OF 53

GEOLOGIC ANALYSIS OF ERTS-1 IMAGERY
FOR THE STATE OF NEW MEXICO

Sandra Feldman[1], Michael Inglis[1], Karl Vonder Linden[2], Charles E. Chapin[2], Rodney C. Rhodes[3], and Frank E. Kottlowski[2]

1 Technology Application Center
The University of New Mexico
Albuquerque, New Mexico 87131

2 New Mexico Bureau of Mines and Mineral Resources; Socorro, New Mexico 87801

3 Geology Department
University of New Mexico
Albuquerque, New Mexico 87131

August 1974
Type III Final Report for the Period August 1972 - March 1974

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

Contract NAS5-21861

GEOLOGIC ANALYSIS OF ERTS-1 IMAGERY FOR THE STATE OF NEW MEXICO

Sandra Feldman[1], Michael Inglis[1], Karl Vonder Linden[2], Charles E. Chapin[2], Rodney C. Rhodes[3], and Frank E. Kottlowski[2]

1 Technology Application Center
The University of New Mexico
Albuquerque, New Mexico 87131

2 New Mexico Bureau of Mines and Mineral Resources; Socorro, New Mexico 87801

3 Geology Department
University of New Mexico
Albuquerque, New Mexico 87131

August 1974
Type III Final Report for the Period August 1972 - March 1974

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

Contract NAS5-21861

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Geologic Analysis of ERTS-1 Imagery for the State of New Mexico		5. Report Date August 1974 6. Performing Organization Code
7. Author(s) S. Feldman, M. Inglis, K. Vonder Linden, and F. E. Kottlowski		8. Performing Organization Report No.
9. Performing Organization Name and Address New Mexico State Bureau of Mines and Mineral Resources; Socorro, New Mexico 87801		10. Work Unit No. 11. Contract or Grant No. NAS5-21861
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type III Final Report August 1972-March 1974 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The purpose of this study was 1) to study ERTS-1 images with emphasis on identifying and subsequently investigating, previously unrecognized geologic phenomena in New Mexico; and 2) to evaluate ERTS imagery as a geologic tool.

Incoming ERTS-1 imagery of the state was studied and evaluated, and a mosaic of New Mexico was prepared using the best quality imagery received. Images of the Rio Grande rift and adjacent areas were analyzed for lineaments and circular features and then compared with existing geologic data. The information was then plotted on the New Mexico mosaic. Much of the information obtained remains to be field checked and correlated specifically with existing mineralized areas.

It was concluded that ERTS-1 imagery alone cannot locate new areas of mineralization; but when combined with the study of low-altitude photographs, geological reports, and careful field checking, may lead to the discovery of new mineral deposits.

17. Key Words (Selected by Author(s))		18. Distribution Statement	
ERTS-1 analysis; lineaments, remote sensing; geologic structure; New Mexico, Rio Grande rift; circular anomalies			
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
NONE	NONE	103	

PREFACE

The purpose of this study was to examine ERTS-1 images in order to identify and subsequently investigate previously unrecognized geologic phenomena in New Mexico and to evaluate the usefulness of ERTS-1 imagery as a geologic tool. Emphasis was placed on structural features in the Rio Grande rift and adjacent areas. Lineaments and circular features in the rift were plotted on the ERTS mosaic of the state which was prepared in conjunction with this investigation, and these were compared with existing data. It was concluded that ERTS-1 imagery is a valuable geologic tool and, when used in conjunction with existing data, low-altitude photographs, and field checking, may lead to the discovery of new mineral deposits.

Work was begun on this project by Dr. Karl Vonder Linden who had played the major role in the ERTS investigation. In September of 1973, he resigned from the New Mexico Bureau of Mines and Mineral Resources. At that time, Sandra Feldman and Michael Inglis at the Technology Application Center (TAC), University of New Mexico, Albuquerque, New Mexico became the principal active investigators on the ERTS contract. TAC had followed the progress of Dr. Vonder Linden, and rapid transition was made.

TABLE OF CONTENTS

Table of Contents Continued.

LIST OF ILLUSTRATIONS

List of Illustrations Continued.

LIST OF TABLES

I. INTRODUCTION

A. Study Objectives

The objectives of this investigation were twofold and as follows:

1. To study ERTS-1 images with emphasis on discovering, and subsequently investigating, previously unrecognized geologic phenomena in the state of New Mexico.
2. To evaluate ERTS-1 imagery as a geologic tool by comparing images with air photos, other satellite photos, geologic maps, and topographic maps of presently recognized features.

We proposed to examine imagery of the entire state of New Mexico to discover additional geologic information, but with emphasis placed on areas which have undergone tectonic deformation and areas which are known to contain mineralization. The short-term objective was to identify previously unrecognized features with long-term emphasis on mapping and interpreting such features by comparison of ERTS-1 imagery with existing maps and photographs of corresponding areas. Both reconnaissance and later detailed field studies were to be carried out in conjunction with the study of imagery.

Results anticipated prior to the actual study were:

1. More geologic information on the state of New Mexico.
   a. A better understanding of the major structural features of the state and of the tectonic forces responsible.
   b. A clearer definition of the major landforms and geomorphic processes.

c. More accurate locations of the boundaries of major drainage features and the identification of past and possible future drainage changes.

d. Identification of areas which warrant future mineral exploration.

2. An evaluation of the usefulness of telemetered satellite imagery as a geologic tool in arid to semi-arid regions.

This report contains a discussion of 1) the general geology of New Mexico, 2) the methodology used in working with the ERTS imagery, 3) general observations in the state identified from ERTS, 4) a more detailed discussion of specified areas, 5) recommendations for future work, and 6) appendices containing support data. A location map of New Mexico for reference throughout this report can be found in Appendix A.

B. Geomorphology and General Geology

The state of New Mexico comprises four geomorphic provinces (Figure 1)—the Colorado Plateau (northwest), the Basin and Range (southwest and south-central), the Southern Rocky Mountains (north-central), and the Great Plains (east). Each of these provinces is distinct geologically and topographically although boundaries between them are transitional.

The Colorado Plateau province covers approximately one quarter of the state and is pervasive over northwestern and north-central New Mexico. The province has been divided into a northern Navajo section and a southern Datil section. The San Juan Basin of the Navajo section is a structural depression with a Tertiary fill resting upon Cretaceous sedimentary rocks which outcrop along the margins. It is the largest basin in the province, covering 10,600 square miles (Thornbury, 1967). The Datil section is mostly volcanic in origin and has much greater relief than the Navajo section. Cenozoic igneous rocks, primarily volcanic in origin, are widespread along the margin of most of the Colorado Plateau province. Age relationships and pattern of eruption and mineralization have been discussed by Elston, et al. (1973).

The Zuni Mountains at the northwest edge of the Datil section is one of the eight major uplifts of the Colorado Plateau province with structural relief of over 5,000 feet (Kelley and Clinton, 1960). In contrast to most of the other uplifts in the province, Precambrian igneous and metamorphic rocks outcrop at the core.

The Basin and Range province in New Mexico has been divided into the Mexican Highland and the Sacramento sections.

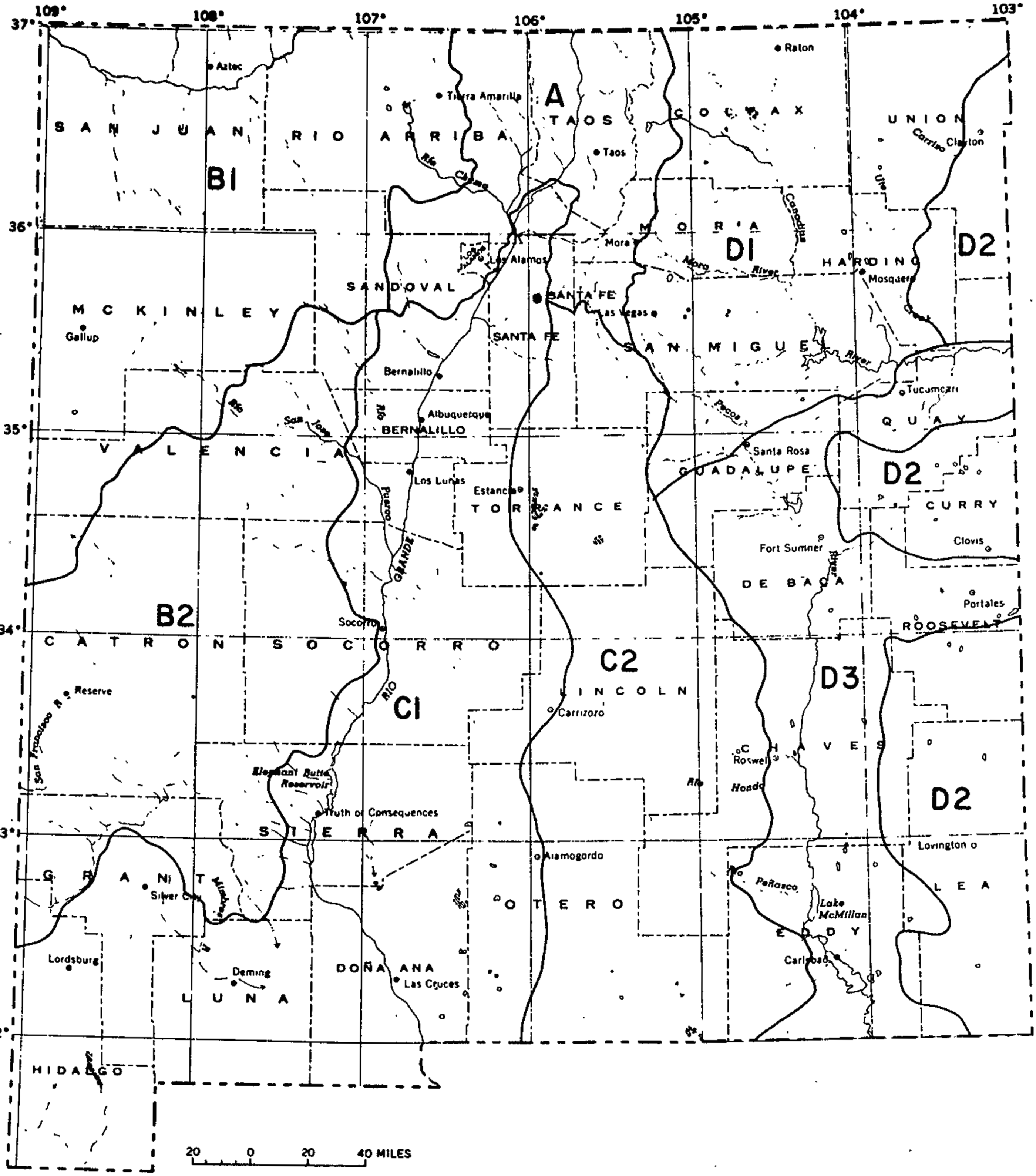


FIGURE 1: Physical divisions of New Mexico (after Fenneman, 1962).

- A. Southern Rocky Mountains
- B1. Colorado Plateaus, Navajo section
- B2. Colorado Plateaus, Datil section
- C1. Basin and Range province, Mexican Highland section
- C2. Basin and Range province, Sacramento section
- D1. Great Plains province, Raton section
- D2. Great Plains province, High Plains section
- D3. Great Plains province, Pecos Valley section

Characteristic of the province are parallel block-faulted mountains separated by intermontane basins. The boundary between the Colorado Plateau and the Basin and Range province is structurally indistinct with some Basin and Range faulting extending into the Colorado Plateau.

The Mexican Highland section comprises about an equal proportion of mountain ranges and high aggraded valleys with external drainage, rather than the closed basins so typical further west. The section, as defined by Fenneman (1962), begins in northern New Mexico and extends south to include the Rio Grande trough and smaller north-south-aligned ranges such as the Sandia, Manzano, Los Pinos, San Andres, Organ, and Franklin Mountains. These ranges are structurally and geomorphically related to the classically defined Southern Rocky Mountain province, although they are generally considered to be in the Basin and Range province. In southwestern New Mexico, Basin and Range faulting and range alignment are oriented northwest-southeast in contrast to the near north-south alignment in the Rio Grande depression. In the Sacramento section, the distinction between basins and ranges is not as pronounced and one grades into the other along gentle slopes. Block plateaus and bolsons are common.

Only a small extension of the Southern Rocky Mountain province occurs in New Mexico. It includes the Sangre de Cristo, Jemez, and Nacimiento Mountains and terminates at their southern end. The ranges are generally aligned north-south, roughly of anticlinal structure, with igneous and metamorphic cores. Contemporaneous folding and faulting resulted from the Laramide orogeny although some was no doubt

doubt inherited from previously developed zones of weakness.

The Great Plains province extends through the United States in a north-south belt and is adjacent to the Rocky Mountain province throughout much of its extent. In central and southern New Mexico it borders on the Basin and Range province. The province is composed primarily of terrestrial sediments and once formed a continual alluvial blanket derived from the erosion of the Rocky Mountain ranges. The Ogallala Formation, capping the Llano Estacado in eastern New Mexico and western Texas, presently covers 20,000 square miles but was previously much more extensive. Foster, et al. (1972), refers to outcrops which have been found west of the Pecos River.

The Great Plains province in New Mexico includes the High Plains, the Pecos Valley, and the Raton sections. The High Plains section has the lowest relief of any section in the state. At the top of the Ogallala Formation, the indurated caprock provides resistance to erosion and hence an escarpment between it and the Pecos Valley section on the west. The Pliocene Ogallala Formation once covered the Pecos Valley. As a result of stream piracy by the Pecos River and headward erosion, only remnants of the Ogallala remain (Reeves, 1972). The easily erodible Permian formations below the Ogallala did not provide much resistance. Permian and Triassic formations and Quaternary alluvium now outcrop throughout most of this section.

The northern Raton section consists of lava-capped plateaus and mesas, dissected remnants of an extensive peneplain. This section differs from the other Great Plains sections in New Mexico by the extensive Tertiary flows and the resultant high relief.

Generalized geologic and tectonic maps of the state are presented in Appendix A of this report.

C. Mineral Deposits

Structurally controlled metallic mineral deposits, in general, occur in a northeast-southwest-trending belt in New Mexico which has been recognized for many years. The belt follows the Rio Grande Valley through most of the state and then deviates to the extreme southwest. It follows the eastern and southern border of the Colorado Plateau province. The relationship between many of the individual deposits, however, has been conjectural. The trend was recognized as early as 1910 by Lindgren, et al., in "The Ore Deposits of New Mexico" and can be traced on more recent maps of metallic deposits in "Mineral and Water Resources of New Mexico" (U.S.G.S., 1965). Other compiled accounts of individual mineral occurrences in New Mexico include those by Anderson (1957) and Howard (1967).

Mineral deposits in New Mexico have been overlaid on the ERTS mosaic of the state. The map is included in Appendix A. Although uranium and potash production is of great economic importance to the state in dollar value, deposits are largely sedimentary with only very limited structural control involved in localizing occurrences. Structurally related economic deposits include copper, lead, zinc, gold, silver, iron, manganese, and molybdenum, with the most economically significant deposits located in the Silver City Central mining district and in the Sangre de Cristo Mountains. The pattern of mining districts in New Mexico follows the Rio Grande graben throughout much of the state.

According to Schmitt (1966) many western ore deposits and intrusives "are associated with, and presumably genetically related to, the major fault zones, orogens, and tectogenes. Intersections are particularly sensitive, as noted by Billingsley and Locke long ago. Triple or more complex intersections are especially potent as localizers for ore districts and smaller mineralized units." Mineralizing fluids are likely to rise at multiple intersections where the crust is most weakened. Circular or curvilinear features, such as volcanic-tectonic depressions, the surface expression of buried intrusives, and offset produced by intersecting fault systems may also serve as indications of associated mineral deposits. Therefore, information leading to the location of new potential mineral areas may be derived from ERTS images by studying lineations and circular features which have not been previously recognized, in and adjacent to the Rio Grande depression.

D. The Rio Grande Depression

The Rio Grande depression, extending from the San Luis Valley in Colorado through New Mexico, is a series of en echelon open basins separated by constrictions of varying widths. Bryan (1938) designated these basins, from north to south, as the San Luis, Espanola, Santo Domingo, Albuquerque-Belen, Socorro, Engle, Rincon or Palomas, and Mesilla basins. Chapin (1971) has recommended the inclusion of several other basins into the rift system by similarity of structure and synchroneity of deformation (Figure 2). In New Mexico, these include a) the Jornada del Muerto and Tularosa basins, separated from the Rio Grande Valley by intrarift horsts; b) the San Agustin Basin, a northeast-southwest-trending graben, bifurcating from the main trough in the vicinity of the Magdalena Mountains; and c) the Estancia and Moreno subsidiary basins of central and north-central New Mexico. Mineral deposits occur in adjacent ranges or horsts, following the trend of the rift system.

Relief is higher along the eastern border of the rift where high ranges are more common than along the western border where relatively low-lying volcanics occur. Chapin (1971) states that minimum uplift was 5,000 to 12,000 feet along the eastern margin with a minimum subsidence of 4,000 to 24,000 feet. A thick sequence of late Tertiary to Quaternary Santa Fe Group sediments and volcanics now fill the trough, masking the original fault scarps, and making it difficult to locate their exact position throughout much of the rift system.

Bounding or external faults, marking the division between horst and graben features, generally have close to a

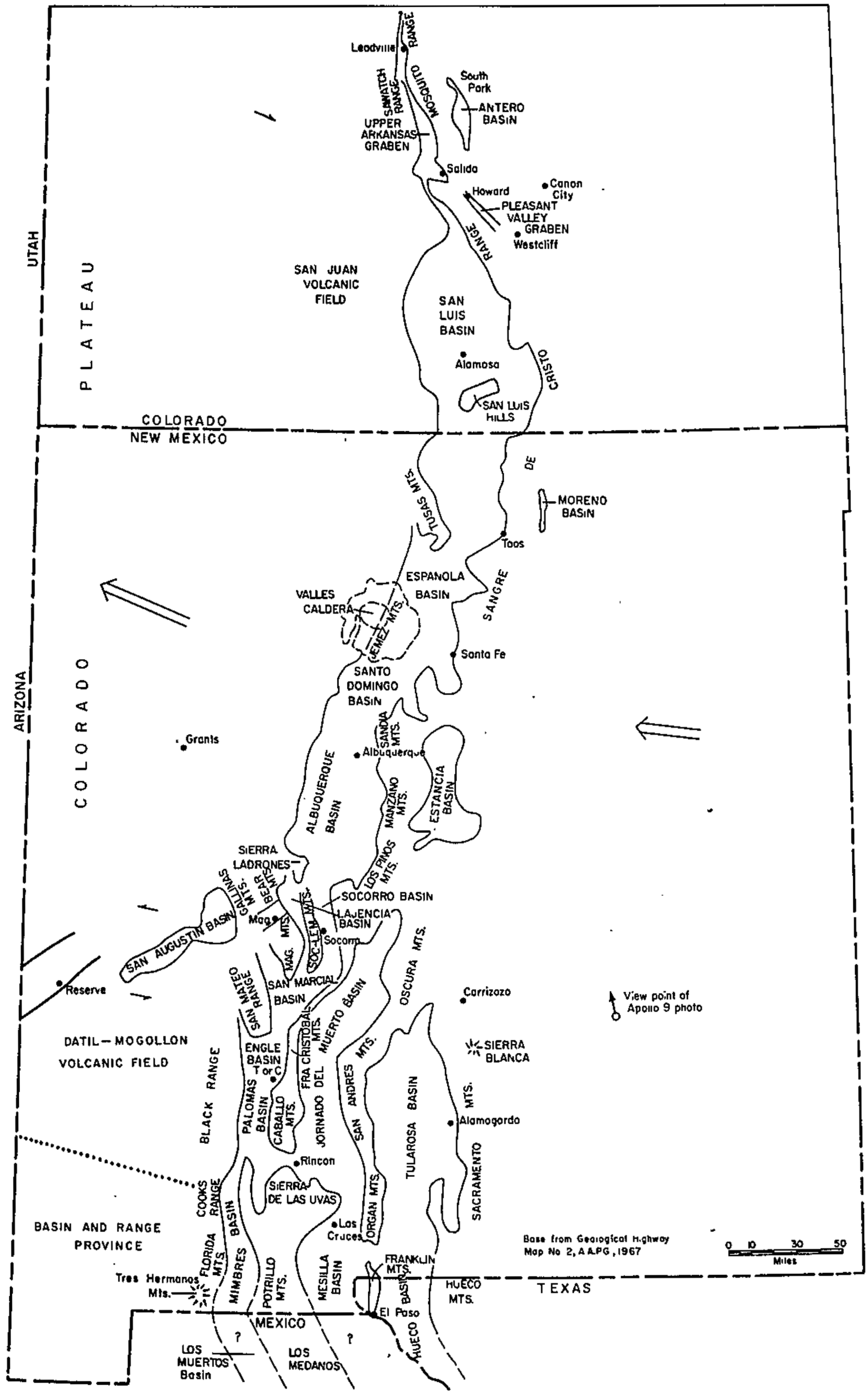


FIGURE 2: Generalized map of the Rio Grande rift (from Chapin, 1972).

north-south trend (Figure 3). Normal faults comprise most of the boundary faulting with a few notable exceptions, one being the Comanche thrust bordering the Lucero uplift, west of Belen (Kelley, 1954). Most northerly trending faults, penecontemporaneous with the rift system are Late Tertiary in age.

Internal range structure consists of folds and both normal and thrust faults. The folding and thrusting has been associated with Cretaceous and early Tertiary Laramide compression (Thornbury, 1967). In the upper Rio Grande area in New Mexico, internal compressional structures are aligned near north-south; the Nacimiento fault, the Seis Canyon fault, and the Mesa Redonda Anticline. The Comanche fault, although sinuous, is north trending. Other thrusts and folds trend northeast-southwest as, for example, the Montosa and Paloma faults in the Los Pinos and Manzano Mountains, the Chupadera Mesa folds, the Tijeras and Golden structures (Kelley, 1954). On Kelley's map (1961), Precambrian foliation also trends northeast-southwest in the Manzano and Manzanita Mountains.

Internal normal fault zones in the upper Rio Grande area generally trend northeast or north. North-aligned faults may have a slight westerly component, but there are few prominent northwest trends on Kelley's maps (1954, 1961). East-west fault trends or alignments occur locally northeast of the Sandia Mountains. The Capitan Mountains, in central New Mexico just east of the rift system, are defined by Chapin (1971) as an anomolous east-west trend. Some of the internal normal faulting in the ranges is synchronous with the external faulting; the age of others is open to speculation.

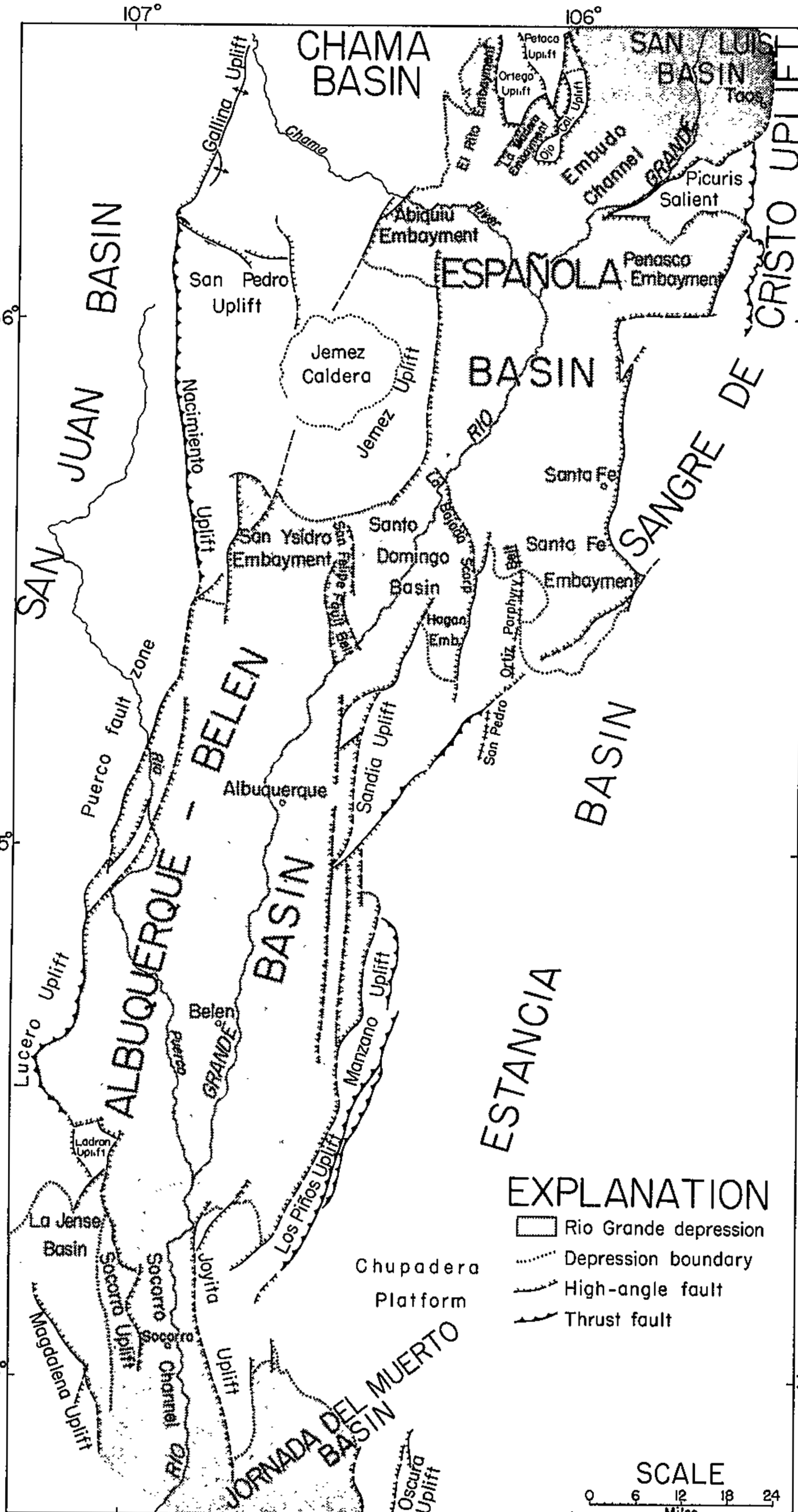


FIGURE 3: Tectonic map of the middle Rio Grande depression (after Kelley, 1954).

Sections of the rift system are still seismically active (Sanford, 1965; Sanford and Cash, 1969; Toppozada and Sanford, 1972; and Sanford, et al., 1972. The record of historic earthquakes reported in the Rio Grande Valley indicates that a quake of magnitude 5 has the probability of occurring each 100 years. Tables in Appendix B list those earthquakes with magnitudes greater than 2.7. Known earthquake epicenters are also plotted along with mineralized areas (Appendix A). As indicated by Sanford, et al. (1972), little correlation appears to exist between recent instrument-recorded micro-seismic zones and known structural features although the majority of earthquakes recorded in New Mexico have epi-centers in the Rio Grande rift (Appendix B).

II. METHODOLOGY

Information on both lithology and structure can be determined to some extent from aerial and satellite photography. Because of the genetic relationship between mineral deposits, tectonic features, and/or lithology, much information leading to the discovery of new mineral deposits can be learned from the analysis of ERTS images. Drainage patterns, photographic tone, continuity or discontinuity, and vegetation may be a response to structure and lithology. The intensity or magnitude of displacement, the depth of a structure beneath the surface, and the age of a structure all relate to its topographic expression, and hence its interpretation from aerial or satellite photographs and images.

Structural and lithologic identifiers can both be used to locate areas of possible mineralization on ERTS images. Mineralization can be related to fracture patterns and/or intrusives. Indicators of both should be examined more closely in the field, especially fault intersections and indications of buried intrusives within the previously defined mineral belt.

The flowsheet in Figure 4 was the proposed Data Analysis Plan for the investigation. In the 16 month contractual period it was originally proposed that work would have progressed through Step 4.

According to Step 1 of our Data Analysis Plan, all incoming ERTS images were initiallly inspected by New Mexico Bureau of Mines and Mineral Resources and later by the Technology Application Center to select images warranting further examination. Unfortunately, good quality imagery

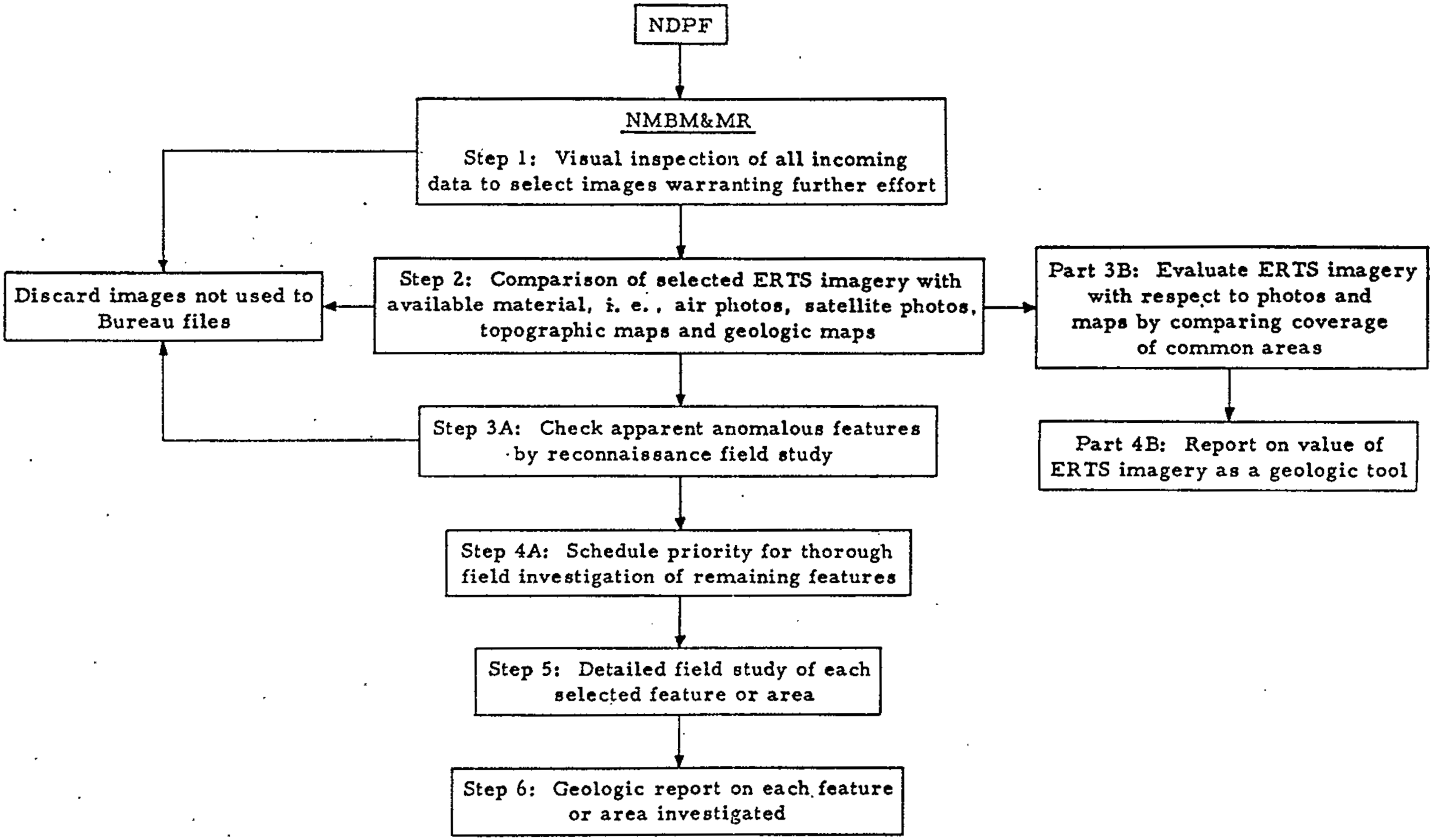


FIGURE 4. Flowsheet illustrating procedure to be followed with each set of images received.

was not received for many months after the initiation of the contract. Toward the end of January 1973 good quality imagery was received; and by mid-March, coverage was extended to two-thirds of the state. Imagery was never received for five separate passes over the state dated between October 28, 1972 and January 13, 1973. The few we have seen from other sources are of good quality.

Figure 5 is a map of New Mexico with ERTS orbits over the state numbered from one to six. Each scene has been given a reference name to facilitate discussion, and these are also shown on the map. Table 1 lists specific orbit numbers (the first four numerals in the scene identification number) and dates.

In Appendix B is a table listing by designated scene name and image ID the best New Mexico scenes which have been received between July 1972 and December 1973. The orbit corresponds to those in Figure 5. We have calculated cloud cover and rated image quality for each. Images or scenes designated "NR" (not received) may have a high percentage of cloud cover, are unavailable or have simply not been received. Specific qualities of scenes which make them more or less conducive for geologic interpretation are noted, such as snow enhancement or scan-line interference. This listing and rating includes only black and white prints received from NDPF User Services dated between July 1972 and December 1973. Also in Appendix B is a table listing by flight the Gemini and Apollo photographic coverage of New Mexico, much of which was used in this investigation.

We would hope that a similar updated and abstracted listing of scenes be made available to individuals interested

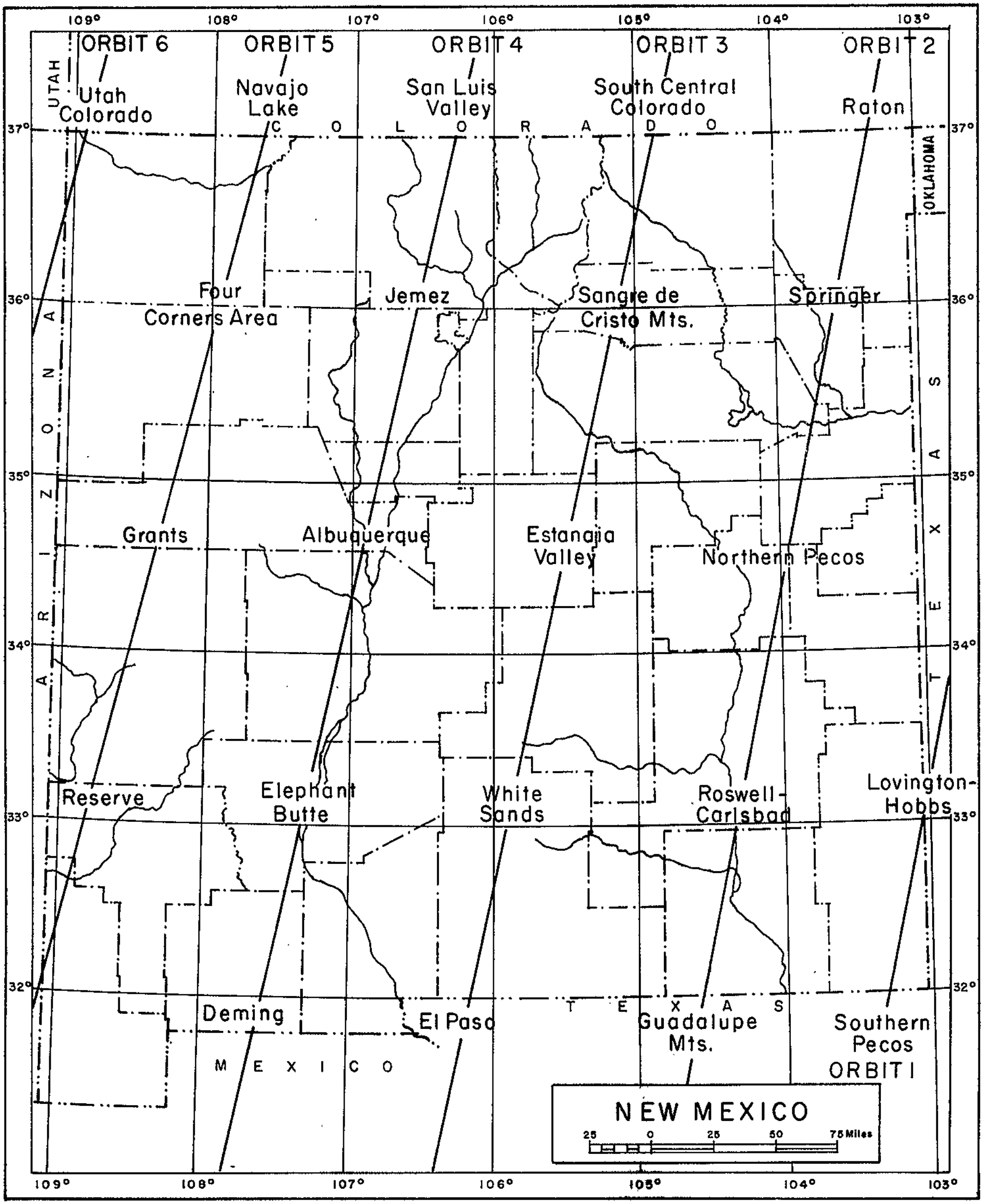


FIGURE 5. New Mexico ERTS orbits and scene names.

TABLE 1

ERTS-1 ORBITS OF NEW MEXICO AND DATES SINCE LAUNCH
July 30, 1972 - December 3, 1973

	ORBIT *					
DATES	6	5	4	3	2	1
July 30-Aug. 4	1012	1011	1010	1009	1008	1007
Aug. 17-Aug. 22	1030	1029	1028	1027	1026	1025
Sept. 4-Sept. 27	1048	1047	1046	1045	1044	1043
Sept. 22-Sept. 27	1066	1065	1064	1063	1062	1061
Oct. 10-Oct. 15	1084	1083	1082	1081	1080	1079
Oct. 28-Nov. 2	1102	1101	1100	1099	1098	1097
Nov. 15-Nov. 20	1120	1119	1118	1117	1116	1115
Dec. 3-Dec. 8	1138	1137	1136	1135	1134	1133
Dec. 21-Dec. 26	1156	1155	1154	1153	1152	1151
Jan. 8-Jan. 13	1174	1173	1172	1171	1170	1169
Jan. 26-Jan. 31	1192	1191	1190	1189	1188	1187
Feb. 13-Feb. 18	1210	1209	1208	1207	1206	1205
Mar. 3-Mar. 8	1228	1227	1226	1225	1224	1223
Mar. 21-Mar. 26	1246	1245	1244	1243	1242	1241
Apr. 8-Apr. 13	1264	1263	1262	1261	1260	1259
Apr. 26-May 1	1282	1281	1280	1279	1278	1277
May 14-May 19	1300	1299	1298	1297	1296	1295
June 1-June 6	1318	1317	1316	1315	1314	1313
June 19-June 24	1336	1335	1334	1333	1332	1331
July 6-July 11	1354	1353	1352	1351	1350	1349
July 24-July 29	1372	1371	1370	1369	1368	1367
Aug. 12-Aug. 17	1390	1389	1388	1387	1386	1385
Aug. 31-Sept. 5	1408	1407	1406	1405	1404	1403
Sept. 17-Sept. 22	1426	1425	1424	1423	1422	1421
Oct. 5-Oct. 10	1444	1443	1442	1441	1440	1439
Oct. 23-Oct. 28	1462	1461	1460	1459	1458	1457
Nov. 10-Nov. 15	1480	1479	1478	1477	1476	1475
Nov. 28-Dec. 3	1498	1497	1496	1495	1494	1493

* The four numeral designators are the first four numbers which are commonly used to identify scenes (ERTS mission + days since launch).

in ERTS imagery of New Mexico through organizations distributing ERTS images to the public. Similar listings for other states would be a useful addition.

A. NASA Data Processing Facility (NDPF) Imagery

According to our standing order with NDPF User Services we were to receive 70mm black and white transparencies and 9 X 9 inch paper prints of scenes with 10% or less cloud cover. A limited number of color composites, both 9 x 9 inch transparencies and prints were also requested, as well as a small number of 9 x 9 inch black and white positive transparencies.

In the early stages of the study, black and white prints were used for analysis and were found to be adequate. As they became available, color composites were used to complement the black and white prints in the distinguishing of lithology and vegetation zones.

As mentioned earlier, cloud and snow patterns obscured many of the mountainous areas in the state in the early imagery; and imagery quality was not as good as mid- to late-1973 imagery. Based on what was received in the early part of the investigation, it appeared that band 5 imagery was the most suitable of the four MSS bands for structural and lithologic interpretation. As the quality of imagery received improved, and mountainous areas became more visible with cloud-free coverage, it was found that band 7 was more suitable for structure in areas of dense vegetation and high relief. In arid basins and in areas of low relief where shrub and grass predominate, band 5 was equally as good as band 7, and even preferable in some cases. Band 6 was also quite satisfactory for lineament analysis, with band 4 being the least satisfactory.

B. Mosaic of the State of New Mexico

In order to get an overview of geologic features in the entire state as seen from ERTS, and to provide a base map for overlays, a photo mosaic was prepared at a scale of 1:1,000,000 using band 5 imagery (Appendix A). Cloud- and snow-free coverage was difficult to obtain in some areas since 1973 was an extremely wet year in New Mexico. The mosaic was prepared in November 1973 and images incorporated were dated no later than August 1973. The images chosen for the mosaic are primarily from the spring and fall of 1972 and the spring of 1973. Although we had originally hoped to use images from a single season, we found that it was not feasible. A late fall mosaic would have been the most satisfactory combining a relatively low sun angle for geologic structure enhancement with snow-free coverage. The 27 individual ERTS images used in the preparation of the mosaic are listed in Table 2. Better quality imagery with a smaller percentage of cloud cover was received subsequently for some areas in the state—especially the Sangre de Cristo and Jemez Mountains in northern New Mexico, and the Black Range in southwestern New Mexico.

The lines along which the images were matched show up on the mosaic as fine wavy tear lines and may not be immediately apparent. Tonal changes will often correspond to tear lines and should not be confused with Earth features. West of the southern Rio Grande, a darker image was used and the match lines here are more obvious. The mosaic provides a total view of the state of New Mexico which was previously not available.

Fracture and lineament trends, as well as circular features in selected areas in the state were plotted on an

TABLE 2

IMAGES USED FOR ERTS MOSAIC OF NEW MEXICO

Orbit 1

1385-16572-5
1061-16575-5
1385-16581-5
1079-16585-5

Orbit 2

1098-17032-5
1098-17034-5
1098-17041-5
1098-17043-5
1062-17042-5

Orbit 3

1333-17090-5
1369-17090-5
1333-17095-5
1333-17102-5
1189-17105-5

Orbit 4

1334-17144-5
1334-17151-5
1334-17153-5
1189-17102-5
1334-17162-5

Orbit 5

1335-17203-5
1335-17205-5
1299-17214-5
1317-17215-5
1317-17222-5

Orbit 6

1066-17254-5
1318-17265-5
1318-17271-5

overlay to the mosaic (Appendix A). Several different methods were used in the process. In some cases, trends were determined directly from the mosaic. Determining and plotting lineament trends on the mosaic made it possible to follow patterns which extended through more than one image, or occurred on the image periphery. However, since the mosaic is comprised of imagery two generations from the NDPF products which we received, there is some quality degradation. Moreover, clouds on the mosaic in the Sangre de Cristo, Jemez, and Nacimiento Mountains mask structural features.

In areas where more detailed analysis was necessary, 9 x 9 band 5 and band 7 prints were examined using a 5x magnifier; and structural features were plotted directly on the prints. These were then transferred onto the mosaic.

C. Image Enhancement

Both photographic and mechanical enhancement methods can be used with ERTS images. Photographic methods can include making use of inherent image characteristics, combining or reprocessing images. Mechanical enhancement generally involves the use of more sophisticated equipment. Several enhancement techniques were used in the study with different degrees of success:

Photo Enhancement	Mechanical Enhancement
1:250,000 Enlargements	I^2S Digicol Viewer
Snow Enhancement	I^2S Addcol Viewer
Stereo	Xerox
	Zoom Transferscope

From the 9 X 9 prints, negatives and then 1:250,000 prints were made of selected areas. This method was found to produce a better quality image than that produced by using the 70mm negatives. Features were identified on the enlargements and then transferred to the 1:1,000,000 mosaic. This was found to be quite satisfactory.

Snow enhancement of structural features was found to be significant in the northern part of New Mexico. Snow cover reduces the gray scale variance or "noise" and thereby aids in lineament detection (Wobber and Martin, 1973). They attribute the lack of snow cover along lineaments or fractures "to accelerated melting rates induced by the higher moisture content of subsurface materials in fracture zones or, the obscuration of snow cover by vegetative overstory." The advantages of snow enhancement in lineament mapping on small-scale imagery has also been noted by Lowman (1967). This technique was used on images of the Sangre de Cristo and Sacramento Mountains using band 7. The use of late fall and early winter imagery takes advantage of low sun angle as an enhancement of geologic structure.

At the initiation of the study it was recognized that modest stereo could be obtained at the periphery of images because of the ten per cent sidelap between images. Toward the end of the study period, however, it was found that good stereo could be obtained over large areas by using the same scene taken on different dates. Six good to excellent quality scenes of the White Sands region fell into two groupings. Each of the groups had different principal points, offset by approximately 16 miles. Using one image from each of the two groups provided stereoscopic coverage.

An I^2S Digicol Viewer (4000 series) and an Addcol Optical Additive Color Viewer (6000 series) were made available to us on a limited basis. Images produced on the Additive Color Viewer were found to be far inferior to false-color composites obtained from NDPF User Services in the winter of 1973-74 and from Spectral Data Corporation and General Electric.

The Digicol Viewer was used to determine if additional information could be obtained on lithology and lineament configurations in the Sacramento Mountain area. In this densely forested area, no lithologic divisions were evident on the four bands or on the color composite. No additional lithologic information was obtained by using the Digicol Viewer, and color changes did not correspond to any identifiable boundary. Many lineament patterns which had already been identified on band 5 and 7 images were also apparent on the Digicol Viewer.

A Xerox copy of one New Mexico image was made on a Xerox 3600-III machine. Upon examination, we found that linear features were enhanced on the Xerox copy. The copy machine reduces the fifteen gray tones on the image to four, thereby increasing the light-dark contrast. This process has been found to be most useful in New Mexico.

After structural features were plotted on the ERTS images, these were then compared to existing geologic and topographic maps and other available imagery. Lineaments or faults which coincided with those previously identified in the literature were indicated in blue. Those with no counterpart on existing maps were indicated in red. Additional lineaments were also added to the overlay at this time to include those which could be identified on ERTS images after having seen them on maps.

Few maps or photos used in the comparative portion of the study were at the same scale as the ERTS images. The Zoom Transferscope has the capability of superimposing maps and images which differ in scale and was found most useful in comparing ERTS images with existing maps and photos.

III. DISCUSSION AND RESULTS OF INVESTIGATIONS

This section includes general observations from ERTS imagery around the state of New Mexico as well as more specific subsections on south-central and southeastern New Mexico. Separate reports included herewith are entitled "Preliminary Investigation of the Mogollon-Datil Volcanic Field, Southwestern New Mexico, from ERTS-1 Imagery" by R. C. Rhodes and "An Evaluation of the Use of ERTS-1 Imagery in the Magdalena Mountains" by S. C. Feldman and C. E. Chapin. All or parts of these areas border the Rio Grande depression. Lineaments and circular features found in the study of images of these regions as well as other adjacent regions are plotted on the mosaic of the state which is included in Appendix A. Plotted features are separated into two categories—those which have been previously identified and those which have been identified from ERTS images. A discussion of circular features is also included in this section.

It was decided to concentrate on study areas within or adjacent to the Rio Grande depression because the Rio Grande Valley and southwestern New Mexico are the areas within the state in which structurally controlled mineral deposits predominate. Copper, zinc, and lead deposits in the Silver City mineralized porphyries (Santa Rita, Hanover-Fierro, and Pinos Altos) are associated with Late Cretaceous to Early Tertiary Laramide activity. Faulting which occurred here during this period is associated with mineralization; many of these faults have been reactivated.

A. General Observations from ERTS

1. Lineaments

Although basically the Rio Grande Valley is a series of basins with en echelon faulting, one alignment appears to go through almost the entire state of New Mexico. It is not plotted as a continuous lineament on the state ERTS mosaic because it cannot be distinguished in all areas. The northern extent of the lineament is the Nacimiento fault. It can then be followed south-southeast lining up with the boundary between the Santa Fe Formation and pediment and terrace sands and gravels on the Geologic Map of the State of New Mexico (Dane and Bachman, 1965). Between La Joya and San Acacia, the southern end of the Albuquerque-Belen Basin, where the Rio Grande River makes almost a 90° bend, the alignment crosses the river. Here it coincides with the Joyita Hills frontal fault. It then lines up with a lineament (tonal change) cutting the alluvial fans which originate in the San Andres Mountains. This alignment, if continuous, would extend for over 250 miles and has not been previously recognized in the literature.

Another notable alignment or lineament which is plotted on the mosaic extends from the Rio Grande Valley in northern New Mexico into the Sangre de Cristo Mountains. It is offset by the Pecos-Picuris Fault and continues northeast through the range. It then lines up with the edge of Raton Mesa and continues into Colorado to follow the near straight course of the Purgatoire River. The lineament is depicted on the mosaic although its total northern extent in Colorado is not shown. It has not been noted on the State Geologic Map (Dane and Bachman, 1965). Indications of this lineament can be seen on

1942 Soil Conservation Service low altitude aerial photographs (DCE-2-9, DCE-2-44) located about eight miles southwest of Cimarron in Colfax County, New Mexico. A mid-Tertiary intrusive on the northwest side is truncated by the lineament which is aligned along a narrow valley. Directly southeast of the lineament are located Cenozoic basalt flows. Quaternary landslide debris is indicated on the state geologic map along this part of the lineament, making its continuation difficult to trace. It is interesting to note that a series of earthquakes occurred in the Cimarron area in 1966 (see Appendix A map with seismic eipcenters plotted) with magnitudes greater than 3 (Northrup and Sanford, 1972).

Crossing the southern end of Elephant Butte Reservoir, near the dam site, a previously unrecognized northeast-trending fault has been mapped from the ERTS images and is plotted on the mosaic in Appendix A. Quaternary volcanic centers and remnants of basaltic flows are located along the identified lineament on the Geologic Map of New Mexico (Dane and Bachman, 1965).

2. Lithology

The youngest lava flows in New Mexico, namely those near Carrizozo, Grants, and San Marcial, are clearly evidenced on the ERTS images. However, the full extent of the latter two as mapped on the State Geologic Map is not obvious because of faulting and coverage by wind-blown sand and alluvium. On the state map (1965) a very small portion of the San Marcial flow (in the Jornada del Muerto, northeast of Elephant Butte Reservoir) is mapped as being covered by dune sand, yet the color composite (1333-17102) shows a much larger area to be inundated.

The Quaternary flow south of Grants is bordered on the southeastern edge by an unmapped lineament. Band 7 images indicate a high concentration of water along the lineament. The three flows mentioned above appear black on all four bands and on the color composites. They are the darkest toned lava flows in the state and are known to be among the youngest.

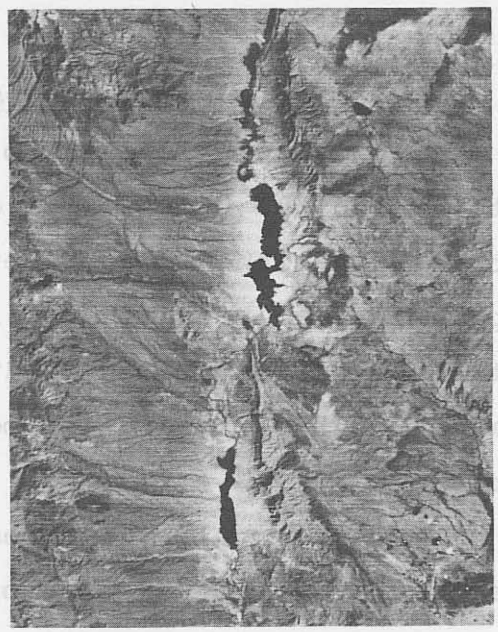
The Permian Abo Formation can be readily identified on ERTS color composites of the San Andres Mountains and the Oscura Mountains as well as in other areas where dense vegetation is not present. It consists primarily of red shales and calcareous siltstones reaching a thickness of over 800 feet in the San Andres Mountains (Kottlowski, et al., 1956). The Abo has a yellow-brown signature on the ERTS color composites (1333-17102 and 1334-17160); yet, even more distinctive, are the yellow alluvial fans which can be traced directly from the Abo beds in the San Andres, Oscura, Sacramento, and Caballo Mountains. In the northern part of the Sacramento Mountains, the Abo is approximately 1,100 feet thick and thins to 500-200 feet at the southern extent (Kottlowski, et al., 1956); yet the yellow fans increase in area to the south. This can probably be attributed to the fact that there is almost a point source of Abo here where it outcrops along the range front and the alluvial slope is extremely low. Abo derived alluvium is limited on the west by U.S. Highway 70. Small Abo outcrops in other areas in the Rio Grande Valley can be spotted and erosional patterns mapped by their distinctive characteristics on ERTS color composites.

3. Hydrology

Drainage features on the ERTS mosaic in the Raton Plateau area were compared with those on the topographic map of New Mexico and with the State highway map prepared by the New Mexico State Highway Department (correct to 1970), all at a scale of 1:500,000. The Vermejo and Canadian River courses, the two major rivers in the region, corresponded on all three. Few tributaries are plotted on the topographic map, but many of those on the State highway map do not correspond in position with those shown on ERTS images. Other tributaries which appear to be of equal order as those drawn are not included on the map. ERTS images will no doubt be a valuable tool in updating drainage and other thematic maps in this area as well as in the more inaccessible regions in New Mexico.

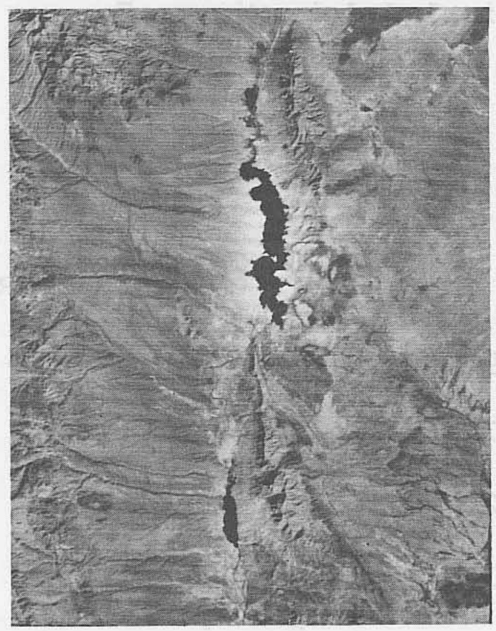
Flooding occurred in the Rio Grande Valley in the spring and early summer of 1973. A series of band 7 images of Elephant Butte and Caballo Reservoirs shows the increase in water storage in both of these reservoirs. Figure 6 is a time sequence of this area. The color composite (1334-17160) dated June 22, 1973, in combination with the sequence, shows areas which have been recently inundated. Light blue water tones imply shallow water areas. In the northern part of Elephant Butte Reservoir, the ponding has encroached upon areas of phreatophyte vegetation. These data, in combination with snow coverage information from ERTS, precipitation data, and ground truth might be valuable in predicting future flooding potential.

6a. August 2, 1972
1010-17152-7



6b. March 6, 1973
1226-17163-7

6c. June 22, 1973
1334-17160-7



6d. October 26, 1973
1460-17134-7

FIGURE 6. Time sequence of ERTS images of Elephant Butte and Caballo Reservoirs, at a scale of 1:1,000,000.

4. Circular Features

Many circular to elliptical features have been identified on the ERTS images of New Mexico and a preliminary classification has been developed. Only some of the circular patterns can be accounted for by existing data. Some of these features are adjacent to existing ore deposits, but such relationships should not be emphasized unless other supporting data exist.

Circular features may be tectonically or geomorphically controlled, or a combination of the two. A limited number are man-made. A preliminary listing of features which may have circular expression are listed in Table 3. Examples of some, which can be explained, and others, which have been identified on ERTS and for which no explanation exists, are included in Figure 7.

FEATURES WHICH MAY PRODUCE
CIRCULAR EXPRESSIONS ON ERTS IMAGES

Geomorphic

1. Karst-type solution depressions
2. Circular alluvial fan development
3. Radial and annular drainage expressions
4. Erosional remnants
5. Topographic basins

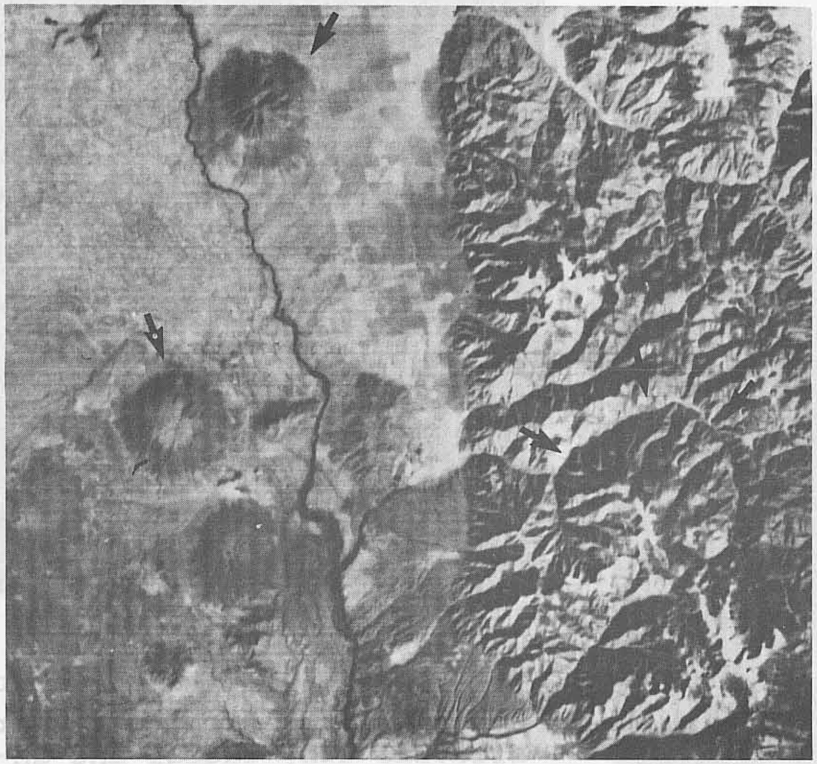
Tectonic

1. Plunging anticlines and synclines
2. Volcanic-tectonic depressions and cauldrons
3. Volcanic cones
4. Exposed intrusives
5. Salt domes

Man-made

1. Circular irrigation fields
2. Miscellaneous, i.e. warhead test area

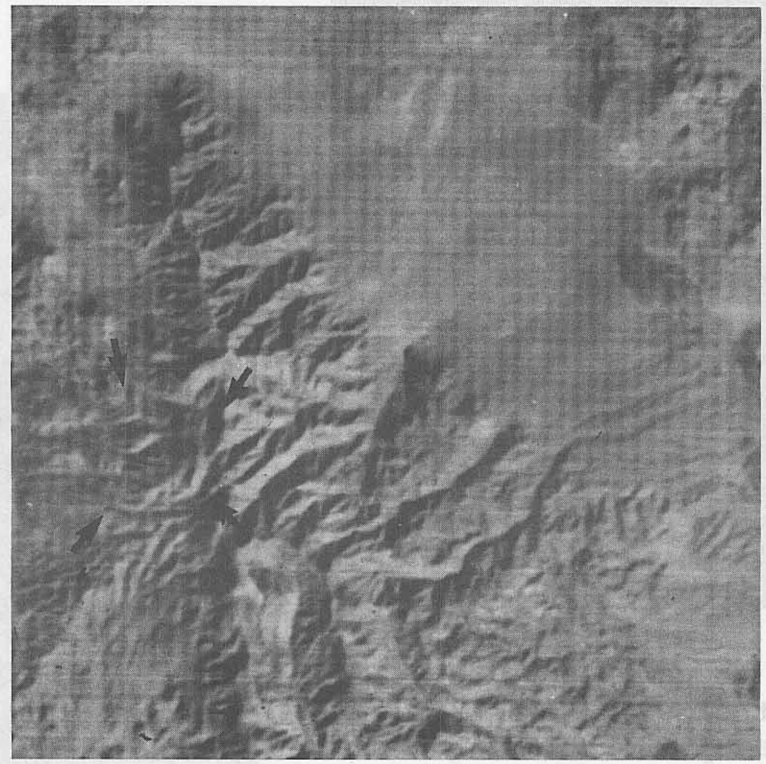
FIGURE 7. Circular patterns from ERTS-1 imagery.



7a. Sangre de Cristo Mountains, Questa area, Rio Grande Valley; volcanic cones, circular fault pattern.

ERTS Image: 1478-17122-7

Scale: 1:500,000



7b. Northern Magdalena Mountains; circular pattern, origin unknown.

ERTS Image: 1460-17134-7

Scale: 1:250,000

B. Investigation of South-Central and Southeastern New Mexico

The area of investigation extends from the western border of the San Andres Mountains to the Pecos River on the east. The northern limit is the Oscura and Capitan Mountains, and the southern limit, the Sacramento Mountains and San Agustin Pass. Figure 8 is an index map of the area.

Previous investigations in the area include those by Kelley (1955, 1971); Kottlowski, et al. (1956); Otte (1959); Pray (1961); Jerome (1965); and Lowman (1972).

For this study, images 1189-17102-5 (Figure 9) and 1098-17043-5 (Figure 10) on a scale of 1:1,000,000 were used to map and identify significant features. These were the best quality scenes available at the time. In some cases, it was found that snow cover enhanced structures in mountainous areas, especially in the Sacramento Mountains. Band 7 images and additional band 5 images were always used to check anomalous features as well as to eliminate minor cloud cover. Also available was a color composite of the Pecos River area (1062-17042). In addition, Gemini and Apollo photographs and various geologic maps were used.

Parts of two geomorphic provinces are present in the study area—the Basin and Range and the Great Plains. The boundary between the two provinces extends along the east slope of the Sacramento Mountains. The Pecos Valley section of the Great Plains Province is a lowland area dominated by highly soluble formations of limestone, dolomite and gypsum producing karst topography. Terrace development is also characteristic of the section. The area from the Sacramento Mountains west to the San Andres is part of the Mexican Highlands section of the Basin and Range province. Here, dominantly north-south-aligned

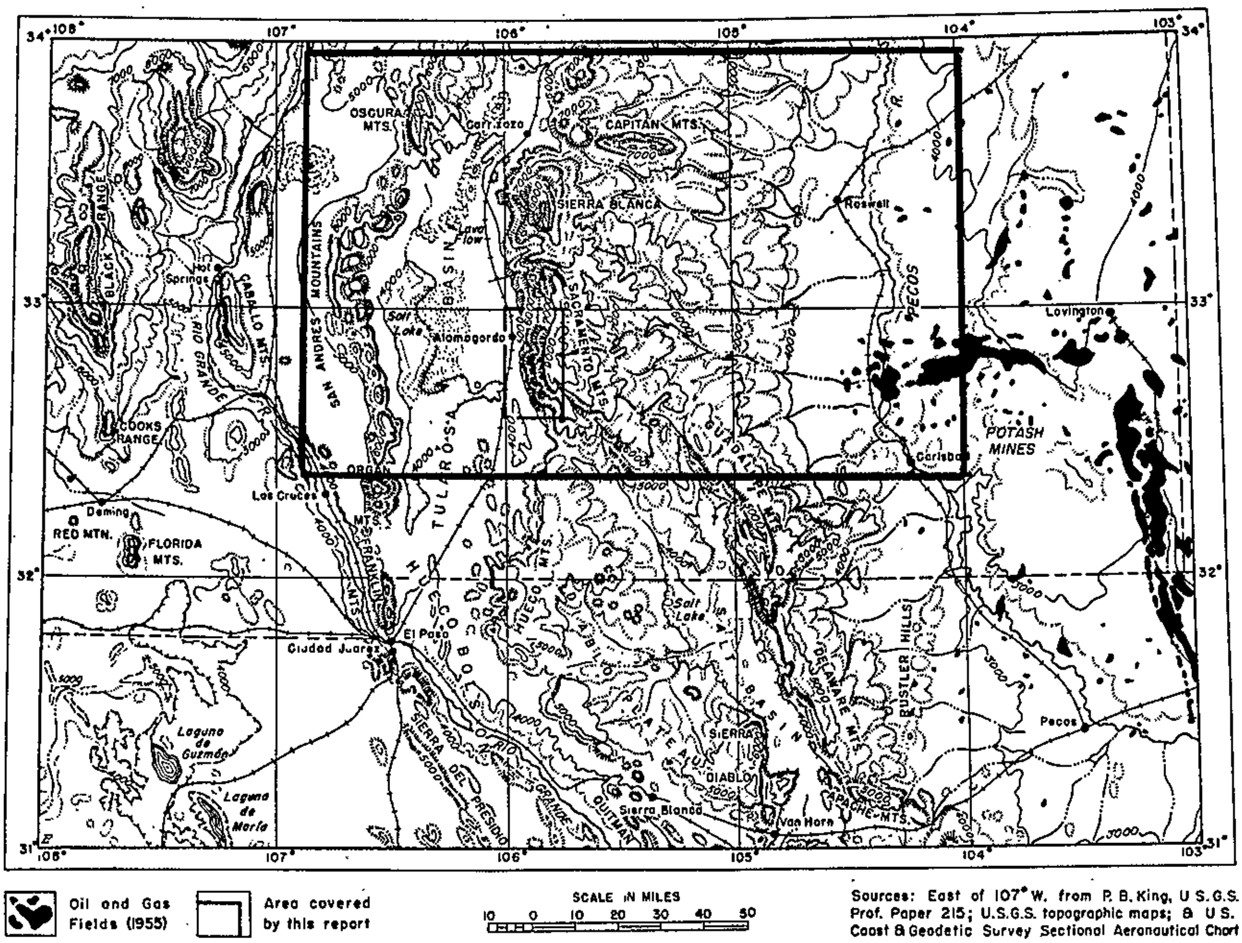


FIGURE 8. Index map of south-central and southeastern New Mexico (from Pray, 1961).

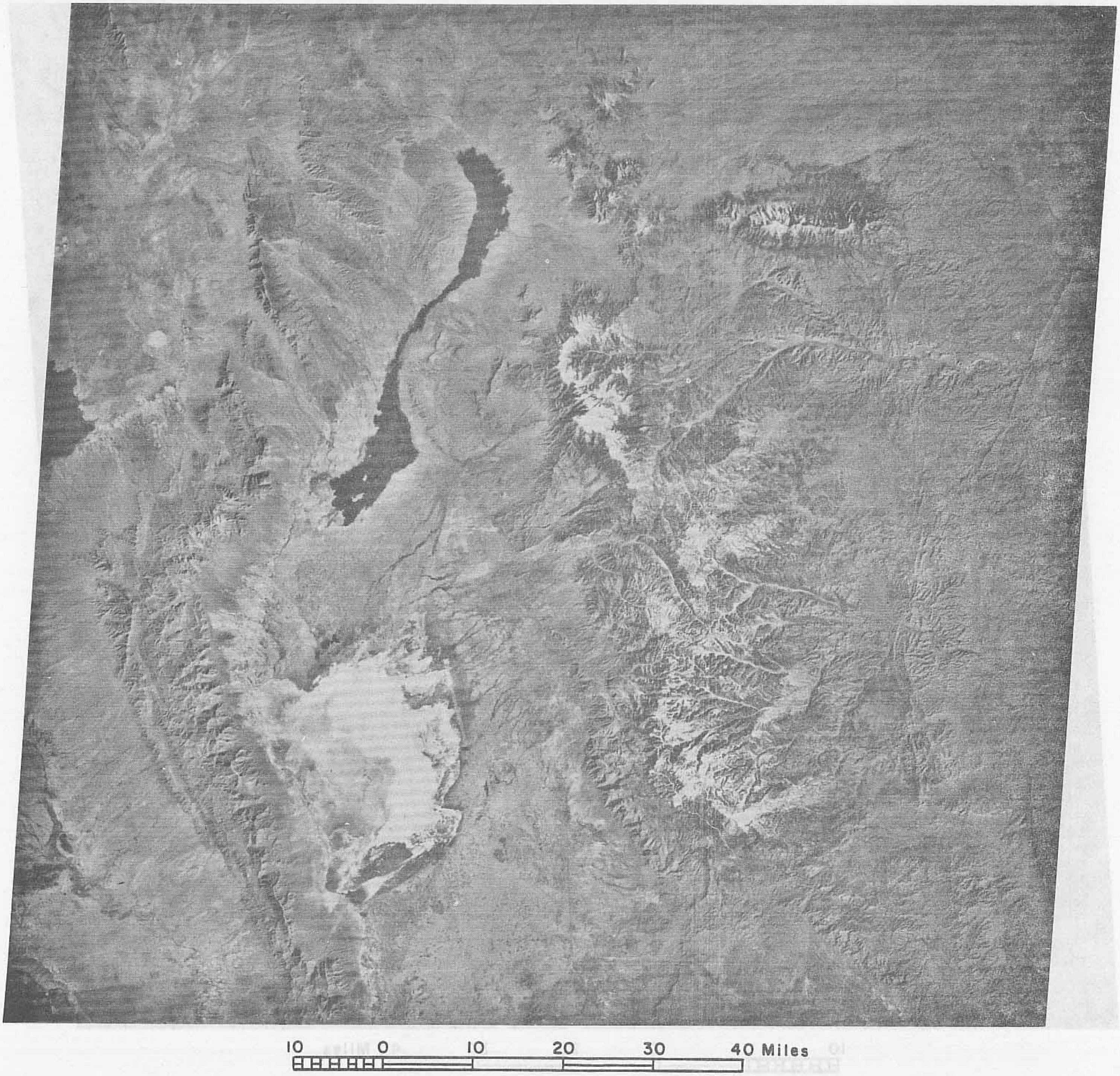


FIGURE 9: ERTS image 1189-17102-5 of the San Andres Mountains, White Sands, and the Sacramento Mountains, New Mexico.

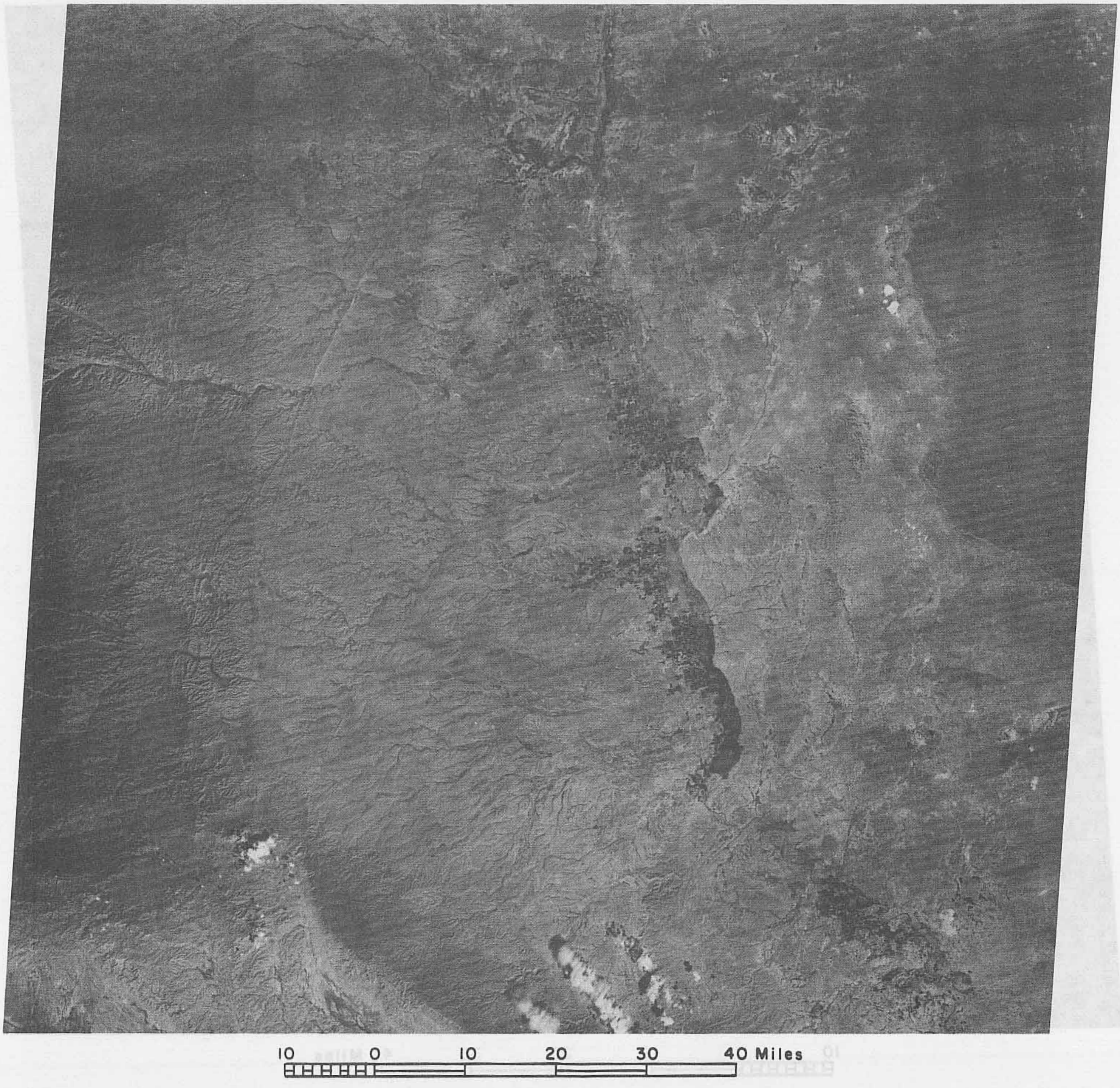


FIGURE 10: ERTS image 1098-17043-5 of the Pecos Valley, New Mexico.

fault block mountains are separated by graben basins (Jornada del Muerto and the Tularosa Basin).

Drainage is internal in the Tularosa Basin, and numerous small lakes can be seen on band 7 (1189-17102-7) in the vicinity of White Sands. Gypsum is eroded from Permian formations in the mountains and transported to this extensive dune field which is located near the north-south midpoint of the basin. North of the playa in the Tularosa Basin is the Holocene Carrizozo lava flow. The Jornada del Muerto west of the San Andres is a partly downfaulted synclinal basin or series of basins with its associated playas and lava flow.

Major normal faulting occurred along the east border of the San Andres and the west border of the Sacramentos. These bordering faults, however, are now covered by alluvium and their actual location has not been determined.

The San Andres Mountains contain formations that range in age from Precambrian to Permian. A small area of Cretaceous sediment has also been found to the north (Kelley, 1955). Tertiary alaskite was intruded into the sedimentary sequence and forms Salinas Peak. The strata of the range dip at about 10 degrees to the west.

The Sacramento Mountains consist of Precambrian to Permian eastward dipping formations interrupted by Tertiary intrusives. The Sierra Blanca Group at the northern extent comprises Tertiary extrusives (andesite to rhyolite breccia, tuff, and flows). Northeast of the Sacramentos lie the Capitan Mountains, an anomalous east-west-striking laccolith. East of the Sacramento Range, the San Andres Formation dips gently into the Pecos Valley and forms the Pecos or Sacramento slope.

1. Land use

Another consideration prior to geologic examination was the identification of man-made features. Some of these features may have land-use implications applicable to other areas in the state; and some might otherwise be attributed to natural causes.

On 1189-17102-5 the most conspicuous man-made feature is a light circular pattern in the Jornada del Muerto northwest of Mockingbird Gap. It has also been cited by other workers from Apollo 9 (Nicks, 1970). The feature is clearly illustrated on Apollo 9 photograph 3805-A. This site, originally thought to be a radar installation, is actually a warhead test area (White Sands Missile Range) from which the vegetation has been removed and the soil stabilized. A similar feature was seen to appear on the east side of the San Andres Mountains, north of White Sands, but only on ERTS images dated after April 10, 1973. A north-south-aligned strip along the eastern edge of White Sands is an acceleration sled track over 10 miles long and a quarter of a mile wide.

A peculiar triangular vegetation pattern was noted directly south of White Sands; one side is formed by the southern extent of White Sands, another by the base of the alluvial fans at the foot of the San Andres Mountains, and the third side by U.S. 70. Along part of its length, the elevated highway appears to control the vegetation on either side of the highway and most probably the drainage. On a 1941 Soil Conservation Service index sheet of the same area and on the individual photographs at a scale of 1:31,680, the vegetation change was not visible even though the highway was a paved road at the time. From New Mexico Highway Department records, it was learned that paving was not completed on this section of the road until 1939. U.S. 70 was made into a four lane divided highway between 1956 and 1958. The topographic map of the area shows that the highway crosses one of the lowest parts of the basin, and we would expect it to disrupt, to some extent the natural drainage patterns. Since 1934 playas have had to be drained because they undermine the road base, and box culverts were later installed. Slight vegetation changes on either side of the road can also be noted as the road continues northeast from White Sands to Alamogordo but are not as marked.

Most land on either side of U.S. 70 is part of White Sands Missile Range and has been controlled by the Department of Defense since at least 1957. No grazing has been permitted; consequently the pattern cannot result from recent grazing-related vegetation changes.

In 1941, it can be assumed that surrounding vegetation had not yet adjusted to or been affected by the highway, but this is not necessarily true today. ERTS images from 1972 and 1973, as well as Apollo 6 photographs, show marked changes in vegetation and also sediment transport (color composite) in the vicinity of the roadway. The present location of the road has caused drainage problems for the Highway Department as well as affecting vegetation and sediment transport. This problem, as seen from ERTS, may serve as an example to transportation planners who must be cognizant of drainage and topography outside of their right of way in order to predict future causes and effects of highway construction.

Another possible vegetation control line has also been noted southeast of the one discussed above. The topographic map locates Orogrande Aqueduct along this line.

Cultivated vegetation patterns have, of course, been noted especially in the Pecos Valley but shall not be discussed here.

2. Lithology

It was found that geologic units could be mapped where there was no major change in vegetation or where transitions coincided with formation contacts. Consistent high relief hampered formation recognition especially in the Sacramento Mountains. On image 1098-17043-5, the San Andres Formation, forming the Pecos or Sacramento slope, grades into Quaternary alluvium in the Pecos Valley. This boundary is evident on the image although it is indistinct. The alluvium appears darker in tone and more mottled than the limestone. The change in image tone, however, also corresponds to a change in slope on the topographic map at about 4,200 feet and presumably the transition from the Lower Sonoran to the Upper Sonoran Zone. Higher on the Sacramento slope, even darker tones can be seen, although there is no formation contact; and the San Andres Limestone still predominates. The color composite shows an intense red, and we would assume that this boundary marks the change from a grassland and shrub association to a pinon-juniper association (at about 6,000 feet), governed by the elevation. Elevations in the Sacramento Mountains and Sierra Blanca rise above 9,000 feet, and no differentiation can be made between the Sierra Blanca extrusive and the Sacramento sediments, except perhaps by drainage density and relief. Differences in tone and relief mark the contact between the Yeso and the San Andres Formations on the west side of the mountains; but the contact cannot be consistently recognized.

In the San Andres Mountains, formation contacts can be more easily distinguished on ERTS images. Here, elevations in general do not rise much above 7,000 feet; and most of the range is included in the Upper Sonoran Zone. Contacts between various Pennsylvanian and Permian formations are clearly visible along the western extent; formation color changes aid in recognation. The change from west to east is from dark grey dolomite (San Andres Formation) to tan sandstone and gypsum (Yeso Formation), to red-brown sandstone, siltstone, and claystone (Abo), to dominantly limestone (Magdalena Group).

3. Structure

In the study area, lineament patterns were drawn directly on images 1098-17043 and 1189-17102 using a magnifier. Some of these features are faults; others indicate fold trends or dikes; and others are unidentified linears. The criteria used in their identification were offset, truncation of structure, and straight-stream segments along with other indications of linear patterns such as tonal changes. Lineaments found in this area are included on the mosaic in Appendix A. Lineaments identified in the literature are distinguished from those identified on ERTS. Dashed lines indicate areas of known folding. The majority of these features are not found on the State Geologic Map (Dane and Bachman, 1965). Joint patterns would not, of course, be shown on the map; faults were not shown on the state map unless they affected bedrock; hence little evidence of faulting is shown in alluvium. More detailed structural maps and discussions of parts of the study area were found in papers by Kelley (1955, 1971); Pray (1961); Otte (1959); and others.

Notable lineaments extending from the Pecos slope into the valley can be seen on the ERTS images, and some of these have no counterpart in the literature. Most are trending northeast, with some trending almost due north. Structural zones of folding and faulting which have been previously identified here include the Border Hills Zone, the Six-Mile Hill Zone, the Y-O Zone, and the K-M Zone. Unidentified lineaments appear to parallel or branch off from these major zones. South of the Y-O Zone, some of the lineaments most probably correspond to facies changes. North-south trends parallel the Tinnie Fold Belt (dashed area southeast of the Capitan Mountains) and may be related to folding.

Internal lineaments as well as border fault scarps have been recognized in the Sacramento Mountains. Some of these have already been reported in the literature, and Lowman (1972) has commented on the lack of dissection of the border scarp in the southwest section indicating relatively recent uplift. In May of 1968, an earthquake epicenter was located in the Sacramento Mountains with a local magnitude of 2.7 to 3.0 (Toppozada and Sanford, 1972) indicating this is still an area of seismic activity.

In addition to magnified image examination, a Digicol Viewer was used to see if structural features could be enhanced. It was found that the information provided by the viewer did not supplement data already obtained with the magnifier but that it might be useful in the future for a "first look" at other images.

IV. SUMMARY AND CONCLUSIONS

The majority of existing aerial photography of New Mexico does not allow for the mosaicking of large areas from different flights primarily because of scale variations. In cases where it is possible, regional trends are often masked by small-scale features. In addition, seasonal and repetitive coverage is often not available. Large-scale aerials, however, are excellent for mapping localized trends and cannot be replaced by satellite imagery. ERTS imagery is a complement to and not a substitute for aerial photography. Perhaps the most important feature of ERTS imagery is its small scale. Regional trends which can be repeatedly overlooked in field investigations may be obvious on the extremely small-scale images.

ERTS imagery is a valuable tool in obtaining additional information on geologic structure, geomorphology, hydrology, and land use in an arid environment, specifically in the state of New Mexico. No new mineral deposits have been located as a result of this study, but many significant faults and circular features have been delineated from ERTS images, adjacent to known mineral localities. ERTS cannot locate new areas of mineralization, but can provide additional information which when combined with the study of low altitude photographs, existing data, and careful field checking, may lead to the discovery of such deposits.

Lineaments and curvilinear features have been identified on the mosaic in Appendix A, and remain to be checked in the field. Multiple lineament intersections, and circular features as possible indications of buried intrusives, may, with further work, lead to the discovery of new mineral deposits; but a definitive statement is premature.

V. RECOMMENDATIONS

A. Field Support for Current Reconnaissance Study

1. Detailed field studies should be undertaken of specific circular features and their relation to known mineral deposits in the area.
2. A field study of the lineament at southern end of Elephant Butte Reservoir should be performed since this is near a dam site and may have land-use implications.
3. Field checking of the lineament extending from the Purgatoire River in Colorado southwest through the Sangre de Cristo Mountains in New Mexico should be undertaken since known mineral deposits occur in the area.
4. A field study should be initiated of the lineament through the alluvium on the west side of the San Andres Mountains if access to the missile range can be obtained.

B. Additional Studies from ERTS Images

1. Drainage corrections on New Mexico maps from the ERTS Mosaic of New Mexico should be made.
2. Lineament mapping should be extended to other areas in the state and lineament orientations defined. This would include a regional tectonic analysis of the western part of New Mexico, with the objectives of
   a. delineating structural boundaries between major physiographic provinces,

i.e., Basin and Range-Colorado Plateau, and

b. identifying Cenozoic volcano-tectonic features which have potential significance in mineral exploration and as geothermal energy sources.

3. Isolineament mapping and its relation to mineral deposits should be investigated.

4. Vegetation patterns as surrogate for mineral zones and geothermal areas should be studied.

5. Environmental impact as related to vegetation should be studied. Low altitude aerial photographs of a large part of New Mexico dating back as far as 1935 are available and can be compared with ERTS images to assess the impact of cultural and physical forces on vegetation and erosion.

C. Development of a Satellite Imagery User Manual for New Mexico

1. Such a manual should contain quality ratings and descriptions of all Gemini, Apollo, ERTS, Skylab, and high altitude imagery of New Mexico along with methodology of approach to geologic interpretation.

2. The need for such a manual has been established by contact with governmental agencies, industry representatives and the public.

D. Production of Multiple-Use Overlays to the Mosaic of the State of New Mexico

1. Information can be obtained partially from ERTS imagery and partially from existing data.

2. This can be tied in with the statewide Land-Use Information System currently in the developmental stage.
3. Information can be stored and retrieved from computer data tapes.
4. Overlays can include:
    a. Metallic Mineral Deposits
    b. Nonmetallic Mineral Deposits
    c. Soils
    d. Vegetation
    e. Land Ownership
    f. Landforms
    g. Tectonics
    h. Political Boundaries and Transportation Networks
    i. Drainage
    j. Existing Land Use

E. NASA Imagery Processing, Distribution, and Evaluation Recommendations

1. The delay on data delivery time should be reduced.
2. The quality of 70mm negatives should be improved.
3. 9x9 negatives should be offered as a data product.
4. Consistency of contrast and illumination of black and white products should be maintained.
5. Many of our image evaluations disagree with those in the U.S. Standard Catalog. Some of those rated poor in the catalog had raster or scan-line interference, but it was not prominent enough to interfere with visual geologic interpretation. We reclassified some of these as being of excellent quality

for interpretation. Therefore, it is suggested that a remark column be added to the catalog to clarify the quality evaluation.

APPENDIX A

Figures

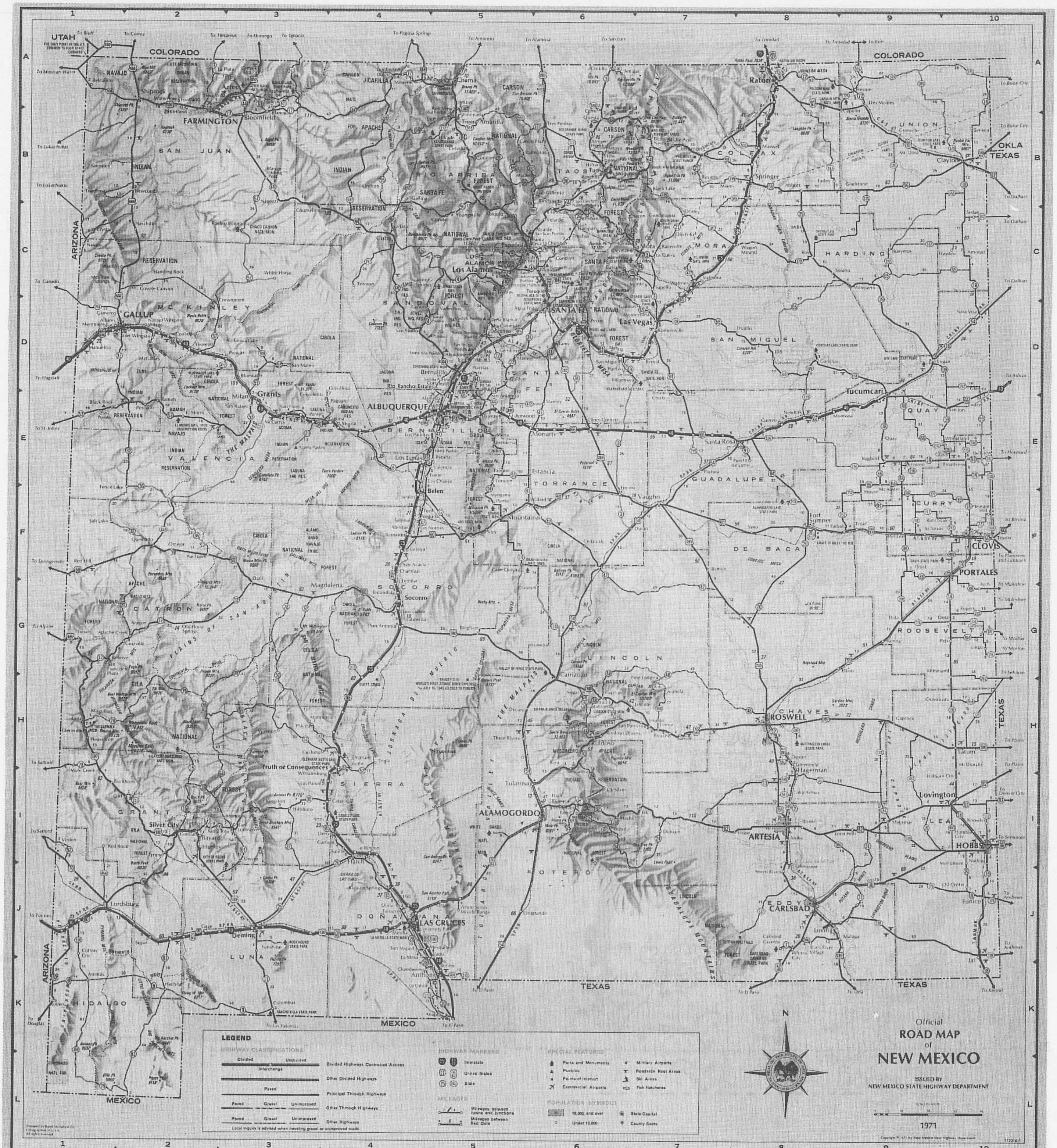


FIGURE 11: Index map showing the location of physical and political units in New Mexico.

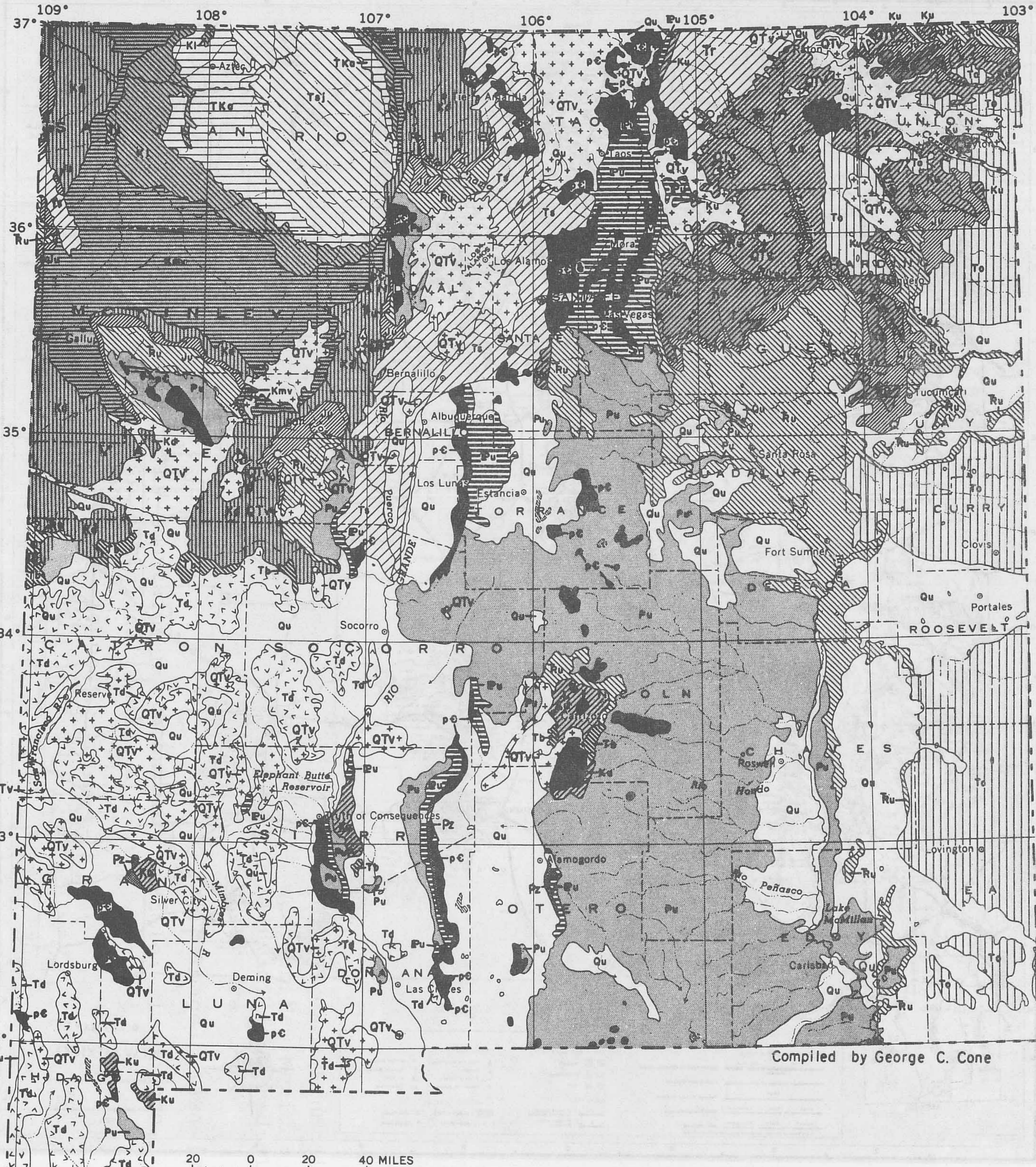


FIGURE 12: Generalized geologic map of New Mexico (from U.S.G.S., 1965).

EXPLANATION

TERTIARY

Qu — Quaternary deposits
Includes some Tertiary rocks

QTv — Quaternary and Tertiary volcanic rocks

Ts — Santa Fe Group
Includes some lower Quaternary rocks

To — Ogalalla Formation

Td — Datil Formation and related volcanics

Tsj — San Jose Formation

Tb — Baca Formation and related units

TKa — Nacimiento and Animas Formations

Tr — Raton Formation

CRETACEOUS

Kl — Upper Cretaceous sedimentary rocks
Post-Mesaverde formations

Kmv — Mesaverde Group

Kd — Mancos and Dakota Formations

Ku — Cretaceous rocks, undivided

Ju — Jurassic rocks, undivided

℞u — Triassic rocks, undivided

Pu — Permian rocks, undivided

ℙu — Pennsylvanian rocks, undivided

P — Mississippian, Devonian, Silurian, Ordovician, and Cambrian rocks, undivided

p€ — Precambrian rocks, undivided

INTRUSIVE ROCKS

Tertiary intrusive rocks
Includes some rocks of Cretaceous age

EXPLANATION

Thrust fault
Sawteeth on upper plate

Normal fault
Hachures on downthrown side

Monoclinal flexure

Ti

Intrusive bodies of probable Tertiary age

Volcanic rocks of Quaternary and Tertiary age

Rocks of Precambrian age

4000

Structure contours on Precambrian surface

Contour interval 1,000 feet. Datum is sea level. Modified from Foster and Stipp, 1961

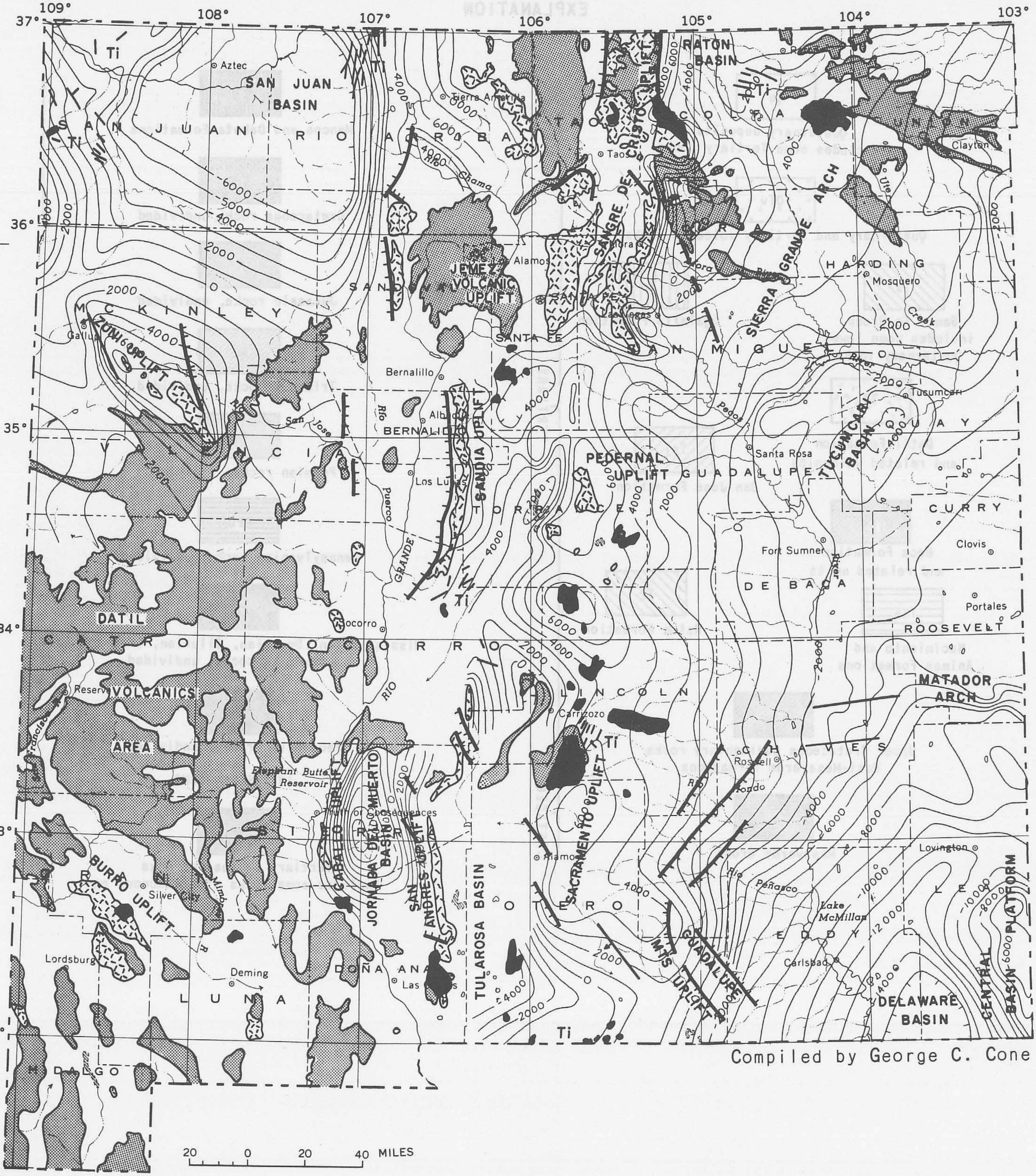


FIGURE 13: Generalized tectonic map of New Mexico (from U.S.G.S., 1965).

Figure 15. Lineaments and circular features delineated from ERTS images.

Figure 14.
Mineralized areas and earthquake epicenters (≥ 2.7 magnitude) in New Mexico.
Explanation:
Size of circles are in proportion to production.
Abbreviations are chemical symbols for the metals mined with the exception of B = barite, and F = fluospar.
■ indicates earthquake epicenters with magnitudes ≥ 2.7 occurring between 1960 and 1971.

APPENDIX B

Tables

TABLE 3

New Mexico Earthquake with Magnitude ≥ 2.7
Between 1960 and 1971

(Sanford, 1965; Sanford and Cash, 1969;
Sanford, et al., 1972; Toppozada and Sanford, 1972)

DATE	MAGNITUDE*	EPICENTER	
		Latitude Degrees N	Longitude Degrees W
1960			
July 22	~3.3	34.4	106.9
July 23	~3.8	34.4	106.9
1961			
July 3	~3.5	34.2	106.9
1962			
Jan. 3	3.0	35.2	103.8
June 14	2.8	35.6	106.9
1963			
Feb. 22	2.9	32.4	107.0
Feb. 22	2.8	32.4	107.0
June 6	3.7	36.7	104.4
Aug. 19	2.9	32.5	107.1
Dec. 19	>3.6	35.1	104.3
1965			
Feb. 3	3.9	35.4	103.4
Feb. 3	4.0	32.1	103.0
Apr. 10	2.7	34.0	107.1
July 28	3.0	33.9	106.8
July 28	2.7	33.9	106.8
Dec. 29	2.9	34.6	105.8
1966			
Jan. 23	5.5**	37.0	107.0
Apr. 21	3.6	35.4	103.0
Aug. 14	4.4	32.0	102.6

Table 3 Continued.

DATE	MAGNITUDE*	EPICENTER	
		Latitude Degrees N	Longitude Degrees W
Sept. 17	3.3	32.1	109.4
Sept. 17	3.6	35.0	103.9
Sept. 24	3.8**	36.5	105.0
Sept. 24	3.6	36.5	105.0
Sept. 25	3.8**	36.4	105.1
Sept. 25	3.7	36.5	105.1
Oct. 3	4.5**	37.4	104.1
Oct. 6	3.4	35.8	104.2
1967			
Jan. 16	>3.6	34.5	107.1
July 29	3.0	33.6	108.7
Sept. 29	3.2	32.2	107.0
1968			
Mar. 9	3.2	32.5	106.0
Mar. 9	3.2	32.6	106.1
May 2	2.9	33.1	105.3
May 19	2.7	34.5	108.0
1969			
Jan. 30	3.4	34.3	106.9
May 12	3.8	31.8	106.4
May 12	3.5	31.8	106.4
June 8	2.7	34.3	105.2
July 4	3.0	36.1	106.1
Aug. 23	3.0	34.8	108.7
1970			
Jan. 12	4.1	36.1	103.2
Nov. 28	3.5	35.0	106.7
Nov. 30	3.0	36.3	106.2
1971			
Jan. 4	3.8	35.0	106.7
Jan. 6	3.0	34.2	107.0
Jan. 27	2.8	34.1	106.6
Feb. 18	3.3	36.2	105.7

Table 3 Continued.

DATE	MAGNITUDE*	EPICENTER	
		Latitude Degrees N	Longitude Degrees W
Apr. 28	2.9	35.8	105.6
May 22	2.8	35.4	107.6
June 4	2.9	36.3	106.6

* New Mexico recorded magnitudes based on S-phase amplitudes unless otherwise noted.

** Magnitude based on P-phase amplitudes recorded out of state.

EXPLANATION FOR TABLE 4

Could cover and the quality of images was evaluated by Technology Application Center personnel and does not necessarily agree with the ERTS U.S. Standard Catalog published by Goddard Space Flight Center.

NA = not available

NR = not received

TABLE 4

Good Quality ERTS-A Scenes of New Mexico
Dated Between July 1972 and December 1973

Photo Number	% Cloud Cover	Remarks
NEW MEXICO ORBIT 1 - CLOVIS-PORTALES		
1061-16575	0	
1097-16582	15	
1313-16584	20	
1331-16582	0	
1349-16581	0	
1385-16574	5	
1457-16460	0	
1493-16553	0	
NEW MEXICO ORBIT 1 - LOVINGTON-HOBBS		
1061-16582	15	
1205-16591	10	
1223-16592	0	
1313-16590	5	
1331-16585	0	
1349-16584	0	
1385-16581	3	
1457-16563	0	
1493-16562	0	
NEW MEXICO ORBIT 1 - SOUTHERN PECOS		
1079-16585	0	
1205-16594	5	
1223-16595	0	
1241-16595	0	
1313-16593	0	
1331-16591	0	
1349-16590	0	
1385-16583	5	
1457-16565	0	
1493-16564	0	

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
1278-17035	0	
1296-17034	0	
1314-17033	15	
1332-17032	5	Band 4 NA
1350-17030	0	
1368-17025	10	
1404-17022	5	
1440-17013	0	Band 6 NA, Scanline interference
1458-17005	0	
1476-17005	0	Bands 5, 6 NA, Snow enhancement, Scanline interference
NEW MEXICO ORBIT 2 - SPRINGER		
1098-17034	0	
1278-17041	0	
1297-17041	0	
1386-17030	8	
1404-17024	15	
1440-17015	0	Band 6 NA, Scanline interference
1476-17012	0	Band 5, 6 NA
1494-17011	0	Scanline interference
NEW MEXICO ORBIT 2 - NORTHERN PECOS		
1062-17033	10	
1098-17041	0	
1224-17044	10	
1278-17044	0	
1386-17033	0	
1476-17014	0	Bands 5, 6 NA
1494-17013	0	Scanline interference
NEW MEXICO ORBIT 2 - ROSWELL-CARLSBAD		
1062-17040	0	
1098-17043	5	
1224-17051	0	
1242-17051	20	
1260-17051	0	Minor snow

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
1278-17050	0	
1386-17035	15	
1458-17021	0	
1494-17020	0	Scanline interference
NEW MEXICO ORBIT 2 - GUADALUPE MOUNTAINS		
1062-17042	0	
1224-17053	0	
1260-17054	0	
1278-17053	0	
1314-17051	5	
1386-17042	15	
1458-17023	0	
1476-17023	10	Band 5, 6 NA
1494-17022	0	Scanline interference
NEW MEXICO ORBIT 3 - SOUTH CENTRAL COLORADO		
1189-17091	0	Snow enhancement
1207-17093	0	Snow enhancement
1261-17094	0	Snow enhancement
1297-17092	8	Minor snow
1333-17090	8	
1423-17074	0	Bands 5, 6 NA, Scanline interference
1459-17064	0	Band 5 NA
NEW MEXICO ORBIT 3 - SANGRE DE CRISTO MOUNTAINS		
1189-17093	0	Snow enhancement Band 7 NA
1207-17095	20	Snow enhancement
1333-17093	5	
1387-17084	8	
1423-17080	0	Band 6 NA, Scanline interference
1459-17070	0	Band 5 NA

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
NEW MEXICO ORBIT 3 - ESTANCIA VALLEY		
1063-17092	0	
1153-17100	0	
1261-17103	0	Snow enhancement
1297-17101	8	
1315-17100	10	
1333-17095	0	
1387-17091	0	
1423-17083	0	Bands 5, 6 NA, Scanline interference
NEW MEXICO ORBIT 3 - WHITE SANDS		
1153-17103	5	
1189-17102	0	5% snow enhancement
1261-17105	0	Minor snow
1297-17104	5	
1315-17103	10	
1333-17102	0	
1387-17093	10	
1459-17075	0	Band 5 NA
1477-17075	0	Bands 5, 6 NA
NEW MEXICO ORBIT 3 - EL PASO		
1189-17105	0	
1207-17111	0	
1261-17112	0	
1279-17111	5	
1297-17110	10	
1315-17105	5	
1333-17104	0	
1387-17100	5	
1405-17094	0	
1459-17082	0	Band 5 NA, Scanline interference
1477-17082	0	Bands 5, 6 NA

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
NEW MEXICO ORBIT 4 - SAN LUIS VALLEY		
1208-17151	0	Snow enhancement
1424-17132	0	Band 5 NA
1478-17122	0	Band 6 NR
NEW MEXICO ORBIT 4 - JEMEZ		
1010-17143	10	
1334-17151	5	
1406-17141	0	
1460-17125	15	
1478-17125	10	Bands 6, 7 NR
NEW MEXICO ORBIT 4 - ALBUQUERQUE		
1064-17150	5	
1298-17160	10	
1334-17153	3	
1388-17145	8	
1406-17143	8	
1424-17141	0	Band 5 NA
1460-17131	0	
NEW MEXICO ORBIT 4 - ELEPHANT BUTTE		
1010-17152	0	Very light
1298-17162	15	
1334-17160	3	
1406-17150	5	
1460-17134	0	
1478-17134	15	Bands 5, 6, 7 NR
NEW MEXICO ORBIT 4 - DEMING		
1334-17162	0	
1388-17154	0	
1406-17152	0	

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
1424-17150	10	Band 5 NA
1460-17140	0	
1478-17140	0	Bands 5, 6 NR
NEW MEXICO ORBIT 5 - NAVAJO LAKE		
1191-17204	0	Snow enhancement
1209-17210	8	Snow enhancement
1245-17211	0	Snow enhancement
1299-17205	5	Snow enhancement
1317-17204	0	Snow enhancement
1335-17203	15	Snow
1389-17195	30	
1407-17193	0	Minor snow
1425-17190	0	Minor snow
1461-17181	0	Minor snow
1479-17180	25	Snow
NEW MEXICO ORBIT 5 - FOUR CORNERS AREA		
1065-17202	0	
1191-17211	0	Snow enhancement
1245-17213	0	Snow enhancement
1299-17212	8	
1317-17210	0	
1335-17205	3	
1371-17203	10	
1389-17201	20	
1407-17195	0	
1425-17193	0	
1461-17183	0	Band 5 NA
1479-17183	0	Scanline interference
NEW MEXICO ORBIT 5 - GRANTS		
1065-17204	0	
1245-17220	0	Snow enhancement
1299-17214	5	
1317-17213	0	
1335-17212	15	

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
1407-17202	0	Band 5 NA
1425-17195	0	Scanline interference
1461-17190	0	Band 5 NA
1479-17185	0	Scanline interference
NEW MEXICO ORBIT 5 - RESERVE		
1101-17215	0	Snow enhancement
1245-17222	0	Snow enhancement
1299-17221	15	
1317-17215	0	
1335-17214	8	
1407-17204	0	
1425-17202	10	
1461-17192	0	Band 5 NA
1479-17192	30	Scanline interference
NEW MEXICO ORBIT 5 - WILCOX		
1083-17215	5	
1101-17221	0	
1263-17225	8	
1299-17223	3	
1317-17222	0	
1335-17221	0	
1407-17211	0	
1425-17204	10	
NEW MEXICO ORBIT 6 - COLORADO-UTAH		
1066-17254	8	
1210-17264	0	Snow enhancement
1246-17272	0	Snow enhancement
1300-17263	30	
1318-17262	0	Dark
1408-17251	0	
1426-17245	0	Bands 5, 6 NA, Scanline interference
1462-17235	0	Bands 5, 6 NA
1480-17235	15	

Table 4 Continued.

Photo Number	% Cloud Cover	Remarks
NEW MEXICO ORBIT 6 - CHUSKA MOUNTAINS		
1210-17271	8	Snow enhancement
1246-17272	5	Snow enhancement
1300-17270	30	
1318-17265	0	Dark
1408-17253	0	
1426-17251	0	Band 6 NA, Scanline interference
1462-17242	0	Bands 5, 6 NA
1480-17241	0	

TABLE 5

GEMINI AND APOLLO NEW MEXICO FRAMES

Flight	Frames	Description
Gemini 4	4-8-13 to 30	Southern New Mexico; low oblique
Gemini 5	5-1-17	Southwestern New Mexico; low oblique
	5-1-18	Southeastern New Mexico; nearly vertical
	5-4-69	South central New Mexico; nearly vertical
Gemini 12	12-10-45	Six states; very high oblique
	12-10-46 to 48	New Mexico; oblique
	12-11-75 to 78	Three states; very high oblique
Apollo 6	6-1443 to 1454	Southern New Mexico; vertical
Apollo 7	7-1949	New Mexico, Arizona (B&W); high oblique
	7-2028 to 2032	Southern New Mexico; near vertical
Apollo 9 Handheld	9-3122 to 3123	New Mexico, Colorado, Utah; oblique
	9-3141 to 3142	New Mexico, Rio Grande Valley; oblique
	9-3264	South central New Mexico; oblique
	9-3282	Southern New Mexico; oblique
	9-3293	South central New Mexico; vertical
	9-3327 to 3332	Southern New Mexico; oblique
	9-3444 to 3460	North central New Mexico, southern New Mexico; vertical to oblique
	9-3571 to 3573	Eastern New Mexico; oblique

Table 5 Continued.

Flight	Frames	Description
Apollo 9		
Multispectral	9-26-3712 to 3714	Extreme southwestern New Mexico
	9-26-3737 to 3739	Southeastern New Mexico
	9-26-3756 to 3757	Southwest of Deming, New Mexico
	9-26-3803 to 3807	Southern New Mexico

REFERENCES

REFERENCES

E.C. Anderson. The metal resources of New Mexico and their economic features through 1954. New Mexico Bur. Mines Min. Res., Bull. 39, 1957. 183 p.

K. Bryan. Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico. In: Regional Planning, Pt. 6, Upper Rio Grande, Washington, Natl. Res. Comm., V.1, Pt. 2, Sec. 1, 1938. p. 197-225.

C.E. Chapin. The Rio Grande rift, Part I: Modifications and additions. New Mexico Geol. Soc. Guidebook 22, 1971. p. 191-201.

C.H. Dane and G.O. Bachman. Geologic Map of New Mexico. U.S. Geol. Survey, 1965.

E.G. Deal. Geology of the Northern San Mateo Mountains, Socorro County, New Mexico: A Study of a Rhyolite Ash-flow Tuff Cauldron and the Role of Laminar Flow in Ash-flow Tuffs. Ph.D. dissertation, Univ. New Mexico, Albuquerque, 1973. 136 p.

W.E. Elston, P.E. Damon, P.J. Coney, R.C. Rhodes, E.I. Smith, and M. Bikerman. Tertiary volcanic rocks, Mogollon-Datil province, New Mexico, and surrounding region: K-Ar dates, patterns of eruption, and periods of mineralization. Geol. Soc. Amer. Bull., V.84, 1973. p. 2259-2274.

N.M. Fenneman. Physical Divisions of the United States. U.S. Geol. Survey Map, 1962.

R.W. Foster, R.M. Frentress, and W.C. Riese. Subsurface geology of east-central New Mexico. New Mexico Geol. Soc. Spec. Publ. 4, 1972. 22 p.

E.V. Howard. Metalliferous Occurrences in New Mexico. New Mexico State Planning Office, 1967. 270 p.

S.E. Jerome. Geology and ore deposits of the Sacramento (High Rolls) mining district, Otero County, New Mexico. New Mexico Bur. Mines Min. Res., Bull. 86, 30 p.

L.C. Pray. Geology of the Sacramento Mountains escarpment, Otero County, New Mexico. New Mexico Bur. Mines Min. Res., Bull. 35, 1961. 144 p.

C.C. Reeves, Jr. Tertiary-Quaternary stratigraphy and geomorphology of West Texas and southeastern New Mexico. New Mexico Geol. Soc. Guidebook 23, 1972. p. 108-117.

A.R. Sanford. An instrumental study of New Mexico earthquakes. New Mexico Bur. Mines Min. Res., Circular 78, 1965. 12 p.

A.R. Sanford, A.J. Budding, J.P. Hoffman, O.S. Alptekin, C.A. Rush, and T.R. Toppozada. Seismicity of the Rio Grande rift in New Mexico. New Mexico Bur. Mines Min. Res., Circular 120, 1972. 19 p.

A.R. Sanford and D.J. Cash. An instrumental study of New Mexico earthquakes, July 1, 1974 through Dec. 31, 1967. New Mexico Bur. Mines Min. Res., Circular 102, 1969. 7 p.

H.A. Schmitt. The porphyry copper deposits in their regional setting. In: Geology of the Porphyry Copper Deposits, Southwestern North America. S.R. Titley and C.L. Hicks (ed.), 1966. p. 17-33.

N.M. Short. Mineral resources, geologic structure and land form survey. In: Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Vol. III, NASA, Goddard Space Flight Center, 1973. p. 30-46.

W.D. Thornbury. Regional Geomorphology of the United States. New York, 1967. 609 p.

S.R. Titley. Geological summary of the Magdalena mining district, Socorro County, New Mexico. New Mexico Geol. Soc. Guidebook 10, 1959. p. 144-148.

T.R. Toppozada and A.R. Sanford. Instrumental study of New Mexico earthquakes, January 1968 through June 1971. New Mexico Bur. Mines Min. Res., Circular 126, 1972. 6 p.

U.S. Geological Survey. Mineral and Water Resources of New Mexico. New Mexico Bur. Mines Min. Res. Bull. 87, 1965. 437 p.

F.J. Wobber and K.R. Martin. Exploitation of ERTS-1 imagery utilizing snow enhancement techniques. In: Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. I, Sect. A, 1973. p. 345-351.

V.C. Kelley. Tectonic map of a part of the upper Rio Grande area, New Mexico. U.S. Geol. Survey, Oil and Gas Invest. Map OM 157, 1954.

V.C. Kelley. Regional tectonics of south-central New Mexico. New Mexico Geol. Soc. Guidebook 6, 1955. p. 96-104.

V.C. Kelley. Tectonic map of a part of the upper Rio Grande area, New Mexico. New Mexico Geol. Soc. Guidebook 12, 1961.

V.C. Kelley. Geology of the Pecos Country. New Mexico Bur. Mines Min. Res., Memoir 24, 1971. 75 p.

V.C. Kelley and N.J. Clinton. Fracture systems and tectonic elements of the Colorado Plateau. Univ. New Mexico Publ. in Geol. No. 6, 1960. 104 p.

F.E. Kottlowski, R.H. Flower, M.L. Thompson, and R.W. Foster. Stratigraphic studies of the San Andres Mountains, New Mexico. New Mexico Bur. Mines Min. Res., Memoir 1, 1956. 132 p.

W. Lindgren, L.C. Graton, and C.H. Gordon. The ore deposits of New Mexico. U.S. Geol. Survey Prof. Paper 68, 1910. 361 p.

P.D. Lowman, Jr. Geologic applications of orbital photography. NASA Tech. Note D-4155, 1967. 37 p.

P.D. Lowman. The Third Planet. Zurich, 1972. 170 p.

O.W. Nicks (ed.) This Island Earth. NASA, 1970. 182 p.

S.A. Northrup and A.R. Sanford. Earthquakes of northeastern New Mexico and the Texas Panhandle. New Mexico Geol. Soc. Guidebook 23, 1972. p. 148-160.

C. Otte, Jr. Late Pennsylvanian and Early Permian Stratigraphy of the northern Sacramento Mountains, Otero County, New Mexico. New Mexico Bur. Mines Min. Res., Bull. 50, 1959. 111 p.

SUPPLEMENT A

A PRELIMINARY INVESTIGATION OF THE MOGOLLON-DATIL VOLCANIC FIELD, SOUTHWESTERN NEW MEXICO, FROM ERTS-1 IMAGERY

by R. C. Rhodes
Department of Geology
University of New Mexico, Albuquerque

I. INTRODUCTION

The ERTS-1 images of the Mogollon-Datil volcanic field (Figure A1) in southwestern New Mexico were studied and compared with available geologic maps in order to evaluate the usefulness of satellite imagery as an aid to regional geologic mapping and the structural interpretation of a large volcanic province. The investigation of the images focused on the identification of major faults and other structural lineaments, and on the recognition of unusual circular features that may reflect eruptive centers or other volcano-tectonic structures. A tectonic sketch map (Figure A2 at a scale of 1:1,000,000 was prepared from the images (1407-17204, 1460-17131, 1460-17134) of the infrared band (MSS-7) supplemented by 4X photographic enlargements of the eastern part of the area. Cloud cover is absent, and the images are of good quality.

II. GENERAL GEOLOGY

The mid-Tertiary Mogollon-Datil volcanic field consists of a complex sequence of andesitic and rhyolitic lavas and ash-flow sheets with subordinate interlayered volcaniclastic sedimentary rocks (Elston, et al., 1968, 1970). Volcanism was initiated at about 40 m.y. ago and continued uninterruptedly for 20 m.y., with a peak of activity in the late Oligocene

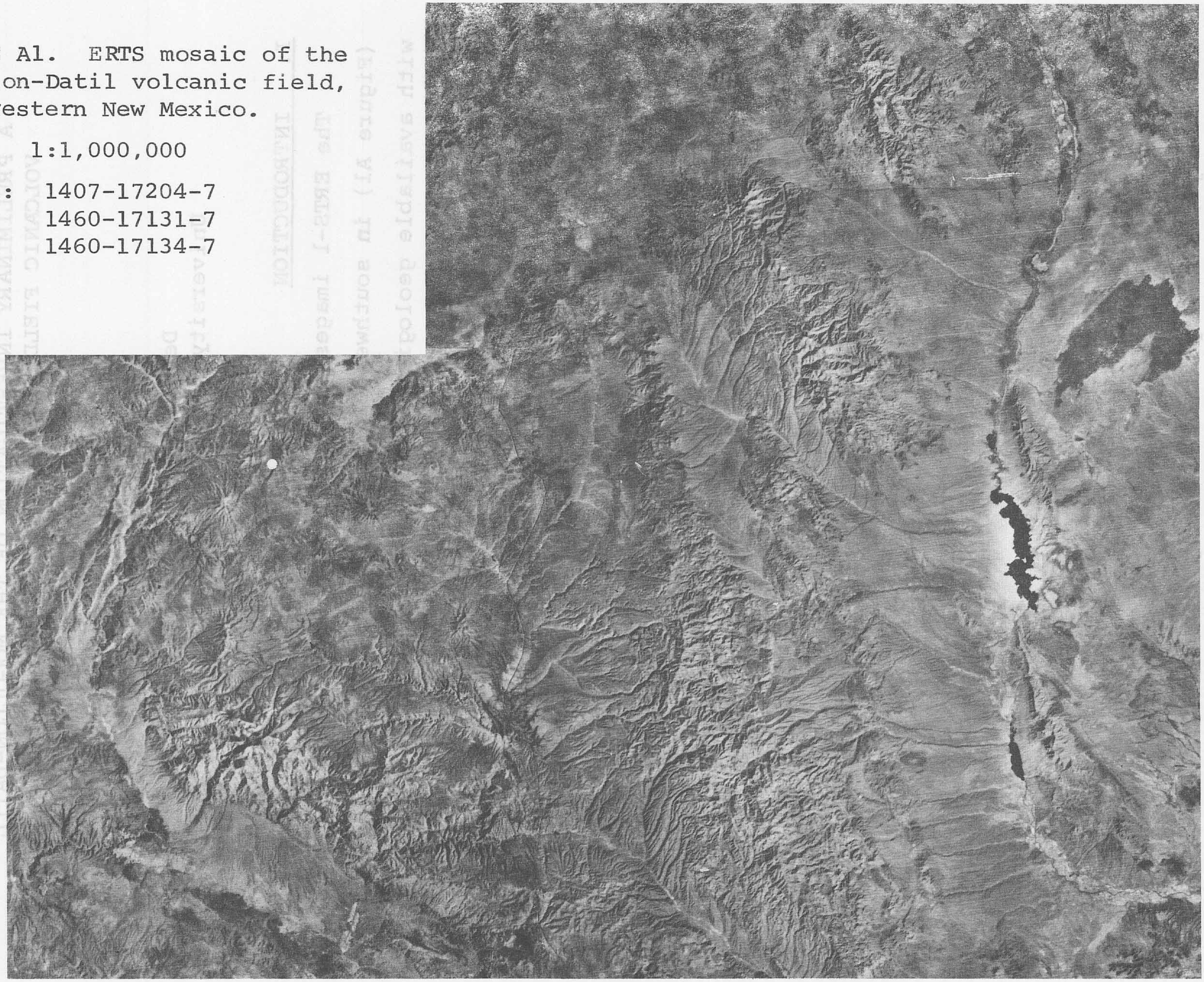
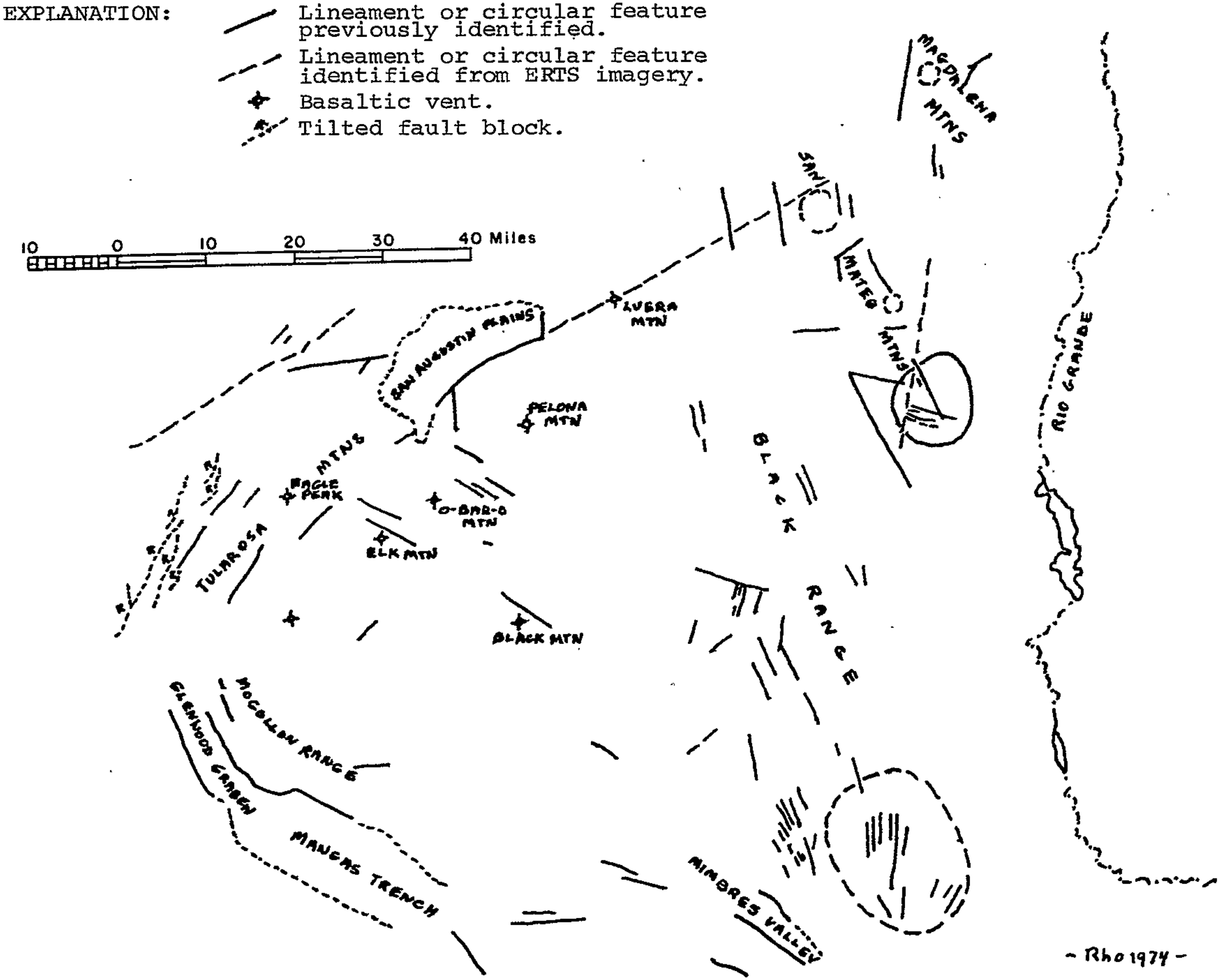


FIGURE A1. ERTS mosaic of the Mogollon-Datil volcanic field, southwestern New Mexico.

Scale: 1:1,000,000

Images: 1407-17204-7
1460-17131-7
1460-17134-7

FIGURE A2. Tectonic sketch map from ERTS imagery of the Mogollon-Datil volcanic province, southwestern New Mexico.



(30-25 m.y. ago) (Elston, et al., 1973). Recent studies have revealed a number of ash-flow cauldrons and other eruptive centers, resulting in an intricate regional structure analogous in many ways to the San Juan province of Colorado (Jicha, 1954; Kuellmer, 1954; Elston, 1957; Ratte, et al., 1969; Ericksen, et al., 1970; Ratte, et al., 1972; Rhodes and Smith, 1972a; Coney, 1974; Deal and Rhodes, 1974; Fodor, 1974; Rhodes, 1974a; Rhodes and Smith, 1974). Major volcanism ceased with the onset of regional Basin-Range tectonism at approximately 20 m.y. ago (Rhodes and Smith, 1972b; Elston, et al., 1973), which occurred concurrently with the initiation of Rio Grande rifting in mid-Miocene time (Chapin, 1971). The Mogollon-Datil volcanic field is interpreted as the surface expression of a major mid-Tertiary batholith (Rhodes, 1974b).

III. SIGNIFICANCE OF ERTS IMAGERY

The relatively advanced state of geologic mapping in the Mogollon-Datil field provides adequate ground control for the interpretation of the ERTS imagery. Lineament patterns on the ERTS images were compared with available geologic maps, and visual evidence of known or suspected volcano-tectonic structures was sought. Special attention was paid to the nature and possible significance of circular features on the ERTS images which may denote volcanic eruptive centers.

A. Lineament Patterns

Late Tertiary Basin-Range and Rio Grande rift faulting has superimposed a strong tectonic overprint upon the mid-Tertiary volcanic field. This is especially the case in the eastern part of the field where a number of isolated ranges such as the Magdalena and San Mateo Mountains exist as eastward-tilted fault blocks within the Rio Grande rift system (Chapin, 1971). Several of the north-trending faults bordering the western sides of the San Mateo and Magdalena Mountains are clearly visible on the ERTS images. A similar north to north-northwest fault pattern can be seen in the Black Range, conforming to mapped fault trends in that area. Farther west, the northwest-trending Mangas Trench and Glenwood Graben are distinct, and the northwesterly fault pattern around Elk and O-Bar-O Mountains can be recognized. An important structural discontinuity is revealed by the northeasterly fault trend in the Tularosa Mountains, which is continuous with the San Agustin Plains arm of the bifurcating Rio Grande rift system (Chapin, 1971), and contrasts markedly with the predominantly northwesterly Basin-Range trend in the Mogollon Plateau. A series of northwest-dipping, tilted fault blocks can be seen around Reserve, conforming to the mapped fault pattern in that area (Weber and Willard, 1959).

Two major northeasterly lineaments on the ERTS images, each approximately 50 km in length, are present in the vicinity of the San Agustin Plains and are not shown on any available geologic maps. These lineaments are probably related to the San Agustin Graben and suggest that this arm of the Rio Grande rift system may be more extensive than previously recognized. It is significant that a suspected mid-Miocene basaltic eruptive center at Luera Peak appears to lie on this lineament.

A major north-northeast lineament in the central San Mateo Mountains can be most easily identified on the 4X photographic enlargements of the ERTS images and has not been recognized previously.

B. Circular Features

Two large circular features, one in the southern San Mateo Mountains and one in the southern Black Range, probably reflect the presence of major ash-flow cauldrons, although neither has been delineated accurately in the field. In the southern San Mateo Mountains, Deal and Rhodes (1974) suggested the existence of a source cauldron for the Vicks Peak ash-flow sheet and included a tectonic sketch map showing the possible outline of the cauldron based on scanty field data. A distinct circular pattern on the ERTS image probably reflects this cauldron and agrees closely with the position of the structure suggested by Deal and Rhodes.

A well-defined elliptical feature in the southern Black Range may reflect the existence of a source cauldron for the Kneeling Nun ash-flow sheet. Available geologic data, including a thick section of Kneeling Nun rhyolite tuff within the proposed cauldron (Ericksen, et al., 1970), possible vents for the tuff (Kuellmer, 1954), and the presence of post-cauldron rhyolite lavas around the southern margin (Jicha, 1954) are compatible with a cauldron in this part of the Black Range. This feature warrants more detailed investigation in the field.

A small but distinct circular feature is present in the northern Magdalena Mountains. On the State Geologic Map (Dane and Bachman, 1965), this area is shown as underlain by late Tertiary rhyolite lava. It is possible that the feature represents an extrusive rhyolite dome or, less likely, local structural doming caused by the intrusion of a shallow pluton. In view of the widespread mineralization in the northern Magdalena Mountains, priority should be given to field investigation of this feature. Other small circular features in the San Mateo Mountains have been compared with the geologic map (Deal, 1973) but have no obvious geologic explanation. These, too, should be field checked and analyzed.

Young basaltic centers of the Bearwallow Mountain Formation (21 m.y. ago) show on the ERTS imagery as small craterlike depressions at the summits of prominent peaks (e.g. Eagle, Elk, O-Bar-O, Pelona Mountains). These are the only eruptive centers in the Mogollon-Datil field that retain vestiges of their original volcanic morphology and so can be recognized on the ERTS imagery despite their small size.

IV. CONCLUSIONS

The complex stratigraphic relationships and detailed structure of the Mogollon-Datil field are too intricate to be resolved on the scale of the ERTS imagery. The small scale yet high detail of the imagery, however, is ideal for interpretation of regional structural trends in the volcanic field and recognition of major volcano-tectonic features. In geologically unmapped terrain, the ERTS imagery has special significance in identifying possible eruptive centers and unravelling the volcano-tectonic framework of the region. Major ash-flow cauldrons not identified during the course of detailed field mapping may be recognized as circular features on ERTS imagery. The unknown volcanic terrain in the Sierra Madre Occidental of Mexico and the Basin-Range province of the United States are areas where the ERTS imagery may be of special significance.

REFERENCES

C. E. Chapin. The Rio Grande rift, Part I: Modifications and additions. New Mexico Geol. Soc. Guidebook 22, 1971. p. 191-201.

P. J. Coney. Structure, Volcanic Stratigraphy, and Gravity Across the Mogollon Plateau, New Mexico. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974.

C. H. Dane and G. O. Bachman. Geologic Map of New Mexico: U.S. Geol. Survey, 1965.

E. G. Deal. Geology of the Northern San Mateo Mountains, Socorro County, New Mexico: A Study of a Rhyolite Ash-flow Tuff Cauldron and the Role of Laminar Flow in Ash-flow Tuffs. Ph.D. dissertation, Univ. New Mexico, Albuquerque, 1973. 136p.

E. G. Deal and R. C. Rhodes. Volcano-tectonic structures in the San Mateo Mountains, Socorro County, New Mexico. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974.

W. E. Elston. Geology and mineral resources of Dwyer Quadrangle, Grant, Lura, and Sierra Counties, New Mexico. New Mexico Bur. Mines Min. Res., Bull. 38, 1957. 86p.

W. E. Elston, P. J. Coney, and R. C. Rhodes. A progress report on the Mogollon Plateau Volcanic Province, South-Western New Mexico. Quart. Colorado School Mines, V. 63, 1968. p. 261-287.

____________. Progress report on the Mogollon Plateau Volcanic Province, Southwestern New Mexico, No. 2. New Mexico Geol. Soc. Guidebook 21, 1970. p. 75-86.

W. E. Elston, P. E. Damon, P. J. Coney, R. C. Rhodes, E. I. Smith, and M. Bikerman. Tertiary volcanic rocks, Mogollon-Datil Province, New Mexico, and surrounding region: K-Ar dates, patterns of eruption, and periods of mineralization. Geol. Soc. Amer. Bull., B. 84, 1973. p. 2259-2274.

G. E. Ericksen; H. Wedow, Jr.; G. P. Eaton; and G. R. Leland. Mineral resources of the Black Range Primitive Area, Grant, Sierra, and Catron Counties, New Mexico. U.S. Geol. Survey Bull. 1319-E, 1970. 162p.

R. V. Fodor. Volcanic geology of the northern Black Range, New Mexico. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974.

H. L. Jicha, Jr. Geology and mineral resources of Lake Valley Quadrangle, Grant, Lura, and Sierra Counties, New Mexico. New Mexico Bur. Mines Min. Res. Bull. 37, 1954. 93p.

F. J. Kuellmer. Geologic section of the Black Range at Kingston, New Mexico. New Mexico Bur. Mines Min. Res. Bull. 33, 1954. 100p.

J. C. Ratte, A. R. Landis, D. L. Gaskill, and R. G. Raabe. Mineral resources of the Blue Range Primitive Area, Greenlee County, Arizona, and Catron County, New Mexico. U.S. Geol. Survey Bull. 1261-E, 1969. 91p.

J. C. Ratte, D. L. Gaskill, G. P. Eaton, D. L. Peterson, R. B. Stotelmeyer, and H. C. Meeves. Mineral Resources of the Gila Primitive Area and Gila Wilderness, Catron and Grant Counties, New Mexico. U.S. Geol. Survey, Open File Report, 1972.

R. C. Rhodes. Volcanic geology of the Mogollon Range and adjacent areas, Catron and Grant Counties, New Mexico. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974a.

____________. Petrologic framework of the Mogollon Plateau volcanic ring complex, New Mexico, surface expression of a major batholith. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974b.

R. C. Rhodes, E. I. Smith. Geology and tectonic setting of the Mule Creek Caldera, New Mexico, U.S.A. Bull. Volcanol., V. 36, 1972a. p. 401-411.

____________. Distribution and directional fabric of ash-flow sheets in the northwestern Mogollon Plateau, New Mexico. Geol. Soc. Amer. Bull., V. 83, 1972b. p. 1863-1868.

______________. Stratigraphy and structure of the northwestern part of the Mogollon Plateau Volcanic Province, Catron County, New Mexico. Univ. New Mexico Publ. in Geol. No. 8, in press, 1974.

R. H. Weber, M. E. Willard. Reconnaissance geologic map of Reserve Thirty-minute Quadrangle. New Mexico Bur. Mines Min. Res. Geol. Map 12, 1959.

SUPPLEMENT B

AN EVALUATION OF THE USE OF ERTS-1 IMAGERY
IN THE MAGDALENA MOUNTAINS

by S. C. Feldman
Technology Application Center
University of New Mexico, Albuquerque

and

C. E. Chapin
New Mexico Bureau of Mines
and Mineral Resources, Socorro

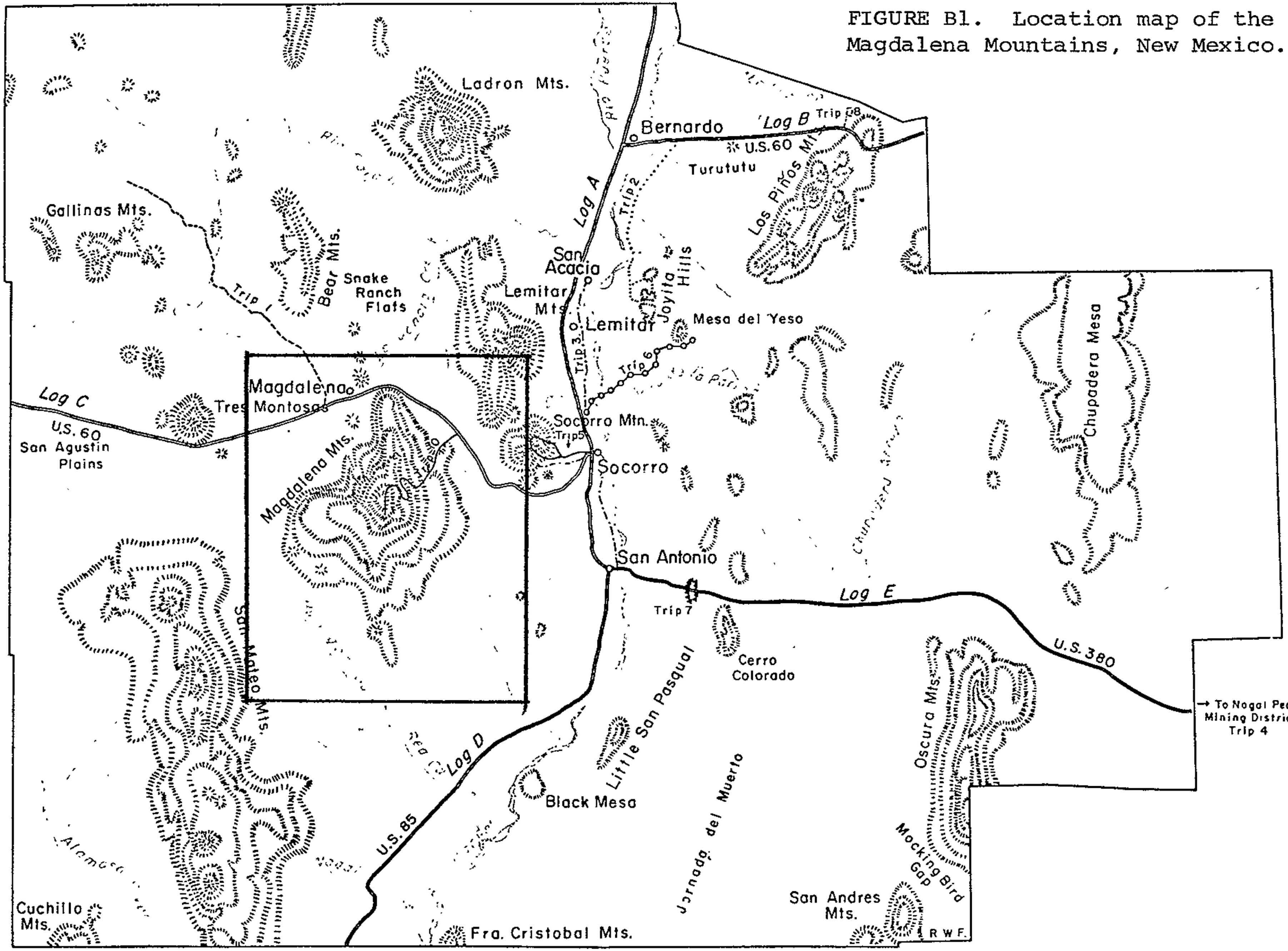
I. INTRODUCTION

The object of the investigation was to evaluate the use of ERTS-1 imagery as a geologic tool with respect to structure, stratigraphy, and mineralization in the Magdalena Mountains, west of Socorro in central New Mexico (Figure B1). ERTS-1 images of the Magdalena Mountains were compared with existing aerial photographs and geologic maps of the region. Bureau of Mines personnel have been studying the Magdalena area over the past few years as part of an ongoing Magdalena project.

Available aerial photography of the region included a photo mosaic at a scale of 1:24,000 made by Aero Service Inc. in 1970. No good quality Gemini, Apollo, or NASA high-altitude aerial photography of the Magdalenas is presently available. ERTS-1 images used in the evaluation included:

Number	Scale	Format
1460-17131-5	1:1,000,000	B&W print
1460-17131-7	1:1,000,000	B&W print
1064-17150-5	1:250,000	B&W print
1460-17134	approx. 1:250,000	False-color composite

FIGURE B1. Location map of the Magdalena Mountains, New Mexico.



II. GENERAL GEOLOGY

Located in central New Mexico west of Socorro, the Magdalena Mountains consist of a northern Precambrian core overlain by a west-dipping hogback of Paleozoic limestones, shales, and quartzites (Dane and Bachman, 1965). It is in these Paleozoic rocks, primarily the Mississippian Kelly Limestone, that the zinc and lead deposits of the productive Magdalena mining district are localized. West and south of the Paleozoic sequence of Kelly, Sandia, Madera, and Abo Formations are extensive areas of Oligocene extrusive rocks which vary from andesitic-latitic breccias to rhyolitic ash-flow tuffs. The eastern margin of the mid-Tertiary Mount Withington cauldron overlaps the western side of the Magdalena Mountains, and an older partially buried ash-flow cauldron is suspected to be present in the southern part of the mountain range (Deal, 1973).

In the late Oligocene, numerous stocks and dike swarms were emplaced in the northern part of the range. The Nitt stock has been dated at 28.0 m.y. and the Anchor Canyon stock at 28.3 m.y.; other stocks have been dated at 27-30 m.y. The intrusion of dikes occurred concurrently and following emplacement of the stocks.

The dominant structural trend in the Magdalenas is north-south. Longitudinal faults with as much as 1500 feet of dip displacement have broken Oligocene and older rocks. These longitudinal faults have an overall orientation of N10°W. According to Titley (1959, p.144), "transverse or east-west faults are present but do not exhibit the continuity or magnitude of displacement that characterize the longitudinal breaks."

Ore deposits in the Magdalena district generally occur as replacement mineralization in the Kelly limestone adjacent to stocks. The ore bodies have a north-south trend and are intimately related to major longitudinal faulting.

III. SIGNIFICANCE OF ERTS IMAGERY

ERTS images of the Magdalena Mountains were compared with a photo mosaic of the same area at a scale of 1:24,000 made by Aero Service Inc. in 1970. It was found that the ERTS imagery provides excellent discrimination of first-order features such as major faults and lineaments and has the advantage of providing regional perspective which is difficult to obtain with the aerial photo mosaic alone.

Secondary structural features, however, are not always apparent on ERTS images, as evidenced in the southern half of the Magdalena Mountains, and in the northern section, south of the town of Magdalena. In the latter area, a rectilinear drainage pattern formed by a series of joints and faults cannot be seen on ERTS images. South of Magdalena, in an area underlain by rhyolite flows, a northwest set of photolinears defined by drainage following closely spaced jointing and faulting was identified on the 1:24,000 aerial mosaic. This fabric was not easily discerned on the ERTS images but could be seen after being located on the large-scale aerial.

On the ERTS imagery of the Magdalena Mountains, the dominant fault and joint trend appears to be northeast. This fabric masks the more important N10^{o}W faults which control the emplacement of stocks and ore bodies. Realization of the presence of a northeast-trending structural fabric, exhibited so clearly on the ERTS images, may contribute to a better understanding of ore emplacement in the Magdalenas.

One of the major northeast-trending lineaments seen on the ERTS images which passes through the center of the Magdalena Mountains had previously been identified from low-altitude photographs. Using ERTS, this lineament appears to extend southwest and northeast of the Magdalena Mountains (Figure B2). Its extension can be traced southwest through the north end of the San Mateo Mountains and south of the San Agustin Plains (see accompanying paper by Rodney Rhodes). To the northeast, it lines up with the dike swarm and vent on Chupadera Mesa, the southern end of the Albuquerque-Belen Basin, and the southeastern margin of the Estancia Basin, marking the southern extent of Precambrian outcrops in the immediate vicinity.

In the west-central Magdalenas there is a strongly developed circular drainage pattern which cannot be explained by existing data. It is less obvious on the aerial mosaic. A recently completed aerial magnetic map on open file at the New Mexico Bureau of Mines and Mineral Resources shows circular anomalies in the vicinity, but none appear to match exactly with the circular drainage pattern. The prominent northeast lineament discussed above cuts through the southern end of the circular feature.

Rock types cannot be differentiated in the Magdalenas either on the ERTS images or on the low altitude mosaic. The area is heavily forested and is near uniformly red on the false-color composite, at least in visual analysis. Bedrock can be differentiated from pediment gravel and alluvium, but finer distinctions cannot be made visually.

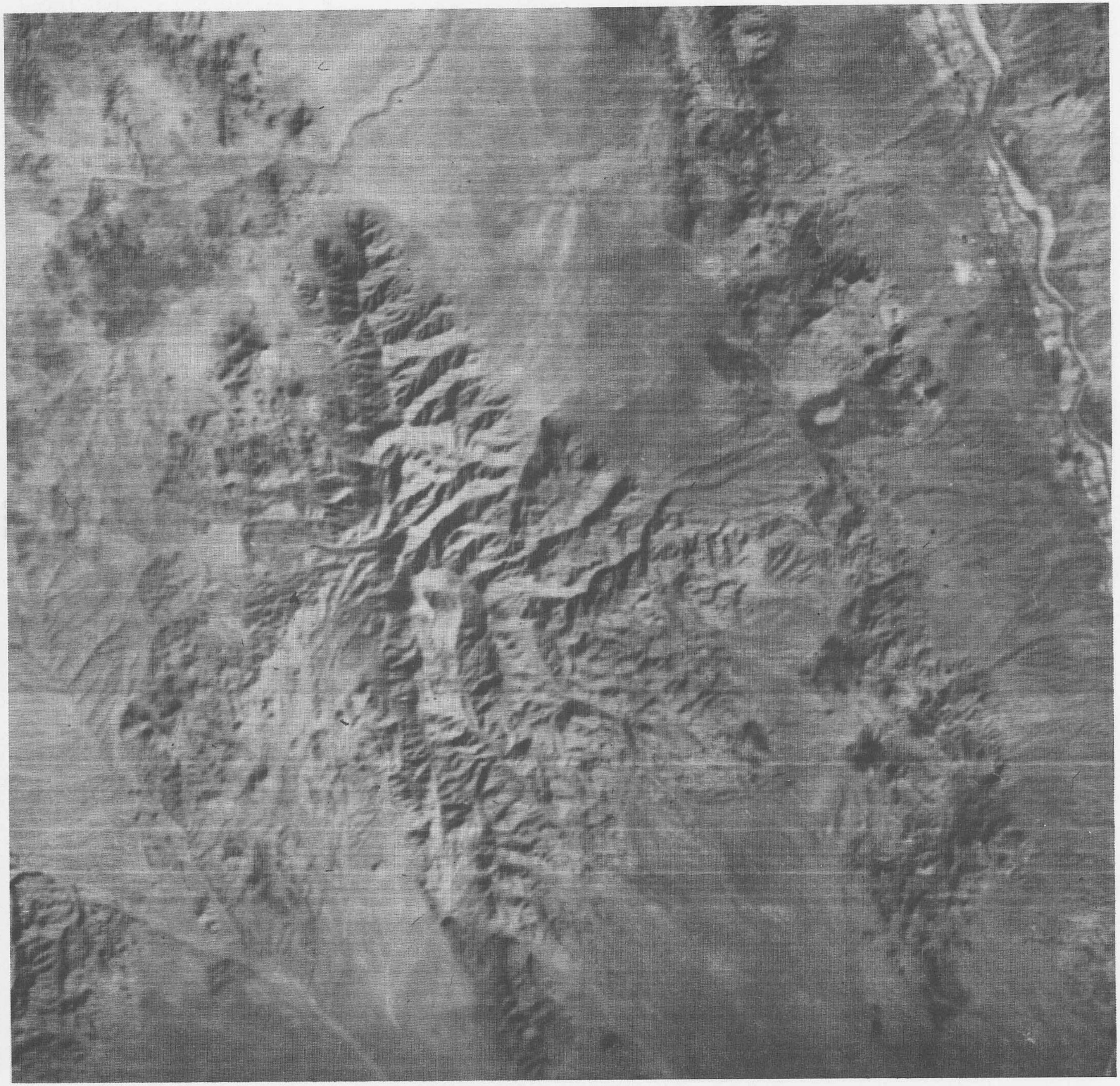


FIGURE B2. The Magdalena Mountains, central New Mexico.

ERTS Image: 1460-17134-7

Scale: 1:250,000

The Tres Montosos stock, two miles in diameter, located northwest of the Magdalenas is recognizable on the ERTS image and on the aerial mosiac. It is difficult to identify on the ground because of a surficial cover of wind-blown sand. Other small stocks in the northern Magdalenas cannot be differentiated, however, from the air. Areas of hydrothermal alteration adjacent to the stocks are very small and are not apparent on the Spectral Data Corporation color composite.

IV. SUMMARY

In summary, the ERTS images of the Magdalena Mountains are excellent for the identification of first-order faults and lineaments. Secondary features are not as obvious. The dominant N10^{o}W faults do not appear as strongly as less important northeast faults. This may be due to the northeast lineament bias resulting from sun angle (Short, 1973). The relative importance of these northeast trends in mineralization remains to be explored.

ERTS imagery is not a substitute for large-scale aerial photographs. Mosaics at 1:24,000 are not generally available for most areas and are costly to produce. When aerial photography can be obtained, ERTS is a valuable complement; in other instances it is an invaluable aid to geologic mapping and analysis.

REFERENCES

E. G. Deal. Geology of the Northern San Mateo Mountains, Socorro County, New Mexico: A Study of A Rhyolite Ash-flow Tuff Cauldron and the Role of Laminar Flow in Ash-flow Tuffs. Ph.D. dissertation, Univ. New Mexico, Albuquerque, 1973. 136p.

N. M. Short. Mineral Resources, geological structure and landform surveys. In: Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Vol. 3 - Discipline Summary Reports, 1973. p. 30-39.

S. R. Titley. Geological summary of the Magdalena mining district, Socorro County, New Mexico. New Mexico Geol. Soc. Guidebook 10, 1959. p. 144-153.