General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

07

STIF

E7.6-10.0.23
CR-145416

A STUDY TO EXPLORE THE USE OF

ORBITAL REMOTE SENSING TO DETERMINE

NATIVE ARID PLANT DISTRIBUTION

W. G. McGinnies (Principal Investigator), J. S. Conn,
E. F. Haase, L. K. Lepley, H. B. Musick, and K. E. Foster
Office of Arid Lands Studies
1201 E. Speedway
Tucson, Arizona 85719

June, 1975

Final Report for Period July, 1971 - December 1974

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

1250A

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. Final	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

A Study to Explore the Use of Orbital Remote Sensing to Determine Native Arid Plant Distribution

5. Report Date

June 1975

6. Performing Organization Code

7. Author(s) W. G. McGinnies (Principal Investigator), J.S. Conn, E. F. Haase, L.K. Lepley, H.B. Musick, K. E. Foster

8. Performing Organization Report No.

9. Performing Organization Name and Address

Office of Arid Lands Studies
1201 E. Speedway
Tucson, Arizona 85719
Arizona Univ. ent

10. Work Unit No.

11. Contract or Grant No.

NAS 5-21812

12. Sponsoring Agency Name and Address

R. Stonesifer, Code 430 (Technical Officer)
Goddard Space Flight Center
Greenbelt, Maryland 20771

13. Type of Report and Period Covered Final Report for July, 1971-December, 1974

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Results of the Research include a method for determining the reflectivities of natural areas from ERTS data taking into account sun angle and atmospheric effects on the radiance seen by the satellite sensor. Ground truth spectral signature data for various types of scenes, including ground with and without annuals, and various shrubs were collected. Large areas of varnished desert pavement are visible and mappable on ERTS and high altitude aircraft imagery. A large-scale and a small-scale vegetation pattern were found to be correlated with presence of desert pavement. A comparison of radiometric data with videorecordings shows quantitatively that for most areas of desert vegetation, soils are the most influential factor in determining the signature of a scene. Additive and subtractive image processing techniques were applied in the darkroom to enhance vegetational aspects of ERTS.

17. Key Words (Selected by Author(s))

Remote sensing, vegetation, plant distribution, distribution patterns, desert varnish, desert pavement, annuals, shrubs, desert soils, Avra Valley, Yuma, and Arizona phenology

18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 60	22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

Objectives

Research was initiated in July 1971 toward the following contract-specified objectives:

1. To determine the distribution of native plant species and plant communities in selected areas of the Arizona Regional Ecological Test Site (ARETS).

2. To determine the phenological variations in plant species in the arid regions of the Arizona Regional Ecological Test Site.

3. To determine unique spectral signatures for selected plant species and related site conditions.

4. To determine the feasibility of using ground truth imagery as an aid to interpretation of orbital imagery.

5. To use knowledge gained from ARETS studies in the interpretation of worldwide orbital imagery.

Scope of Work

Research centered around the objectives and included the following: 1) study of the vegetation, physiography and soils of the Yuma study area, resulting in a vegetation map of the area; 2) study of the phenological variations in plant species located on eight Avra Valley study plots; 3) the study of spectral signatures for Avra Valley study areas, including development of a theory of a method for determining the reflectivities of natural desert areas from ERTS data, taking into account sun angle and atmospheric effects on the radiance seen by the satellite sensor; 4) analysis of the relative importances of various radiometric components on the total spectral signature; 5) study of desert pavement soils of the Yuma-Quartsite area. Desert pavement soils, readily apparent on

ERTS imagery of the Yuma-Quartsite area, are also seen on imagery of Saudi Arabia. The correlation has aided in the interpretation of these areas.

Conclusions and Recommendations

Research performed has shown that with the exception of the Yuma soil-vegetation correlation phenomena, only very gross differentiations of desert vegetation communities can be made from ERTS data. Vegetation communities having obvious differences in density on ERTS imagery, such as saguaro, palo-verde, creosote bush, and riparian, can be separated on the Avra Valley imagery while communities more similar in density such as creosote bush and saltbush could not be differentiated. This report suggests that under arid conditions large differences in density are needed before the signatures of two different vegetation types can be differentiated on ERTS imagery. This is due to the relatively insignificant contribution of vegetation to the total radiometric signature of a given desert scene. Where more detailed information concerning the vegetation of arid regions is required, larger scale imagery is appropriate.

The theory for determining the reflectivities of natural areas from ERTS data, which takes into account sun angle and atmospheric effects, was never tested due to problems in obtaining reflectance data from ERTS transparencies for two small calibration areas (100 meters across) needed for the calibration equation. If the data could be obtained from the imagery with the aid of a micro-densitometer, or from computer compatible tapes, the reflectivities for vegetation communities in the vicinity of the calibration areas could be calculated, thus aiding in vegetation community discrimination.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF TABLES

BODY OF REPORT

INTRODUCTION

Purpose

In the past, the natural geography of plants was determined through studies conducted on the ground. At various locations on the globe, the vegetation has been analyzed to determine species and community composition. From these data boundaries of species, genera, and community distributions are inferred.

While the distribution maps that arise from ground collected data show general outlines of distributions, they are by no means precise, since an extraordinary amount of data would be required to make a ground based distribution map exact. Remote sensing has been used as a tool in collecting the necessary data in an effort to gain an increased degree of preciseness in plant distribution mapping without spending the corresponding increased effort and funds.

It follows that satellites such as ERTS or other spacecraft should be the "ultimate" data gatherers for distribution mapping since their great distance from the earth lends them readily to the study of large areas of the earth's surface.

Our project, then, was to explore the use of orbital remote sensing to determine native arid plant distribution. In July 1971, research was initiated.

Description of Study Areas and Scope of Work Performed

Two areas were extensively studied as a part of this project: the Yuma-Quartsite area and the Avra Valley area. Both areas are within the boundaries of the Arizona Regional Ecological Test Site.

Yuma-Quartsite Study Area

Climate

The Yuma-Quartsite area near Yuma, Arizona, represents extreme desert

1

conditions with the lowest annual rainfall in Arizona. This rainfall approaches being the lowest in North America and is similar to that of the drier deserts of the world. There are two peak periods of rainfall, one occurring in the summer months associated with unstable, warm moist air circulating around the Bermuda high which emanates from the Gulf of Mexico, and the other occurring in the winter months when frontal storms come in from the California coast. The average annual rainfall of about 3.30 inches (Green 1964b) occurs to a larger extent in the winter than in the summer, with 1.9 inches falling in the winter and 1.4 inches falling during the summer months (Green 1964a). Rainfall is more variable in the summer than in the winter and five rains may make up the entire annual amount for some years (op. cit.).

Summer temperatures are often extreme and are marked by a large amount of fluctuation. From late May through early September daytime temperatures can be expected to be above 100° F and may be in excess of 115° F. The average summer temperature is 83.7° F (Green 1964b).

Figure 1-1.
STUDY AREAS

Winter temperatures are quite mild, the average temperature for the winter months being 60.0° F. Temperatures below freezing are rare (op. cit.).

Physiography and Geology

The Yuma-Quartsite study area is located in the Basin and Range Physiographic Province of North America, characterized by numerous mountain ranges which rise abruptly from broad valleys or basins. The mountain ranges, which include the Tank, Laguna, Muggins, Castle Dome (3793'), Middle, and Kofa (4828'),
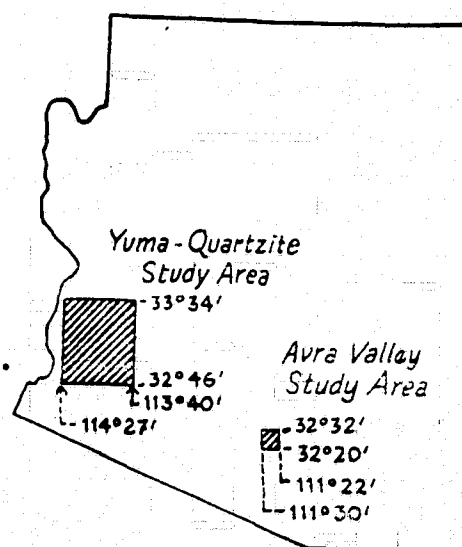
have a northward trend while the drainage tends toward the southwest and is through-flowing. The Gila River is the major watercourse.

It is thought that the structure of the Basin and Range Province in Arizona was the result of periodic deformation and igneous activity taking place primarily during older Precambrian, at the close of younger Precambrian, between Cretaceous and Tertiary, during Tertiary, and during Quarternary time (Lance and Wilson 1960, Wilson and Moore 1959). A wide range of rock types are found in the mountain ranges of the study area. The most abundant are volcanic rocks ranging in composition from andesitic to rhyolite, gneiss, schists and sedimentary rocks (Wilson 1960).

Alluvial plains occupy the intermountain basins and may be several thousand feet deep (Martin 1963). The upper slopes of the plains, where they grade upward toward the mountains, resemble alluvial fans and are referred to as bajadas. Pavement-like soils are characteristic of many areas of this region.

Vegetation

The vegetation of the Yuma-Quartsite study area is quite xeric in nature. An abundance of ironwood, a frost sensitive tree of the lower Sonoran Desert, is characteristic of the region. Typical vegetation communities of the area include: foothill paloverde-ironwood, occurring on gently to moderately sloping bajadas; creosote bush-bursage, occurring on gently sloping lower bajadas and on nearly level plains or "mesas" below the lower bajadas; creosote bush-mesquite, occurring along washes of the valleys; and creosote bush-ocotillo, found on dissected alluvium where moderately steep slopes prevail. In general, the flora is typical of the lower Sonoran Desert.

Scope of Work Performed

The vegetation, physiography, and soils of the Yuma-Quartsite area were studied during two trips made to the area, in March and June 1973. During the

the course of these studies, it was found that large dark areas on the bajadas of the desert mountains correspond to areas of varnished desert pavement. Large-scale and small-scale vegetation patterns were found to be correlated with the presence of the desert pavement. Using this correlation, a map was made of the area with the use of ERTS image #1069-17441, high-altitude aircraft images, and ground truth data. As a part of the study, the nature of desert pavement soils was extensively studied.

Avra Valley Study Area

Climate

The climate of the Avra Valley study area is less severe than that of the Yuma-Quartsite area. Partly because of the Avra Valley's higher altitude, temperatures tend to be cooler and rainfall more plentiful. The average annual rainfall of about 11 inches tends to occur more in the summer than in the winter (Green 1964b). Summer precipitation averages 6.7 inches while winter precipitation averages 4.5 inches (Green 1964a). Summer rains are often short in duration, . spotty, and of a violent nature. These occur in response to unstable, moist air emanating from the Bermuda high located over the Gulf of Mexico. Winter storms are longer in duration, widespread, and more gentle in nature. These rains are a result of frontal systems moving east through Arizona from the California Coast.

Summer temperatures are high. From late in May until the middle of August temperatures above 105° F are likely (Green 1964b). Temperatures above 115° F are rare, however. The average summer temperature is 79.0^{o} F. Winter temperatures are mild with an average winter temperature of 55.9^{o} F. Temperatures below freezing are infrequent (op. cit.).

Cold air drainage from surrounding mountains occurs in canyon and valley bottoms. Thus, the lowest land may have a temperature $5-25^{o}$ F lower than sur-

rounding areas a few feet higher (Shreve 1912).

Physiography and Geology

The Avra Valley study area, west of Tucson, is also part of the Basin and Range Physiographic Province. The Avra Valley is a north trending intermountane basin bounded by the Tucson Mountains (4677') on the east and by the Roskruge and Silverbell Mountains on the west. The valley is an alluvial plain having many intertwining washes (the largest being Brawley Wash) that have cut down into the valley fill alluvium to some extent on the margins of the floodplains.

A large variety of rock types are found in the mountain ranges bordering the Avra Valley. Most abundant are volcanic rocks ranging in composition from rhyolite to basalt, intrusive igneous rocks of granitic or granodioritic composition, schists, gneiss and sedimentary rocks (Cooley 1967).

Vegetation

The vegetation of the Avra Valley study area is characteristic of the upper Sonoran Desert.

Various different vegetation communities are found in the study area where the conditions for growth of community members are met. The most extensive vegetation assemblage consists of creosote bush with bursage occurring on the fine-textured alluvial soils of the lower bajadas and valleys. On the higher bajadas and lower mountain slopes the vegetation is dominated by foothill palo-verde, saguaro, and ironwood. Riparian communities dominated by blue palo-verde or mesquite are common along watercourses.

Scope of Work Performed

Eight study sites were selected in the Avra Valley using high-altitude color and color infrared photography and ground truth information. Homogeneous areas representative of the various vegetation types in the valley were chosen:

1, 2, 3	Creosote bush and annuals: The sites are on different soil types and support different amounts or kinds of annuals and different densities of creosote bush;
4	Rothrock grama grass, burro-weed, and annuals,
5	Mesquite, burro-weed, and snakeweed;
6	Desert grassland, three-awn and other perennial grasses, mesquite, and blue paloverde;
7, 8	Foothill paloverde, saguaro, triangleleaf bursage, and many other perennial species.

These sites were visited monthly so that information regarding the plant phenology of each area could be collected. At each site color infrared and ordinary color slides were taken simultaneously at various vertical, low-oblique, and high-oblique angles. The complete set of slides provides a record of the plant phenology of each site for nearly one year.

Comparison of the relative abundances of vegetation at the sites to ERTS color-enhanced imagery of the same dates shows the importance of spring annuals in influencing the spectral signatures of the sites. The unusually high rainfall of 1972-73 resulted in a large abundance of spring desert annual plants. From the ground truth pictures it is known that these annuals grew in larger abundances on some sites than on others. This differential growth could be spotted on color enhanced ERTS imagery taken during the time of peak spring annual growth. It has been found that the differential growth of spring annuals in various communities may help to separate the communities on ERTS imagery.

In an effort to study the vegetational aspects of the ERTS imagery, radiometric data of the various radiometric components such as soil, soil with detritus, and various shrubs were collected on the ground with an ERTS Exotech radiometer. Also, radiometric surveys of selected portions of the Avra Valley area,

including several of our study areas, were made from an aircraft flying at low altitude. Comparison of the ground-based radiometric component data with the airborne radiometric data yields information on the relative importances of the various components in determining the overall radiometric signature. The low altitude overflights did not correspond to ERTS-1 flyover dates.

CHAPTER I: SPECTRAL SIGNATURE DETERMINATIONS FROM ERTS-1 MSS DATA

Since plant communities have certain spectral signatures, it should be possible to identify them on ERTS imagery if 1) the spectral signatures of the communities are known; and 2) the signatures can be taken from the imagery. In order to quantitatively determine spectral signatures of plant communities directly from ERTS data, atmospheric variables affecting the radiance, as sensed by the satellite multispectral sensor, must be taken into account.

Philip N. Slater, of the University of Arizona Optical Sciences Center, supplied a model describing the relationship between light incident on the area, atmospheric effects, scene characteristics, and the resulting radiance as sensed by the multispectral sensor. The model is graphically represented in Figure 1-1 and mathematically described by the following equation:

$$I_{sensor} = (I_{sun} + I_{sky})\rho\tau + I_{us} \tag{1}$$

where:

I_{sun} = direct solar radiation incident on the area

I_{sky} = diffuse sky radiation incident on the area

I_{sensor} = radiance of an area of spatially uniform reflectivity as sensed by the spacecraft sensor

ρ = reflectivity of the area

τ = transmissivity of the atmosphere along the path from the scene to the spacecraft

I_{us} = radiant energy scattered upwards by the atmosphere over the area

All of these terms are wavelength-dependent but the subscript λ has been omitted for clarity.

$$I_A = (I_{Sun} + I_{Sky})\rho_A \tau + I_{us}$$
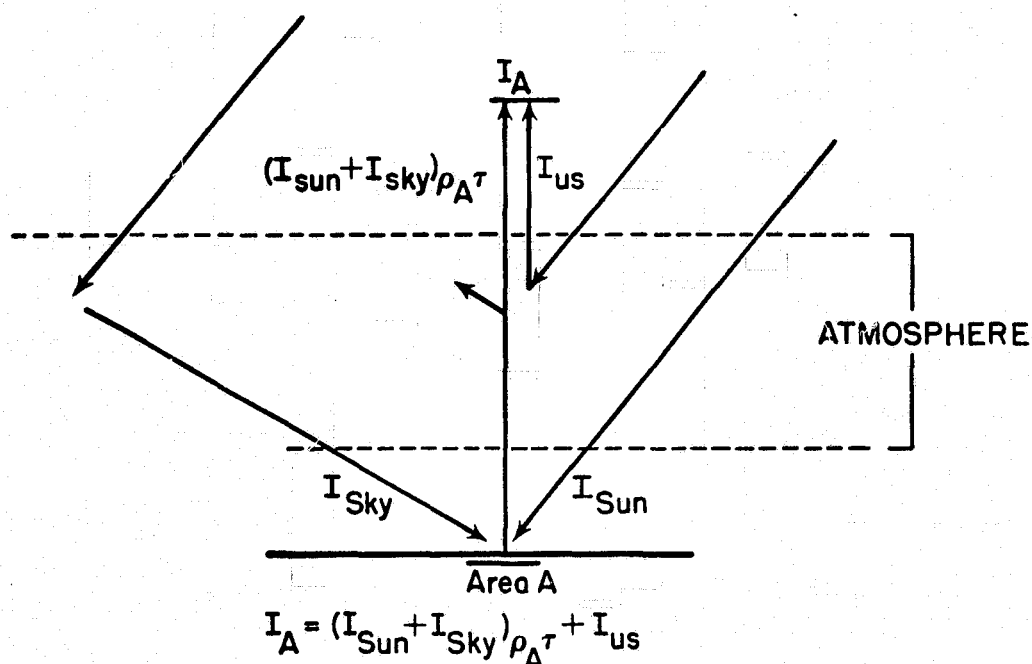
Figure 1-2 Atmospheric Effect Model

The theory of a method for determining the reflectivity of an area from ERTS data has been developed which requires a limited amount of ground truth data if certain assumptions are made. The theory is derived from the model presented by Dr. Slater. Suppose that radiance values (I_A, I_B, I_X) are available for three areas, A, B, and X, from spacecraft data of a given date. A and B are calibration areas for which the reflectivities (ρ_A and ρ_B, where $\rho_A \neq \rho_A$ are known from ground truth measurements. The problem is to determine the reflectivity of area X (ρ_X), for which no ground truth spectral signature data are available.

Rearranging the terms in Equation 1,

$$\rho_A = \frac{I_A - I_{us}}{(I_{sun} + I_{sky})\,\tau} \tag{2}$$

and,

$$\rho_B = \frac{I_B - I_{us}}{(I_{sun} + I_{sky})\,\tau} \tag{3}$$

and,

$$\rho_X = \frac{I_X - I_{us}}{(I_{sun} + I_{sky})\,\tau} \tag{4}$$

when areas A, B, and X have an atmosphere of transmissivity τ over them.

Dividing Equation 2 by Equation 3,

$$\frac{\rho_A}{\rho_B} = \frac{I_A - I_{us}}{I_B - I_{us}} \tag{5}$$

and solving equation 4 for I_{us},

$$I_{us} = \frac{\rho_B I_A - \rho_A I_B}{\rho_B - \rho_A} \tag{6}$$

Substituting for I_{us} in Equation 1:

$$(I_{sun} + I_{sky})\,\tau = \frac{I_A - I_{us}}{\rho_A} \tag{7}$$

Substituting Equations 6 and 7 into Equation 3:

$$\rho_X = \frac{\rho_A \left[I_X (\rho_B - \rho_A) - \rho_B I_A + \rho_A I_B \right]}{I_A (\rho_B - \rho_A) - \rho_B I_A + \rho_A I_B} \tag{8}$$

Thus, we can use Equation 8 to determine the reflectivity of area X from spacecraft measurements of I_A, I_B and I_X, and ground truth measurements of ρ_A and ρ_B.

The equation can be applied to data of each of the ERTS MSS bands and can be expressed in terms of reflectivity ratios. The ratio of infrared reflectivity to red reflectivity is useful in vegetation studies since vigorous green foliage reflects strongly in the infrared but weakly in the red, while other surfaces, such as desert sand, have reflectivity ratios approaching unity.

If it is assumed that I_{us} and $[(I_{sun} + I_{sky})\tau]$ are the same for areas A, B, and X at the time of the overflight, and if the atmosphere is reasonably homogeneous and stable over the areas, the ground truth data (ρ_A and ρ_B) do not have to be taken at the time of the overflight, but can be taken on another day.

Testing of this theory was never completed due to a lack of the micro-densitometric equipment necessary to obtain reflectance data for the relatively small calibration areas. The capability for obtaining the reflectance information from ERTS computer compatible tapes was not available to us at that time.

CHAPTER II: AVRA VALLEY VEGETATION PHENOLOGY STUDY

High-altitude color and color infrared photography (ERAP Mission 101) was used in conjunction with a ground search to locate large (1 mi^2), relatively homogeneous sites in the Avra Valley for data collection. Eight sites, which include a variety of vegetation types and soil conditions, were chosen:

1, 2, 3   Creosote bush and annuals; the sites are on different soil types and support different amounts or kinds of annuals and different densities of creosote bush;

4   Rothrock grama grass, burro-weed, and annuals;

5   Mesquite, burro-weed, and snakeweed;

6   Desert Grassland: three-awn and other perennial grasses, mesquite and blue paloverde;

7, 8   Foothill paloverde, saguaro, triangleleaf bursage, and many other perennial species.

The locations of the sites are shown in Figure 2-1, an ERTS image of the Avra Valley area.

At each site several scenes were photographed at vertical, low oblique, and high oblique angles from a 12-foot ladder, using 35 mm color and color infrared film to obtain matching photographs. Since the primary purpose of the photographs was to record phenological changes and the accompanying changes in spectral signature, each scene at each site was rephotographed at several periods from November 1972 to June 1973. To supplement the photographs, observations on species composition and phenology were recorded at each site.

The 1972-1973 winter was unusually favorable for the growth of annuals. Rainfall for the period between February 1 and April 1 totaled 3.31 inches, contrasted to an average for that period of 2.02 inches. Shown by the photographic record of the study areas is a gradual increase in abundance of winter annuals to

Figure 2-1. Avra Valley Study Site Locations

a high point in late April 1973, followed by a gradual decrease in annual plant cover with increasing aridity. Also shown by the photographs are large differences in the amount of winter annual cover at the various study areas. Figure 2-2 is a photograph taken April 12 of the creosote bush site located on North Sandario Road. This site produced one of the highest densities of winter annuals. Figure 2-3 shows the foothill paloverde-saguaro site located on Sandario Road south of Milewide Road on the same date. Note the almost complete absence of winter annual plants.

Figure 2-2.   Creosote Bush Site (N. Sandario Rd.) April 12, 1973

Figure 2-3.   Foothill Paloverde-Saguaro Site (N. Sandario Rd.) April 12, 1973

14

The differences in annual cover associated with differences in perennial vegetation type are noticeable on false-color infared composites of the Avra Valley area for the period coinciding with peak winter annual growth. Figure 2-4 is a false-color infrared composite (1102-17274-4, 5, 7) of the Avra Valley for the November 2, 1972 flyover date. On this date, annual plant cover was very low. Figure 2-5 is a false-color infrared composite (1264-17283-2, 5, 7) for April 13, 1973, coinciding with the time of peak annual plant growth. Comparison of the two composites shows the influence of winter annuals on the spectral signatures of the areas where they grow in large abundance. Since the annuals are more abundant in some communities than in others, the change in spectral signatures may help to separate the different communities on ERTS imagery.
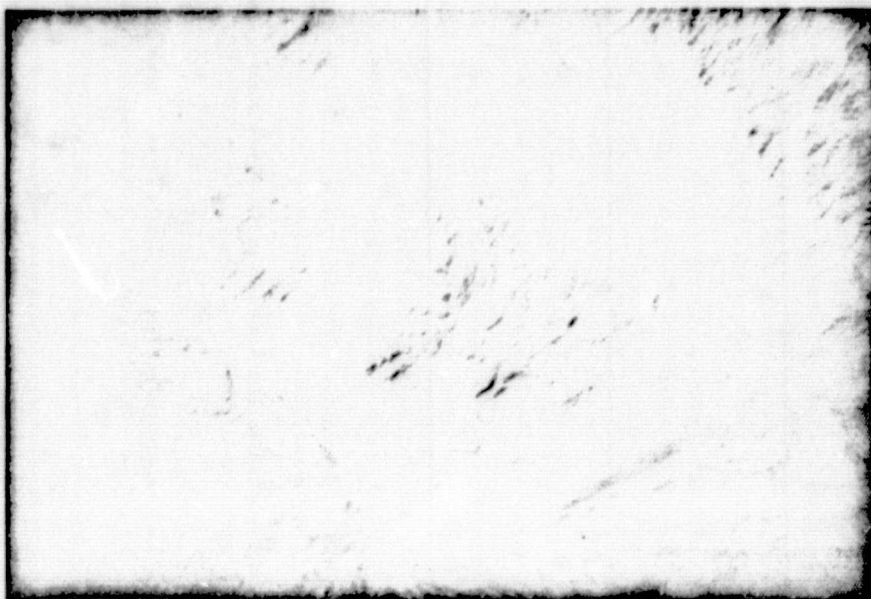
Figure 2-4. False-color Infrared ERTS Composite of the Avra Valley November 2, 1973

Figure 2-5. False-color Infrared ERTS Composite of the Avra Valley April 13, 1973

CHAPTER III: EDAPHIC AND TOPOGRAPHIC FACTORS IN RELATION TO ANNUAL PLANT GROWTH WITHIN THE AVRA VALLEY

A study was made in January 1974 to determine the possible causes for the differences in abundance of annual plants at the various Avra Valley study sites. Dr. D.F. Post, soil scientist of the Department of Soils, Water, and Engineering, College of Agriculture, University of Arizona, participated in the study and collected the soils data.

At each site a pit was dug and the soil of each horizon was field analyzed as to texture, structure, and carbonate content. The soil of each site was tentatively classified and fitted into the NCSS soils classification system that had been previously determined as a result of the Tucson-Avra Valley Area Soil Survey. After the soils had been classified into types and series, the additional known properties of the soils, available in the soil survey, could be inferred.

As is shown in Table 3-1, sites having more fine soils with a comparatively high water-holding capacity in the upper few inches of the soil profile and with level topography had the largest abundance of spring annuals. This is of little surprise since the lack of water is the major limiting factor to plant growth in arid regions. Any factor that serves to increase the amount of water available for plant use in the upper inches of soil is of great benefit to plant establishment and growth.

It would also be expected that soils with a high water-holding capacity would be of a greater benefit to annual plants than perennials in areas of ephemeral rainfall however. This is because annual plants can complete their life cycles in a short period of time, thus taking advantage of the abundant moisture held in the soil at relatively low tensions during the rainy season. Plants with longer life cycles would have to cope with the high moisture tensions associated with the high cation exchange capacity (CEC) of high water-holding capacity soils during dry periods.

17

TABLE I

Spring Annual Plant Abundance in Relation to Edaphic and Topographic Factors

Site	Soil texture		Topography	Spring annual plant abundance
Rothrock grama	surface-	loamy fine sand	level	many
	subsurface-	sandy loam		
Creosote bush–North Sandario	surface-	sandy loam	nearly level	many
	subsurface-	sandy loam–light sandy clay loam		
Paloverde–Saguaro (white rocks)	surface-	loamy fine sand and gravel		
	subsurface-	sandy loam–light sandy clay loam	slightly sloping	few
Paloverde–Saguaro (red rocks)	surface-	gravelly loamy fine sand and rocks	2–4% slope	
	subsurface-	gravelly sandy loam		few
Creosote bush–West Milewide	surface-	fine sandy loam–very fine sandy loam		
	subsurface-	fine sandy loam–very fine sandy loam	level	most

18

CHAPTER IV: GROUND TRUTH SPECTRAL REFLECTIVITY SIGNATURES

Ground Studies

In conjunction with the ground truth photography of the Avra Valley, measure-
ments were made of the spectral signatures of the separate scene components
from a ladder or tripod, using an Exotech ERTS radiometer which measures the
radiation in the four ERTS spectral bands (0.5-0.6 μ, 0.6-0.7 μ, 0.7-0.8 μ,
0.8-1.1 μ). The reflected radiation from a shrub or the ground was measured
using lenses with a fifteen degree aperture, with the radiometer pointing vertically
downward. Incoming radiation was measured with the diffuse collectors in place,
and the instrument pointing vertically upward. Reflectivity values were obtained
by dividing reflected radiation by incoming radiation for each wavelength band.

Spectral signature data were obtained for the following types of scene
components:

1. Two shrub species, creosote bush and bursage in April and in June.
The shrubs were vegetatively active in April and dormant or semi-dormant in
June. The view of the radiometer included the crown of the plant, and whatever
ground, ground cover, and shadow were visible through the plant foliage.

2. Ground with living annuals in April and dead annuals in June.

3. Bare ground.

The radiometric data from April and June provide a contrast between spectral
signatures during a peak of vegetative activity following the winter rains (April)
and during a period of reduced vegetative activity during the fore-summer drought
(June). In April, the winter annuals had reached their peak development and some
plants were beginning to wilt and die. The creosote bush and bursage, both peren-
nials, had abundant bright green leaves (bright grey-green on bursage). In June,
the winter annuals were dead and no summer annuals had germinated. Creosote
bush and bursage had lost many leaves, and those remaining were dead or very

19

brownish and wilted or semi-dormant.

Samples of the ground truth spectral signature curves are shown in Figures 4-1 anu 4-2. A comparison of the spectral signatures of ground surfaces partially covered by living annuals in April with those of the same scenes in June when the annuals were dead indicated that the presence of the living annuals did not increase infrared reflectivity, but lowered red reflectivity. A comparison of April creosote bush (vegetatively active) with June creosote bush indicated that red reflectivity was low for both, but infrared reflectivity was lower in June than in April.

Comparison and classification of spectral signatures as displayed in the graphical form of Figures 4-1 and 4-2 is difficult. Most methods of concise characterization of spectral signatures involve some comparison of red and infra- red reflectivity when vegetation amounts or activity are of interest. The ratio of infrared to red reflectivity has been commonly used as an index of vegetative activity, but this ratio may not be the best way of concisely expressing the spectral signature of a scene. We have compared this method of expressing spectral sig- natures with a two-dimensional method which preserves the information contained in the absolute values of the red and infrared reflectivities.

The spectral signatures plotted in Figures 4-3 and 4-4 were first categorized according to the nature of the scene, as indicated in the legend. The "annuals and ground" category includes all scenes which included living annuals, even though many of these scenes had only a sparse cover of annuals. The "ground with litter" category includes scenes with old grayish litter partly covering the soil surface, and those with fresh yellowish litter of the dead annuals. A few scenes of soil which, due to erosion, completely lacked any cover of litter or plants on the bare mineral soil comprise the "bare ground" category. This category is noted by its own symbol, but it plotted along with the "ground with litter" category to make a cluster of all scenes which lack living plant material. A few scenes in the "annuals
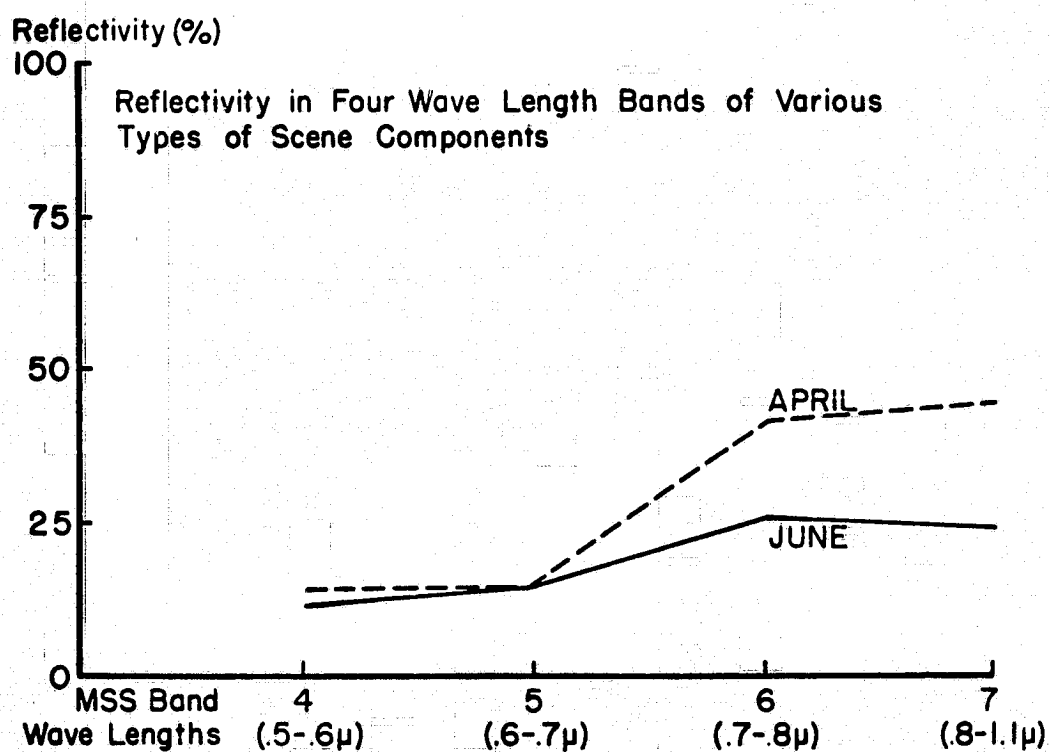
Figure 4-1 CreosoteBush Type.
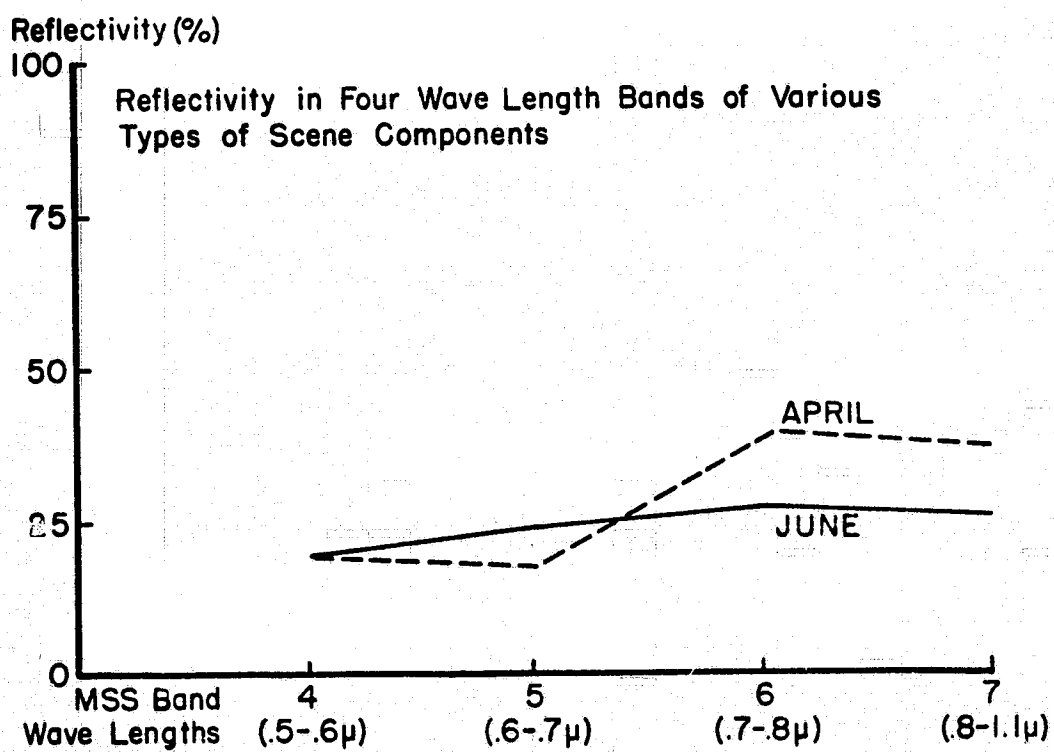
Figure 4-2 Bursage Type.

and ground" and "ground with litter" categories are denoted by special symbols. These scenes were on an area covered with red rock and may deviate somewhat from the general pattern because of the unusual signature of the red rock fragments on the soil surface.

In Figure 4-3, the signatures are plotted as points along a single axis representing the ratio of infrared (MSS Band 7) reflectivity to red (MSS Band 5) reflectivity. While the signatures of ground with annuals are mostly separated from the signatures of ground with living annuals, the signatures of creosote bush and bursage are not distinguishable from other categories.

The signatures are plotted according to both infrared (Band 7) reflectivity and red (Band 5) reflectivity in Figure 4-4. Lines are drawn to indicate the boundaries of the cluster of points of each category, except that the "red rock" points were not included with the "annuals and ground" category. The similarity of these signatures to those of scenes which lack living plants is not surprising considering the low infrared reflectivity of the soil surface and the very sparse cover of annuals at this site.

It is evident that signatures of the various categories are more distinctly characterized in Figure 4-4 than in Figure 4-3. Some relationships between the signatures of the various types of scenes are apparent in Figure 4-4.

The signature clusters of dormant or semi-dormant creosote bush and especially bursage approximate a "darker" extension than the "ground with litter" cluster. This is probably partly due to the large amount of ground surface visible through the shrub foliage, the similarity in signature of the plant tissue and the ground, and the presence of shadows cast by the shrub stems and leaves.

Interpretation of ERTS spectral signature data would seem to require ground truth spectral signatures for whole plant communities. Community reflectivity values could be measured directly or calculated from reflectivity data for the
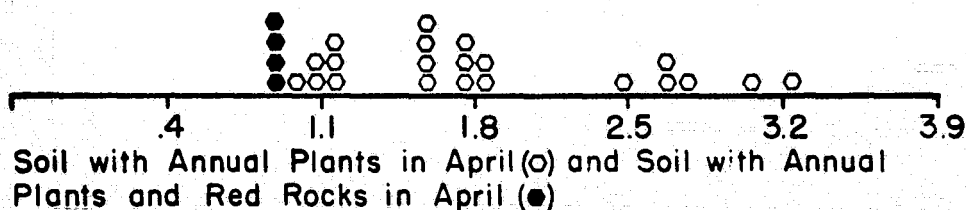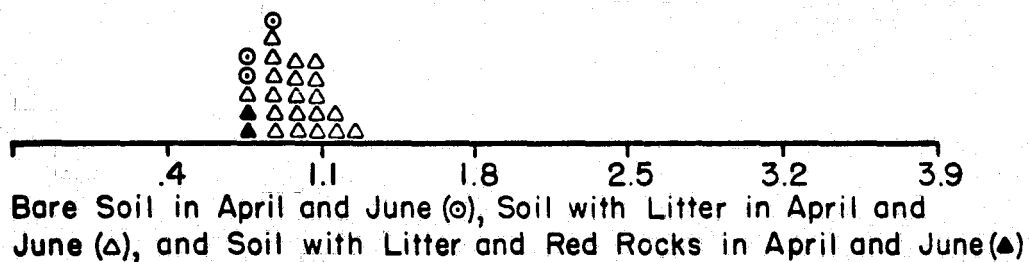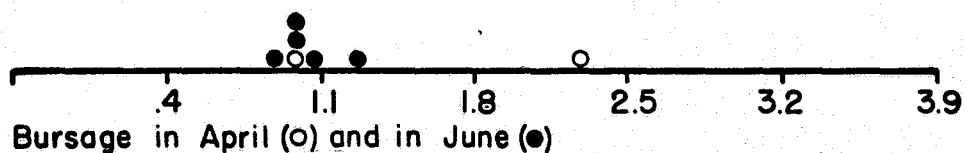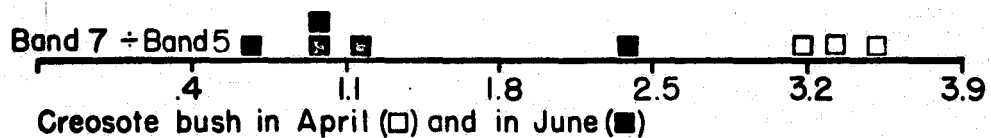
Figure 4-3   Ratio of MSS Band 7 (0.8-1.1μ) Reflectivity to MSS Band 5
(0.6-0.7μ) Reflectivity for Various Types of Scene Components.

Reflectivity in
MSS Band 7 (%)

Creosote bush in April
Creosote bush in June
Bursage in April
Bursage in June
Bare soil in April and June
Soil with litter in April and June
Soil with litter and red rocks in April and June
Soil with annual plants in April
Soil with annual plants and red rocks in April

Reflectivity in MSS Band 5 (%)
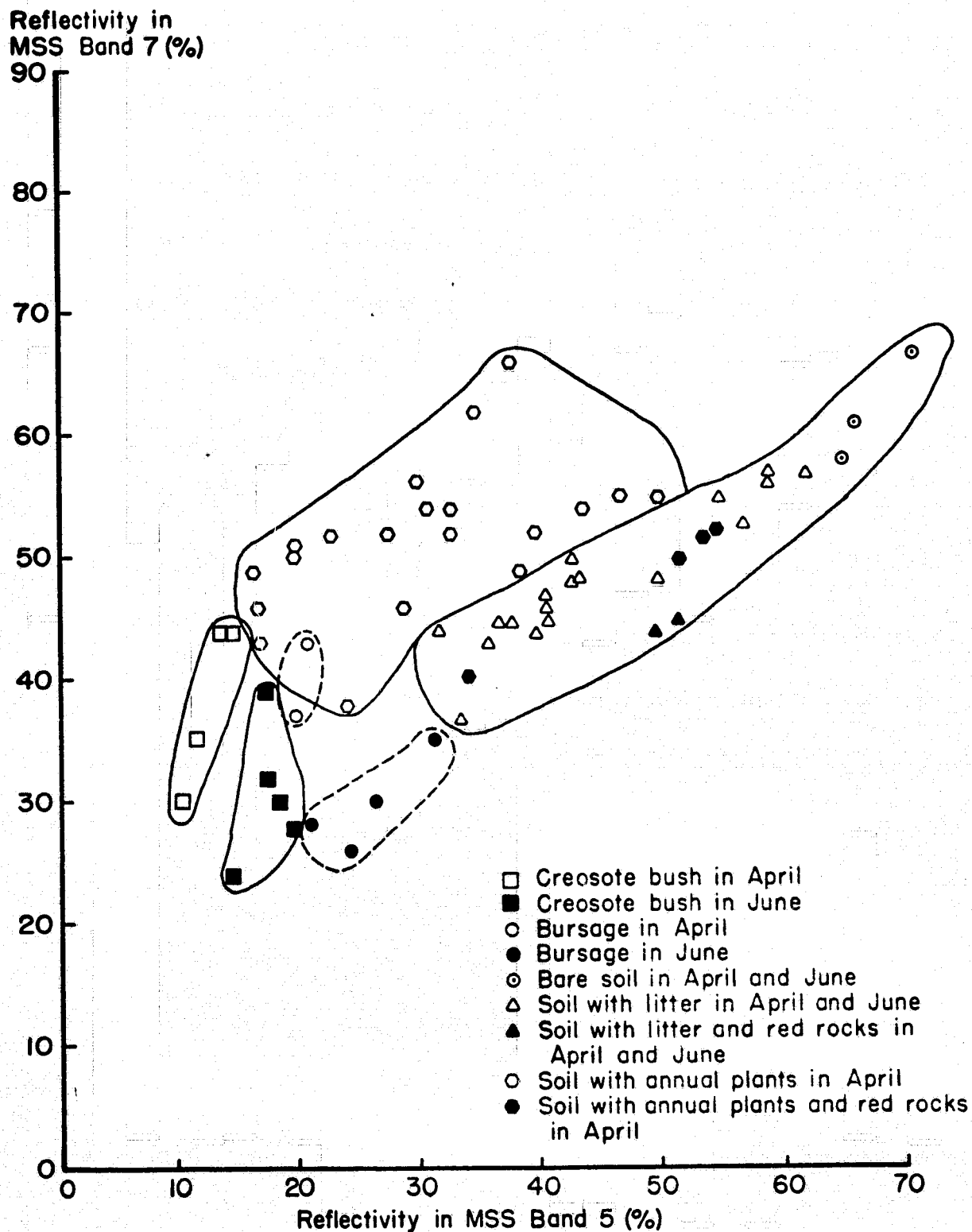
Figure 4-4   Reflectivity in MSS Band 7 (0.8-1.1μ) vs. Reflectivity in MSS Band 5 (0.6-0.7μ) for Various Scene Components.

individual components of a scene (ground, each type of shrub or tree cover) if the relative area of each component is known. For desert plant communities, direct measurements (as from a light plane) seems preferable, since shadows extending beyond the crowns of shrubs or trees are a part of the community signature which would be difficult to sample accurately on the ground.

It should also be pointed out that since shadows are part of a community signature, part of the seasonal change in spectral signature (as taken at ERTS overflight time) will be due to changes in the amount and distribution of shadows, which are in turn a result of changes in sun angle. Without adequate ground truth data, this could cause difficulties in inferring phenological change from seasonal changes in ERTS spectral signatures.

Airborne Radiometric Study

In an effort to compare the ground truth radiometric data collected at our Avra Valley sites to that collected by ERTS, an airborne radiometer-videotape recorder interface was designed to provide for the collection of radiometric data over selected Avra Valley study sites from a small aircraft. In our previous radiometric study of the Avra Valley sites, radiometric data were taken for the various components of each scene. It was then shown quantitatively that each radiometric component such as vegetation, soil, and litter of dead plants, differed from the other components radiometrically, but combined in some way to produce the overall radiometric signature. It was hoped that the low-altitude radiometric data when compared to ground-based radiometric data of the various scene components would yield information on how the components integrated to form the signature of a scene.

The radiometric data collection system employed for the low altitude study made use of an Exotech ERTS radiometer mounted over a hole in the bottom of a CESSNA 206 that fed continuous data to a SONY AV-3400 videotape recorder via

an interface. The system was developed by L.K. Lepley and based on a similar system used by A.M. Williamson of the Environmental Characterization Branch, Army Corps of Engineers. Construction and design was a result of the efforts of Evan Rosen, a member of the investigation team.

The terrain below the aircraft is viewed by a video camera that looks down the spotting scope of an Exotech ERTS radiometer as the image is recorded on magnetic tape. Simultaneously the data from the four channels of the radiometer plus spoken comments are coded by frequency modulation and entered on the sound track of the videotape.

The data collected represent a continuous record of the radiometric signatures of areas over which the airplane was flown. A SONY RF unit and a television set were employed with the videotape recorder to locate the portions of the tape on which the radiometric data of various study sites were recorded. A volt meter coupled to the interface was used to decode the data from the sites.

Airborne radiometric data were collected April 18, 1974, for six sites in the Avra Valley:

1) Rothrock grama grass site: supporting Rothrock grama grass, burro-weed and annuals;

2) Saguaro-Paloverde-Granite Rock site: foothill paloverde, saguaro, triangleleaf bursage, and many other perennial species;

3) Creosote bush West Milewide Rd. site: creosote bush and annuals;

4) Green Field site: very heavy growth of corn;

5) Plowed Field site: bare plowed soil.

Ground truth data of the six sites were collected the day after the overflight.

Due to the malfunction of the interface, a back-up system was employed to record the data. This unit consisted of two volt meters coupled to radiometer channels 5 and 7 and a 35 mm single-lens reflex camera which recorded the meter

readings as the aircraft passed over the study sites.

This sytem was flown May 21, 1974, over the six previously described Avra Valley sites. This date did not correspond to an ERTS flyover. Ground truth data of the sites were collected the following day.

Airborne radiometric data plus ground truth radiometric data for the scene components were plotted as red (Band 5) versus infrared (Band 7) for each site except Bare Field and Green Field. The latter two sites were plotted together to facilitate comparison.

As is shown by the graphs (Figures 4-5, 6, 7, 8, and 9), soils are the most important factor in determining the overall spectral signature of desert plant communities. Vegetation in these areas had only a small effect on the spectral signature. These results point out the difficulty in isolating and examining the relatively small vegetation parameter of the desert communities. In the face of such a large soil to vegetation ratio, large differences in green plant biomass are required to cause small differences in spectral signatures. Therefore, native arid plant communities with similar vegetation densities are difficult to separate.

% Reflectivity in MSS Band 7 (0.8-1.1μ)

Legend:
△ Soil with litter
□ Creosote bush
● Airborne signature

% Reflectivity in MSS Band 5 (0.6-0.7μ)

Figure 4-5 Reflectivities of Creosote Bush Site Scene Components Compared to Overall Airborne Scene Reflectivity.

**% Reflectivity in
MSS Band 7 (0.8-1.1μ)**

% Reflectivity in MSS Band 5 (0.6-0.7μ)

○ Bursage
△ Creosote bush
▽ Paloverde
□ Soil
● Airborne signature

Figure 4-6   Reflectivities of Paloverde-Saguaro-Granite Site Scene
Components Compared to Overall Airborne Scene Reflectivity.

% Reflectivity in MSS Band 7 (0.8–1.1μ)

Legend:
- O Bursage
- △ Creosote bush
- ▽ Paloverde
- □ Soil
- ● Airborne signature

% Reflectivity in MSS Band 5 (0.6–0.7μ)

Figure 4-7   Reflectivities of Paloverde-Saguaro-Red Rock Site Scene
Components Compared to Overall Airborne Scene Reflectivity.

% Reflectivity in MSS Band 7 (0.8-1.1μ)

◊ Burro weed
☐ Soil with litter
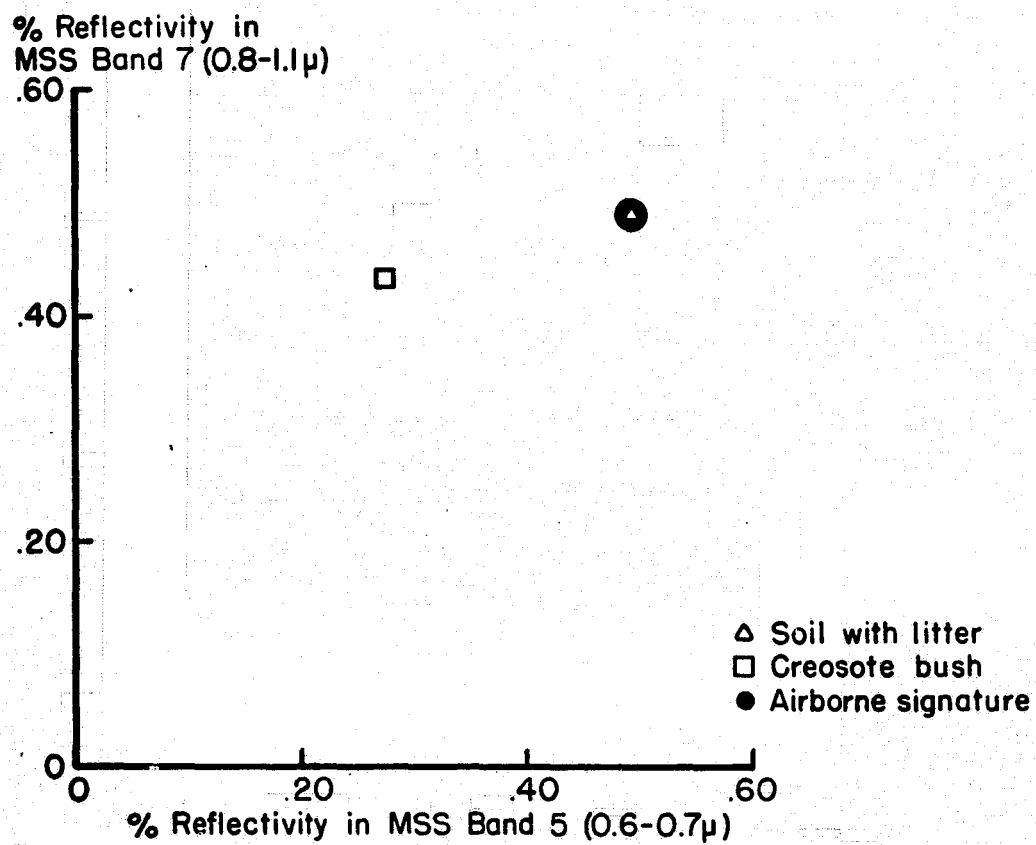● Airborne signature

% Reflectivity in MSS Band 5 (0.6-0.7μ)
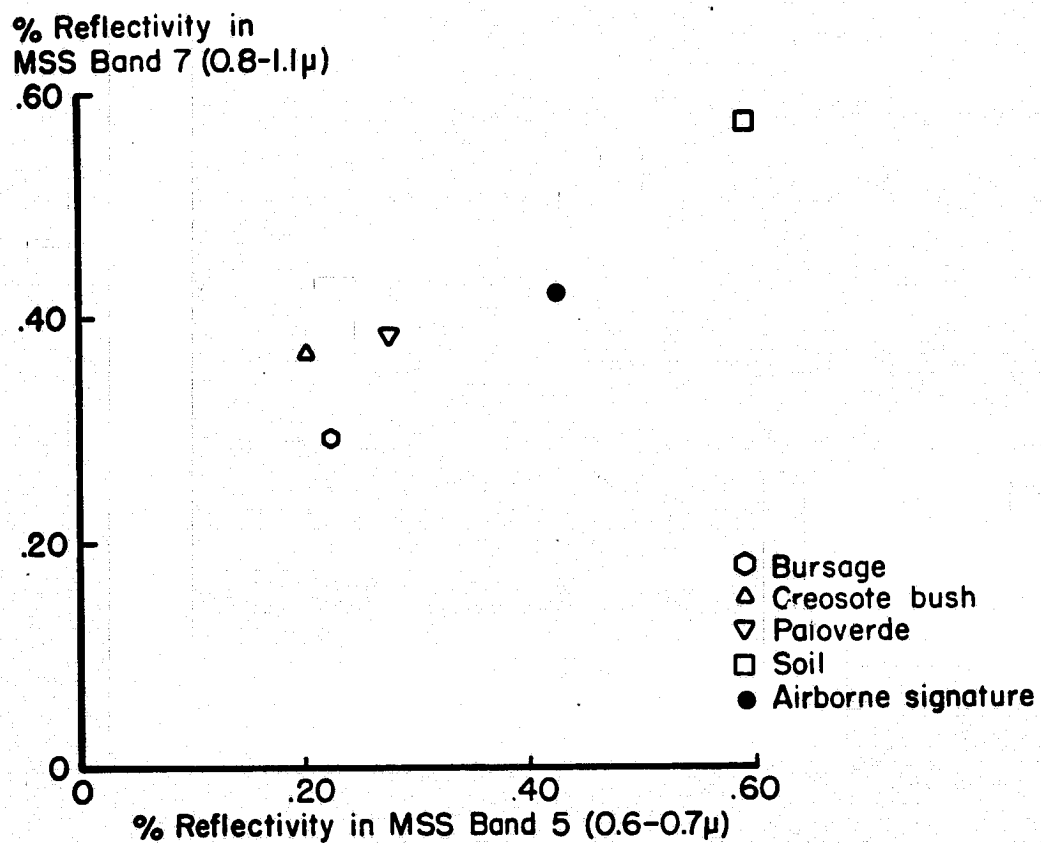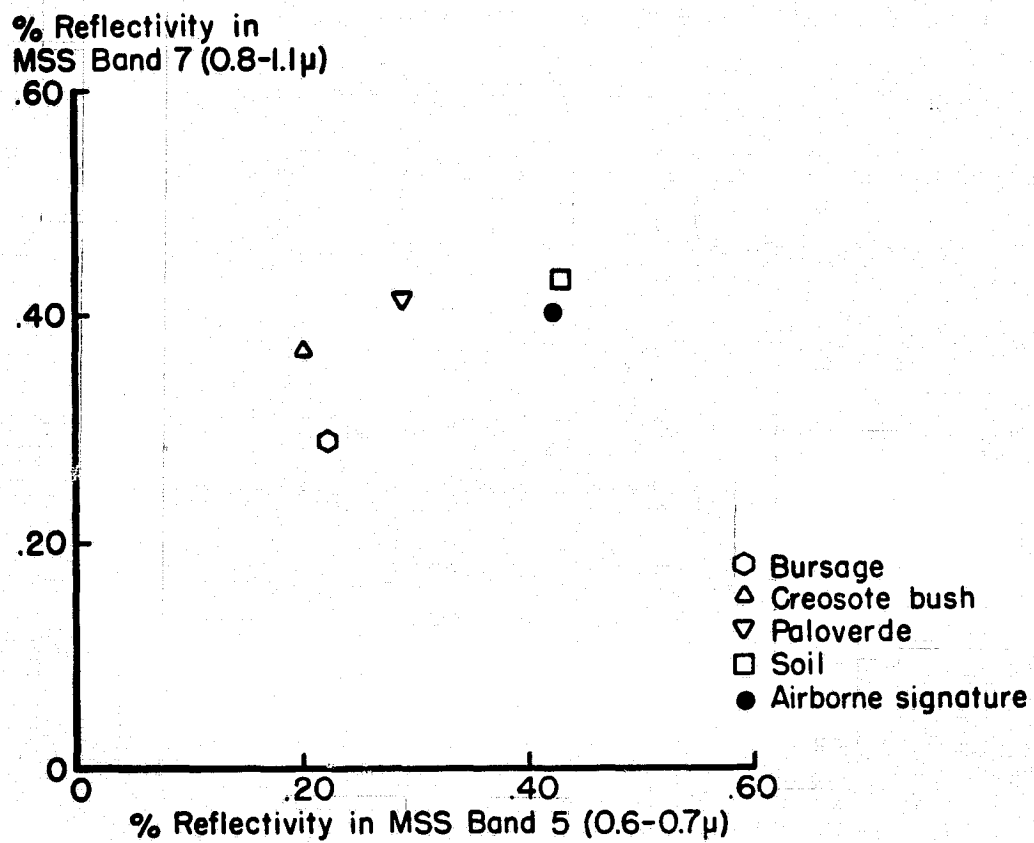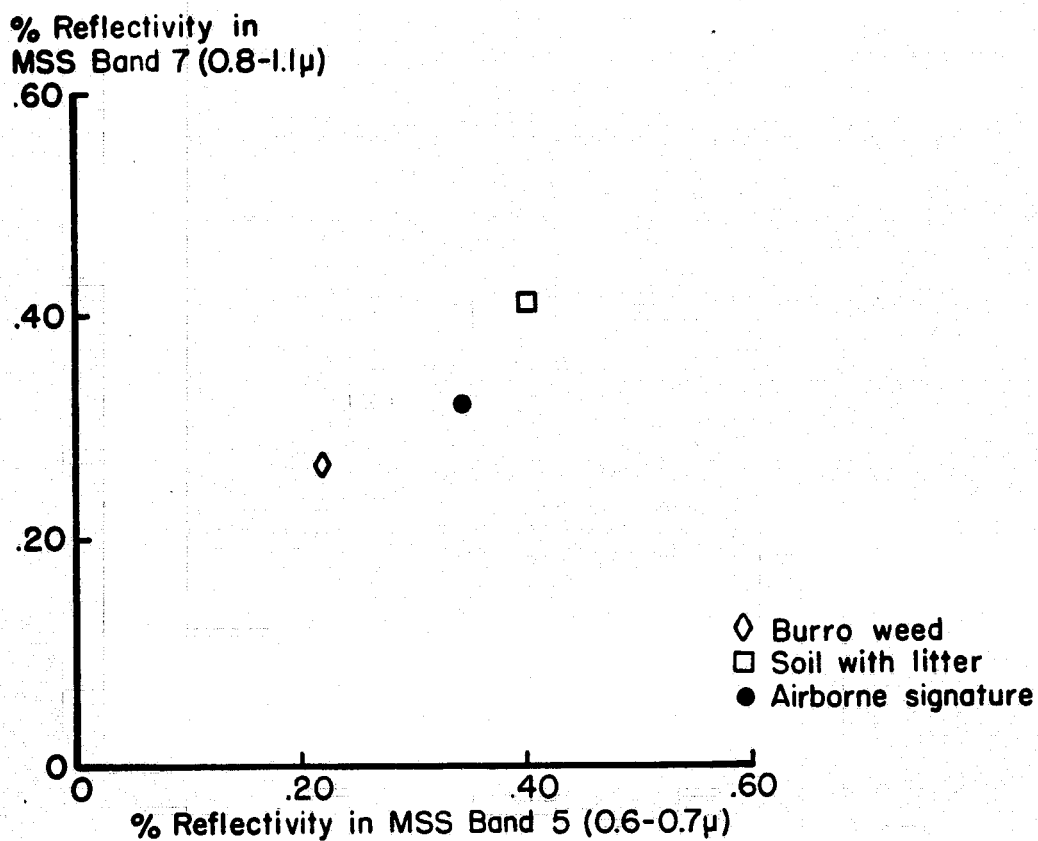
Figure 4-8   Reflectivities of Rothrock Grama Site Scene Components
Compared to Overall Airborne Scene Reflectivity.
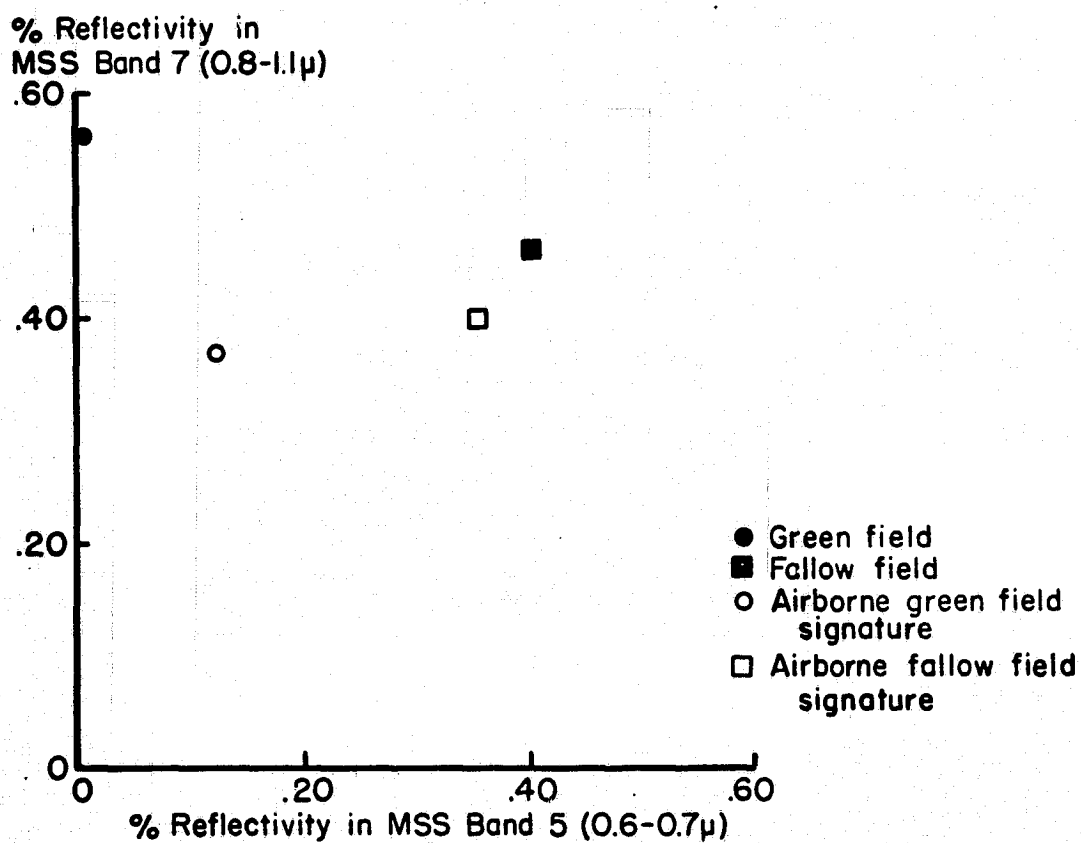
Figure 4-9 Reflectivities of Fallow and Planted Fields Compared to
Overall Airborne Scene Reflectivities.

CHAPTER V: PHOTOGRAPHIC IMAGE ENHANCEMENT TECHNIQUES AND DISCRIMINATION OF PLANT COMMUNITIES IN THE AVRA VALLEY

Introduction

Multispectral masking techniques developed by Molineux (1965), Stark, Barker, and Lee (1972a, 1972b), and modified by L.K. Lepley, were employed with ERTS Bands 5 and 7 to enhance the vegetational aspects of ERTS linear density transparencies which included the Avra Valley study sites.

As was shown by Stark, Barker, and Lee (1972b) binary photographic masks can be combined in logical combinations so that only objects within a predetermined spectral signature range will be visible. Objects outside of this range are blacked out.

These spectral gates are referred to as "equivalence class masks" by Stark, et al., because they mask out everything except the class of objects possessing a specified brightness range within a certain spectral range.

Two logical sequences of equivalence mask combinations were devised to enhance native arid vegetation of the Avra Valley from ERTS data. Each sequence was carried out using June 25, 1973, ERTS MSS 9-inch transparencies (image #E 1337-17332). Bands 5 (.6-.7 μ) and 7 (.8-1.1μ) were employed. Linear density transparencies were used because of their better definitions in light-toned areas where the native arid vegetation is often found. Figures 5-1 and 5-2 outline the steps in each sequence.

Sequence Methods

Both sequences began with the enlargement of ERTS MSS Bands 5 and 7 nine-inch linear density positive transparencies. The enlarged negatives were then contact printed onto ortho film. The exposure times were manipulated to correspond to the spectral thresholds characteristic of native arid vegetation. For Sequence I, the thresholds set for the production of the first high-contrast
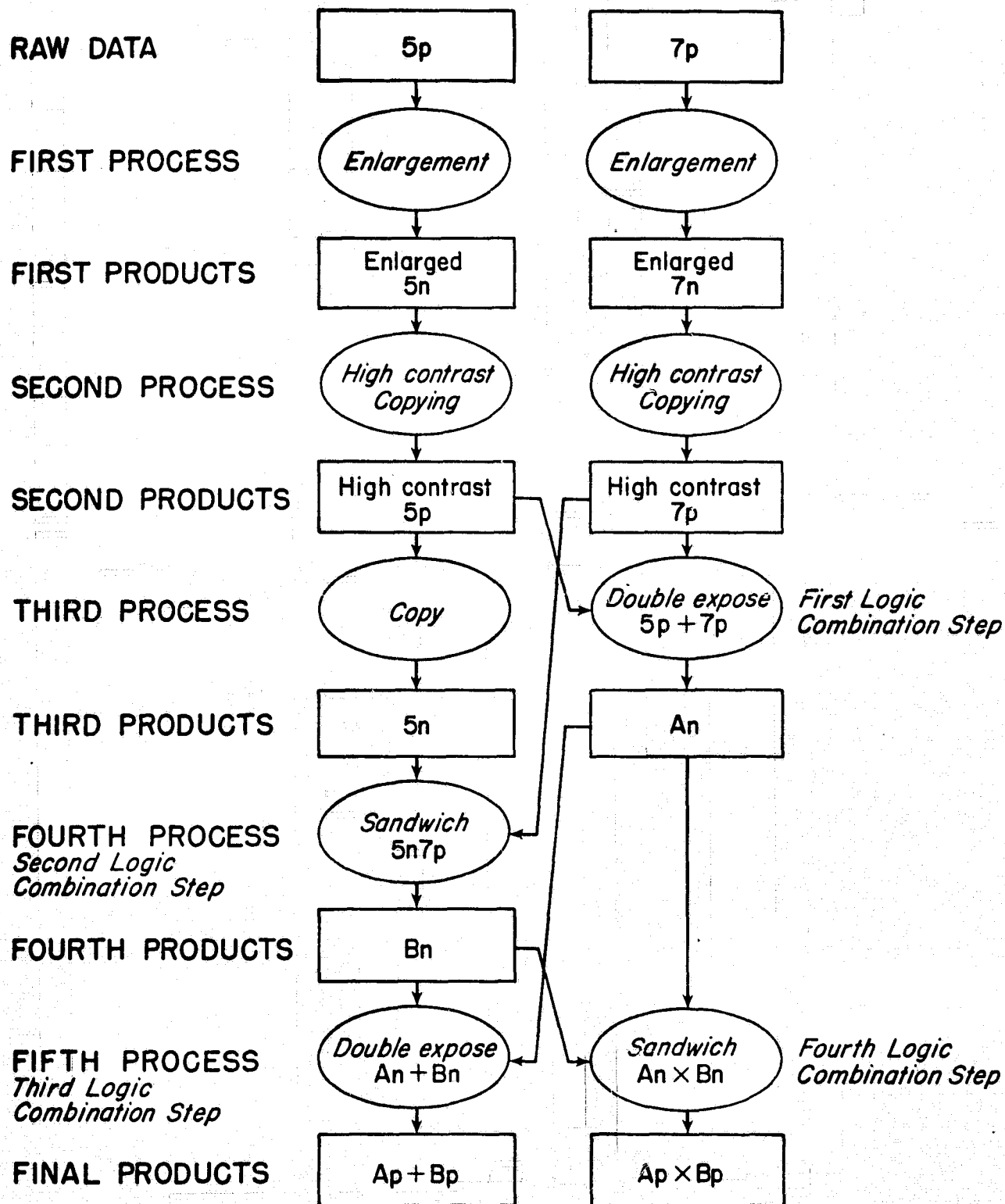
Figure 5-1   Flow Diagram for Enhancement Sequence I
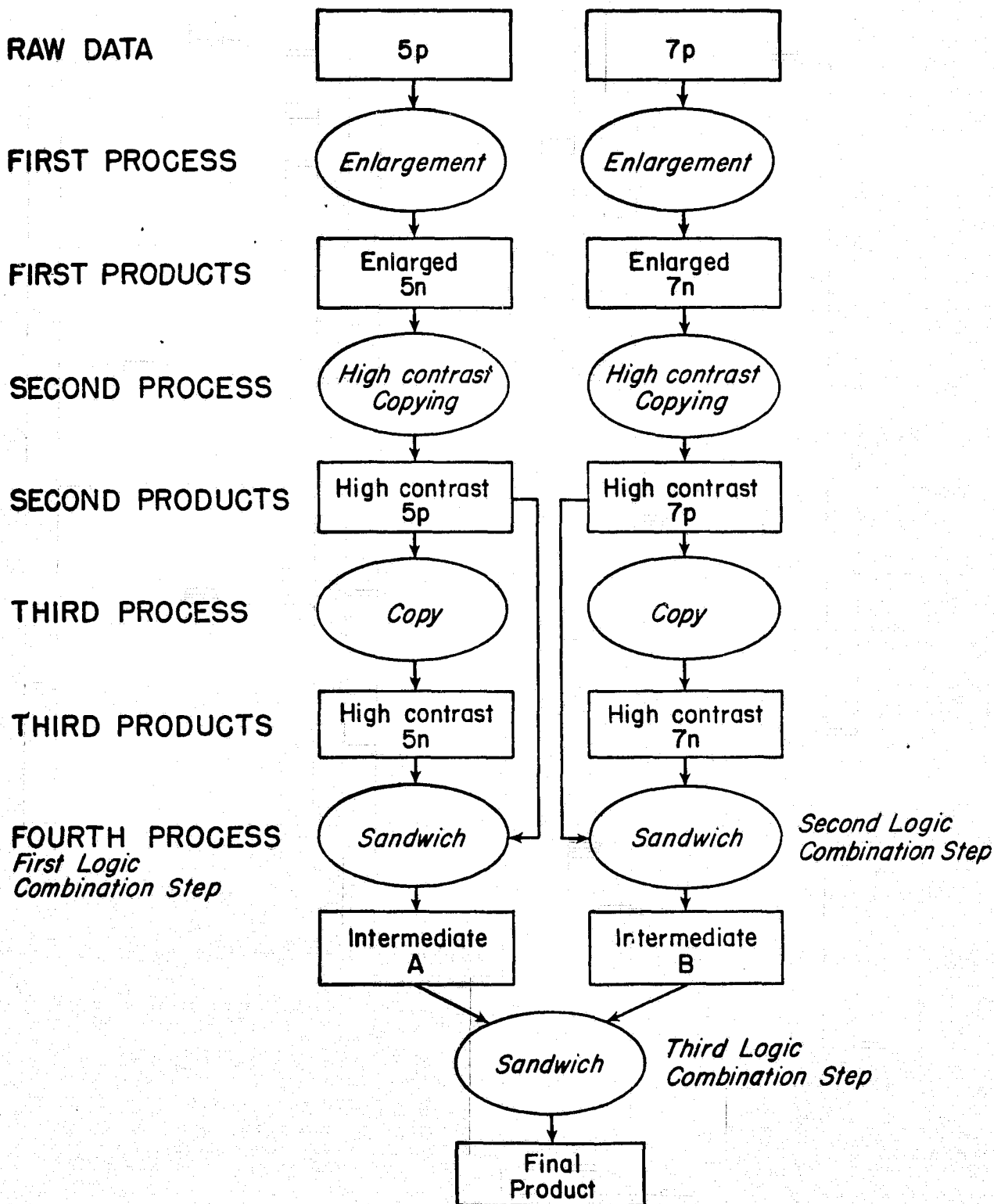
Figure 5-2 Flow Diagram for Enhancement Sequence II

positives from the enlarged negatives was such that areas of known arid plant growth were nearly opaque for MSS Band 5 and nearly transparent for MSS Band 7 (see Figures 5-3 and 5-4). A high-contrast negative of Band 5 was made by contacting the high-contrast positive onto panchromatic film. Vegetation is nearly transparent on this transparency as is shown in Figure 5-5.

High-contrast positives were made from the enlarged Band 5 and 7 negatives to begin logic Sequence II. Threshold values for these transparencies rendered desert vegetation nearly transparent. Negatives of Bands 5 and 7 were made by contacting dense high-contrast positives that showed native vegetation to be nearly opaque. Vegetation was rendered nearly transparent on these negatives as is shown by Figures 5-6 and 5-7.

Sequence I

As is shown by the Figure 5-1 flow diagram, the first step of the logic combination (L.C.) is to double expose high-contrast positives of MSS Bands 5 and 7 on the same panchromatic sheet to produce an intermediate A_n. As a result of the effects of the double exposure, vegetation is rendered middle grey, rock rendered transparent, and soil rendered dark as is shown in Figure 5-8. Logic combination (L.C.) step 2 consists of sandwiching the high-contrast Band 7 positive and high-contrast Band 5 negative onto ortho film to produce intermediate B. This sandwiching, or image subtraction, results in the vegetation being rendered opaque while soil and rock are transparent (see Figure 5-9).

L.C. step 3 is to double expose intermediates A and B onto panchromatic film. On the resulting transparency vegetation is almost transparent, soil is grey, and rock is black as is shown by Figure 5-10.

Step 4 is to sandwich intermediates A and B onto panchromatic film. Vegetation is transparent, rock is black and soil is very light as a result of this sandwich as is shown by Figure 5-11.

Figure 5-3. High-Contrast Band 5

Figure 5-4. High Contrast Band 7

Figure 5-5. Negative, Band 5
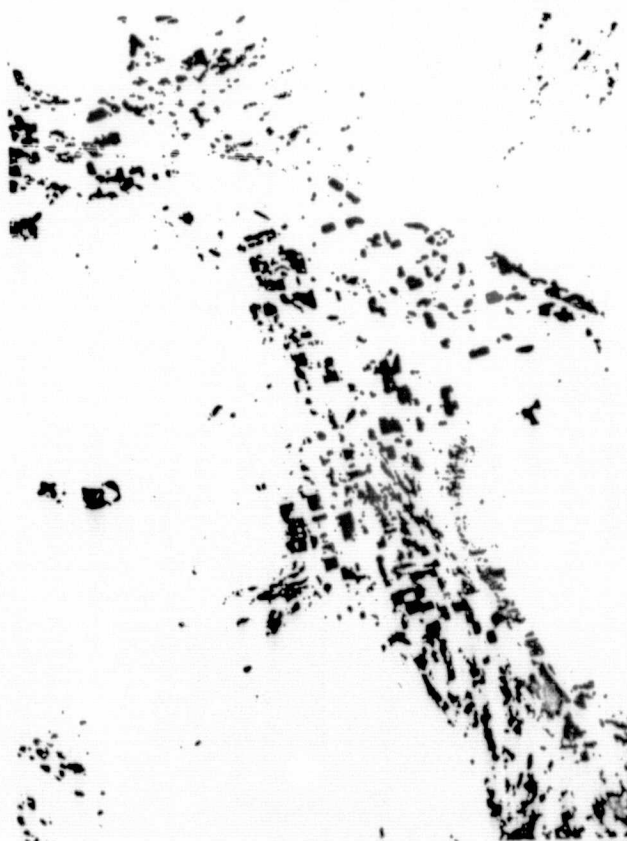
Figure 5-6. Negative, Band 7

38

Figure 5-7. Negative, Band 5

Figure 5-8. Method I, Intermediate A

Figure 5-9. Method I, Intermediate B

Figure 5-10. Method I, Double
Exposure of A and B

39

Figure 5-11. Method I, Sandwich of A and B

Figure 5-12. Method II, Intermediate
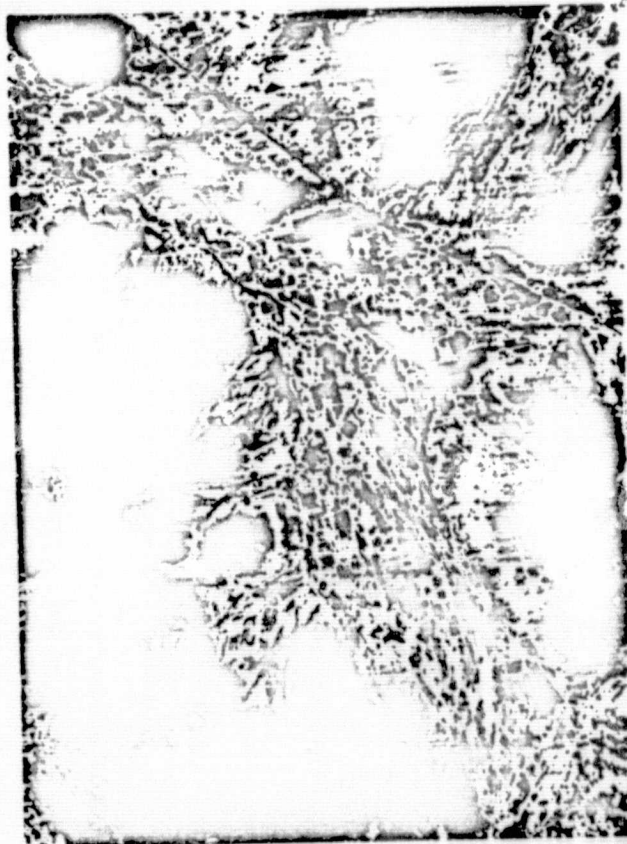
Figure 5-13. Method II, Final Product

Sequence II

The first step of the logic combinations for Sequence II is to copy a sandwich of the high-contrast Band 5 negative and high-contrast Band 5 positive onto ortho film. As is shown by Figure 5-12, the resulting intermediate A shows vegetation to be nearly opaque while soils and rock are nearly transparent.

Step 2 is to copy a sandwich of a high-contrast Band 7 positive and a high-contrast Band 7 negative onto ortho film resulting in intermediate B. Vegetation is nearly opaque on this intermediate while soil and rock are nearly transparent.

The third and final L.C. step for Sequence II is to copy a sandwich of intermediates A and B onto panchromatic film. In the final product vegetation is nearly transparent while soil and rock are nearly opaque (see Figure 5-13).

Table 5-1 outlines the component nature of the transparencies at each step and shows how they change as a result of image addition and subtraction.

Analysis of Final Photographic Products

Both logic sequences enhance desert vegetation to a great degree. Sequence I products when viewed simultaneously through a multispectral viewer allow for the differentiation of 3 vegetation categories: saguaro-paloverde, riparian, and creosote bush. The Sequence II product allows for the differentiation of paloverde-saguaro, creosote bush, riparian-silt, and bare soil categories. The Sequence I equivalence class making logic succeeds in separating the riparian communities from areas of bare soil while Sequence II logic does not. The Sequence II category boundaries are more distinct than are the Sequence I boundaries, however, since fewer resolution-lowering registering steps were required.

Boundaries of the before-mentioned vegetation and soil categories were traced on the view screen of a multispectral color additive viewer for Sequence I final products. These boundaries were checked against NASA high-altitude imagery and field observation. Actual riparian communities and areas of bare

41

TABLE II

Scene Component Natures as Influenced by Multispectral Masking

LOGIC SEQUENCE I

Logic Combination

Step 1 (double expose)

	Band 5 (pos)	Band 7 (pos)	Result (neg)
vegetation	opaque	trans	gray
soil	trans	trans	dark
rock	black	black	trans

Step 2 (sandwich)

	Band 5 (neg)	Band 7 (pos)	Result
vegetation	trans	trans	black
soil	black	trans	trans
rock	white	black	trans

Step 3 (double expose)

	A	B	Result
vegetation	gray	black	light
soil	dark	trans	gray
rock	trans	trans	black

Step 4 (sandwich)

	A	B	Result
vegetation	gray	black	trans
soil	dark	trans	very light
rock	trans	trans	black

Step 5 (double expose)

	A	B	Result
vegetation	light	trans	black
soil	gray	very light	dark
rock	black	black	trans

TABLE II
(cont'd) .

LOGIC SEQUENCE II

Logic Combination Step 1 (sandwich)

	Band 5 (pos)	Band 5 (neg)	Result A
vegetation	nearly trans	nearly trans	nearly opaque
soil	trans	nearly opaque	nearly trans
rock	nearly opaque	trans	nearly trans

Step 2 (sandwich)

	Band 7 (pos)	Band 7 (neg)	Result B
vegetation	nearly trans	nearly trans	nearly opaque
soil	trans	opaque	trans
rock	opaque	trans	trans

Step 3 (sandwich)

	A	B	Result
vegetation	nearly opaque	nearly opaque	nearly trans
soil	nearly trans	trans	nearly opaque
rock	nearly trans	trans	nearly opaque

ground were found to correspond closely to the bare ground and riparian categories shown on the color enhanced Sequence I addition and subtraction transparencies.

In comparison to the non-enhanced high-altitude color, color infrared, and SLAR imagery of the Avra Valley, the ERTS equivalence class products show the various categories of arid vegetation in a more distinct fashion. The paloverde-saguaro vegetation category is almost impossible to differentiate from the creosote bush category on high-altitude color and color infrared imagery. Radar shows the distinction somewhat more clearly, but the distinction is most clear on the enhanced ERTS imagery. Areas of bare soil and riparian vegetation are much more detailed on high-altitude color, color infrared, and SLAR imagery, however.

Vegetation Map of Avra Valley Study Area

A vegetation map of a large portion of the study area was prepared from ERTS equivalence mask final products. In addition to the enhanced ERTS imagery and ground truth data, color imagery from NASA high-altitude Mission No. 101, site 30, was used in preparation of the map. Agricultural areas and roads were delineated through the use of the high-altitude imagery but all other categories were taken from the ERTS images.

Descriptions of the Vegetation Types Mapped in Figure 5-14

A. SILT AND BARE SOIL

Vegetation

These areas are very sparsely vegetated, with only a few mesquite and creosote bush growing. Many dead mesquite stumps are present, however, suggesting that these areas were vegetated in the not too distant past. A known drop in the water table due to the pumping of water for irrigation purposes may
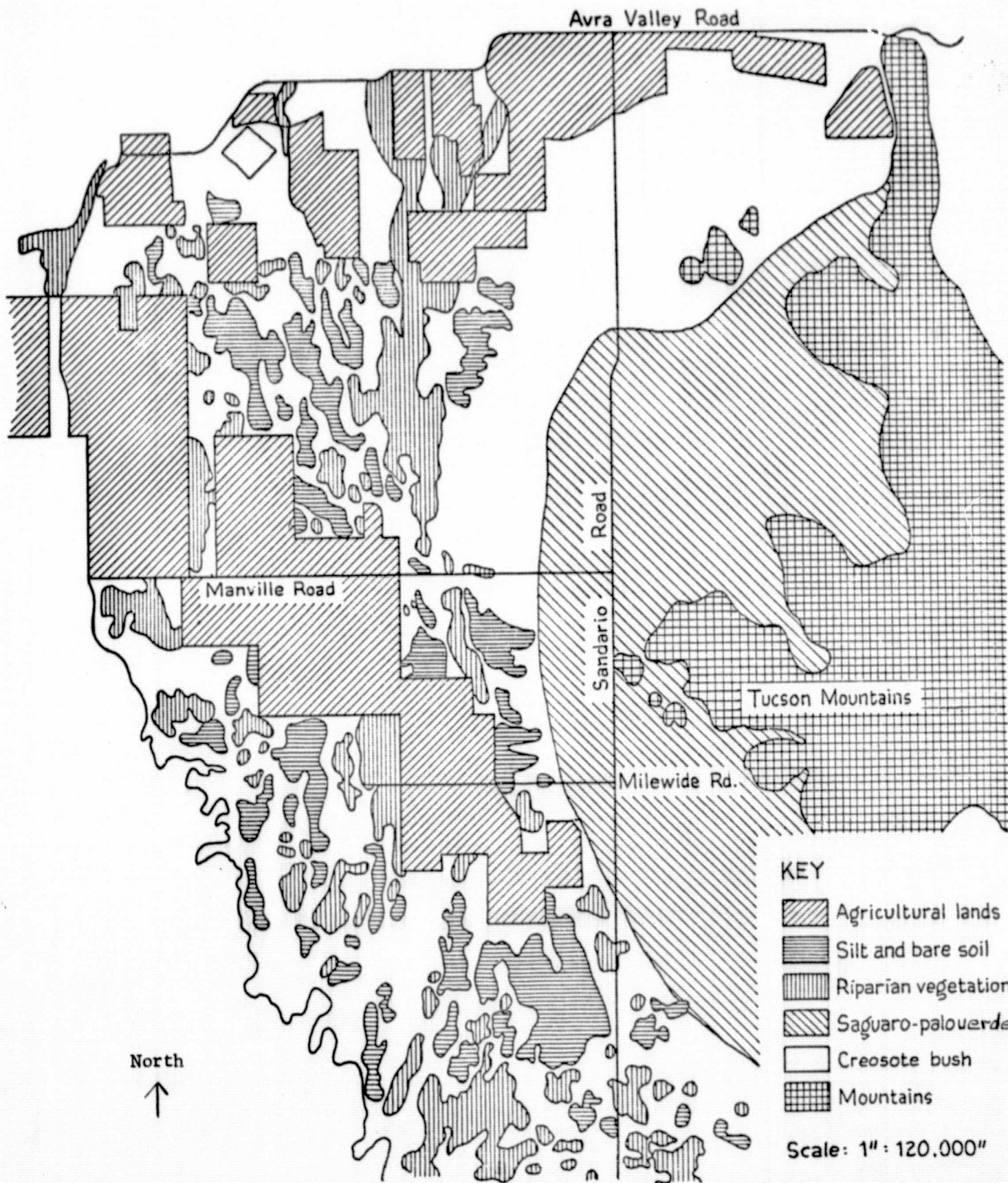
Figure 5-14. Vegetation Map of a Portion of the Avra Valley.

Avra Valley Road

Manville Road

Sandario Road

Tucson Mountains

Milewide Rd.

North

KEY

Agricultural lands

Silt and bare soil

Riparian vegetation

Saguaro-palouerde

Creosote bush

Mountains

Scale: 1" : 120.000"

be the cause of the death of the mesquite.

Physiographic Relations

Loose, silty soil occurs on level to slightly sloping topography. These barren areas are often on the outskirts of mesquite areas and are from 20 to 400 yards wide. It appears that sheet erosion has been very severe in these areas.

B. RIPARIAN VEGETATION

Vegetation

Very dense stands of mesquite with a few large ironwood trees form the canopy. Whitethorn acacia occupies the middle strata and sometimes becomes arborescent. The herb-small shrub layer is largely absent under the dense canopy; however, snakeweed, burro-weed, and wolf berry grow in the clearings where there is less shade.

Physiographic Relations

The silty soil is heavily dissected and eroded. The water channels are deeply cut and are hard bottomed. The areas surrounding the mesquite areas are often severely sheet-eroded and devoid of vegetation.

C. CREOSOTE BUSH

Vegetation

The creosote bush communities are comprised almost completely of creosote bush with a few small mesquite and triangleleaf bursage intermixed. The washes are vegetated with large mesquite, blue paloverde, and ironwood. Canyon ragweed and burro-weed grow along the banks of the watercourses.

This vegetation category has less vegetative cover than any category except silt and bare soil.

Physiographic Relations

The soil is generally silty and only slightly dissected. The topography is level and water channels are few and far apart. The individual creosote bushes are often surrounded by a mound of silt.

D. SAGUARO-PALOVERDE

Vegetation

The vegetation of this category varies depending on its location on the mountains and bajadas. The category includes the creosote bush-paloverde-saguaro ecotone and is held together primarily by the copious presence of foothill paloverde and saguaro. As a whole, the saguaro-paloverde category has a much higher density than does the creosote bush or silt-bare soil categories.

On the lower bajadas creosote bush, mesquite, triangleleaf bursage, ironwood, ocotillo, burro-weed, and several species of cholla cactus are found along with paloverde and saguaro.

In the washes large foothill paloverde, ironwood, canyon ragweed, mesquite and desert hackberry are found.

Upper bajadas have much the same species composition, but with a few differences: ironwood and burro-weed are not present; however, plants such as the barrel cactus, fairy duster, limber bush, catclaw acacia, ratany, teddy bear cactus, desert zinnia, and brittle-bush are common.

At the higher elevations of the foothills and slopes of the Tucson Mountains, jojoba grows abundantly.

Physiographic Relations

The mapped paloverde-saguaro community is found on the bajadas, foothills. and slopes of the Tucson Mountains.

Bajadas tend to be slightly to highly sloping. Soil particles vary from very fine (at the bottoms of the bajadas) to course (at the tops of the bajadas). Upper

bajadas seem to be much more rocky than lower bajadas.

The bajadas are greatly dissected by watercourses. The watercourses vary from a few meters across to more than 20 meters. The bottoms of the stream-beds are usually sandy.

The foothills and slopes of the mountains are very rocky and quite steep. Rock outcroppings and cliffs are quite common.

Streambeds in the foothills and mountains are very steep and deeply entrenched. Bedrock is often found at the bottom of the stream channels.

E. AGRICULTURAL LANDS

These areas were delineated to avoid confusion in interpreting the map. Except for their rectangular pattern, fallow fields would be mistaken as silt-bare soil areas and planted fields would be mistaken for riparian areas on the enhanced ERTS transparencies.

F. MOUNTAINS

The Tucson Mountains appeared as a distinct category even though the vegetation is of the saguaro-paloverde variety. The unique "dark" spectral appearance of the mountains is due to the abundance of rock and not to a vegetation difference.

CHAPTER VI: ANALYSIS OF SOILS AND VEGETATION ASSOCIATED WITH DESERT PAVEMENT OF THE YUMA AREA

Vegetation Map of Yuma Study Area

On ERTS imagery of Yuma County, there is a contrast between the dark tones of some bajadas and the lighter tones of other bajadas. Ground truth observations made at the Yuma study area in late March and early June 1973 revealed that the contrasts are due to the presence and absence of desert pavement, a close-set, continuous gravel layer on the soil surface. It was also revealed that there are vegetation differences between the bajadas with large areas of desert pavement and those bajadas lacking desert pavement. Using this ground truth correlation between the various types of desert pavement and vegetation present thereon, a vegetation map of the study area was prepared from ERTS image E-1069-17441. In addition to the ERTS imagery and ground truth data, imagery from NASA U-2 flight 73-016 was used in the preparation of the map. Six types of natural areas as well as agricultural areas were delineated and described. Urban and agricultural areas are delineated on the map but are not mapped in detail because the study of these areas is outside the scope of this investigation. Mountainous areas are delineated on the map, but the vegetation types of the mountains are not described because limited accessibility would have greatly increased the time necessary for adequate ground truth data collection.

Descriptions of the Vegetation Types Mapped in Figure 6-1

TYPE A: PALOVERDE-IRONWOOD. Desert Pavement on Interfluves

Vegetation

Except for an occasional creosote bush or bursage, and a few annuals, all the vegetation occurs in drainageways, that vary in size from small rills to large washes. The aspect is dominated by foothill paloverde and sometimes blue paloverde, ironwood, and occasional individuals of saguaro.

49

Type A   Paloverde and Ironwood with highly developed desert pavement
Type A'   Paloverde and Ironwood with little or no desert pavement
Type B   Creosote bush and Bursage
Type B'   Creosote bush, Mesquite and Big Galleta
Type C   Creosote bush and Ocotillo
Type AC   A mosaic of types A and C
Type M   Mountainous areas
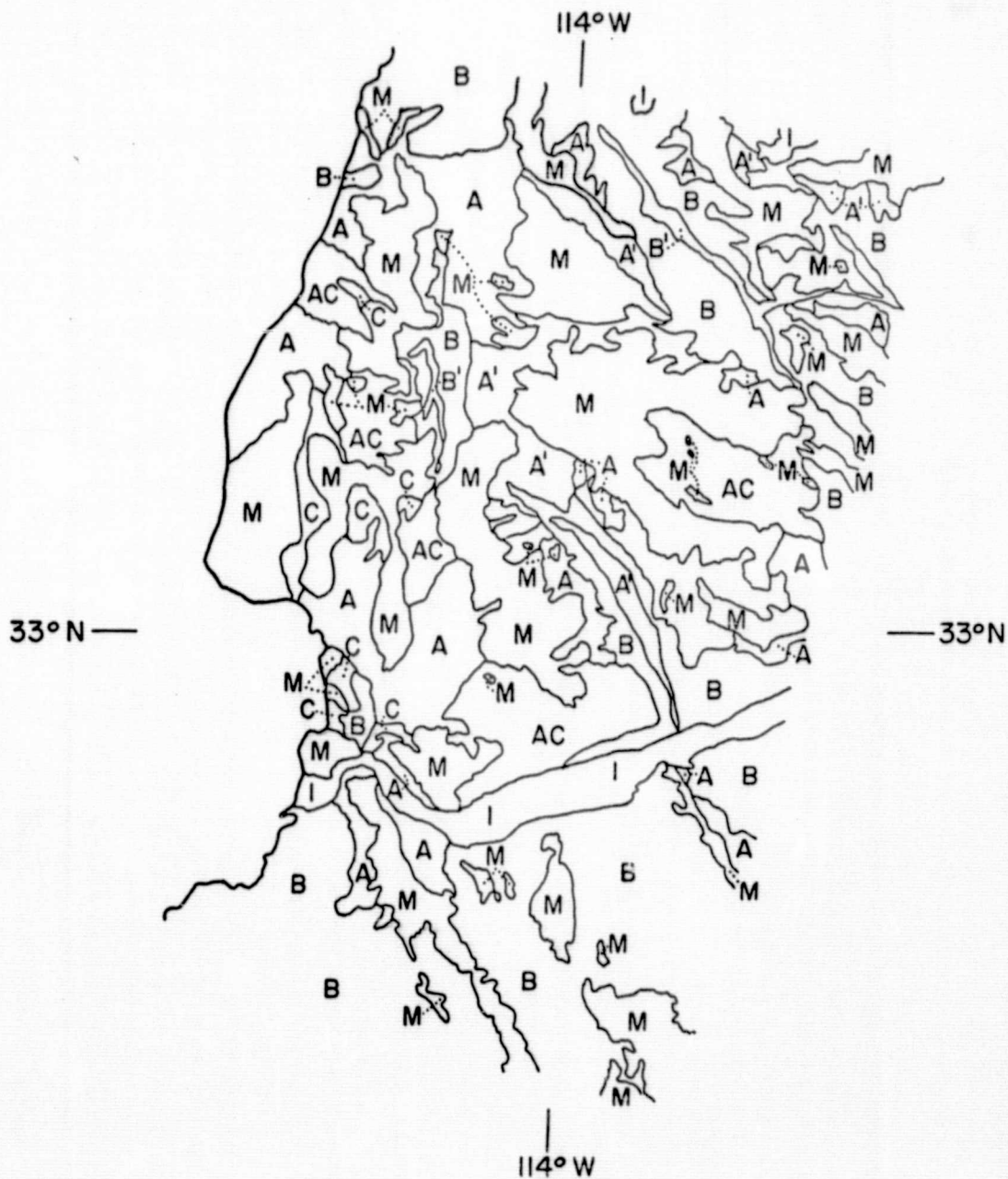Type I   Agricultural areas

Figure 6-1   Vegetation Map of Yuma Study Area Prepared from ERTS Image
E-1069-17441.

In the small rills are found creosote bush, bursage, and brittlebush, with infrequent small individuals of blue paloverde and ironwood. A few ocotillo occur on the slopes of the more deeply incised rills. In the large washes, paloverde and ironwood are larger and more numerous than in the small rills. All of the shrubs mentioned above occur in the large washes, along with the following species: desert-lavender, smoke-tree (at lower elevations only), canyon ragweed, catclaw acacia, jojoba, and bebbia. The most abundant winter annual in this area in May 1973 was plantain.

Physiographic Relations

This vegetation type occurs on gently sloping bajadas. Between washes and rills are smooth, level or gently sloping areas covered with dark brown desert pavement. Between washes and rills the gravel stones are covered with a thin dark brown varnish, which is apparently a weathering phenomenon. These interfluves with varnished desert pavement have almost no plants on them, except in one situation which is discussed below.

Shallow rills or drainageways three to ten meters wide and less than two meters deep traverse the pavement areas. The soil surface in these rills is commonly covered with a discontinuous gravel layer, but few of the stones have the dark brown varnish coating. There is some soil visible between the small stones. The discontinuity of the gravel surface layer, and especially the lack of dark varnish coatings, result in the rills having a much lighter soil surface tone than the interfluves.

Larger washes, which are wider than the rills and two to four meters deep, also traverse the pavement areas. The soil surface in the wash area is sandy and rough in the small channels, but there are also islands of relatively level, partially gravel-covered surface. Nowhere in the wash area are varnish covered rocks prominent on the surface.

On the level varnished pavement areas there are circular areas, mostly two to six meters in diameter, of lighter soil surface color. On some of these the surface gravel layer is discontinuous and the center is slightly mounded and lumpy. On others little mounding is evident and there is nearly continuous gravel pavement surface. On all of these circular areas, the dark varnish is absent from most of the surface gravel. As with the rills, the discontinuity of the gravel surface and especially the lack of varnish on the surface gravel make these areas very light-toned in contrast to the surrounding dark pavement. These circular areas of fresh soil and rock are apparently due to the activity of burrowing rodents. On these circular areas, creosote bush and white bursage may occasionally be found, and the winter annual plantain is common, but vegetative cover is sparse.

TYPE A': PALOVERDE-IRONWOOD. Desert Pavement Weakly Developed or Absent

Vegetation

Species present are those listed for Type A, with foothill paloverde and ironwood usually dominating the aspects.

Physiographic Relations

This type occurs on gently sloping bajadas and on moderately sloping alluvial fans at the bases of mountains. On the bajadas, microtopography is similar to Type A, but there is less strongly developed pavement with varnish, resulting in a lighter soil surface tone. On the sloping alluvial fans at the base of the mountains, the microtopography is rough, with many small rills and large boulders on the surface. There are no nearly level pavement-like surfaces. The soil surface tone in the alluvial fans is relatively light.

TYPE B: CREOSOTE BUSH-BURSAGE

Vegetation

Together, creosote bush and bursage dominate this vegetation type in aspect and in coverage. The relative abundance and size of these two species varies somewhat according to local conditions. On sandy soils, they are joined by big galleta and on stony soils by ocotillo. In some areas, mesquite is common in the washes, but in other areas foothill paloverde and ironwood are the wash trees. Few other shrubs are of major importance in this vegetation type. The winter annual cover of late March 1973 was variable in composition, possibly in response to differences in soil factors. Plantain was common everywhere.

Physiographic Relations

The various types of creosote bush-bursage community occur on gently sloping lower bajadas and on nearly level plains or "mesas" below the lower bajadas. Variations in the relative abundance of the two dominant species, and the occurrence and abundance of subdominant species appear to be correlated with variations in soil factors, especially soil texture. Big galleta occurs on sandy soils, and ocotillo occurs on gravelly soils. Our observations do not allow us to generalize about the relationship between relative abundance or coverage of the two dominants and soil texture. Phenology of the perennials might be expected to vary with soil type, but since our observations were limited to the peaks of the winter wet and fore-summer dry seasons, differences in the timing of leaf drop and leaf color changes at the end of the wet season were not included in our observations.

Generally, this vegetation type occurred on nearly level areas, sometimes with hummocks under the shrubs. In the vicinity of the Yuma Proving Ground headquarters, this community occurs on rolling hills. Large washes with "riparian" trees (mesquite or paloverde and ironwood) are very widely spaced in this vegetation type.

There is usually much bare soil exposed at the surface, with only scattered gravel which lacks a dark varnish. In some areas, there are a few small areas of desert pavement with varnish like that described for Type A. Generally, then, the soil surface in this vegetation type is light-toned, especially in sandy areas.

TYPE B': CREOSOTE BUSH-MESQUITE

Vegetation

In this variant of Type B, white bursage may be absent and the creosote bush may be less dense. There are discontinuous clumps of mesquite about two or three meters tall, with dense big galleta under and between the mesquite clumps.

Physiographic Relations

This type occurs along the largest washes of some of the valleys. The soil is fine textured without gravel, and there is evidence of water flow into these areas from the surrounding bajadas. There may not be a well-defined wash channel, but rather a broad flat area that shows evidence of sheet flooding over the surface. Outside of the mesquite-galleta clumps, much of the highly reflective soil surface is exposed, but in the clumps themselves most of the soil surface is covered by vegetation.

TYPE C: CREOSOTE BUSH-OCOTILLO

Vegetation

Creosote bush and ocotillo are the major dominants in this type, but the total coverage of these and other shrubs is very low compared to the other vegetation types. The creosote bush are relatively small. On the slopes, cholla cacti are subdominant. In the washes between the hills are foothill paloverde and ironwood as well as many of the shrubs listed for the large washes in Type A.

Plantago *insularis* was the most common winter annual in March 1973.

Physiographic Relations

This vegetation type is found on dissected old alluvium. Moderately steep slopes are prevalent. The soil surface is covered with stones and gravel which lack the dark varnish of pavement gravel. The natural color of some of the stones is dark, however. The soil surface is generally light-toned, but not extremely so.

TYPE A + C: This is a mosaic of Types A and C, with each type retaining its own characteristics.

Imagery Characteristics of the Vegetation Types

Type A can be distinguished from the other types by its dark tone on all wavelength bands of ERTS imagery, and by its occurrence on the bajadas proper rather than in drainageways in the center of the valleys. The dark tone is obviously due to the considerable area of desert pavement, the individual stones of which are coated with a dark brown varnish or weathering surface. The light-toned circular areas, possibly a result of present or previous rodent activity, are visible on high-altitude color infrared imagery but not on ERTS imagery.

Type A' does not have as dark a tone as Type A, because in the former type the dark desert pavement areas are absent or less well developed. In some parts of Type A', the landforms and the distribution of vegetation in relation to the landforms are similar to Type A. In these areas, the flat interfluves are not as dark on the ERTS or high-altitude imagery as the flat interfluves of Type A. Further study would be needed to determine why these interfluves are not as dark on the imagery as the analogous interfluves of Type A. Possible factors might be the amount of true soil surface visible between the surface stones, the

number of surface stones on which the dark varnish has formed, or a lighter color of the varnish itself. Also, there might be smaller area of flat interfluve on which the dark pavement typically occurs. Geologic or mineralogical factors appear to be involved in the intensity of dark pavement development, since the dark pavement is less well-developed on outwash from rhyolitic and andesitic outcrops.

The gray tone of Type A' is intermediate between Types A and B on all ERTS bands. It was difficult to determine the location of the transition zone between Types A and B on the bajada below the west side of the Kofa Mountains. On the high-altitude color infrared photographs, it was evident that a change from high drainage density to lower drainage density occurred at approximately the transition zone between Types A and B. Also, individual trees of paloverde or ironwood can be detected on this imagery. Therefore, we used the high-altitude color infrared to determine the location of this transition.

Type B characteristically exhibits a very light tone on all ERTS wavelength bands. This is undoubtedly due to the large amount of exposed, light-colored desert soil. There are some slightly darker streaks or spots evident in the Type B areas. Some of these are apparently due to small areas of dark desert pavement, but such areas are very infrequent in Type B. Other slightly darker areas in Type B are apparently due to locally higher densities of vegetation or litter.

Most of the Type B' area is lighter in tone than the adjacent Type B. The clumps of mesquite and big galleta appear as distinct dark spots. Infrared reflectance of the clumps increases in late spring when the mesquite and galleta put out new leaves. This type is recognized by the presence in valley bottoms of very light areas with distinct dark clumps strung out along the drainageways.

Soil Factors in Relation to Vegetation and ERTS Imagery in the Yuma Area

Soil samples collected at many of the ground truth photo sites were analyzed

56

by the University of Arizona Agricultural Experiment Station (Tables 6-1 and 6-2).
Samples 1-5 are from a variety of sites on the bajadas, plains, and dissected
alluvial hills of the study area. There was no desert pavement at these sites.
Samples 7-10 are from sites with varnished desert pavement on the surface.
Sample 6 was taken from a non-pavement gravelly terrace in a large wash area
traversing the pavement area. Locations are described in Table 6-3.

The pavement soils have unique physical and chemical characteristics.
The A horizon is a light pinkish gray vesicular layer composed of prismatic peds
approximately three inches in diameter. This layer is almost free of gravel and
has less sand than the B horizon. The B horizon is friable reddish brown gravelly
and cobbly loam. The physical structure of these pavement soils is very similar
to that described for other soils beneath varnished desert pavement in other areas
(Nevada: Springer 1958). Both horizons are saline-alkali, with perhaps slight-
ly lower salinity in the A horizon. Chemical analysis of some soils under desert
pavement in Nevada also showed salinity with high exchangeable sodium (data for
Bitterspring gravelly loam in S.C.S. and Nev. Ag. Expt. Sta., 1970).

These soil data allow us to suggest a hypothesis about the vegetation dif-
ferences between the pavement-covered areas and the adjacent rills and washes,
and between bajadas with and without extensive areas of desert pavement.

Soils with high ESP (exchangeable sodium percentage) and low soluble salts
are generally very impermeable due to the deflocculation of the clay colloids.
High salt concentration in the infiltrating water will prevent deflocculation of the
clay particles and allow adequate infiltration. Even though the pavement soils are
saline as well as sodic, we would expect infiltrating rainwater to quickly leach
most of the soluble salts from a thin layer of soil near the surface. Then the
clay colloids of this leached layer would be expected to disperse and a very im-
permeable surface layer would be present. Most of the subsequent rainfall would

TABLE III

Texture of Selected Pavement and Non-Pavement Soils of Yuma County, Arizona

Location	Depth[1] (in.)	% >2 mm	% of < 2 mm fraction			Texture Class
			% Sand	% Silt	% Clay	
Non-pavement soils:						
1	0-3	0.5	63.6	33.2	3.2	sandy loam
2	0-3	3.4	79.7	16.4	3.9	loamy sand
3	0-3	0.4	20.4	74.9	4.7	silt loam
4	0-3	35.2	60.5	35.0	4.5	g. sandy loam
5	0-3	29.4	64.3	32.3	3.4	g. sandy loam
6	0-3	13.2	58.0	37.4	4.6	sandy loam
Pavement soils:						
7	0-4	1.6	23.6	62.7	13.7	silt loam
7	5-8	62.2	47.3	41.3	11.4	v.g. loam
8	0-2	4.8	27.8	56.3	15.9	silt loam
8	5-8	32.8	43.4	40.2	16.4	g. loam

[1]Superficial gravel and stones were not included in surface soil samples.

TABLE IV

Chemical Data for Selected Pavement and Non-Pavement Soils of Yuma County, Arizona

Location	Depth[1] (in.)	pH paste	pH 1:5	CEC meq./100g	Exch. Ca meq./100 g	Exch. Mg meq./100 g	Exch. Na % (ESP)	$EC_e \times 10^3$	(cal.) ppm	% $CaCO_3$ equivalent
Non-pavement soils:										
1	0-3	8.15	8.9	5.0	4.7	0.3	0.8	0.33	231	
2	0-3	8.2	8.9	5.3	4.9	0.3	0.7	0.31	217	1.79
3	0-3	8.0	8.5	13.6	12.6	0.9	0.5	0.35	245	10.0
4	0-3	8.05	8.6	12.5	11.7	0.6	1.7	0.37	259	
5	0-3	8.05	8.6	10.9	9.9	0.8	1.2	0.42	294	
6	0-3	8.1	8.6	7.5	6.9	0.5	0.6	0.33	231	
Pavement soils:										
7	0-4	8.0	8.85	17.9	12.9	0.9	23.0	6.40	4,480	14.1
7	5-8	7.55	8.0	17.1	11.5	1.7	22.5	29.00	20,300	8.8
8	0-2	7.6	8.3	17.1	11.9	0.6	27.0	25.00	17,500	
8	5-8	7.45	8.0	11.6	8.6	0.5	21.9	33.00	23,100	

[1]Superficial gravel and stones were not included in surface soil samples.

TABLE V

Location of Soil Sampling Sites in Yuma County

Location No.

1   N 1/4 of E 1/4 of Sec. 27, T6N, R19W*
                     11.8 mi. N of U.S. 60-70 on U.S. 95
                     elev. 875'

2   SE corner of Sec. 32, T8S, R17W*
                     0.4 mi. S of 18 on Ave 36E
                     elev. 345'

3   SW 1/4 of Sec. 17, T2S, R19W*
                     1/4 mi. W of approx. 1 mi. SSW of Stone Cabin on U.S. 95
                     elev. 1530'

4   not surveyed
                     11.6 mi. N of Castle Dome Mine Road on U.S. 95 (near 1197'
                         point)
                     elev. 1190'

5   SW corner of N 1/4 of Sec. 34, T1N, R19W*
                     U.S. 95 at Palm Canyon Road
                     elev. 1340'

6 & 7   not surveyed
                     5.4 mi. NE of U.S. 95 on Castle Dome Mine Road
                     (at Kofa Game Range Boundary)
                     elev. 1020'

8   NE 1/4 of SE 1/4 of Sec. 34, T5N, R19W*
                     4.5 mi. N of U.S. 60-70 on U.S. 95
                     elev. 830'

*Gila and Salt River Base Line and Meridian

run off into adjacent washes, where ESP is not high (Sample 6, Table 6-2) and infiltration rates are probably high. As the pavement soil dries after the rain, the soluble salts leached from the thin surface layer would be drawn back into this layer by capillarity. Thus, this thick sodic non-saline surface layer would not be present when the soil was dry. The saline-alkali soils under the desert pavement in Nevada are reported to have much runoff due to slow infiltration (S.C.S. and Nev. Ag. Expt. Sta., 1970).

The lack of plant cover on the desert pavement areas (the interfluves) is not surprising in light of these data. The chemical and osmotic effects of the high sodium and high salinity, combined with a probable lack of moisture below the upper layers of soil, present a very harsh environment, indeed. The apparent absence of desert halophytes is somewhat puzzling, however, since these plants are able to tolerate saline conditions elsewhere in the desert.

We have noted above that bajadas with extensive areas of desert pavement support paloverde and ironwood and a variety of other shrubs (in the rills and washes) all the way down to the center of the valley. Bajadas without desert pavement support this community only on the uppermost parts, with creosote bush and bursage (Type B) on the lower part. We believe this is so because, on a bajada with pavement, a given amount of rainfall will be concentrated in the drainages by the runoff from the pavement areas, whereas on the non-pavement bajadas this same amount of rainfall will be distributed more evenly over the whole area. The redistribution of rainfall on the pavement bajadas creates a mosaic of habitats, some more xeric (the pavement areas), and other less xeric (the rills and washes) than the more uniform habitat of the bajadas without desert pavement. Therefore, the rills and washes crossing the pavement support a less xerophytic plant community than the bajadas without desert pavement.

Yuma Area--Saudi Arabia Imagery Correlations

In discussing our correlations between ERTS imagery and ground truth studies of the Yuma desert pavement areas with Carol Breed of the U.S. Geological Survey (MMC #331, A Study of Morphology, Provenance, and Movement of Desert Sand Seas in Africa, Asia, and Australia), we have aided in the interpretation of dark areas corresponding to the Yuma desert pavement areas which are seen on ERTS imagery of Saudi Arabia. This correlation is extremely important since ground truth data for many of Breed's et al., study areas are scarce or non-existent, and for interpretation of ERTS imagery they must rely on comparisons with North American analogs for which ground truth data are available.

REFERENCES

Cooley, M.E., 1967. Arizona highway geological map. Arizona Geological Society.

Green, C.R., 1964a. Seasonal precipitation and temperature data for selected Arizona stations. Technical Report on Meteorology and Climatology of Arid Regions, 12, University of Arizona, Institute of Atmospheric Physics.

_____1964b. Distribution of rainfall in Arizona. Technical Report on Meteorology and Climatology of Arid Regions, 13, University of Arizona, Institute of Atmospheric Physics.

Kearney, T.H. and R.H. Peebles, 1969. Arizona Flora. University of California Press, Berkeley and Los Angeles.

Lance, J.F. and E.D. Wilson, 1960. Geology in Arizona, its people and resources. University of Arizona Press, Tucson.

Martin, P. S., 1963. The last 10,000 years, a fossil pollen record of the American Southwest. University of Arizona Press, Tucson.

Molineux, C.E., 1965. Aerial reconnaissance of surface features with the multiband spectral system. Paper presented at Third Symposium on the Remote Sensing of Environment, University of Michigan.

Shreve, F., 1912. Cold air drainage. Plant World 15:5.

Shreve, F. and I.L. Wiggins, 1964. Vegetation and Flora of the Sonoran Desert. Stanford University Press, Stanford.

Stark, H., H.C. Barker and D. Lee, 1972. Some new techniques for processing remotely obtained images by self-generated spectral masks. Applied Optics, Vol. I, II.

Stark, H., E. García and H.C. Barker, 1972. Variance measurements by a coherent optical method with applications to image processing. Applied Optics, Vol. II, IV.

Wilson, E.D., 1960. Geologic map of Yuma County, Arizona. Arizona Bureau of Mines, University of Arizona, Tucson.

Wilson, E.D. and R.T. Moore, 1959. Structure of basin and range province in Arizona. Arizona Geological Society Guidebook II.

APPENDIX

Scientific and Common Names for Plants Mentioned

Common Name	Scientific Name
barrel cactus	Ferocactus Wislizeni
bebbia	Bebbia juncea
big galleta	Hilaria rigida
blue paloverde	Cercidium floridum
brittle-bush	Encelia farinosa
burro-weed	Aplopappus tenuisectus
canyon ragweed	Ambrosia ambrosioides
catclaw acacia	Acacia Greggii
cholla cactus	Opuntia spp.
creosote bush	Larrea tridentata
desert hackberry	Celtis pallida
desert lavender	Hytis Emoryi
desert zinnia	Zinnia pumila
fairy duster	Calliandra eriophylla
foothill paloverde	Cercidium microphyllum
ironwood	Olneya tesota
jojoba	Simmondsia chinensis
limber bush	Jatropha cardiophylla
mesquite	Prosopis juliflora
ocotillo	Fouquieria splendens
plantain	Plantago insularis
ratany	Krameria parvifolia
Rothrock grama grass	Bouteloua Rothrockii
saguaro	Carnegiea gigantea
smoke tree	Dalea spinosa
snakeweed	Gutierrezia lucida
teddy bear cactus	Opuntia Bigelovii
three-awn	Aristida spp.
triangle-leaf bursage	Ambrosia deltoidea
white bursage	Ambrosia dumosa
wolf berry	Lycium spp.

(Kearney and Peebles 1969; Shreve and Wiggins 1964)

BIBLIOGRAPHY

1972 Bimonthly Progress Reports

NTIS* No.

E72-10159   Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #1. Office of Arid Lands
Studies, University of Arizona. 2 pages.

E72-10314   Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #2. Office of Arid Lands
Studies, University of Arizona. 2 pages.

1973 Bimonthly Progress Reports

E73-10520   Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #3. Office of Arid Lands
Studies, University of Arizona. 4 pages.

E73-10659   Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #4. Office of Arid Lands
Studies, University of Arizona. 4 pages.

Conn, J.S., L.K. Lepley and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #5. Office of Arid Lands
Studies, University of Arizona.

Conn, J.S., L.K. Lepley and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type I Report #6. Office of Arid Lands
Studies, University of Arizona.

1973 Six-Month Reports

E73-10369   Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type II Report #1. Office of Arid Lands
Studies, University of Arizona. 28 pages.

Musick, H.B., E.F. Haase, and W.G. McGinnies. A study to
explore the use of orbital remote sensing to determine native
arid plant distribution. Type II Report #2. Office of Arid Lands
Studies, University of Arizona.

*Available through the National Technical Information Service, U.S. Department
of Commerce, 5285 Port Royal Road, Springfield, VA 22151.

Papers Presented

Musick, H. B., and E. F. Haase, 1973. The use of ERTS-1 Multi-spectral Imagery to Determine Native Desert Plant Distributions.
> Paper presented at 17th Annual Meeting of the Arizona Academy of Science, University of Arizona.

Musick, H. B., W. G. McGinnies, E. F. Haase, and L. K. Lepley, 1973. ERTS-1 Imagery and Native Plant Distributions.
> Paper presented at 4th Annual Meeting of ARETS Symposium, University of Arizona.

Published Papers

Musick, H. B. 1975. Barrenness of Desert Pavement in Yuma County, Arizona. Arizona Academy of Science 10:24-28.

Musick, H. B., W. G. McGinnies, E. F. Haase, and L. K. Lepley 1973. ERTS-1 Imagery and Native Plant Distributions, p. 338-346.
> In Proceedings of the 4th Annual Conference on Remote Sensing in Arid Lands, University of Arizona. 374 p.

Index