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Multispectral analysis of ERTS imagery by color enhancement

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MULTISPECTRAL ANALYSIS OF ERTS IMAGERY BY COLOR ENHANCEMENT

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Abstract

The Earth Resources Technology Satellite (ERTS) program has supplied the scientist with high resolution multispectral imagery of a large portion of the earth. Photographic and electronic methods of image enhancement are not universally available to those who might profit from such endeavors.

Diazo products were found to be satisfactory for creation of false color enhancement of ERTS multispectral data. The purpose of the enhancement was to make the Diazochrome composite comparable to more sophisticated methods for the purpose of interpretation. The basis of the enhancement was the standard false color infrared composite, with negative and positive Diazochrome masks to enhance selected terrain features.

Major advantages of the enhancement were 1) color renditions were similar to those found on a false color infrared composite, 2) the enhancement process was repeatable, 3) the greater contrast between terrain objects improved interpretation. Interpretability of the enhancement was shown to be restricted by the small scale of the ERTS imagery.

Processing of Diazochrome is simple and requires no darkroom. The high contrast, inherent with the Diazochrome film are not suited for continuous tone reproduction without use of some enhancement technique.

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I. Introduction

The purpose of this research was to develope a simple and inexpensive method to analyze ERTS multispectral data. The basic premise was that visual analysis of the imagery will satisfy most needs, but that the multispectral view can add to the interpretation process providing the proper format can be developed. Colwell (1973) has presented several advantages of multispectral imagery from space. It was not the purpose of this research to demonstrate the usefulness of ERTS imagery. However, to derive any advantage from multispectral imagery, a special method of analysis must be used. This requires a substantial investment; particularly for the scientist or planner who may use the imagery as only an occasional tool rather than doing remote sensing research.

The two methods most often described by researchers for analyzing multispectral imagery are additive color viewers and automatic data processing. To achieve good results the additive color viewer requires optics that are matched both geometrically and chromatically; and are therefore very expensive. Automatic data processing requires sophisticated equipment and highly trained personel. In addition, to achieve utility in analysis a visual output is required which in turn requires some sort of interface between the computer and a cathode ray tube (CRT) display.

A more common method in use is printing the imagery on color film producing a color rendition of the multi-spectral data. In using the ERTS data, the result is similar to that produced by false color infrared film, often referred to as camouflage film. However, even though this method is relatively inexpensive and produces desireable results, a darkroom equiped for printing and processing color film is required. This problem is further complicated by the need to fit the color balance to meet the purpose of interpretation (Hunter and Bird, 1970).

To overcome the need for complex processing methods an amonia developing, diazo color film was used. The advantage of this film was that it is easily processed and requires no darkroom. The false color infrared composite was the basis of the data format used for interpretation. To improve the color contrast, an enhancement procedure was developed using the principle of the negative mask. The following criteria was established for evaluation of the method:

1. The method must be simple and inexpensive.

2. Results must be repeatable within acceptable limits.

3. Results (i.e. color renditions) must be related to physical properties of terrain features. This is to say that the results must be predictable.

The final test was the usefulness of the enhancement for interpretation. This, of course, was restricted by the usefulness of the ERTS system as a whole. The true test only can be applied with use by many interpreters under a number of conditions. A mapping procedure was presented to demonstrate the interpretability of the enhancement, and to compare it to a standard infrared color composite.

II. Description of ERTS I Data

The ERTS I satellite was launched on July 23, 1972, and has since produced a great amount of multispectral imagery. Whereas space imagery has been of interest since the beginning of the space program (NASA, 1971) the ERTS project is unique in that, due to its sun synchronous orbit, it can produce imagery of the same area every 18 days. This gives the scientist the advantage of both a multispectral and a temporal view of the earth.

The ERTS mission was to provide for the broad objective of "repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis" (NASA, 1972, ERTS Data User's Handbook). In evaluating the usefulness of the ERTS system, it must be kept in mind that its purpose was to determine the feasibility of a space imagery system, not to necessarily produce imagery immediately useful to all phases of science and engineering. Its contribution as an experimental system, to provide multispectral imagery at a low cost, is considerable. It is for this reason as much as any other that ERTS multispectral data was used in this research.

A. Description of Imaging System

Imagery is obtained from two sensor systems; a four channel multispectral scanner (MSS), and a three camera return vidicon system (RBV). The RBV system was not considered in this research.

The MSS system is a line scan device that utilizes a scan perpendicular to the spacecraft tract, with spacecraft motion providing the along track advance. Optical energy is sensed simultaneously through four bandpass filters in the visible and near infrared portion of the electromagnetic spectrum. Each band covers the following portion of the spectrum:

MSS BAND	WAVELENGTH REGION (Microns)	SPECTRAL REGION
1	.5-.6	blue-green
2	.6-.7	red
3	.7-.8	infrared
4	.8-1.1	infrared

The data is recorded on magnetic tape and is available to the user in several forms depending upon the need. The data used in this research was in the form of 9x9 inch black and white film positives; each band being represented by one film positive. Therefore a single image can be any combination of four black and white film positives. This facilitated the analysis of individual bands and the formation of various false color enhancement schemes.

Each film positive is exposed with a 15 step density wedge. The exposure of the wedge relates directly to the energy in front of the lens of the sensor. Since this step wedge is subject to the same processing errors as the film image, it serves as a macro-scale calibration. The maximum voltage response exposes the first block, with each subsequent block representing one-fourteenth less energy. Block 15 represents no response. The maximum voltage response corresponds to the following energies as seen by the sensor:

BAND	MAXIMUM ENERGY (mW/Em^2)
1.	2.48
2.	2.00
3.	1.76
4.	4.60

A more detailed discussion concerning the ERTS system can be found in the Earth Resources Technology Satellite--Data User's Handbook (NASA, 1972).

III. Basis of Multispectral Enhancement

In order to meet the criteria of repeatability and predictability (see Introduction) the enhancement procedure must be designed with consideration given to the energy relationship between the terrain object being sensed and its representation on the film image. This relationship is outlined in Appendix I. The basis of the method is that the reflectivity of natural materials is, in part, a function of wavelength. It is this property that produces color in nature. For example, healthy vegetation appears green because of its peak reflectance in the green portion of the visible spectrum. When imaging in various portions of the spectrum, each object will have a unique set of responses. This spectral signiture is the underlying theory behind automatic digital processing of multispectral data. A major problem with interpretation through signiture analysis is the lack of apparent contrast between many natural objects, and the ever changing natural atmospheric conditions that affect the imagery.

Despite the problems of signiture analysis, the concept of the multispectral response is useful for the purpose of enhancement. Whereas there is not enough contrast between many features to allow reliable interpretation, enhancement of selected density ranges within each band will produce a false color rendition of a scene that has more contrast than would otherwise be possible. The increased contrast is a result of the fact that all photographic films only have a limited range of exposures for which contrast will be produced. By isolating key ranges of exposures and by using negative masks, this range of contrast can be extended. The selection of the favorable density ranges was based on the theoretical consideration (outlined in Appendix I) and on inspection of selected imagery.

IV. Subtractive Color Theory

The method of using additive color theory in enhancement of multispectral imagery has been well described (A.S.P. Manual of Color Aerial Photography, 1968). The basic process consists of projecting an image onto a screen through a particular color filter. Through the addition of several images in different colors a single full color image can be formed. As an example, if three photographs were taken of the same object through a green, red, and blue filter a color picture could be formed by projecting green, red and blue light through the respective film imaged onto a screen. If all three images were in registration (i.e. they overlay each other perfectly) the resulting image will have approximately the same color rendition as the origional scene.

The formation of the color image is a function of the composition of the color used to project the image and the response of the eye. Since the human eye is believed to sense color through a set of sensors (referred to as rods and cones) any color can be approximately reproduced by the addition of three primary colors; the sensation of color being derived from the relative amounts of each primary color. By altering the amount of any one, the sensation (hence the color that is seen) is altered.

Because of the sensitivity range of the eye, certain colors cannot be properly reproduced. However, the tri-stimulus method works for a large range of colors and is the underlying theory of photographic reproduction of color, and of color classification.

The use of additive color in the formation of true color images had been demonstrated as early as 1871 by James Clark Maxwell (Hunt, 1957). However, it was not thought useful for the formation of color photographs. Thus several other clever, if impractical, methods were attempted before the tri-stimulus color method was incorporated into photography. Instead of the method of adding color however, the subtractive method was used.

In subtractive color renditions, light is transmitted through a series of filters with each absorbing a certain amount of a primary color. The light that is transmitted, or that which is not subtracted, is sensed by the eye, as in the additive process to form the sensation of a particular color. As a simplified example, consider the three additive primaries, red, blue and green. If a filter is made to absorb each, the following scheme can be developed:

Absorbs	Passes	Subtractive color
red	blue+green	cyan

green	red+blue	magenta
blue	red+green	yellow

Therefore, if white light is defined as unit amounts of each primary color the following colors could be produced in the following manner.

white-------magenta and yellow filter------red formed
white-------magenta and cyan filter--------blue formed
white-------cyan and yellow filter---------green formed

The color film used in this research is described in Appendix II. Each sheet of film developes in one of the subtractive colors. By exposing each MSS band on the appropriate color film, a full color rendition could be produced by making a composite of the three layers. As an example, consider the formation of a false color infrared composite using the MSS bands 1 (green), 2 (red), and 4 (infrared):

Band 1	exposed on yellow film
Band 2	exposed on magenta film
Band 4	exposed on cyan film

A feature with a bright response in the infrared band would leave only the yellow and magenta layers to absorb light. Thus, such an object would appear red. This accounts for the red appearance of healthy vegetation on the false color infrared composite. With increasing response in the green, the color rendition of vegetation would approach magenta in color. The approximate hue that other features would appear can be reasoned in the same manner.

A more rigorous approximation of the color could be obtained by using a method such as C.I.E. color classification. However, the exact nature of the reflectance-density relationship must be known (Appendix I) as well as the characteristics of the film dyes. It is doubtful that such an approach would benefit the interpreter, it being primarily a method to test the quality of processing.

V. The Spectral Enhancement

A. Photographic Process

To understand how the energy relationships described in section III can be exploited photographically the properties of Diazochrome should be noted (Appendix II). The diazo material produces a very high contrast, in which only a short range of densities are copied. Either the higher densities are below the base level, or the lower densities are "burnt off". As a result, selected information may be removed by either increasing or decreasing exposure. By using several images, many levels of information can be reproduced in an array of colors.

To illustrate how this can be applied, first consider a single black and white image for which both the positive and negative is available. If three colors of film are used (in this case three subtractive primaries) the image could be reproduced with each color denoting a density range. Such an enhancement is often called a density slice. This can be accomplished by exposing a positive in cyan such that most of the density wedge on the annotation block is reproduced. A second positive is then made in magenta with exposure such that only the highest densities remain on the film. The same procedure is done for the negative, except that yellow is exposed such that nearly the full range is reproduced. A magenta negative is then exposed such that only the darkest densities remain (which would represent the lightest areas on the positive). The composite of the four images produces a color image in which at least six ranges of densities can be reproduced in color. The hue variation between densities is gradual, and therefore an infinite range of colors is involved. The gradual range of colors as opposed to a sharp break between the density ranges is not found in a true density slice (Ross, 1969) but the same purpose can be served.

The purpose of the density slice is to classify various density levels, which in turn classify the energy levels of the reflected light. Since the density patterns are manifestations of the terrain reflectance, it is reasonable that the same procedure could be used to isolate certain spectral response patterns found on the multispectral imagery. The procedure is similar to that of the density slice except that a combination of positives and negatives from several bands are used.

Consider three types of reflectors; vegetation, soil or rock, and water. The tremendous contrast seen between the three types is demonstrated by the success of the standard infrared composite.

However, more subtle differences found within each class are often difficult to obtain for all features on any one image. For example, an image exposed to better define rock and soil may not have detail in areas of low reflectance such as vegetated areas. To obtain better contrast in areas of vegetation, the detail in areas of rock and soil may be sacrificed.

By using both positives and negatives, a false color image can be produced that includes information from all bands and yields contrast throughout the brightness range. Where contrast is desired in a specified range the film is exposed to put the center of the contrast portion of the D-log E curve within that range. Where the brighter regions are to be enhanced, a negative image is used for the exposure. The only problem is to determine the exposures and the best selection of color films for each exposure.

B. Development of the Technique

As a means of developing the techniques described above, imagery was obtained of the Monterey-San Francisco area. The selection of the area was based on the large number of features present, the contrasts between physiographic features within the area, and because the frame had been well described previously (Colwell, 1973).

The standard infrared composite was the first enhancement method investigated and was the basis for most of the work that followed. Two such composites were constructed; one using MSS bands 1, 2, 3, and one using MSS bands 1, 2, 4. Both produced similar results, however since the two infrared bands are unique to themselves, there are some differences, and the choice of using either band 3 or 4 depends on the purpose of the interpretation.

The composite using MSS band 3 for the infrared layer demonstrated several unique qualities. While it appeared that band 3 produced somewhat less contrast than band 4, much more detail can be seen in the sediment patterns of the large water bodies (area 1 on Figure 1). This is to be expected considering the spectral response patterns for water. Water that is relatively pure has a very low response in both bands. However, water that is turbid retains a relatively higher response into band 3 but drops off in band 4. Therefore, a composite made with band 4 would not show the contrast between clear water and water with a higher sediment load.

Inspection of the tidal flat areas revealed some other interesting differences between the two composites. The area denoted on the overlay of the image stands out well on the band 4 composite. This is a result of the absorbance of infrared energy in the portion of the spectrum in which band 4 is sensitive. However, much greater contrast can be seen between various areas within the tidal flats on band 6. This is evident in areas 3 and 4. Again, the difference in the absorbance characteristics between bands 3 and 4 is probably the major factor. Energy is absorbed in the band 4 region of the spectrum throughout the wetlands, while absorption within the band 3 region is more selective.

Other such differences in contrast can be noted in areas of vegetation. For example, urbanized areas such as area 5 have a much greater contrast on the band 4 composite than on the band 3. This can be attributed to the nature of the spectral response curves for some vegetation and soils. Figure 2 demonstrates this difference. Within the region of band 3 the contrast in reflectance of vegetation between the visible and infrared regions has not yet been realized. Therefore, the color contrast on the image is not as great. Band 4 yields the maximum contrast between the two types of reflectors and therefore in such cases displays the maximum in contrast.

A density slice was made of each band to better determine the theoretical relationships developed between the object on the ground and its appearance on the image. The trends determined in Appendix I could be related to the individual images. Table 7 was compiled by comparison of colors on the image to the corresponding colors found on the density wedge at the bottom of the image.

The possibility of improving interpretation of individual black and white images by using the density slice enhancement has beeen noted (Ross, 1969). However, on the Diazochrome density slices the contrast was not that great. This is probably a result of using too short of exposure on the negative images; causing a poor rendition of the brighter densities. Generally the time involved in making an enhancement probably would not justify the advantage over the black and white image. In using such a method the densities cannot be divided into more than 6 color ranges, even with proper exposure. The human eye can easily determine at least that many shades of gray if not more. Further, it should be noted that no additional information is included on such an image; which is the case for the multispectral enhancement.

C. Design of Enhancement

With the knowledge obtained from the theoretical analysis, and from the inspection of the density slice, a special enhancement using the masking technique was designed. The purpose of the enhancement was to take advantage of the differences in spectral response of each object listed in Appendix I.

The enhancement scheme is shown diagramamtically in Figure 3. The reasoning for each component of the composite is as follows:

1. Band 4. A yellow positive is used to exploit the difference in vegetation in the band.

2. Band 5. A magenta positive is used to form the basis for contrast within band 5.

3. Band 5. A yellow positive is exposed for a long period of time to exploit the difference in vegetation reflectance in band 5. It has been noted that some vegetative areas reflect a significant amount of energy in the red portion of the spectrum while others do not. This difference often does not appear on the diazochrome infrared composite or on composites made with color film having poor color balance. It also serves to provide more contrast to sediment patterns since pure water has a relatively low reflectance in band 5.

4. Band 5. A cyan negative is used to provide a contrasting color to areas of high reflectance. It was noted that many features such as roads, grassland, and stream beds, did not display the contrast expected simply because they were "burnt off".

5. Band 6. A cyan positive is used to better define areas of varying water quality and depth. It also provides better contrast in tidal flats; a function of the energy absorbed by water.

6. Band 7. A magenta negative is used to enhance the differences in infrared reflectances of some vegetation.

Exposure for each layer of the composite must be altered to account for sun angle and quality of original imagery. This may be established by a few trial exposures.

One significant aspect of the special enhancement scheme is that basically the results are similar to those obtained with the infrared composite; though a much greater variety of hues is involved. The flexibility of the human interpreter would overcome the problem of the unorthodox color scheme; especially once the interpreter became more experienced with the imagery.

VI. Interpretation of Enhanced Imagery

A primary advantage of the multispectral enhancement is that, once the exposure levels are established for the particular set of imagery, the enhancement method is a standard procedure. Thus, the results are standard in the same sense that the color renditions of a false color infrared composite are standard. To demonstrate the applicability and usefulness of this advantage, imagery was selected for a different set of terrain conditions for interpretation. Important factors that were considered were interpretability of the ERTS imagery and advantages of the enhanced imagery over the standard infrared composite.

A. Purpose of Interpretation

An interpretation problem was selected that was dependent on 1) multispectral information and 2) within the capabilities of the ERTS system. The major restriction on the choice of the interpretation problem was determined to be the small scale of the imagery.

The imagery selected covered the Mississippi Valley in Southeastern Missouri and Northeastern Arkansas. Date of coverage was 2 October 1972, during which about half of the agricultural area appeared to be under crop cover. A United States Department of Agriculture Soil Survey (February, 1971) was available for Pemiscot County, Missouri, and it was decided to map the major soil associations within the county based on ERTS imagery. Mapping was done using the enhancement as an image format. A standard infrared composite was also prepared for purpose of comparison with enhancement to determine if, in fact, there was an advantage in using the enhanced imagery.

By using Pemiscot County as a type area, interpretation keys for the soil associations were established. The area directly south of Pemiscot County (Mississippi County, Arkansas) was then mapped, based on the established keys. The second map was compared to the published soil survey of Washington County to determine the accuracy of the interpretation. A practical application of such a project would be a reconnaissance survey of an unmapped area for which a detailed soil survey was being planned.

B. Soil Associations Mapped

A soil association is defined as a "landscape that has a destinctive proportional pattern of soils" (U.S.D.A., 1971). Units mapped from the ERTS imagery were inferred to be a combination of differences in 1) topographic land form and 2) agricultural practice. It was impossible to map soil associations directly from the imagery since such features as agricultural practice did not necessarily coincide with soil associations as determined from field mapping. However, by a detailed comparison of the soil map and the imagery, a set of mapping units were developed for which the soil associations could be predicted. The problem of matching the map unit with the soil association was further complicated by the use of a different system of classification of soil associations in the soil survey of Mississippi County. The relationship between the map units and expected soil associations are as follows:

MAP UNIT	ASSOCIATION	
	Pemiscot County	Mississippi County
1	Commerce-Crevasse-Caruthersville; Hayti-Portageville-Cooter (along boundaries of unit).	Convent-Morganfield-Crevasse; Tunica-Bowdre-Sharkey (along boundaries of unit).
2	Hayti-Portageville-Cooter	Tunica-Bowdre-Sharkey
3	Dundee, Wardell-Sharkey	Amagon-Dundee-Cravasse; Sharkey-Steele, Sharkey-Crowley
4	Sharkey	Amagon-Dundee-Cravasse; Sharkey-Steele, Sharkey-Crowley

Interpretation was based on the following keys:

MAP UNIT	INTERPRETATION KEY
1	Represented by recent coarse grained alluvium;

mainly inferred on appearance of point bar deposites and meander scars. Such features are expressed by differences in farming practices which assume a characteristic crescent shape.

2 Represented by recent fine grained alluvial material. Interpretation was based on association with unit 1 since origin is similar for both types of soils; the major difference being the energy available for sediment transport during deposition which favored deposition of fine grained material.

3 Corresponds to the old natural levee of the Mississippi River. Interpretation was based on a natural change in farming practice, fields being either cleared or planted in hay or small grain. This unit was difficult to delineate and is probably the least reliably defined.

4 Represented by soils formed on old Mississippi Alluvium. Interpretation was based on a homogenious texture with no particular geometric orientation of fields. This unit was differentiated from unit 2 by absence of meander scars.

C. Contribution of Enhancement

The basic mapping keys used for most of the interpretaion were geometric in nature. However, many of the geometric patterns were better delineated on the enhancement as a result of greater contrast developed on the imagery. Several of the meander scars upon which interpretation was based may have been overlooked without the benefit of the enhancement process. Of course, nothing can be seen on the enhancement that cannot be seen on the standard infrared composite. However, several features apparent on the enhancement, are not particularly noticeable on the standard composite. Examples of such areas were wood-covered land that was too small to be recognized by means of shape or texture. These areas appeared as a darker red on the standard composite but as orange on the enhancement. Most field crops, such as corn and soybeans, have a "redish" hue. The major difference was noticeable in the appearance of features that would normally appear gray or light blue on the infrared color composite, but appeared in various hues of green and blue in the enhanced image depending upon the spectral response.

D. Comparison of Soil Survey and Interpretation Based Map

It was observed that Units 1 and 2 corresponded well with those of the soil survey map. Of course, both are easily predicted by virtue of their association with the Mississippi River. Some isolated areas mapped from the imagery as Unit 1 in Mississippi County were classified within a soil association other than the one predicted. This probably was the result of the differences in the manner in which soil associations were grouped in the two soil surveys.

Unit 3 was mapped entirely on the basis of the difference in color found on the enhancement. It probably is impossible to correlate this color difference with any property of the soil.

A major problem in comparison was the presence of soil associations found in Mississippi County which were not found in Pemiscot County. The boundaries of such associations were noted, although the physical properties of the soil were difficult to determine. Such areas were not readily apparent on the standard composite. The unassigned units, of course, would be an important consideration in planning a soil survey since a greater amount of coverage might be justified for undetermined areas. Areas for which interpretation was possible would only require verification. This could provide for a more efficient detailed field mapping program.

VII. Conclusions

The primary purpose of the enhancement process was to develope the application of the Diazochrome false color composite such that it would be comparable to other, more complex methods for use in interpretation. The interpretation of the enhanced images was noticeably better than that of the standard infrared composite for the test area studied. The usefulness of the enhancement process appeared to be limited primarily by the capabilities of the ERTS system.

In addition, the enhancement process is applicable for any multispectral imagery, providing the imagery has the proper format (i.e. the ability to be registered without some optical correction). Also, the method is not restricted to diazo materials.

These improvements in interpretation, however, must be considered with respect to the interpretation benefits provided by electronic enhancement methods. While the procedure does not provide the same flexibility as the electronic enhancement systems, it is relatively inexpensive, convenient, and can be carried out with a minimum of processing equipment.

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Vita

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The author is married to the former Bonnie Jim Cape of Steelville, Missouri.

Appendix I

The Spectral Response

The spectral response is defined by this writer as the composite of all of the factors that define the final image used for interpretation. Under such a definition, the spectral response is a function of the scene being imaged, the imagery system and all subsequent processing steps. All of the components involved vary to some extent and to define a general relationship is impossible. However, the enhancement technique presented in this thesis is based upon the spectral nature of the ERTS imagery. Therefore a theoretical discussion of the numerous factors that affect the imagery is warrented; if only to give an appreciation of the variability that can be expected.

A. The Energy Flow Concept

The factors affecting the reflected energy that reaches the sensor, whether at low altitude or from orbit are many and varied. Of most basic concern is the reflectivity of the terrain element. The degree to which this can be determined is a matter of how well the other variables can be determined. A simplified equation relating the major components of the spectral response to the energy that the MSS sensor receives can be given as:

$$N = \frac{1}{\pi} (HRT) + N_n \qquad (1)$$

WHERE

N = Radiance viewed by lens

H = Irradiance of ground scene due to direct sunlight and skylight

R = Reflectivity of scene

N_n = Radiance of atmosphere

T = One-way atmospheric transmission along nadir path

Radiance and irradiance are functions of both wavelength and sun angle, reflectivity and atmospheric transmission are functions of wavelength and are dimensionless. (NASA, 1972, ERTS-Data User's Handbook)

This equation demonstrates the energy flow characteristics of the spectral response. If it can be assumed that the sun is the only source of illumination, the energy incident on the sensor is merely sunlight that has been altered in some way by all of the components of the spectral response. This is shown disgrammetrically in Figure 6. While it is still not possible to precisely evaluate each component of the equation, this concept yields a useful way in which to approach an understanding of the nature of the response.

The sun offers a variable source of illumination to the earth. This variation is a function of not only the wavelength but also the time of year. The variations with season can be as much as 7 per cent and are caused by numerous factors, one of the most important being the variation in distance between the earth and sun with season. For the most part the variation of the sun's energy can be assumed to be solely a function of wavelength unless extremely precise work is being considered.

B. Atmospheric Effects

Light energy interacts with the atmosphere, depending on the nature of the atmospheric composition and the wavelength of light. For a given light source and a given atmospheric layer, the greater the path length the greater the interaction. Therefore the problem of atmospheric effects on multispectral data can be divided into two components; effective path length and atmospheric composition. Both produce significant results on the visual record and could therefore be considered as factors in imaging processing.

The problem of the effective path length can best be described with reference to Figure 7. If both the sensor and the sun are directly overhead (sun and nadir angle are both 90°) the incident and reflected light

Table I

Types of Atmosgheric Models

MODEL	SCATTER A FUNCTION OF	PARTICAL SIZE
Rayleigh	$(\text{wavelength})^{-4}$	Less than .1 wavelength (e.g. atmospheric gasses)
Mie	$(\text{wavelength})^{-1.3\mp.06}$	Greater than .1 wavelength.
Nonselective		Greater than 10 wavelengths

(After Jensen, 1968)

would each traverse one thickness of atmosphere. Assuming that the line of sight of the sensor is always orthogonal to the earth's surface, reflected light will always traverse one thickness. (This is assuming that there is no significant difference between the line of sight through the principal point of the image and other portions of the image. This assumption is probably good in the case of the ERTS, since its altitude is over 500 miles with only a 100 mile field of view. For low altitude sensors this assumption must be modified for several considerations.) The sun angle varies both with time of day and with season, which in turn alters the effective path length of the incident light. If the sun angle were 30°, the incident light would traverse two atmospheric thicknesses (ignoring atmospheric refraction). Therefore, even with a given atmospheric composition, the illumination can be expected to change significantly with time.

Since the effective path length is, for the most part, a matter of simple geometry, its effect can be predicted. Figure 8 shows the sort of relationship one might expect. The most-obvious effect, of course, is the reduction of total scene brightness.

The interaction of light with the atmosphere poses a more complex problem; for not only is the composition of the atmosphere difficult to predict, but the understanding of how a given atmospheric layer interacts with light is tenuous.

Table I shows the general relationship between partical size and scattering, the most significant interaction to wavelengths in the visible and near infrared portions of the spectrum. From this, several important relationships can be derived. For example, where Rayleigh scattering predominates (clear day) most of the scattering occurs with shorter wavelengths. Under such conditions, the two components of illumination, direct sunlight and skylight, have a ratio of about 7:1 (Jenson, 1968). Since skylight is scattered sunlight, it can be expected to have a markedly different spectral composition. One ramification of this spectral composition is that shadowed areas, which are mostly illuminated by skylight, will have much different spectral responses; with the response in shorter wavelength portion of the spectrum being predominate. On such a clear day situation, the contrast between areas lighted by direct sunlight and skylight should be great in the infrared portion of the spectrum.

With increasing haze the sunlight to skylight ratio becomes more nearly one and the spectral nature of the scattering more closely adheres to the Mie theory. Unlike models for Rayliegh scatter, Mie scatter can be very complex, although like Rayliegh scatter, Mie scatter favors the shorter wavelengths.

The degree to which scatter effects an object's apparent reflectance could be estimated by either applying a model atmosphere or by using corrections based on measurements of known properties (Ross, 1973). For the purpose of this research it is doubtful that exact measurements of atmospheric effects would be beneficial. The requirements of the methods to be presented are of necessity quite general. It is therefore only necessary to understand the qualitative effects on the image.

The most obvious effect that the atmosphere will have on an image is to cause a color shift on any color image. This can be seen on any color photograph taken at high altitude without the proper filter. In this case the image involved will appear too blue due to the effects of scattering.

Another important effect of scattering is the general degradation of the contrast between objects. With increasing haze, the amount of contrast between two objects (particularly low reflecters) will become less. Such loss in contrast is greatest in the images in the shorter wavelengths. This can be seen by comparison of the MSS band 1 and 4. Again, this is a ramification of the scattering models listed in Table I. The major causes of the loss of contrast due to scattering is the increase in nonimage forming light (N_n in equation 1) and the attenuation of the image forming light (T). From a space platform as much as half of the energy may be non-image forming and contrasts are reduced from over 11:1 to less than 5:1 (NASA, 1972, ERTS-Data User's Handbook).

C. Reflectance of Natural Objects

If it can be assumed that atmospheric effects can either be accounted for or disregarded, the reflectance of the terrain object can then be determined, though the ultimate usefulness of that determination can still be questioned in light of the variable nature of the spectral response. To appreciate the problem of deriving useful information from the spectral response, consider the reflectance of a plant. Suits (1972) has developed a mathematical model of the spectral reflectance of a vegetative canopy (e.g. leaf compared to soil). The basis of this model is a multiple layer (e.g. leaves, bark or stems, soil etc.) system that diffusely reflects light energy. The complexity of such a model should be noted. For example, a factor such as moisture stress may not only affect the internal structure of the leaf

(National Academy of Sciences, 1970) but may also affect the orientation of the leaf due to "droop". This in turn will alter the surface area exposed to the sensor relative to other layers in the canopy (e.g. leaf compared to soil). In such a case, two completely different responses could be expected depending upon which factor (leaf morphology or orientation) was dominate.

The reflectance of other types of natural objects are no less complicated when considered in light of their natural surroundings. Reflectance of rock and soil depends upon degree of weathering, moisture content, mineralogy, sun elevations, sun azimuth, and botanical associations. If all of the variables are considered in light of similarities between their spectral response curves (Lyon, 1970) the tenuity of using the spectral response is readily seen.

Despite the tremendous variability of natural objects, some general classification is possible. Section E gives the reflectance for several types of natural reflectors. The responses have been roughly grouped into three classes; vegetation, neutral reflectors (rock and soil), and water, snow and ice. This system is not new and has been used for the basis of mapping features such as flood water (Piech and Walker, 1972).

Of course, deviations from this classification can be expected. Many "neutral" reflectors have greater reflectance in the longer wavelength portion of the spectrum (Condit, 1967). Such a deviation should not present a problem for even a soil that has high infrared reflectance will contrast with vegetation since it would, at the same time, lack the low reflectance in the red portion of the visible spectrum which is characteristic of vegetation. Of much greater consequence, are simularities between features such as bare soil and dried grass, or water with a high sediment load and saturated soil. This of course is the problem of using spectral response for analysis that was noted above.

D. System Parameters

So far in the discussion, the variables that affect the spectral response have been considered independent of the system used to gather the data. Whether a camera or a multispectral scanner is used as a sensor, the relationships previously discussed will present the same problems, and equation (1) will still be valid. However, the interpreter does not see the energy that reaches the sensor, instead, he sees an image that is a representation of that energy. The nature of the sensing system is an integral part of any interpretation and must be considered before a valid analysis is made.

Important examples of this, with respect to the ERTS system, are bandwidth and resolution element. The energy that is incident on the sensor is representative of a large portion of the electromagnetic spectrum within the visible and near infrared region. The sensor is only capable of seeing, or recording, energy represented by wavelengths .5 microns to 1.1 microns. Further, the record that is preserved is an integration of energy that is received within each band. Instead of recording a spectral curve, the total amount of energy received within the four relatively large bandwidths is sensed. The significance of this was given by Yost (American Society of Photogrametry, 1968) who pointed out that two objects with very different spectral response curves may appear the same color on a color photograph. (Of course, color film is sensitive in even wider bands than the MSS.)

In addition to the integration of energy within each spectral band, the sensor integrates energy within a finite area on the ground. This area is often referred to as the resolution element. However, smaller objects can be detected by virtue of the fact that they represent such a contrast that they dominate the scene. For this reason, features such as highways may be detected even though it is smaller than the resolution element. Since the background is included in the sample, a sensorimetric measurement of such a feature would be in error. Also, the dimensions of such an object would appear to be too large. This combined integration is demonstrated in Figure 9.

Once the energy has been sensed by each band, it is recorded and relayed to the earth. To relay the data to the ground, each response that is sampled is converted into digital form. In this conversion process, the maximum amount of energy that is recorded is that amount that produces a maximum sensor voltage output. This maximum response varies for each band. Thus, a given amount of energy incident on each set of sensors corresponding to each band produces a different response. This relationship between the energy on the sensor and the film density produced on the images used in this research is given in Chapter II.

E. Reflectance-Density Relationships

To this point, the various components of the spectral response have been noted. The significance of each factor has been indicated to some extent but no real guidelines have been given. To be useful for interpretation, the relationships between the various components must be in some useful form.

A visual analysis for multispectral data should not greatly different from analysis of other types of remote sensing data since large portions are based on geometrical patterns. The contribution of the multispectral aspect is to obtain better contrast between certain terrain features and to give additional indicators for interpretation. To do this more efficiently a method to relate the reflectance of ground features to densities measured on the film is required.

Figure 6 gave the schematic presentation of the energy flow. This was expressed by equation (1). The relationship between the energy incident on the sensor and the film density was also shown. If the values for the variables in the equation can be determined, the theoretical basis for the enhancement techniques can be established, for the problem of enhancement of features on the film is simply solved. One only need to correlate what is on the film with the features on the ground.

It is obvious that it is impossible to develope a general relationship between reflectance and film density since the factors involved are by no means constant. What is possible, however, is to develope a relationship for a typical condition. The basis for the enhancement was, in fact, derived from inspection of the imagery. It would be useful to demonstrate, in a theoretical sense, how the enhancement is designed. The following table was developed from measurements made by Rogers and Peacock (1973) in conjunction with the ERTS program.

Table II

Values for Spectral Response Components

For Equation (1), Page 34

BAND	H	T	N_n	
1	8.41	.81	.274	N_n for 49° zenith angle with "average haze" conditions.
2	8.14	.865	.118	
3	7.38	.909	.082	
4	5.02	.913	.1062	T is for one atmospheric layer.

This data was based on a single set of measurements and is assumed to be typical.

Using the values from Table II and equation (1), the relationship between reflectance and and energy incident on the sensor can be demonstrated.

Table III

Energy Reflectance Relationships

BAND	ENERGY REFLECTANCE RELATIONSHIP
1	$N_1 = 2.16\ R + .27$
2	$N_2 = 2.24\ R + .12$
3	$N_3 = 2.13\ R + .08$
4	$N_4 = 1.46\ R + .11$

Consider the following reflectances.

Table IV

Typical Reflectances in Percent

OBJECT	BAND 1	2	3	4	
Water:	9.3	5.5	2.8	.9	(1)
Dry Loam:	6.7	6.79	6.10	14.01	(2)
Scotch Pine:	6.1	5.2	15.9		(3)
Peat Bog:	13.5	10.8	41.3		(3)

(1) Rogers and Peacock, 1973
(2) Lyon, 1970
(3) Steiner, Thomas, 1960

Additional values can be found in terms of energy incident on the sensor. For exa,ple, Table V contains values suggested by NASA (ERTS-Data Users Handbook).

Table V

Typical Reflectances in Energy

OBJECT	BAND 1	2	3	4
Wheat:	.322	.225	.320	.810
Pine:	.345	.292	.490	1.410
Sycamore:	.355	.400	.690	1.590
Snow:	1.590	1.312	1.110	.780
Grass:	.612	.570	.468	.933

From the above tables approximate density values, expressed in terms of density stepwedge number, for the three types of natural reflectors can be estimated.

Table VI

Typical Reflectance in Terms of Density Values

REFLECTOR	BAND 1	2	3	4
Vegetation:	13	14-12	13-7	10-11
Water:	13	14-13	14	15
Soil:	13-12	14-11	13-12	14-12

Table VII

Measured Density Values of Selected Objects*

REFLECTOR	BAND 1	2	3	4
Vegetation:	13-10	14-12	11-5	11-3
Deep Water:	13	13-14	14	14
Urban Areas:	10	11	9-11	9-11

* Measurements are from the imagery of Monterey Bay (sun angle 55°).

It was from the above considerations that the enhancement used in this research was developed. The values were found to be affected most by sun angle and much longer exposures were required for a sun angle less than 45°. With this exception, the results appeared to be typical.

Another consideration involved was atmospheric scatter. This was most critical in band 1, since in many cases over half of the sensed energy is derived from nonimage forming light.

Appendix II

Properties of Diazochrome

A. General Description

Diazochrome is a ultraviolet sensitive, amonia developing diazo material. The material used in this research is a high contrast material intended for half-tone reproduction. This makes the material somewhat unsuitable for full-tone reproduction (as is the case with the ERTS imagery) but highly suitable for the enhancement technique presented.

One of the major advantages of Diazochrome is its simplicity. Its low sensitivity as to visible light makes it essentially room-light safe. Development has little effect on the final result as long as full development is achieved.

B. Exposure and Development of Diazochrome

Exposure of the Diazochrome film was accomplished with a sunlamp mounted on a photo-copy stand. Using such a light source, exposures of several minutes were required. Normally, exposure can be accomplished in a vacuum plate-maker utilizing a metal Halide U.V. light source in a matter of seconds. The choice of exposure would be dependent upon the capital available for equipment.

Development of the Diazochrome films can be accomplished in any closed container in which amonia vapor has been allowed to collect. A common method is to use a large glass jar, with the amonia vapor introduced by an amonia-soaked sponge. If available, an amonia processor may also be used.

It was found that complete development could be obtained in a few minutes. However, the cyan material generally required at least 30 minutes to develope.

C. Exposure-Density Relationships

To determine the range of densities that could be copied with contrast, a D-log E curve was developed (Figure 9) for each color film. Exposure was defined as the log of the product of time of exposure and film transmission of original image. For example, if a density of 1 (T = .1) was copied with an exposure time of 5 minutes the exposure would be .5. Any light source could be calibrated to the curve by making a few trial exposures.

Density measurements were also made of each film through the green, red, and blue filters of a transmission densitometer (Figure 10). This was done to determine the nature of the spectral absorption dies used in the color film. Additional measurements were made at various combinations of film densities and exposure to determine the validity of the law of reciprocity.

Of ultimate concern is what exposure time must be used to place the contrast portion of the D-log E curve in the desired density range. A stepwedge from an ERTS image was exposed on all three film types and measurements were made of the resulting densities. From the results of these tests and the previous measurements a curve was developed to determine the range of densities that will be exposed with contrast as a function of relative exposure time (Figure 11). Other light sources used for exposure would have to be calibrated to this curve. The results of these measurements are given at the end of the appendix.

D. Printing Procedure

The composites used in this research were constructed by contact printing the original image onto the appropriate color film for the proper exposure time. This was achieved by placing the original film image and the Diazochrome under a glass plate with the emulsion side of each film in contact. The films were placed over a flat-black surface to eliminate a general "washing out" of the image due to reflection. Due to the long exposure times involved, and because of the warm-up characteristics of the sunlamp, the image was placed under the lamp while it was turned on.

While development is not a critical part of the processing of Diazochrome, long exposure of the material to the amonia vapor causes some dimensional instability. This is especially noticeable if development takes longer for a standard period of time, such that all are developed fully. The film cannot be over-developed.

Registration is accomplished by placing the first layer of the composite on a light table, with each subsequent layer registered as it is placed. When all layers are registered they are secured with a common staple.

Table VIII

Density
Measurements on Diazochrome

(5 Minute Exposures on 20 Step Density Wedge)

Magenta

Step	Filter Blue	Green	Red	Neutral
1.	.04	.06	.02	.04
2.	.06	.10	.02	.06
3.	.15	.22	.02	.12
4.	.33	.49	.03	.23
5.	.50	.80	.04	.34
6.	.63	.99	.04	.42
7.	.75	1.19	.04	.48
8.	.82	1.26	.04	.51
9.	.90	1.32		.52
10.	.92			.52
11.	.92			.55
	D max=.92	D max=1.4	D max=.04	D max=.55

Cyan

Step	Filter Blue	Green	Red	Neutral
1.	.08	.08	.15	.14
2.	.12	.22	.24	.24
3.	.16	.34	.36	.44
4.	.17	.49	.50	.60
5.	.20	.60	.65	.74
6.	.22	.70	.74	.89
7.	.26	.84	.86	1.02
8.	.27	.88	.89	1.07
9.	.28	.92	.92	1.101
10.	.30	.95	.94	1.12
	D max=.33	D max=1.04	D max=1.01	D max=1.24

(Table VIII Continued)

Yellow

Step	Blue	Filter Green	Red	Neutral
1.	.08	.04	.02	.03
2.	.13	.04	D max=.02	.04
3.	.29	.04		.04
4.	.47	.05		.04
5.	.66	.05		.04
	D max=.76	D max=.06		D max=.04

For exposure of:
20 minute exposure measurements from step 9 were as follows:

cyan:	neutral=.73	red=.64	blue=.20	green=.61
magenta:	neutral=.16	red=.03	blue=.21	green=.34
yellow:	neutral=.03			
	Base=.04		Base Density.	

For exposure of:
8 minute exposure measurements from step 5 were as follows:

cyan:	neutral=.53	red=.47	blue=.15	green=.43
magenta:	neutral=.17	red=.04	blue=.22	green=.36
yellow:	neutral=.04	red=.03	blue=.43	green=.05
	Base=.04			

Table IX

Density Stepwedge Calibration

Kodak Density Stepwedge #3

Step	Density
1.	.20
2.	.35
3.	.51
4.	.66
5.	.82
6.	.96
7.	1.10
8.	1.26
9.	1.41
10.	1.56
11.	1.70
12.	1.84
13.	2.05
14.	2.16
15.	2.30
16.	2.43
17.	2.59
18.	2.75
19.	2.92
20.	3.09

ERTS Stepwedge

Step	Density
1.	.16
2.	.18
3.	.19
4.	.20
5.	.22
6.	.24
7.	.27
8.	.30
9.	.34
10.	.44
11.	.54
12.	.67
13.	.91
14.	1.58
15.	2.60

Appendix III

Figures

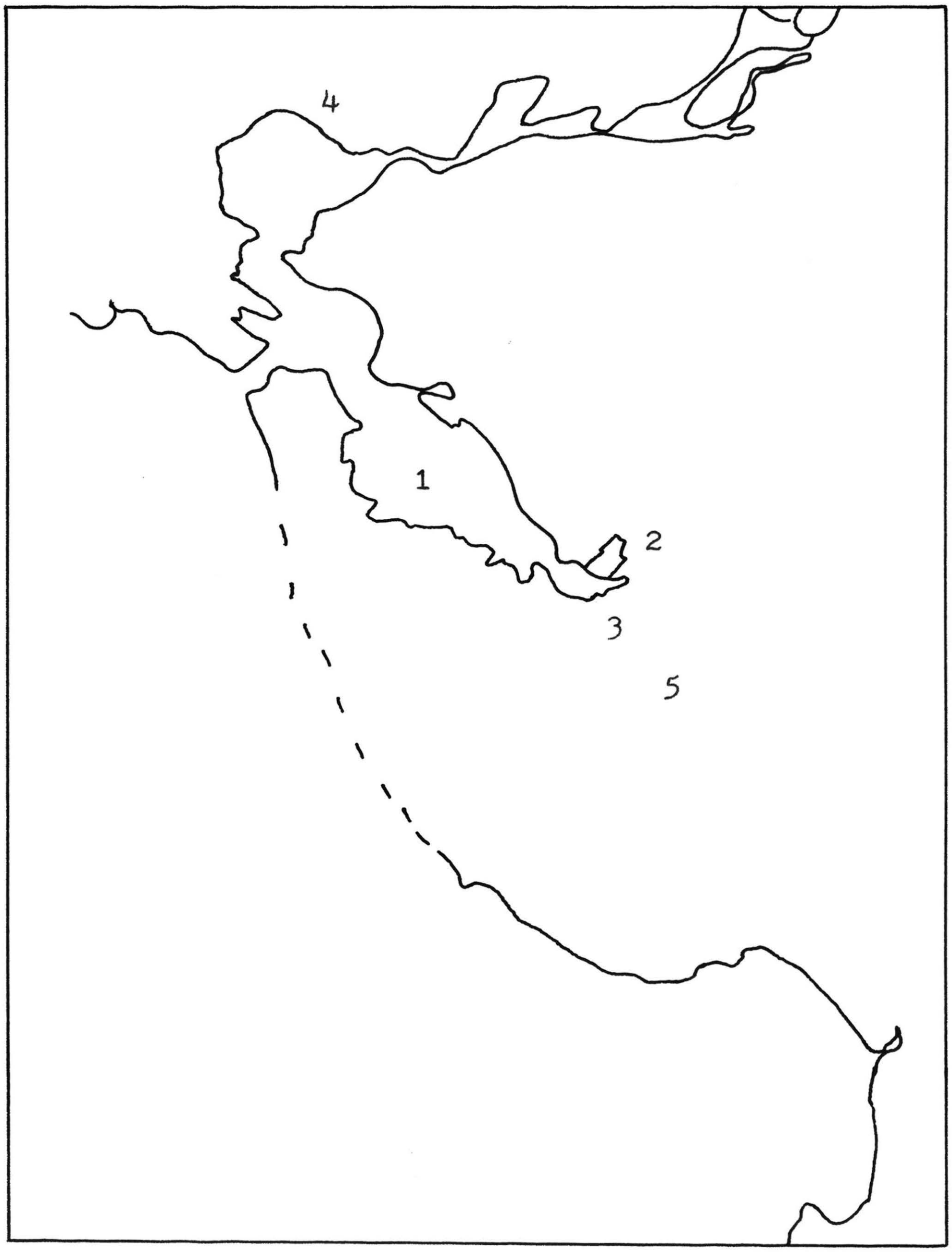


FIGURE 1. OVERLAY OF THE SAN FRANCISCO-MONTEREY FRAME

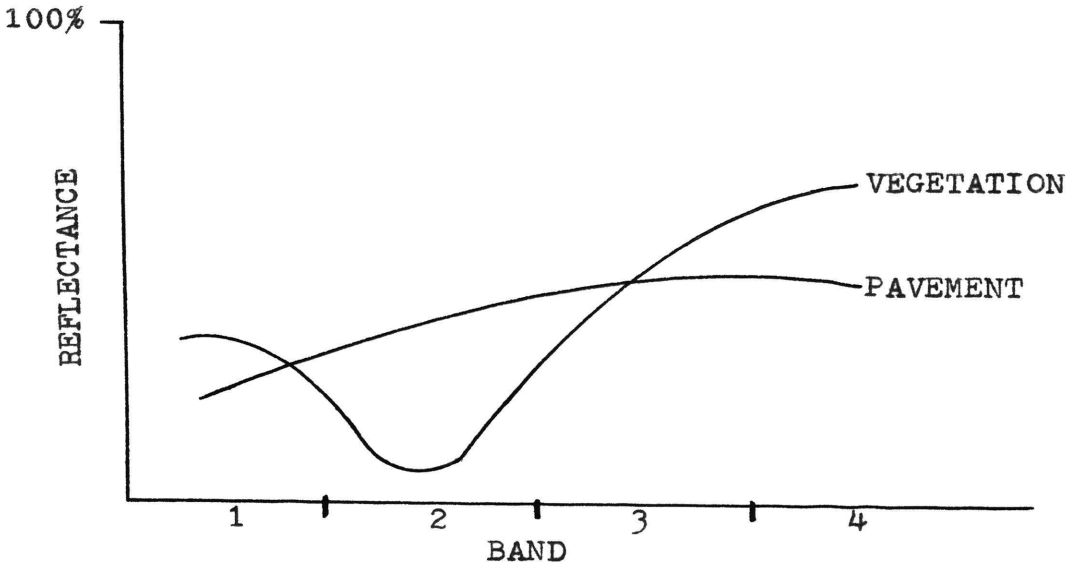


FIGURE 2. COMPARISON OF REFLECTANCE OF VEGETATION AND URBAN AREAS

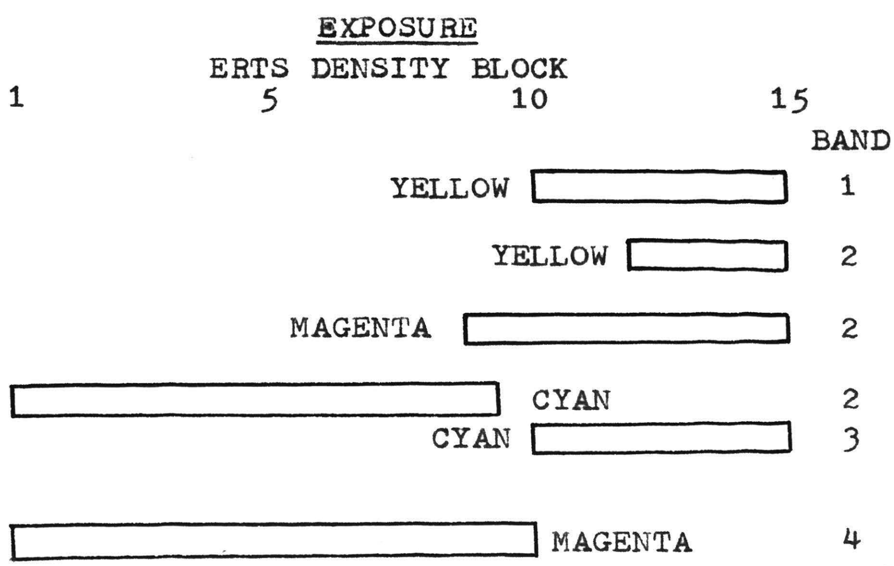


FIGURE 3. DIAGRAMMATIC ILLUSTRATION OF ENHANCEMENT

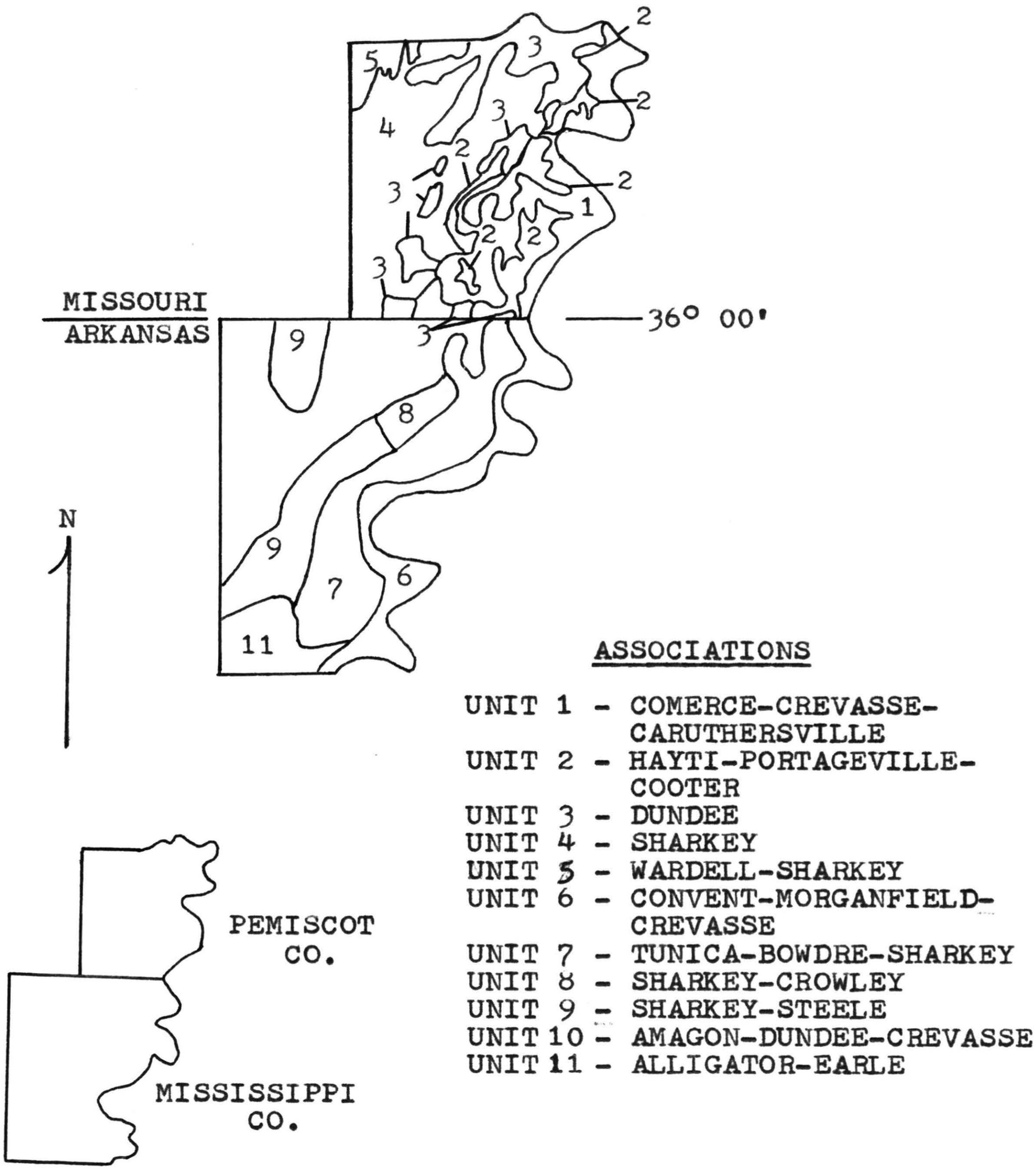
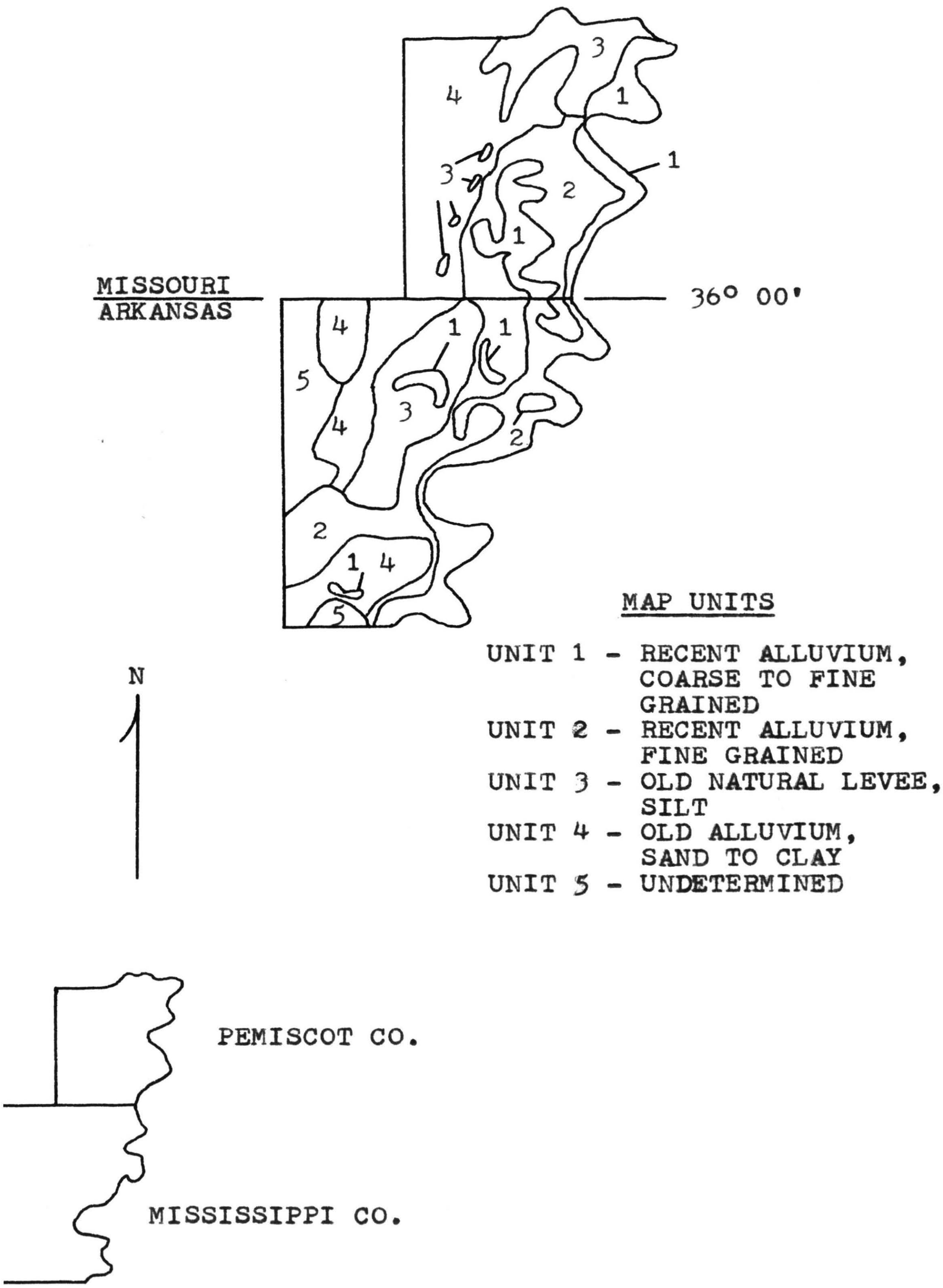


FIGURE 4. MAP OF SOIL ASSOCIATIONS



[GURE 5. MAP BASED ON INTERPRETATION OF ERTS IMAGERY

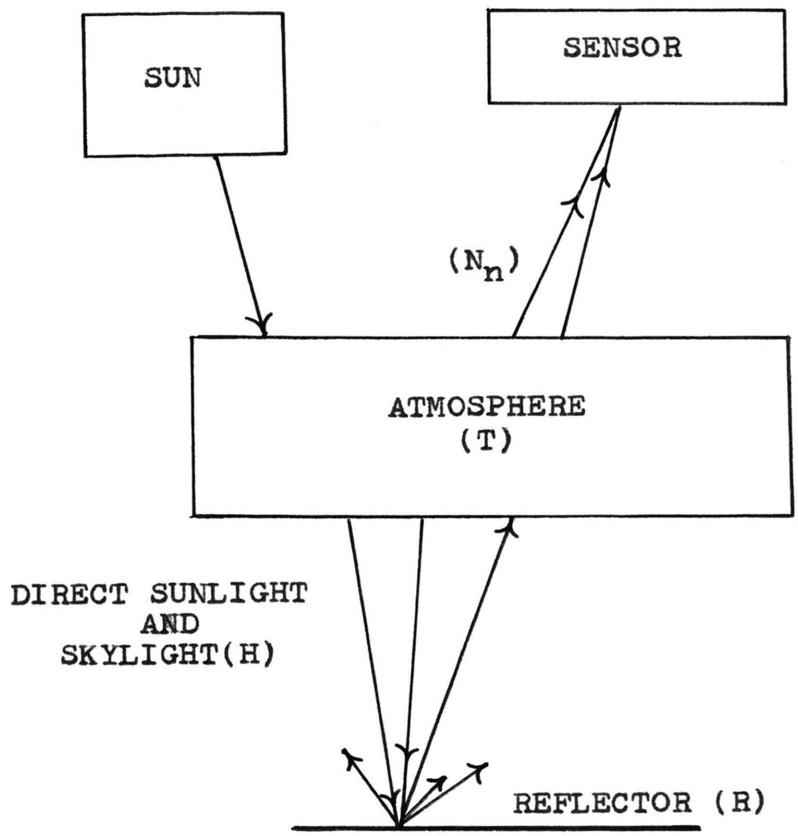


FIGURE 6. ILLUSTRATION OF ENERGY FLOW CONCEPT

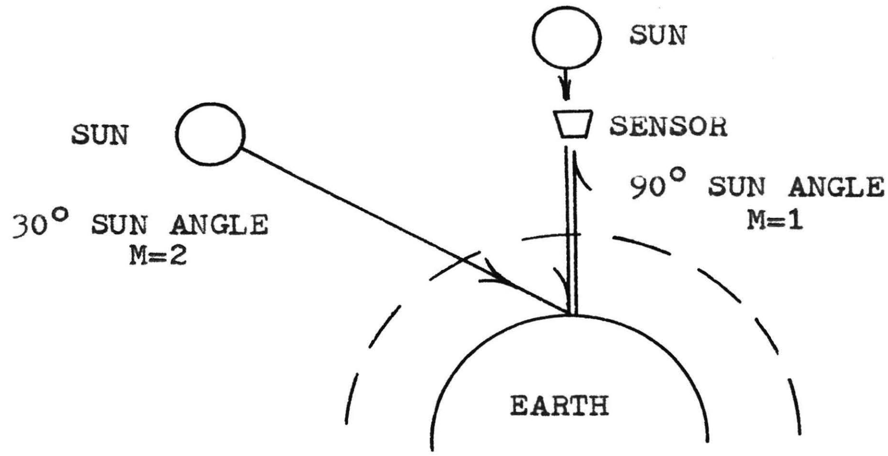


FIGURE 7. ILLUSTRATION OF EFFECTIVE PATH LENGTH

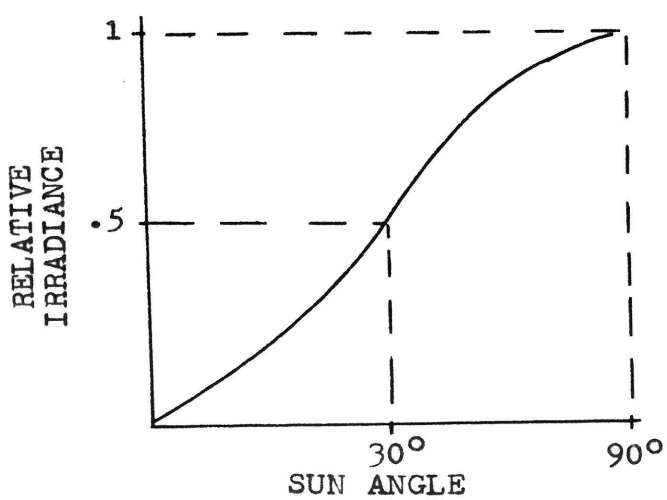


FIGURE 8. GRAPH OF SUN ANGLE VERSUS IRRADIANCE

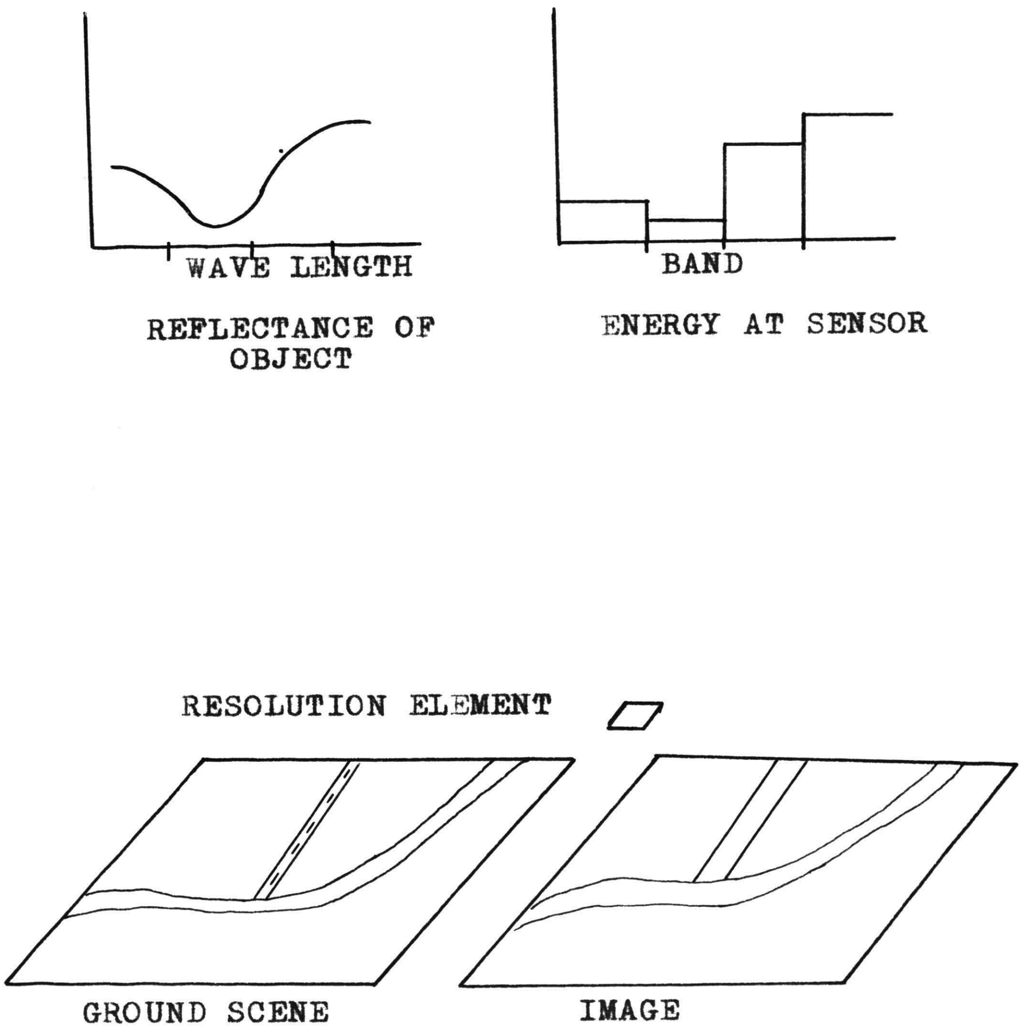


FIGURE 9. ILLUSTRATION OF SYSTEM PARAMETERS

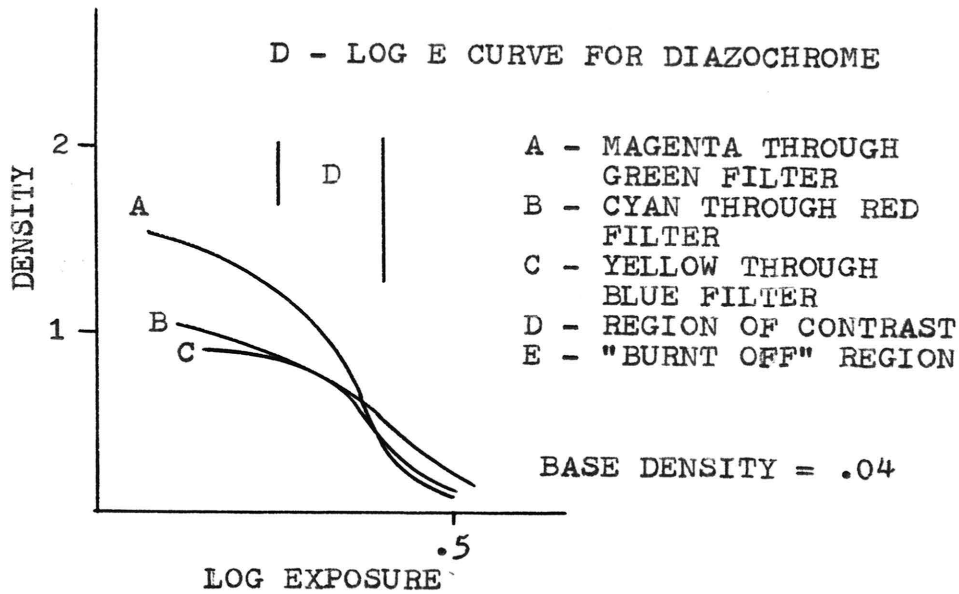


FIGURE 10. GRAPH OF D - LOG E RELATIONSHIP FOR DIAZOCHROME

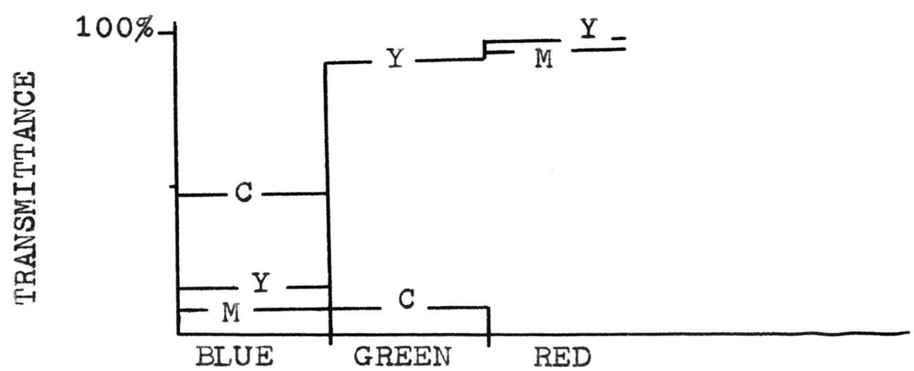


FIGURE 11. SPECTRAL TRANSMITTANCE OF DIAZOCHROME

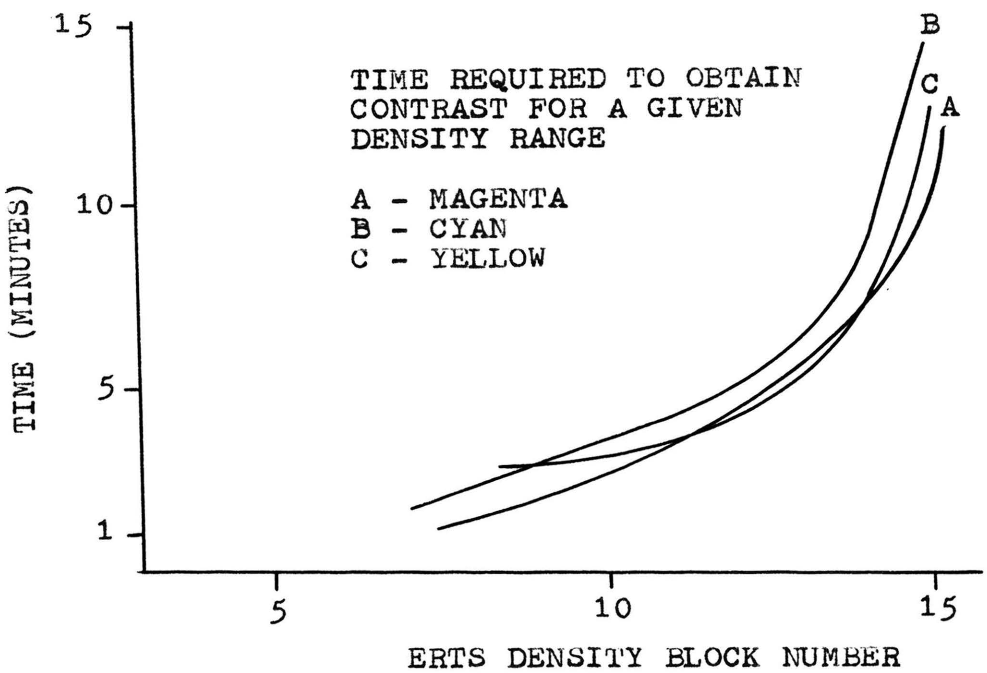
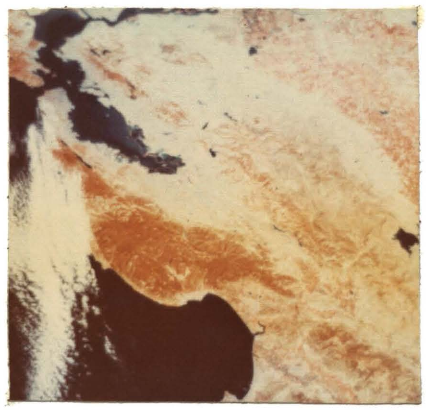
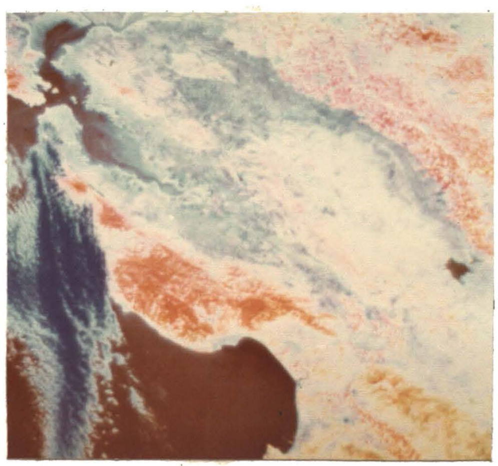


FIGURE 12. EXPOSURE CURVES FOR ERTS IMAGERY



STANDARD INFRARED COMPOSITE



ENHANCEMENT

FIGURE 13. PHOTOGRAPHS OF SAN FRANCISCO-MONTEREY FRAME

237320