagery and data with the objective of preparing a report as part of her coursework. This was successful and we acknowledge her interest and efforts along with those of Doctor Baird. As a long time associate and colleague, he has also been instrumental in establishing the logic of our program and the selection of the test site.

To the following individuals, we extend our appreciation for their interest and important contributions:

Professor Rex Peterson, University of Nebraska, for methods of analyzing and enhancing imagery and providing cooperative joint analysis of ERTS images.

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Dr. Floyd Sabins, Chevron Research, for assistance in initiating operation of our I^2S viewer and providing methods for enhancement of 70mm film.

Dr. Donald S. Ross, consultant, for advice and cooperation in analyzing Skylab S192 data and ERTS 70mm MSS film.

Professor Jim Combs, University of Texas, an old time colleague and helpful associate, for his suggestions in the field of geothermal studies.

Dr. Monem Abdel-Gawad, formerly of North American Rockwell Science Center, for his able criticism and suggestions in the formulation of our program.

Mr. Cliff Gray, California Division of Mines and Geology, and his assistant Wilma Ashby, for providing access to the reference material, records, and maps of their office.

Dr. S. Parker Gay, Applied Geophysics, Inc., Salt Lake City, Utah, who was very helpful in understanding and applying the principles of "the new basement tectonics," fundamental concepts in the analysis of space imagery. This unique approach applied to the geological studies of this report has been responsible for the location of many new lineaments, arcuate structures and other geologic features.