DATA COLLECTION PLAN FOR GEOLOGICAL REMOTE SENSING IN THE VOLCANIC TERRAIN OF TRANS-PECOS TEXAS, ASVT TEST SITE 5

prepared by

Robert J. Finley
Robert W. Baumgardner, Jr.
Bureau of Economic Geology
The University of Texas at Austin
Austin, Texas 78712

in cooperation with

The Texas Natural Resources Information System

and

The National Aeronautics and Space Administration

TDWR/TNRIS IAC No. (80-81)-0715

May 31, 1980

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Scope

This document describes a ground and aircraft data collection plan to be carried out as part of the Texas Applications System Verification and Transfer (ASVT) Project, which is a joint effort of the Texas Natural Resources Information System (TNRIS) Task Force and the National Aeronautics and Space Administration (NASA). The Texas Department of Water Resources/TNRIS has contracted with the Bureau of Economic Geology for the preparation of this Data Collection Plan (DCP), to be initially implemented during the period June-August 1980 as described herein. This DCP applies to a test site in the Trans-Pecos region of Texas, which is one of five test sites designated within the state. Previously, a ground data collection plan had been prepared for the coastal test site (Finley, 1978), and a plan is in preparation for the High Plains test site.

1.2 Test Site Objectives

The part of Trans-Pecos Texas included within the ASVT test site includes four mining districts, mostly active in the past, as well as numerous prospects or occurrences (Garner and others, 1979). Commercial interest in the Shafter District (fig. 1) is high, and production of silver may resume in that area within the next few years. Mineral resources known to occur within the test site include silver, fluorspar, lead, manganese, copper, zinc, barite, and uranium. Many of these metallic and nonmetallic mineral resources are spatially related to Tertiary volcanic calderas, or cauldrons (McAnulty, 1976; Henry, personal communication, 1980). Three such centers of igneous intrusive and extrusive volcanic rocks have therefore been selected for intensive study within a larger area of volcanic rocks. These are the Quitman, Chinati, and Christmas Mountains (fig. 1), all of which contain known areas of mineralization.

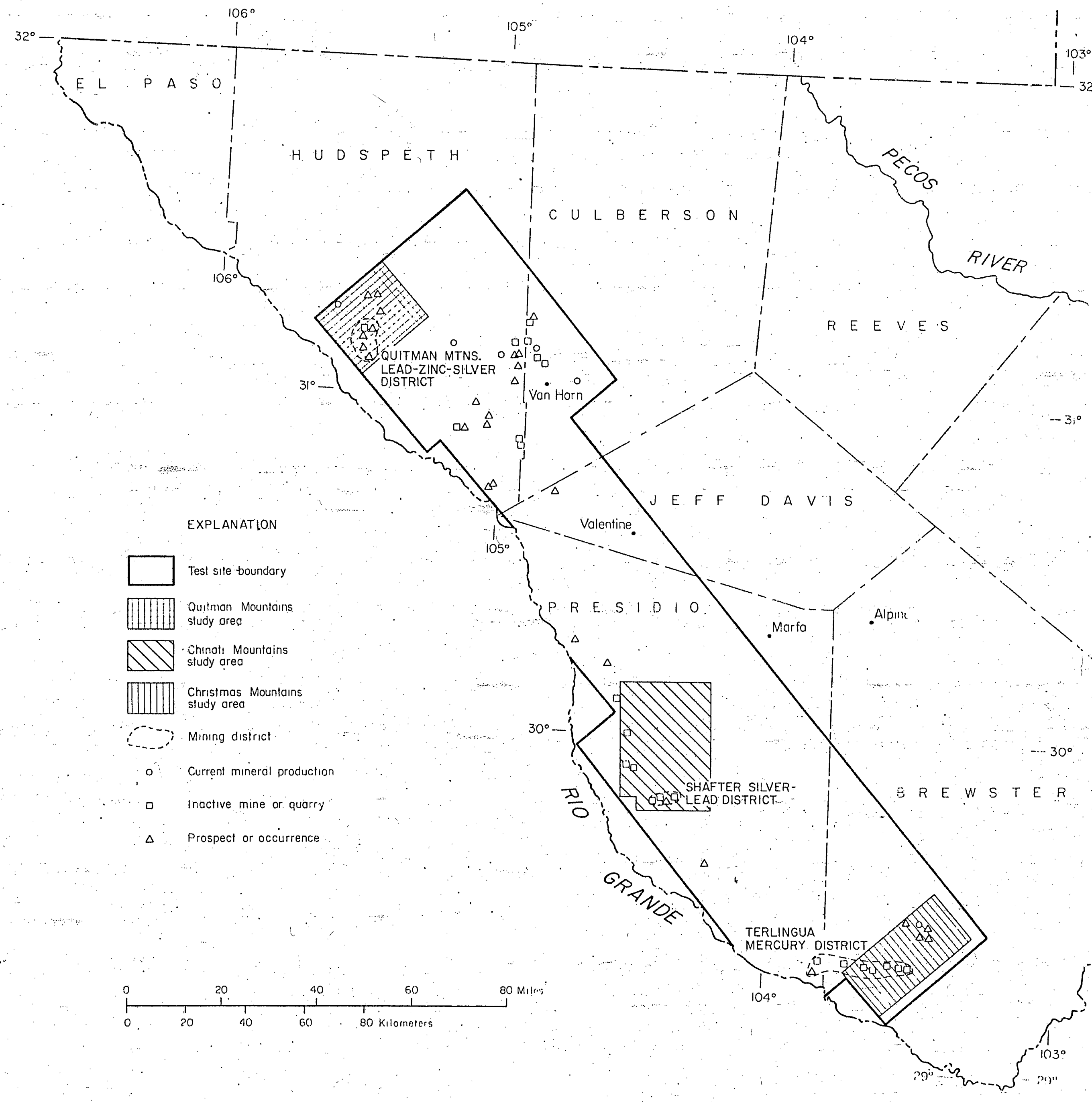

Figure 1. Trans-Pecos test site and vicinity, showing mineral production and occurrences (from Garner and others, 1979).

The objectives of this study are (1) to test and apply remote sensing techniques as a tool for general geologic mapping in complex volcanic sequences often including terrain that may be inaccessible, (2) to differentiate rock types within the volcanic sequence with emphasis on rock types that are specifically related to mineralization, and (3) to detect directly hydrothermal alteration zones of the type that may be associated with mineralization. These applications of remote sensing techniques fall within the role of the Bureau of Economic Geology in providing extensive advisory, technical, and informational services relating to the natural resources of Texas.

1.3 The Trans-Pecos Test Site

The Trans-Pecos test site trends NW-SE through parts of five counties in West Texas (fig. 1). The long dimension of the site is approximately 307 km (190 mi), and the approximate width varies from a minimum of 51 km (32 mi) to a maximum of 67 km (42 mi). Physiographically, the test site is within the Trans-Pecos Basin-Range Province (Kier and others, 1977) and is characterized by mountain ranges and intervening basins of alluvial fill. The mountains within the test site are primarily composed of fine-grained volcanic rocks, generally of rhyolitic, trachytic, or basaltic composition (Garner and others, 1979). Both extrusive and intrusive volcanic igneous rocks are present, often in complex associations developed during multiple stages of volcanic activity. Structurally, the test site is part of the Diablo Platform, an area of past moderate uplift, except for the southeastern end of the site that overlies part of the buried Ouachita Mountains front.

Mean annual rainfall over the test site is 305 mm (12 inches) or less per year, and the natural vegetation is a desert shrub, savanna (Kier and others, 1977). Bailey (1978) classifies the region as the tarbush-creosotebush section of the Chihuahuan Desert Province. Characteristic vegetation includes thorny shrubs in open stands to closed thickets and some short grass in association with the shrubs. All climax vegetation is drought tolerant. Perennial grasses include black grama, threeawns, and burrograss;

shrubs include creosotebush, tarbush, fourwing saltbush, acacias, and mesquite (Turner, 1977). Overall, the vegetative cover is sparse, except toward the interior of the inter-range basin fills where more extensive grass cover is present, such as the Marfa Plain near Marfa in Presidio County.

Soils of the region are light reddish-brown to brown sands, clay loams and clays, most of which are calcareous and some of which are saline. Rough, stony lands are also present (Kier and others, 1977). Many soils in the region are shallow to very shallow.

As a result of sparse vegetation and thin soils, bedrock is reasonably well exposed to airborne and satellite remote sensing devices. The area is therefore suitable for attempts to detect altered and unaltered rock types without relying strictly on geobotanical methods, as must be done in areas of heavy vegetative cover. Some interference from vegetation is expected, however, in relating spectral signatures to specific rock types. A combination of data types (aerial photography and multispectral scanner imagery) from platforms at several different altitudes may be most helpful in overcoming this problem. To this end, three areas of intensive study have been selected within the test site (fig. 1) wherein ground data collection and collection of data by aircraft will be concentrated.

1.3.1 Test Site Intensive Study Areas

The intensive study areas are described here in order of importance to this investigation. These descriptions were prepared in consultation with Dr. Christopher D. Henry, of the Bureau of Economic Geology, whose ongoing work in West Texas relates to geothermal resources, geologic mapping of complex volcanic sequences, and potential for caldera-related mineralization in the region.

1.3.1.1 Chinati Mountains

The Chinati caldera includes all of the Chinati Mountains and is a roughly circular feature 20 km (12.4 mi) by 23 km (14.3 mi) (McAnulty, 1976). The volcanic rocks of Oligocene age include a sequence of rhyolite and trachyte flows more than 1,000 m (3,300 ft) thick. As the younger West Chinati stock, which consists of a monzodiorite margin and a core of porphyritic hornblende granite (fig. 2) (Cepeda, 1979), was intruded, it tilted the overlying volcanic rocks. Along the north side of the Chinati caldera is evidence for an older, buried caldera, the Infiernito caldera; an ash-flow tuff is evidence of its active phase (Henry, personal communication, 1980).

Mineralization in the Shafter District (fig. 1) lies along the south margin of the Chinati caldera and is found within a Permian dolomitic limestone in veins and along bedding. Mineralization is a hydrothermal emplacement associated with the magmas of the Chinati caldera. Altered volcanic rocks are present but are not mineralized. Ring fracture intrusions of porphyritic hornblende andesite are present in the Shafter area and may be related to the source of mineralization, but further investigation is required.

The sequence ascribed to the Infiernito caldera includes (1) a rhyolitic flow over Permian and Cretaceous sediments, (2) a porphyritic flow of intermediate silica content, and (3) a thick ash-flow tuff, followed by intrusion and late doming to tilt the rock units to the north (Henry, personal communication, 1980). All parts of this volcanic sequence show some hydrothermal alteration, occasionally showing an intense, bleached appearance. This alteration occurs over a large enough area that it should be detectable using remote sensing data. There may be some potential for associated mineralization, but no occurrences are known. Because flow-banded rhyolites have been intruded along a fracture zone in this same area, lineaments and their relationship to the alteration zone should be examined using remote sensing data.

Other mineralization in the Chinati Mountains includes uranium mineralization along fractures in a rhyolite porphyry intrusion (the Shely prospect), and disseminated copper in an outlier of the West Chinati stock. The West Chinati stock itself contains potentially commercial deposits of lead, zinc, silver, and fluorspar (McAnulty, 1972).

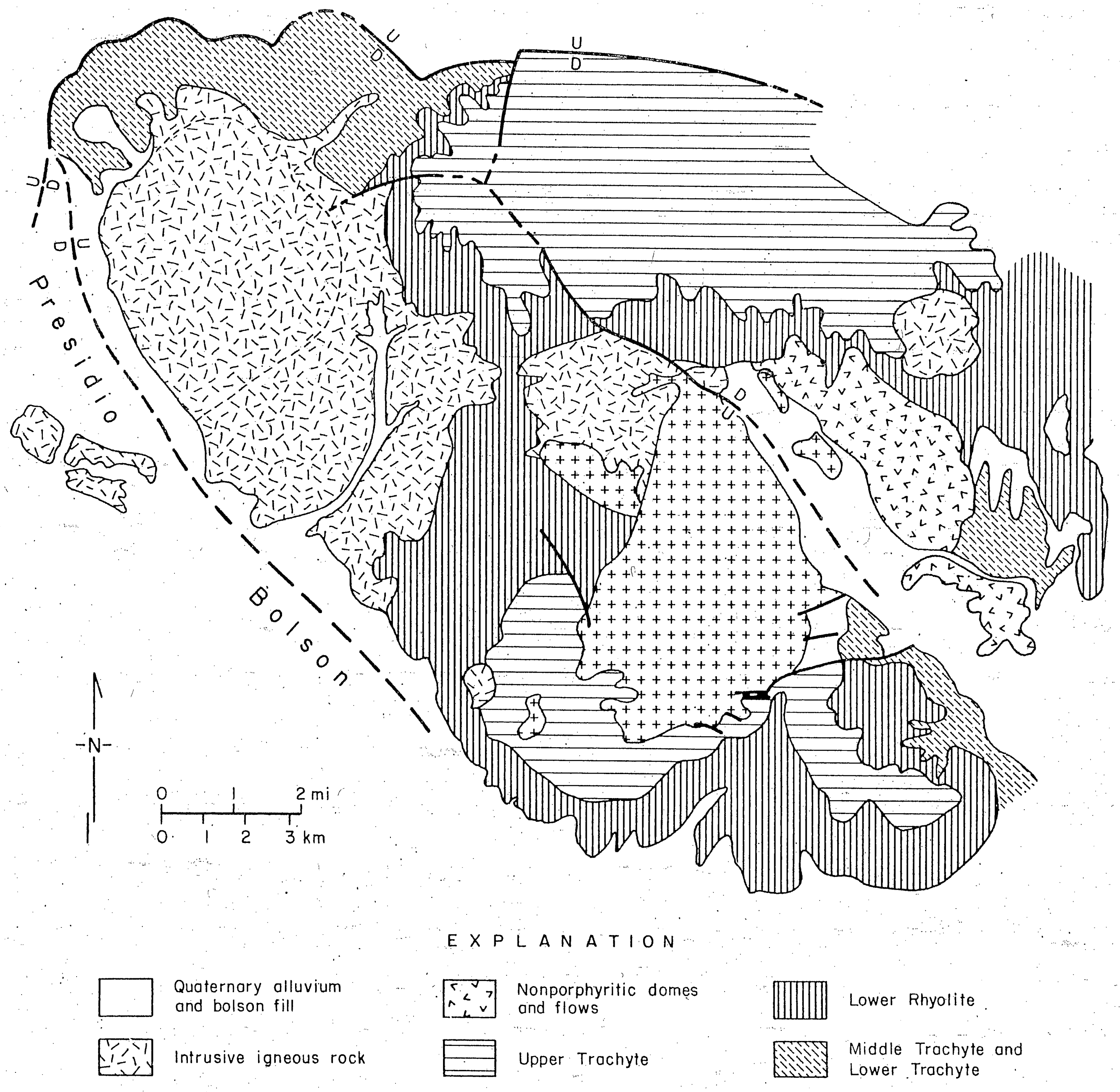

Figure 2. General geologic map of Chinati Mountains caldera (from Cepeda, 1979).

1.3.1.2 Quitman Mountains

The Quitman Mountains are also a volcanic feature with ash-flow tuffs and other extrusive igneous rocks as caldera fill. Lead, zinc, silver, copper, and minor molybdenum sulfide mineralization is associated with an intrusive igneous stock in the northern part of the intensive study area (fig. 1) (McAnulty, 1976). Fluorspar has been found as veins within a sheeted zone and prospected over a distance of several hundred feet (McAnulty, 1974); this suggests that the relationship of lineaments and such occurrences should be investigated. Fluorspar is also associated with the Sierra Blanca igneous intrusives northwest of the Quitman Mountains (Garner and others, 1979).

1.3.1.3 Christmas Mountains

The Christmas Mountains are located in the southeast part of the test site (fig. 1) and include both intrusive and extrusive igneous rocks of Tertiary age. Numerous small intrusions occur within Brewster County in the area around this intensive study site. Many of these, as well as intrusions within the Christmas Mountains, have been hydrothermally altered (Henry, personal communication, 1980).

Fluorspar is present at contacts of rhyolite and other igneous rocks with Lower Cretaceous limestones such as the Buda and Santa Elena Limestones. The rhyolite is altered and may be the source of the fluorine, which has reacted with the calcium carbonate to form the fluorspar deposits. Most of the deposits are small, and many are difficult to reach, even on foot (McAnulty, 1974).

1.4 Objective of Surface Observations

Surface observations will be aimed at providing collateral data that will assist in developing classification techniques for use with the remote sensor data. Geologic mapping at a scale of 1:250,000 has been completed for the entire Trans-Pecos region as part of the Geologic Atlas of Texas (Barnes, in progress). At that scale, however, individual rock types within Tertiary intrusive and extrusive igneous complexes are not differentiated. Data from work in progress by Dr. Christopher D. Henry and Timothy

W. Duex of the Bureau of Economic Geology will be utilized to document spectral differences among rock types in these complexes at scales as large as 1:24,000.

No ground observations are planned to coincide with the Landsat satellite overpass. An effort is being made to coordinate weather predictions available in Houston and Austin with actual cloud-cover observations in Marfa (fig. 1) at overpass time. U.S. Department of Agriculture Soil Conservation Service personnel in Marfa are being contacted in this regard.

Once Landsat data have been successfully collected, field observations of the relative radiance of different rock types present in the caldera complexes will be made. These should be carried out shortly (within several weeks) after the Landsat overpass so that the sun angle is similar to that associated with the Landsat data. Further activities in support of the surface observation objective are listed in Section 2.3.

2.0 DATA REQUIREMENTS AND ACQUISITION

A selection of Landsat products will be utilized by the ASVT Project Team as part of analysis of the Trans-Pecos test site. These requirements are outlined here, as is the need for surface and airborne data.

2.1 Landsat Data Requirements

Landsat data are to be provided by Landsat-3, with four bands of Multispectral Scanner (MSS) data, and by four Return Beam Vidicon (RBV) images corresponding to each Landsat scene over the test site. Because of the possible present lack of Landsat-3 MSS data along the west boundary of the image area, parts of four and possibly five scenes will be needed to cover the entire test site (fig. 3). All Landsat products will be sent to TNRIS for indexing, storage, and retrieval to support the ASVT Project Team.

MSS Products

(1) Computer-compatible tapes, all data

(2) Black-and-white positive transparencies, 1:1,000,000 scale, all bands

(3) FCC positive transparency, 1:1,000,000 scale

(4) FCC paper print, 1:250,000 scale

(5) Black-and-white paper prints, 1:250,000 scale, bands 5 and 7

(6) Black-and-white positive transparencies, 1:3,369,000, all bands

RBV Products

(1) Black-and-white positive transparency, 1:500,000 (four for each MSS scene where coverage includes part of the test site)

(2) Black-and-white negative transparency, 1:500,000 (four for each MSS scene where coverage includes part of the test site)

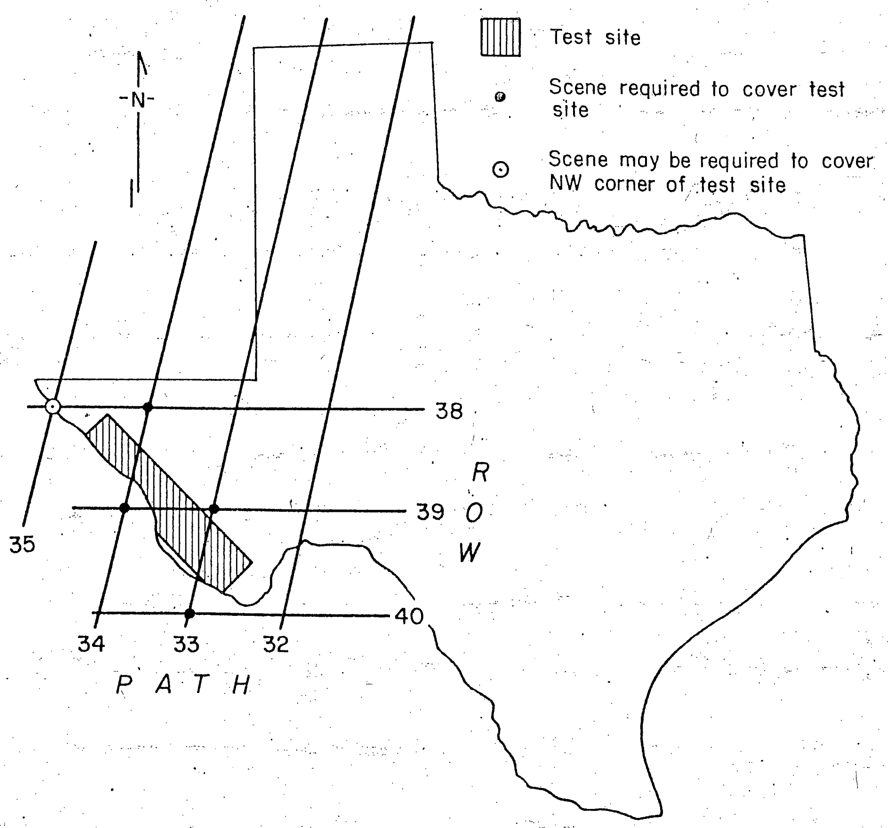

Figure 3. Path/row index map for Landsat scenes covering parts of the Trans-Pecos test site.

(3) Black-and-white positive paper prints, 1:125,000 or as large a scale as available (four for each MSS scene where coverage includes part of the test site)

The following schedule of Landsat-3 overpasses will cover parts of the Trans-Pecos test site:

Path 33	Path 34	Path 35
June 18, 1980	June 19, 1980	June 20, 1980
July 5, 1980	July 6, 1980	July 7, 1980
July 23, 1980	July 24, 1980	July 25, 1980
August 10, 1980	August 11, 1980	August 12, 1980

Data from Path 35 may be required to cover the northwest part of the test site owing to possible lack of data recovery in part of each Landsat scene.

2.1.1 Landsat Data Acquisition

Landsat products defined above will be obtained by TNRIS through the EROS Data Center.

2.2 Aircraft Data Requirements and Acquisition

Aerial photography is an effective means of providing natural resource information at large scales and high resolution and of aiding in the analysis of small-scale, low-resolution Landsat data. This is especially true over the Trans-Pecos volcanic terrain, much of which is not readily accessible. Aircraft data are required to (1) support the development of analysis techniques within the Remote Sensing Information Subsystem (RSIS), (2) evaluate other sensor systems and components, such as NS-001 scanner data and higher resolution RBV imagery, (3) determine the optimum mix of aircraft and satellite data that will meet the resource information needs of state agencies, and (4) develop and carry out an evaluation of Landsat-derived classification products using aerial photography in conjunction with ground data and published information. The primary aircraft support will be provided by NASA, utilizing cameras and scanners as outlined below.

2.2.1 NASA Aircraft

NASA aircraft will obtain aerial photographs of the entire Trans-Pecos test site, scale of 1:120,000, and over three intensive study areas (fig. 1) at a scale of 1:30,000. Multispectral scanner data will be obtained in conjunction with the photography. All imagery and scanner data will be titled and indexed in accordance with standard NASA procedures to show the location and extent of coverage.

2.2.2 Sensor Parameters

The NASA aircraft data acquisition will be governed by the following requirements and constraints:

(1) High-Altitude Data Acquisition (1:120,000)

Aircraft: RB57 at 18,288 m (60,000 feet) altitude

Area of coverage: Entire test site (fig. 1)

Sensors: Zeiss 152-mm (6-inch) focal length camera with color film (EK Type SO-397, haze filter)

Zeiss 152-mm (6-inch) focal length camera with color-IR film (EK Type 2443, Wratten No. 12 filter)

RS-18 scanner simultaneous with photography

Overlap: 60% forward overlap and 30% sidelap over total area with Zeiss cameras

Permissible cloud cover: 10% maximum

(2) Low-Altitude Data Acquisition (1:30,000)

Aircraft: C130 at 4,572 m (15,000 feet) altitude

Area of coverage: Three areas within the test site (fig. 1)

Sensors: Zeiss 152-mm (6-inch) focal length camera with color film (EK Type SO-397, haze filter)

Zeiss 152-mm (6-inch) focal length camera with color-IR film (EK Type 2443, Wratten No. 12 filter)

NS-001 scanner is mandatory in 0.63-0.69, 1.55-1.75, 2.08-2.35, and 10.4-12.5 micron bandwidths; other bandwidths are highly desirable

Overlap: 60% forward overlap along flight line with Zeiss cameras

Permissible cloud cover: Maximum of 5% within flight line area

Table 1 lists bandwidths associated with three airborne multispectral scanners that may be utilized for data collection. The NS-001 scanner is to be used exclusively in the C-130 because the 1.55 to 1.75- and 2.08 to 2.35-micrometer bandwidths are needed for geologic applications. It is recognized that the RS-18 scanner cannot be operated for low-altitude data acquisition. Radiometer data are to be collected along flight lines to aid in calibration of the thermal infrared channel of the multispectral scanners.

2.2.3 Aircraft Deployment

The flight window for the C-130 and RB-57 aircraft is June 16, 1980, through July 11, 1980. There are no requirements for these aircraft to synchronize operations either with each other or with the Landsat-3 overpass. Experience in the area indicates that cumulus cloud build-up often begins around noon if it is to occur. The early part of the usual 10 a.m. to 2 p.m. data acquisition period is therefore likely to be the most favorable.

2.2.4 NASA Aircraft Data Products

The following products are to be supplied by NASA to TNRIS for indexing, storage, and retrieval to support the ASVT Project Team:

(1) Two second-generation color positive transparencies derived from all color and color infrared original rolls.

(2) One second-generation black-and-white positive transparency of selected bands (see table 1) of multispectral scanner data, as well as one set of negatives for the same data.

Table 1. MSS Sensors and Bandwidths (in microns), available at NASA/JSC for aircraft operations.[1]

NS-001	M^2S	RS-18
.45 - .52	.38 - .44	.5 - .6
.52 - .60	.44 - .49	.6 - .7*
.63 - .69*	.49 - .54	.7 - .8
.76 - .90	.54 - .58	.8 - .9
1.00 - 1.30	.58 - .62	10.0 - 12.0
1.55 - 1.75	.62 - .66*	
2.08 - 2.35	.66 - .70	
10.4 - 12.5	.70 - .74	
	.76 - .86	
	.97 - 1.06	
	8.05 - 13.7	

[1]Bands indicated with an asterisk (*) will be provided to ASVT Project Team as black-and-white positive transparencies (and as negatives) for data review purposes.

(3) Digital scanner data, in computer-compatible tape format (Universal JSC format).

(4) Indexes to all imagery and data showing the location and extent of coverage.

(5) Copies of mission logs and any associated materials that help to define mission parameters and existing conditions (e.g., weather, time-of-day, etc.).

2.2.5 State Agency Aircraft

The Texas General Land Office (GLO) operates a twin-engine Beechcraft Baron with a Fairchild camera and a 152-mm (6-inch) focal length lens. This aircraft will be available should additional, large-scale photography be required of specific locations within the test site. Such a requirement could arise during data analysis. This aircraft will not be operated during initial data acquisition.

2.3 Surface Data Requirements and Acquisition

2.3.1 Project Team Observations

In contrast to operations in the Coastal Applications Test Site (Finley, 1978), no project team observations are needed in conjunction with the Landsat overpass. If we cannot obtain the cooperation of U.S.D.A. personnel for cloud cover observations at overpass time, it may be necessary to have a project team member in the area. However, Bureau of Economic Geology personnel will probably be engaged in geologic mapping within the test site during June and may assist with weather observations.

Following collection of Landsat data, observations of the relative reflectance of various substrate types will be made using an Exotech hand-held radiometer. This device utilizes the same four spectral channels as does the Landsat MSS. Results will be useful in refining the delineation of different substrate and substrate-vegetation mixes from Landsat and airborne MSS data. The collection of ground data will be constrained by access to privately owned ranchland within the intensive study sites.

Permission is readily gained to enter some tracts, while for others it is unlikely that entry will be allowed.

2.3.2 Observations at Existing Facilities

Most observations at existing facilities would relate to applications other than the primary geological applications within the test site. An investigation of rangeland condition, for example, would require rainfall records for several months preceding the Landsat overpass. At present it is not anticipated that observations at existing facilities will be required to evaluate Landsat imagery over the test site other than to review rainfall in the few days before the overpass. Such a review is required if tonal differences owing to varying soil moisture are noted on any of the remote sensing data.

2.3.3 Weather Data

Weather data to meet the possible requirement noted in Section 2.3.2 are available from local observers cooperating with the National Weather Service. The nearest first-order weather station is at El Paso, Texas, some 128 km (80 mi) northwest of the northwest margin of the test site. Daily rainfall is recorded at Van Horn, Valentine, Marfa (fig. 1), and at Candelaria and Presidio within Presidio County along the Rio Grande. Data is also available for Sierra Blanca, near the Quitman Mountains in the northwest part of the test site.

2.3.4 Published Reports

The bibliography attached to this plan includes additional publications about the geology of the Trans-Pecos region not referred to specifically in the text. Most of these have been prepared by the Bureau of Economic Geology. Also included are references to processing of remote sensing data for geologic applications. These publications are under review to help develop the appropriate processing procedures for data from the Trans-Pecos test site.

2.3.5 Map Availability

Published geologic maps are listed in the bibliography (Section 4.0). Topographic mapping at 1:24,000 scale is only in progress or programmed for parts of the Trans-Pecos test site, notably in parts of Presidio and Brewster Counties. Parts of these areas are covered, however, by 15-minute quadrangle maps dated 1917. Analysis of the Chinati Mountains intensive study area (fig. 1) may be impacted by lack of 7.5-minute topographic map coverage.

3.0 REFERENCES

Bailey, R. G., 1978, Description of the ecoregions of the United States: USDA Forest Service, Intermtn. Reg. Ogden, Utah, 77 p.

Barnes, V. E., project director, in progress, Geologic atlas of Texas: Univ. Texas, Austin, Bur. Econ. Geology.

Cepeda, J. C., 1979, The Chinati Mountains caldera, Presidio County, Texas: in Walton, A. W., and Henry, C. D., eds., Cenozoic geology of the Trans-Pecos volcanic field of Texas, Univ. Texas, Austin, Bur. Econ. Geology Guidebook 19, p. 106-125.

Finley, R. J., 1978, Remote sensing data collection plan, test site 1 (coastal), Texas Natural Resources Inventory and Monitoring System, Applications System Verification and Transfer: Texas Natural Resources Information System, Austin, Texas, 56 p.

Garner, L. E., St. Clair, A. E., and Evans, T. J., 1979, Mineral resources of Texas map: Univ. Texas, Austin, Bur. Econ. Geology, scale 1:1,000,000.

Kier, R. S., Garner, L. E., and Brown, L. F., Jr., 1977, Land resources of Texas: Univ. Texas, Austin, Bur. Econ. Geology, 42 p.

McAnulty, W. N., Sr., 1972, Mineral deposits in the West Chinati stock, Chinati Mountains, Presidio County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 72-1, 13 p.

McAnulty, W. N., Sr., 1974, Fluorspar in Texas: Univ. Texas, Austin, Bur. Econ. Geology Handbook 3, 31 p.

McAnulty, N., 1976, Resurgent cauldrons and associated mineralization, Trans-Pecos Texas, in Woodward, L. A., and Northrop, S. A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geol. Soc. Spec. Publ. No. 6, p. 180-186.

Turner, A. J., 1977, Soil survey of Jeff Davis County, Texas: USDA Soil Conservation Service, Texas Agricultural Experiment Station, 93 p.

4.0 BIBLIOGRAPHY

Albritton, C. C., Jr., and Smith, J. F., Jr., 1965, Geology of the Sierra Blanca area, Hudspeth County, Texas: U.S. Geol. Survey Prof. Paper 479, 131 p.

Amsbury, D. L., 1958, Geology of the Pinto Canyon area, Presidio County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Quad. Map No. 22, with text.

Anderson, A. T., and Smith, A. F., 1975, Application of Landsat imagery to metallic mineral exploration in Utah: Proc. Amer. Soc. Photogrammetry, Oct. 26-31, 1975, p. 286-298.

Baker, C. L., 1927, Exploratory geology of a part of southwestern Trans-Pecos Texas: Univ. Texas, Bur. Econ. Geology Bull. 2745, 70 p.

Ballew, G., 1977, Alteration mapping at Goldfield, Nevada, by cluster and discriminant analysis of Landsat data: Proc. 11th International Symp. on remote sensing of environment, April 1977, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), p. 783-790.

Barnes, V. E., 1968, Geologic atlas of Texas, Van Horn-El Paso sheet: Univ. Texas, Austin, Bur. Econ. Geology.

Barnes, V. E., 1979, Geologic atlas of Texas, Emory Peak-Presidio sheet: Univ. Texas, Austin, Bur. Econ. Geology.

Barnes, V. E., 1979, Geologic atlas of Texas, Marfa sheet: Univ. Texas, Austin, Bur. Econ. Geology.

Blodget, H. W., Gunther, F. J., and Podwysocki, M. H., 1978, Discrimination of rock classes and alteration products in southwestern Saudi Arabia with computer-enhanced Landsat data: NASA technical paper 1327, Goddard Space Flight Center, Greenbelt, Maryland, 34 p.

Bureau of Economic Geology, 1943, Texas mineral resources: Univ. Texas, Austin, Bur. Econ. Geology Pub. 4301, 390 p.

Carlson, G. C., 1978, Mapping ultramafic rocks by computer analysis of digital Landsat data: Ph.D. dissertation, Dartmouth College, Hanover, New Hampshire, 222 p.

Collins, W., 1978, Analysis of airborne spectroradiometric data and the use of Landsat data for mapping hydrothermal alteration: Geophysics, v. 43, no. 5, p. 967-987.

Daily, M., Elachi, C., Farr, T., Stromberg, W., Williams, S., and Schaber, G., 1978, Application of Multispectral radar and Landsat imagery to geologic mapping in Death Valley: NASA, Jet Propulsion Laboratory, Pasadena, Cal., JPL Publ. 78-19, 47 p.

Dietrich, J. W., 1966, Geology of the Presidio area, Presidio County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Quad. Map No. 28, with text.

Eargle, D. H., 1956, Some uranium occurrences in West Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. of Investigations 27, 23 p.

Flawn, P. T., 1952, The Hazel copper-silver mine, Culberson County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. of Investigations 16, 23 p.

Groat, C. G., 1972, Presidio Bolson, Trans-Pecos Texas, and adjacent Mexico: Univ. Texas, Austin, Bur. Econ. Geology Rept. of Investigations 76, 46 p.

Hundemann, A. S., 1977, Remote sensing applied to geology and mineralogy (a bibliography with abstracts): National Technical Information Service, NTIS/PS-77/0676, Springfield, Virginia.

Hunt, G. R., 1977, Spectral signatures of particulate minerals in the visible and near infrared: Geophysics, v. 42, no. 3, p. 501-513.

King, P. B., 1935, Outline of structural development of Trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 221-261.

Lonsdale, J. T., 1940, Igneous rocks of the Terlingúa-Solitario region, Texas: Geol. Soc. Amer. Bull., v. 51, p. 1539-1636.

McAnulty, W. N., Sr., 1967, Fluorspar in Brewster County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 67-2, 16 p.

Missallati, A., Prelat, A. E., and Lyon, R. J. P., 1979, Simultaneous use of geological, geophysical, and Landsat digital data in uranium exploration: Remote Sensing of Environment, v. 8, p. 189-210.

Raines, G. L., Offield, T. W., and Santos, E. S., 1978, Remote-sensing and subsurface definition of facies and structure related to uranium deposits, Powder River Basin, Wyoming: Economic Geology, v. 73, p. 1706-1723.

Robinson, J. E., and Carroll, S., 1976, Enhancing of geological definition in Landsat data: Third Canadian Symp. on Remote Sensing, Edmonton, Alberta, Sept. 1975, ed. by G. E. Thompson (Canadian Aeronautics and Space Institute, Ottawa), p. 145-153.

Rowan, L. C., and Abrams, M. J., 1979, Evaluation of Landsat multispectral scanner images for mapping altered rocks in the east Tintic Mountains, Utah: NASA-CR-158863, Rept. 78-736, Geol. Survey, Reston, Va., 136 p. NTIS SAP: HC A07/MF A01.

Rowan, L. C., Goetz, A. F. H., and Ashley, R. P., 1977, Discrimination of hydrothermally altered and unaltered rocks in visible and near infrared multispectral images: Geophysics, v. 42, no. 3, p. 522-535.

Udden, J. A., 1918, The anticlinal theory as applied to some quicksilver deposits: Univ. Texas, Austin, Bur. Econ. Geology Bull. 1822, 30 p.

Vincent, R. K., 1973, Ratio techniques for geochemical remote sensing: Proc. Fourth Ann. Conf. on Remote Sensing in Arid Lands, Nov. 1973, Off. of Arid Land Studies, Univ. Ariz., Tucson, p. 181-198.

Woodward, L. A., Callender, J. F., Gries, J., Seager, W. R., Chapin, C. E., Shaffer, W. C., and Žilinski, R. E., 1975, Tectonic map of the Rio Grande region, Colorado-New Mexico border to Presidio, Texas: New Mexico Geol. Soc. 26th Guidebook, Las Cruces country, in pocket.