A TEST OF THE CONCEPT AND PRACTICAL APPLICATION OF MULTIBAND RECONNAISSANCE

By
ROBERT N. COLWELL
JERRY D. LENT

A report of research performed under NASA Grant NGR/05-003-080 for the
National Aeronautics and Space Administration
Office of Space Sciences and Application

By personnel of the
SCHOOL OF FORESTRY, UNIVERSITY OF CALIFORNIA

Final Report

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ABSTRACT

In recent years many scientists have come to regard multiband reconnaissance as the ideal means by which earth-resource inventories might be made. Frequently, however, they have arrived at this decision without having a necessary appreciation for both the advantages and limitations of a multiband reconnaissance system. Likewise they have lacked information on the various means by which multiband techniques might be optimized for their use. The research reported herein is directed toward an examination of the potential advantages, limitations and means of optimizing such techniques. Use is made of both artificial and natural target arrays to illustrate the concepts of tone signature analysis and color additive image enhancement.

A means is illustrated for determining, from a large number of available film-filter combinations, which ones are the best to use for a two-band reconnaissance system, and for progressively larger numbers of bands, up to and including six. This technique entails the selection of bands which will give the maximum opportunity for displaying each feature of interest in a distinctive color on the composite image.

It is recognized that multiband reconnaissance missions frequently will have to be conducted for the benefit of several different investigators. Some of these investigators will have primary interest in one group of resource features while others will be interested in quite a different group. In such instances, compromises obviously will be necessary when these investigators are attempting to agree upon the specific bands to be used in their multiband system. The above-mentioned

procedure should facilitate the intelligent making of these compromises. It provides a means of permitting each investigator to estimate, for each compromise that is under consideration, and for each feature of interest to him, the loss in image interpretability that will result. If each investigator were to employ this method it would likely lead to a selection of the multiband system most compatible and generally useful to all parties concerned. It also would provide an intelligent basis for deciding whether the incorporation of an additional band or two in the multiband system would lead to a more favorable cost/benefit ratio.

The claim sometimes is made that no multiband photographic reconnaissance system is likely to provide information beyond that readily obtained through the use of multi-layer color films, such as Ektachrome, Anscochrome, and Infrared Ektachrome. This claim is examined in the light of the extreme variability in tone or color values exhibited by such imagery on successive photo reconnaissance missions. From a detailed examination of available imagery from NASA's Earth Resources Test Sites, it is concluded that, to maintain a uniformly high accuracy of resource inventory, the imagery must be of uniformly high quality, mission after mission. This quality consideration is especially applicable to the obtaining of a uniform color rendition for each type of resource feature on successive missions. There can be little question but what this objective is more nearly achievable through the taking of separate multiband black-and-white exposures, followed by the reconstituting of such imagery in color composite form. Furthermore, with continued improvement in the ability to register each of the multiband images (i.e., to superimpose it precisely over the other multiband images) far better spatial resolution should be obtainable through use of multiband photography than is possible with multi-layer color films. This is attributable to improvements in the signal-to-noise ratio when the image is formed from several negatives instead of just one. Several important examples of reconstituted color photos on which the above conclusions are based have been viewed on the projection screen. However, most of these could not be prepared as color prints in time for inclusion in this report because the multiband black-and-white photos were only recently flown. Such examples will be made the subject of a special supplemental report, to be submitted in the near future.

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A TEST OF THE CONCEPT AND THE PRACTICAL APPLICATION OF MULTIBAND RECONNAISSANCE

by

Robert N. Colwell and Jerry D. Lent
School of Forestry, University of California

I INTRODUCTION

As the world's population increases and its supply of natural resources dwindles, the need increases for placing these resources under wise management. An important first step in the right direction is that of obtaining accurate resource inventories. The National Aeronautics and Space Administration, through its Earth Resources Program, seeks to develop techniques for making these inventories with the aid of photography and related imagery taken from earth-orbiting spacecraft. Naturally, such earth-orbital photography and imagery--to be of maximum value for inventory purposes--must possess certain characteristics which will enable the greatest ease and success in its interpretability. The multiband approach for airborne and spaceborne reconnaissance systems incorporates many of these necessary characteristics. This approach is based on the concept that unique photographic tones may only be resolved and identified by analysis of photos and/or imagery which have been obtained in more than one spectral band. The research reported herein is designed to relate some of these image characteristics to the concept of multiband reconnaissance, and to demonstrate its practical advantage in providing greater amounts of information for use by the image analyst than would more commonly be available through conventional photographic missions.

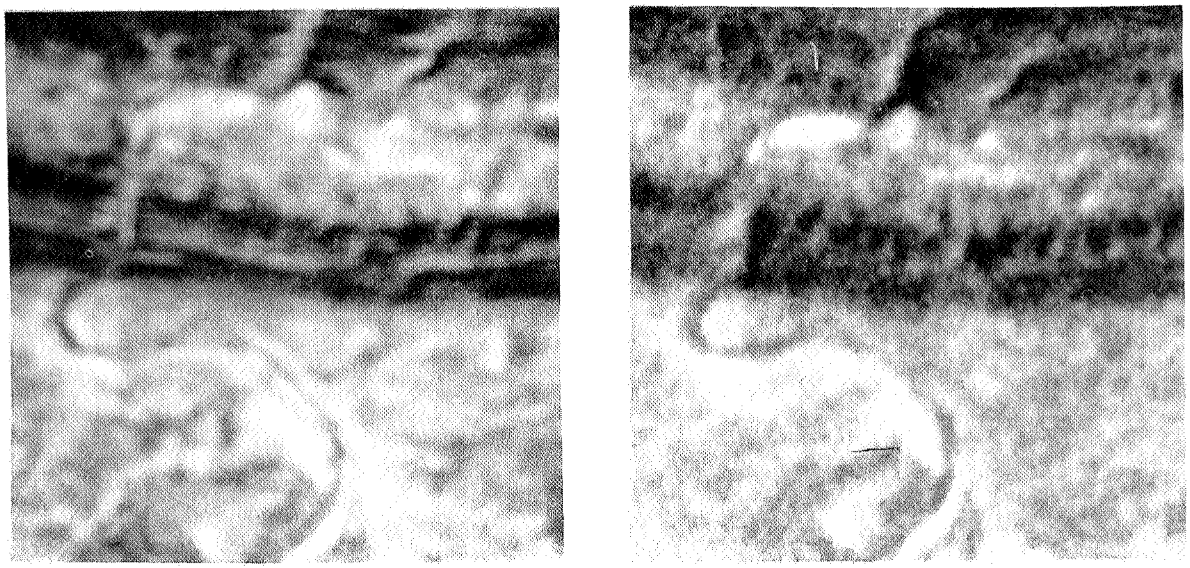


Figure 1. Conventional low-altitude vs spaceborne photographs of a remote Australian region which have been processed to approximately similar ground scales and resolution in order to illustrate the similarity of tone renditions, despite the divergent photographic altitudes. The reader is invited to compare tones on each of the two illustrations: the one on the left was taken from a conventional flying altitude of 25,000 feet and the one on the right from 871,000 feet (approximately 170 miles).

Generally speaking, the higher the altitude from which imagery is taken, the greater the reliance which an image analyst must place on an object's tone characteristics, and the less reliance he can place on the object's shape, texture and other image characteristics (see Figure 1). Rarely does an important Earth resource feature exhibit a unique tone when photographed with only one film-filter combination. However, if such a feature is photographed simultaneously with several film-filter combinations, there is good prospect that the feature will exhibit a unique combination of tones on this multiband photography. Such a combination of tones is traditionally referred to by remote sensing scientists as a "tone signature".

Most authorities in the remote sensing field would agree that the foregoing is an accurate statement of the theoretical basis for our conducting multiband remote sensing research under the NASA Earth Resources

Program. Beyond that rather elementary point of agreement, however, the authorities tend to be divided into two camps.

One camp, noting that the useful wavelength range for multiband photography traditionally is from about 0.4 to 1.0 microns, asserts that color films such as Ektachrome, Anscochrome and Infrared Ektachrome provide virtually all of the useful information obtainable within this wavelength range. They argue that such color films, by virtue of their containing three dyes, each of a different color and different wavelength sensitivity, automatically provide multiband photography in the most suitable wavelength bands. Even the most complex multiband photographic systems would rarely if ever yield more information, they assert (see Figure 2). Consequently, they see little need for further development of reconnaissance systems that would require the taking of multiband black-and-white photos and the eventual reconstituting of them into composite color images.

The other camp maintains that existing color films, while useful, exhibit important deficiencies, all of which might be overcome through use of a black-and-white multiband reconnaissance system. Specifically: (1) any given color film permits the use of no more than three spectral bands, (2) each band has a fixed wavelength range which may or may not coincide with the wavelength range <u>best suited</u> for obtaining unique earth-resource tone signatures, (3) once a color film has been made, there is little opportunity to alter the extent to which each dye contributes to the composite color image since each dye has a fixed sensitivity, and since the click of a single shutter (whatever the shutter speed and f-stop setting) automatically governs the exposure in all three bands, and (4) spatial resolution is lost in the color film since all of the dyes are embedded in one complex multi-layered emulsion. Consequently, when such color films are used, some of the wavelengths of radiant energy must find their way through several layers before encountering the dye that will respond to them; spatial resolution must surely be lost in the process.

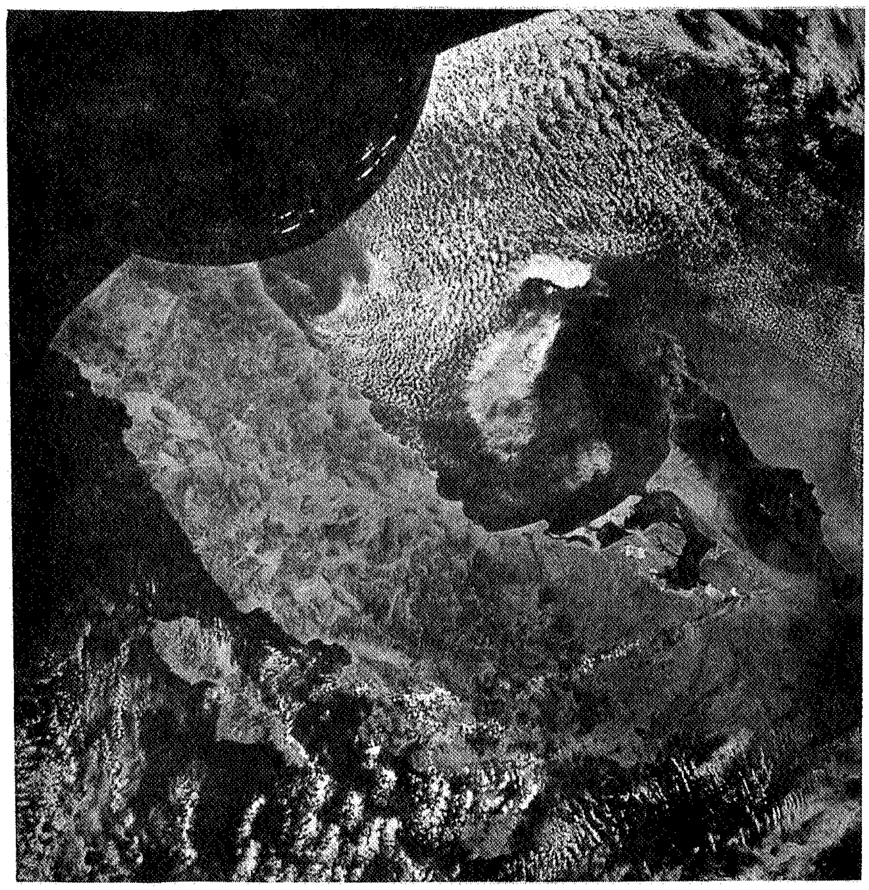


Figure 2. Shown here is a representative photograph of the earth's surface taken on an earth-orbital Gemini mission. Color films of the type shown here commonly possess poorer spatial resolution than conventional black-and-white films. Notice the blueness due to atmospheric scattering of blue light. As discussed in the text, some scientists would argue that such a color film automatically provides the interpreter with multiband photography in the most suitable wavelength bands; other scientists maintain that existing color films exhibit important deficiencies.

Proponents from this second camp emphasize that the desired flexibility, in all of the above respects, is readily provided by a system in which multiband black-and-white photographs are taken through separate lenses and are projected in common register through selected filters onto a screen. Not only should one be able to obtain better spectral resolution by such a system, but better spatial resolution as well. Theoretically, the "signal-to-noise ratio" which governs spatial resolution is improvable through such a system by an amount equal to the square root of "n", where "n" is the number of separate black-and-white negatives used in constructing the composite image. Thus, through use of a 4-band system, a 2-fold improvement in spatial resolution should be attainable, but only if the four bands used are initially recorded on separate sheets of photographic film and then carefully registered to form a composite image.

There would appear to be an additional element of flexibility inherent in the separate multiband approach,--one of particular importance to those seeking to automate photo interpretation to the maximum extent possible: analytical computer programs might be devised with which (1) to make statistically sound determinations of the tone signatures of various objects, based on densitometric readings from the separate black-and-white multiband images of them, and (2) to exploit these determinations by means of photo electric scanners which would automatically identify each feature from its tone signature.

There also is the possibility, say proponents from the second camp, of fortifying multiband photography with imagery obtained in various thermal and microwave bands to which photographic emulsions are not sensitive. Black-and-white imagery is obtainable in these additional bands, however, through the use of optical-mechanical scanners (in the thermal infrared region) and image-forming equipment (in the microwave region).

The time when additional light should be shed on the debate that separates these two camps is now. It is believed that the research reported herein provides valuable data, both quantitative and qualitative, that will help resolve the numerous questions that have been raised by this debate. If so, the research should also provide timely guidance for the design of optimal reconnaissance systems for use in NASA's Earth Resource Program.

II. BASIC CONSIDERATIONS

A. Basic Matter and Energy Relationships

In considering how multiband reconnaissance can give useful information about the Earth's natural resources, we must understand something about the minimum unit of electromagnetic energy,--the "photon". Electromagnetic waves can differ not only in wavelength, but also in energy content. When a photon of any specific energy strikes a boundary of solid matter, a number of interactions are possible. Mass and energy are conserved in accordance with basic physical principles, and the photon can either be:

1. transmitted, that is, propogated through the solid matter;
2. reflected, that is, returned unchanged to the medium in which it previously was traveling;
3. absorbed, giving up its energy largely into heating the matter;
4. emitted, (or more commonly re-emitted) by the matter as a function of temperature and structure, at the same or different wavelength, or,
5. scattered, that is, deflected to one side and lost ultimately due to absorption or further scatter.

Transmission, reflection, absorption, emission and scattering of electromagnetic energy by any particular kind of matter are selective with regard to wavelength, and are specific for that particular kind of matter, depending primarily upon its atomic and molecular structure. In view of this fact we can, in principle, identify the material comprising a target (e.g., a natural resource feature on the Earth's surface) from any record which is sufficiently detailed to show the target's spectral transmission, reflectance, absorption, emission and/or scattering properties.

Since a basic consideration in image analysis is the identification of objects or targets, it naturally follows that the more that is known about these properties, relative to the objects in question, the more readily can an identification be made by interpretative procedures.

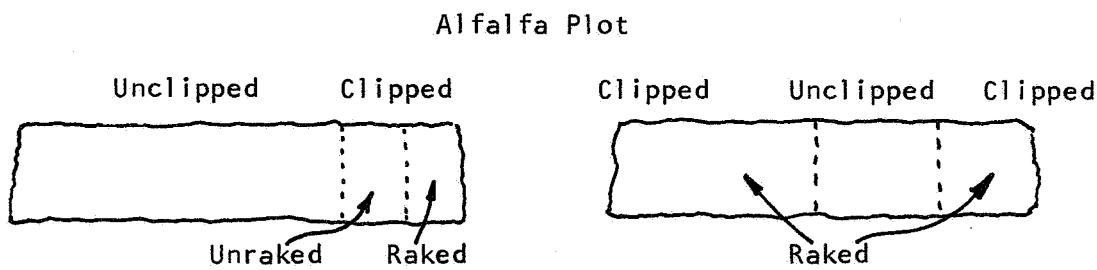
B. Photographic Relationships in Terms of Energy Levels

The brightness or tone with which an object is recorded on a photograph, thermograph or other form of imagery depends largely on the amount of energy which the object reflects and emits within the spectral band employed in obtaining that imagery. Two or more objects may reflect and emit exactly the same amounts of energy in one spectral band; if so, the image analyst cannot differentiate them on the basis of tone when all available imagery has been taken in only that band. It is very unlikely, however, that the objects will reflect and emit exactly the same amount of energy in <u>all</u> spectral bands for which there is a remote sensing capability. Consequently, if the objects are photographed in two or more properly-selected spectral bands, it should be possible to differentiate them. Furthermore, it may be fully as informative, in some instances, to know that two objects have the <u>same</u> reflectance and emission characteristics in one spectral band as to know that they have <u>different</u> reflectance characteristics in a second spectral band. Alternately stated, a more complete "tone signature" should be obtainable from imagery obtained in two or more properly selected bands than from imagery obtained in only one band, and the more complete the tone signature, the more certain the identification. Thus, photo-like images, called "thermograms" which provide a measure of heat emission rather than light reflectance, also may contribute valuable elements to the tone signature that is derivable by multiband reconnaissance.

Since the tone signature of a rock, soil or vegetation type (as obtained by multiband reconnaissance) often indicates the composition of that type, great importance should be ascribed by the image analyst to the use of tone signatures for interpreting natural terrain features, including those of primary interest in the making of natural resource inventories. However, the validity of the tone signature concept can be demonstrated even more clearly and efficiently in some respects through the use of concentrated target arrays containing various abstract objects (e.g., variously colored panels) together with vegetation and terrain samples that have been removed from their native environment and placed in the target array. Realization of this fact is reflected in certain aspects of the research described in this report.

Inherent in this brief discussion so far is the realization that a major task of applying the multiband reconnaissance concept is that of selecting the proper spectral bands with which to sense data and procure imagery. Owing to variability in the spectral properties of targets, an analytical approach is necessary to resolve this problem. Besides the spectral characteristics of objects, there are other factors which require attention by image analysts since they can affect markedly the tone signatures of the resultant imagery.

"Temporal" factors, such as time of day, time of year and vegetational state of development, are independent of all the image-taking parameters listed on page 10 (except solar illumination, perhaps). However, these variables play an integral role in defining resultant tone signatures. For example, alfalfa that has been recently mowed exhibits a vastly different energy response than unmowed alfalfa or alfalfa that has grown back following a previous mowing (see Figure 3).



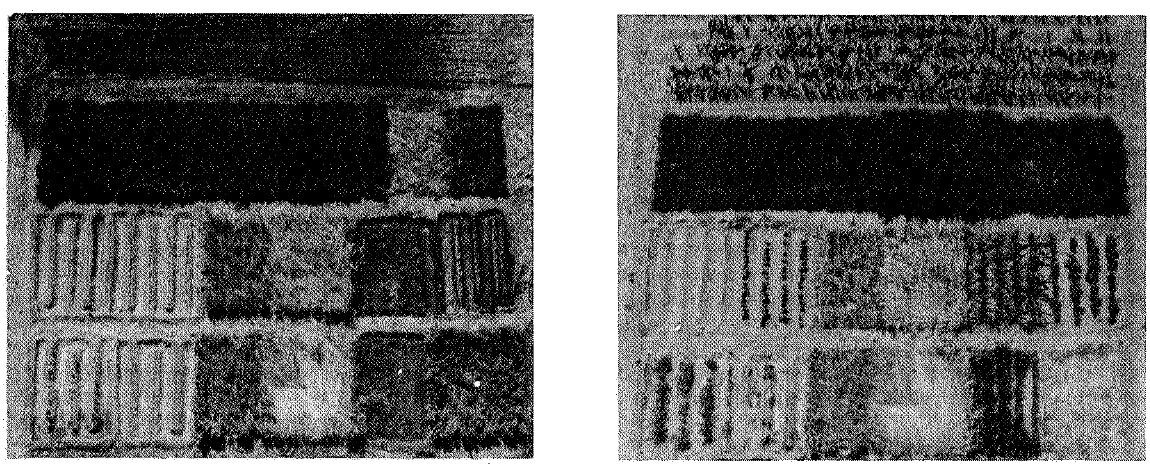


Figure 3. Part of the alfalfa shown in this photo has been clipped to simulate mowing. The plot is growing near the base of a water tower at the Davis campus of the University of California to facilitate its being photographed from the tower's catwalk, 150 feet above the plot. Notice the color difference for raked and unraked vegetation on the left-hand illustration. The right-hand illustration was taken one month later and shows subtle color differences due to a variety of clipping operations across the plot. The tone signature for this type of crop would obviously vary as its vegetation state changed.

Other factors which also affect tone signatures include the spatial orientation of the target with respect to surrounding objects; goniometric factors relating to sun angle with respect to camera and target position; and polar variations in energy reflectance. All of these factors, while they may be regarded as limitations or disadvantages with respect to defining tone signatures, may actually be exploited to the benefit of the photo interpreter or image analyst in certain instances. They become limitations, however, when they are ignored completely.

Adequate "ground truth" information can assist the interpreter to deal with tonal aberrations that might be caused by variability of one or more of the five factors just discussed: temporal, spatial, spectral, goniometric and polar.

C. Target Tone Signature Analysis

The brightness, or tone, with which an object is registered on a photograph, thermograph or other image forming medium is dependent upon the following parameters and their interaction:

1. The amount of energy which the object reflects and/or emits throughout the electromagnetic spectrum.

2. The spectral sensitivity of the imaging medium (film sensitivity, primarily).

3. The spectral bandwidth of filters that are used in conjunction with specific films.

4. The "illuminating" energy source which impinges on the object (sunlight energy, e.g.).

5. The preferential scattering by atmospheric haze particles of both the illuminating energy and energy being emitted by or reflected from the object.

Before adequate interpretation can be made of airborne or spaceborne multiband imagery, it is important to determine the spectral response of each terrain feature that is to be identified. Mindful of this requirement, the principal investigators and their associates previously had conducted a great deal of research designed (1) to determine spectral reflectance characteristics of the various terrain features that are encountered in each of several official NASA Test Sites, and (2) to determine from these spectral characteristics the specific spectral bands that should be used when making a multiband reconnaissance of such sites. By one means or another, a large amount of imagery in the selected bands already had been obtained of these sites. In a limited number of instances, detailed interpretation of this imagery had been performed and carefully field checked. As a result of these efforts, it had already been demonstrated that the making of a statistical analysis of spectrometric data can be of great value in selecting the optimum spectral bands for use in natural resources surveys. Consequently, under the present research effort the principal investigators sought primarily to build on their previous research and to avoid needless duplication of it. For example, in many instances further use was made, in this research, of the vast amount of imagery that already was available in one form or another, as a result of research performed in the two previous years under NASA grants.

A major objective of the research reported upon in the following pages has been to facilitate the designing of meaningful multiband experiments for the Apollo program (beginning with EO-2), since that program will provide an opportunity to test the feasibility of mapping the earth's resources through use of multiband earth-orbital imagery.

As the number of spectral bands within which data is to be gathered is increased, the task of identifying each object and condition from its multiband tone signature can become astronomic unless the image analyst is provided with some special form of equipment. At least three solutions to this data analysis problem are worthy of consideration:

Method No. 1 The multiband imagery of a given portion of the terrain is reconstituted as a single color composite. Each type of feature is then identified merely through visual perception of the color exhibited by it on the composite color imagery. When this method is employed, it is common practice to project simultaneously onto a viewing screen all of the black-and-white images of a given portion of the terrain that have been obtained with the multiband reconnaissance system. The color rendition is achieved by the use of colored filters. Each black-and-white frame is projected, usually in lantern slide form, through a filter of suitable hue. For any feature, the intensity of that particular hue, as seen on the color composite, is governed by the various gray-scale values (tones) exhibited by the feature on the corresponding black-and-white lantern slides. Numerour examples of color imagery produced in this fashion appear in subsequent portions of this report.

Method No. 2 A battery of photo-electric (brightness sensitive) scanners is used to scan all of the multiband black-and-white images simultaneously. For each of the multiband images of a given area of terrain, a scanner is assigned. The scanners, operating in unison, scan the black-and-white multiband images line-by-line, progressing from the top of the frame to the bottom. Because all of the multiband images have identical geometry, all of the scanners simultaneously view conjugate images. Consequently, a multiband tone signature automatically is read out by the battery of scanners for each "x" and "y" coordinate position that is scanned. Theoretically, each spot scanned is in this way found to have a tone signature identical with that of some particular object or condition that was studied in the calibration phase. In its ultimate form this method results in an encoded automatic print-out on tape, indicating the objects and conditions encountered at every "x-y" coordinate position appearing in the multiband imagery. At present such a method has not been perfected, but even with its present limitations it is able to provide a sufficient degree of automatic image analysis to greatly reduce the amount of work required of the image analyst himself.

Method No. 3 The multiband reconnaissance system records on magnetic tape, rather than on film, the electronic signal strength from each object in each spectral band. From that point forward, the procedure is the same as that described in Method 2. The essential difference is that Method 3 permits "real-time" analysis of signal strength emanating directly from the objects when they are recorded, while in Method 2 only signal strengths coming from processed images of the objects can be analyzed. If, in Method 3, photo-like images are desired, these can be produced from the original tape records, but usually merely as a by-product. Conversion of data from analog to digital mode will allow statistical manipulations to be performed for evaluation of the identification process in operation.

III. EXPERIMENTAL PROCEDURE

A. Obtaining Multiband Photography of Color Panels

As the first step in making a basic study of the multiband tone signatures of various kinds of objects and conditions, a target was constructed that contained several panels of carefully-selected colors, as illustrated in Figure 4. Because of its portability, this target could be readily photographed under controlled conditions, using a large number of photographic films and filters.

Other special target arrays were studied where a greater variety of materials and more subtle color changes could be anticipated but without the controls over variability that the laboratory color panel array permitted. Figure 4 shows the format of the color panel.

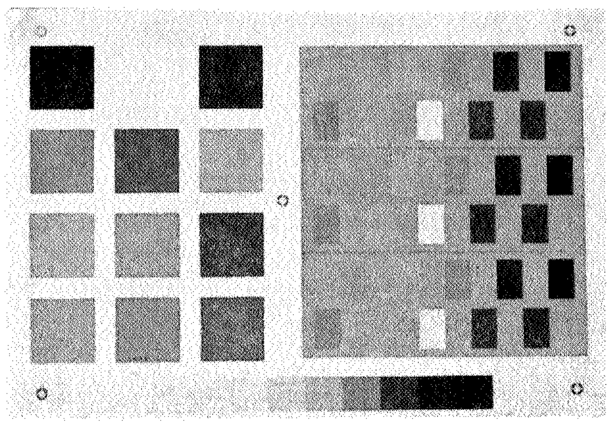


Figure 4. Color panel display. See text below for description.

The twelve colors seen as squares on the left hand portion were selected with an attempt to cover the range of fundamental colors throughout the visible spectrum. One black square and one white square were included to complete the array. The pigment used (egg-tempera) was selected because it exhibits a very flat response; hence, undesirable specular reflectance could be held to a minimum. On the right-hand portion of the panel array, the additional colors appearing as rectangles were applied to three background surfaces, each of a different color. The background colors were dull brown at the top, charcoal in the middle, and a flat green surface at the bottom. For each of these surfaces a second series of color chips (egg-tempera, again) was applied and the chips were arranged in the same sequence on all backgrounds. These ten colors closely simulate vegetative, soil and related terrain colors commonly encountered in nature. At the bottom of the panel is a Kodak standard Grey Scale which permits control over proper exposure values for the many film-filter combinations which were studied.

Fifteen black-and-white film-filter combinations were used in photographing the color panel display. Illustrations of these combinations are shown in Table 1 with the filter transmission data included. They are tabulated to facilitate visual comparisons. Each example is derived from an optimum exposure in terms of negative film densities. The many tonal contrasts and shifts that are exhibited here are similar to those exploited in making identifications of terrain features based on their tone signatures. Terrain features respond to other signature-forming factors, however, (slope, aspect, moisture, etc.) which complicate the interpretative process unless ground control is maintained. The shifts observed in the color spectrum of Table 1 are independent of all other factors except pigment reflection. This fact makes employment of the principle of tone signature analysis reasonably simple.

From the earlier discussion of factors governing photographic tone, it will be recalled that the integration of film sensitivity, filter transmittance, illumination source, spectral scattering and target spectral reflectance will define a specific tone value dependent on photographic exposure settings. As applied to the color panel photos of Table 1, the chief variable parameters involved in this integration are filter transmittance and pigment reflectance. However, in the present study, it was not the intent of the authors to integrate the curves in an effort to predict tone values since this technique can be referenced in their previous studies.

Suffice it to say that for any film-filter combination the resultant interaction of these factors defines the tone value for each feature, which in turn serves as one element of its tone signature. The multiband concept allows for a greater degree of definition of tone signature merely by providing more of the elements that comprise that signature. Tone analysis in one band, for example, may yield several alternatives as to the identify of a specific target. However, the addition of further tone signature elements obtained in other portions of the electromagnetic spectrum will place each object in a unique tone signature category if the spectral regions for photography have been properly selected.

The color panel array was then photographed using a large number of different Wratten gelatin filters with a Polaroid panchromatic type black-and-white film of high sensitivity. Each film-filter combination was exposed at different f-stops and shutter speeds, bracketing the optimum exposure level. Densitometric readings of the black squares, the white squares and the Grey Scale chips led to the selection of the optimum exposure as the one exhibiting the maximum optical density range from black to white. Figure 5 below is an illustration of the color panel array without a filter being employed.

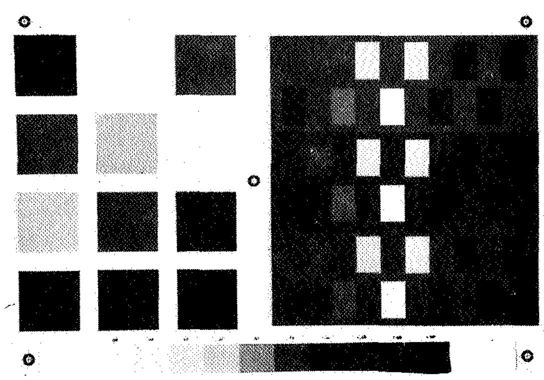


Figure 5. Black-and-white unfiltered illustration of color panels. On the negative from which this print was made, densitometric readings could readily be obtained. Variations of tones can be examined for each color square of the array using different spectral bands, as determined by the transmission characteristics of each Wratten filter used (see Table 1).

B. Selecting Optimum Film-Filter Combinations for Various Multiband Systems

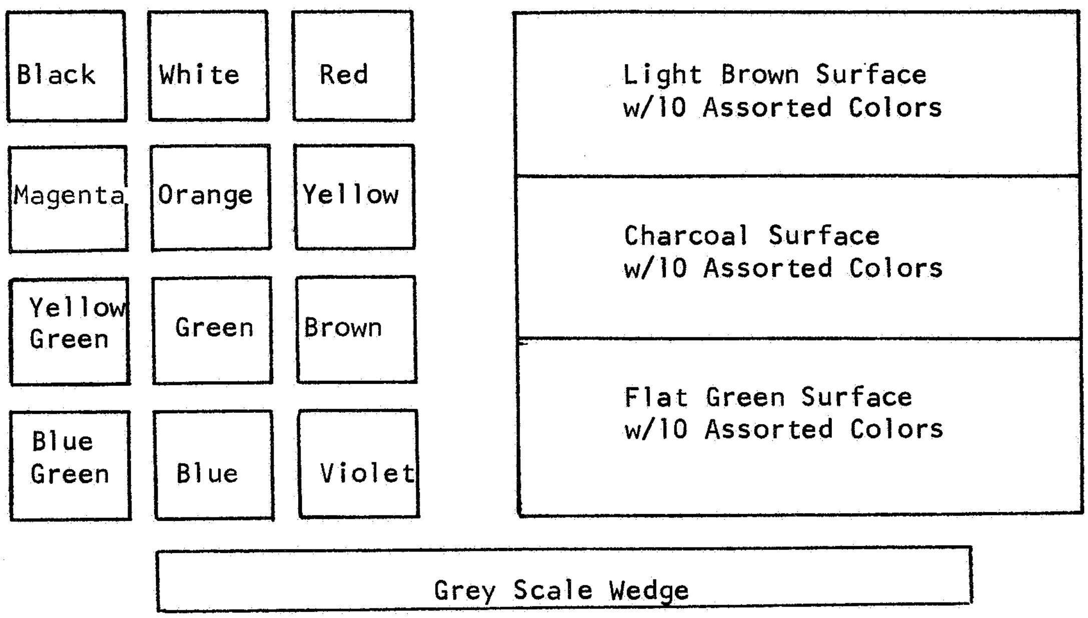
Each negative of the illustrated panel array included in Table 1 was subsequently measured using a Welsh Densichron densitometer. Optical densities were recorded for each of the twelve colored squares, the background surfaces (brown, charcoal and green) and the grey scale steps. These optical densities therefore served as quantitative tone signatures for the pigments and surfaces involved. Use of this controlled simplified array afforded a method of comparing filters and resultant tone signatures, and yielded a basis for projecting to other targets of interest.

Table 2 contains a summary of the measured optical densities (reduced for presentation in histogram form) for the fifteen possible combinations. For each color square there is a histogram of comparative negative densities, or tones, for the various filters used. These densities are referenced to a negative exposed without the use of a filter (labeled "OPEN"). The histograms reveal the effect of each filter used in the study in helping to define the ultimate tone signature for each color square. The histogram scales denote the relative degree of divergence from the "OPEN" optical density measurement.

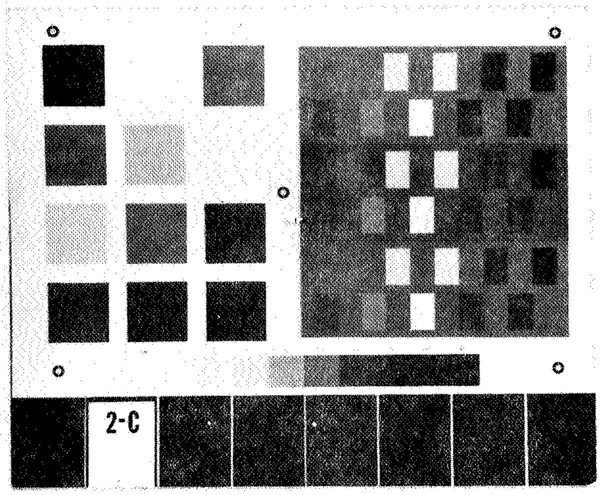
In this discussion, densities on the negative are referred to as "negative optical densities". Filters listed to the left of the "OPEN" measurement (indicated by 0.0 on the lower scale of Table 2) yield lighter negative optical densities, or conversely, darker positive reproductions. Filters listed to the right of the "OPEN" measurement yield darker negative optical densities; hence, lighter <u>positive</u> tones would occur than when exposing without a filter. Negative optical densities for each color square

Table 1

Color Panel Array



The following illustrations depict tone shifts within the color panel array (see Figure 4) for each of the fifteen Wratten filters employed. Along side the photo print is a graph of the respective filter transmittance data yielding these various tones. The fifteen Wratten gelatin filters used (2C, 8, 12, 25A, 30 35, 47B, 61, 65A, 70, 72B, 73, 75, 90 and 99) were selected to cover many spectral bandwidths and are presented in numerical order in the following table.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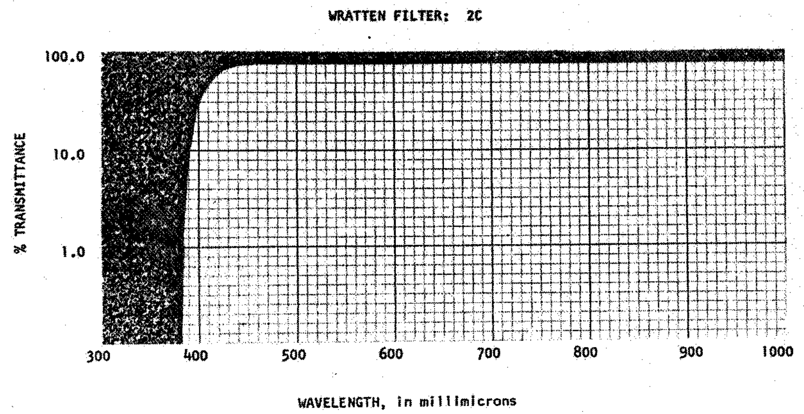
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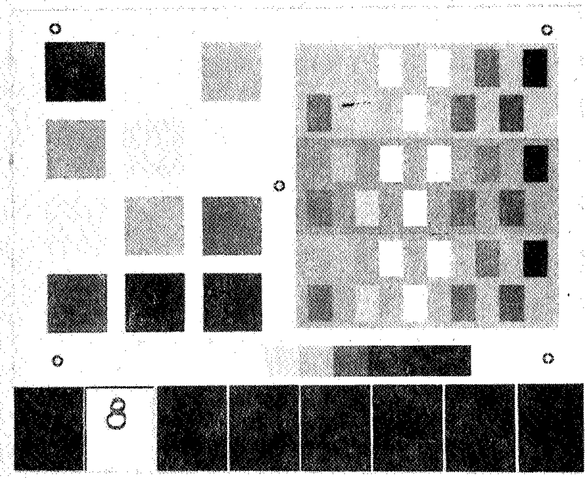
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons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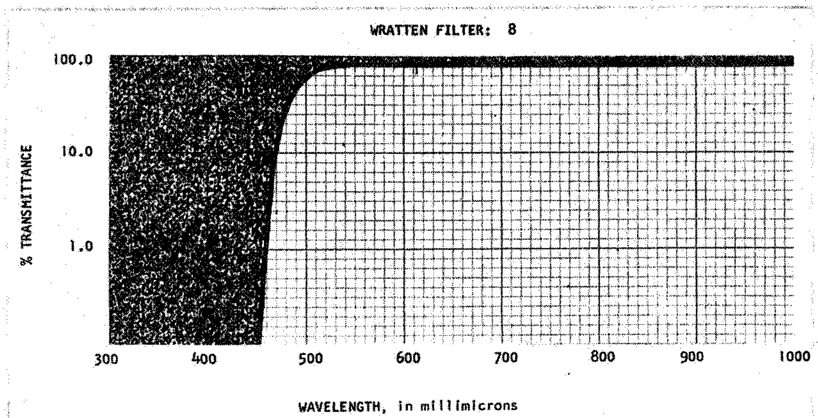
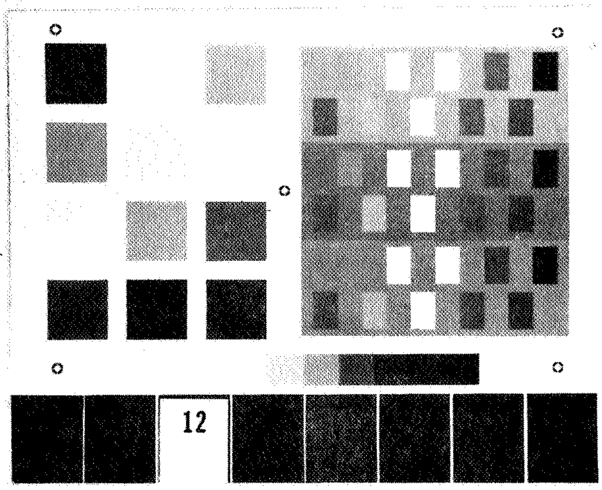

WRATTEN FILTER: 8
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons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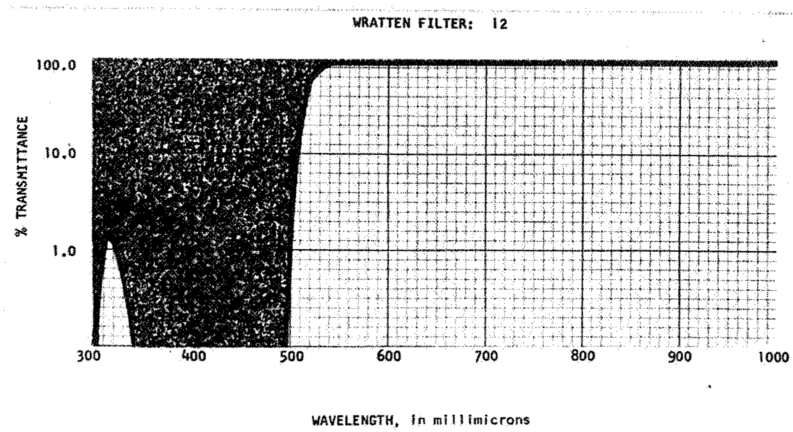
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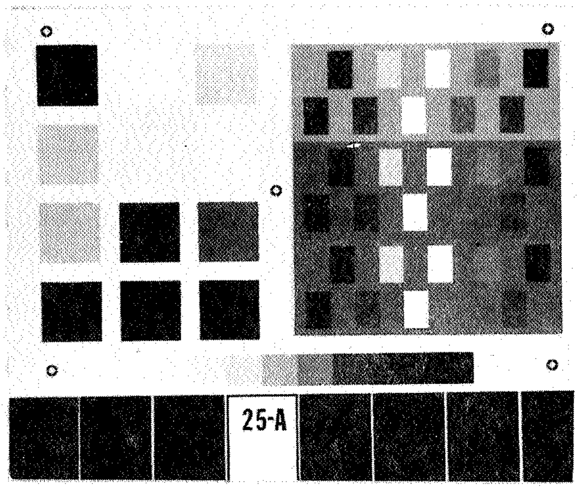
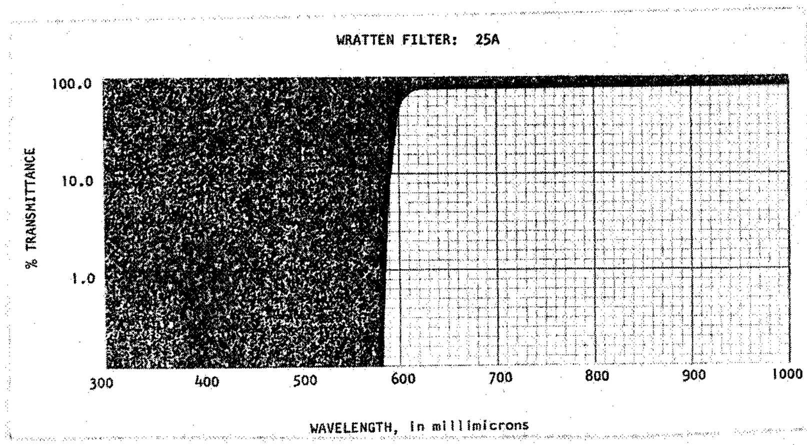
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


25-A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1.0
% TRANSMITTANCE
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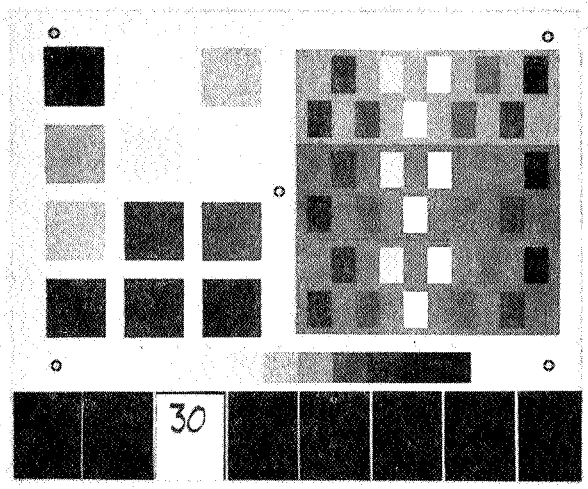
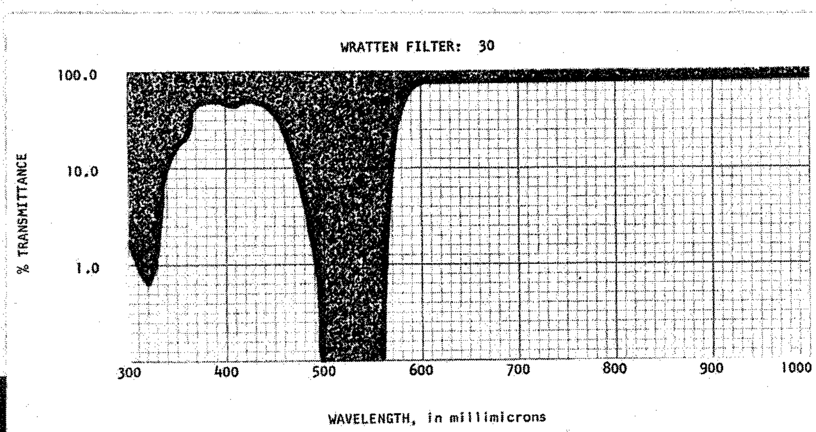
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


30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% TRANSMITTANCE
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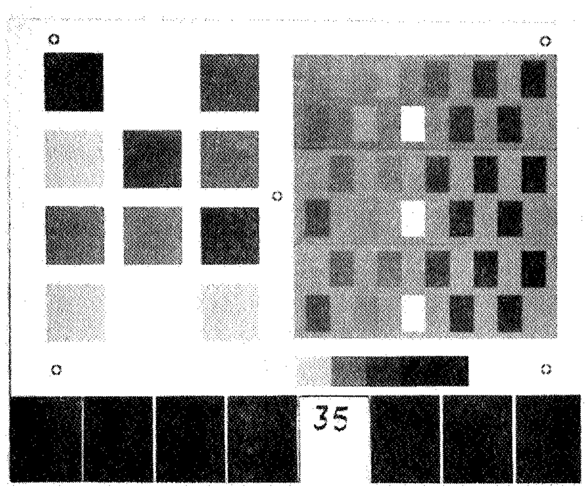
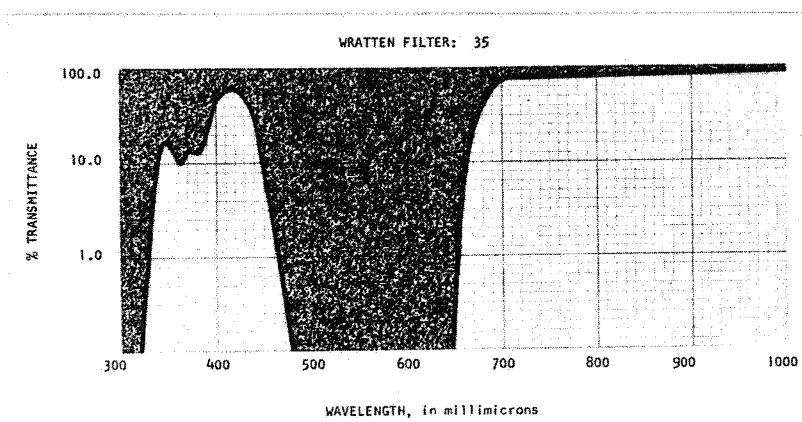
700
800
900
1000
WAVELENGTH, in millimicrons


35


WRATTEN FILTER: 35
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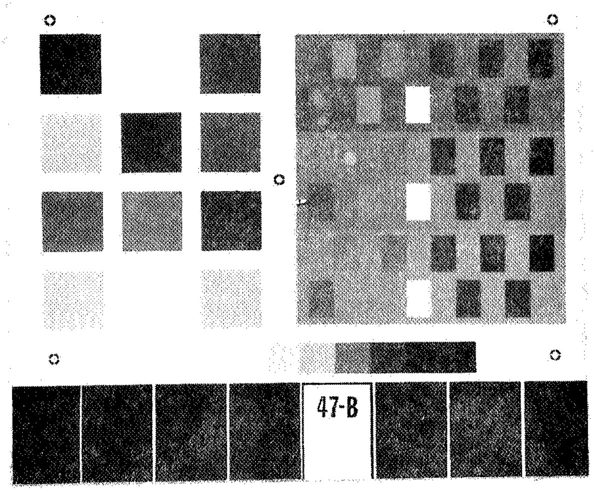
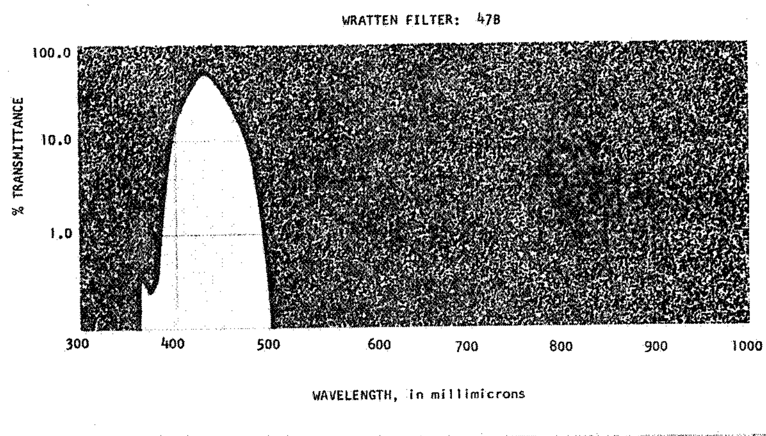
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


47-B


WRATTEN FILTER: 47B
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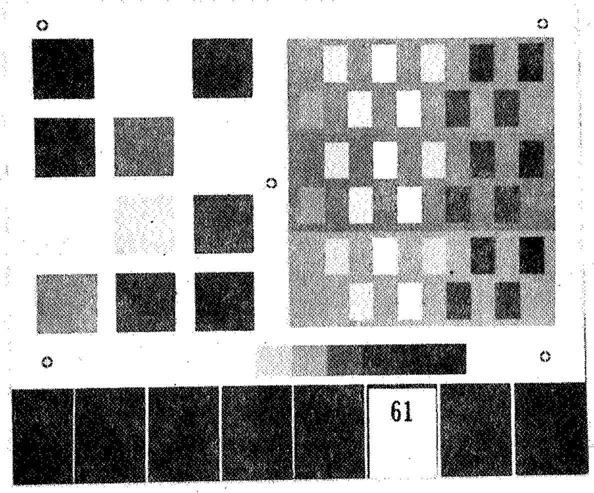
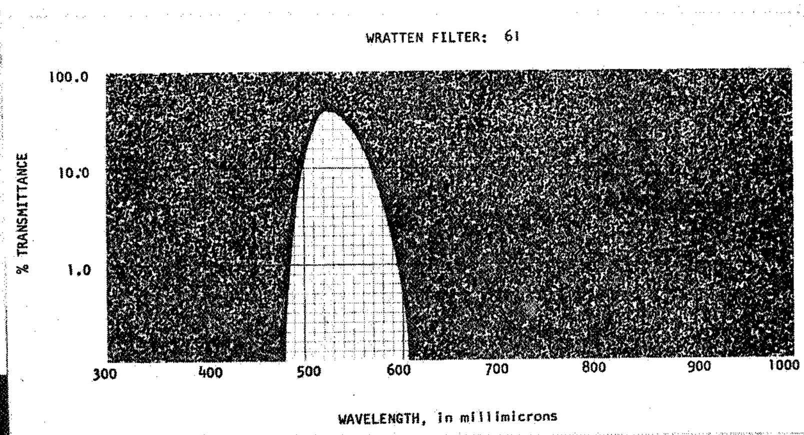
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


61


WRATTEN FILTER: 61
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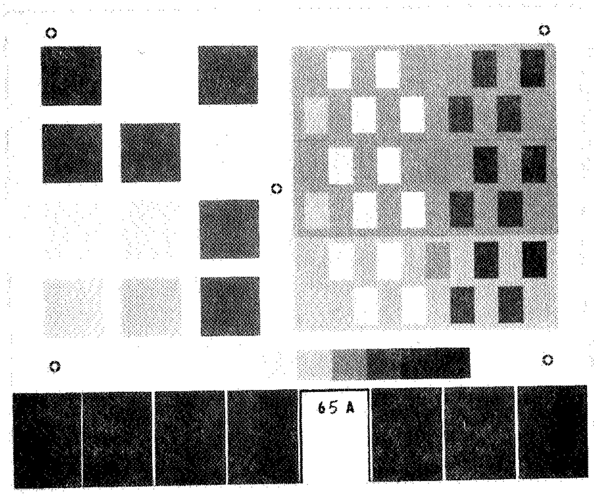
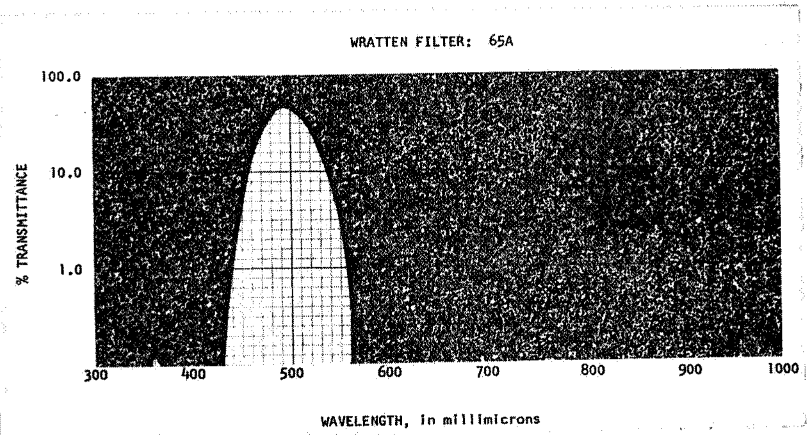
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


65 A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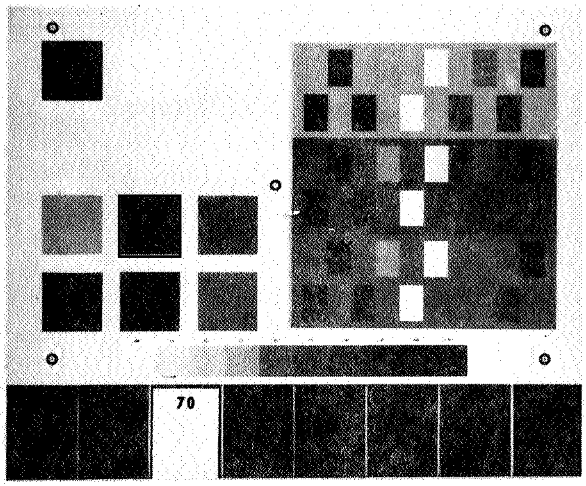
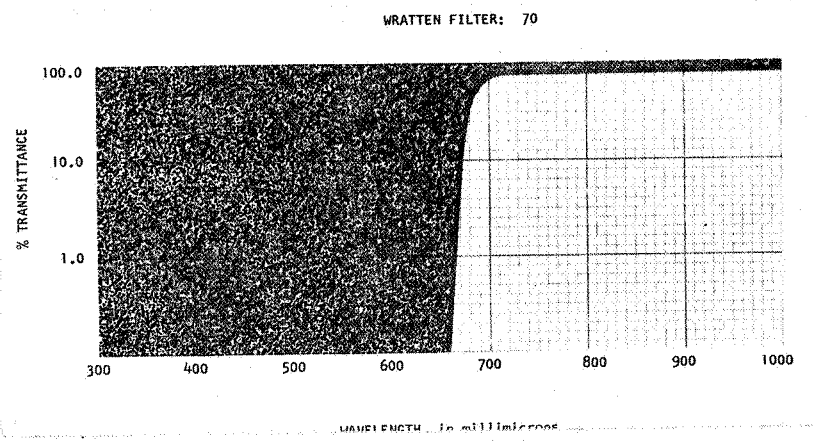
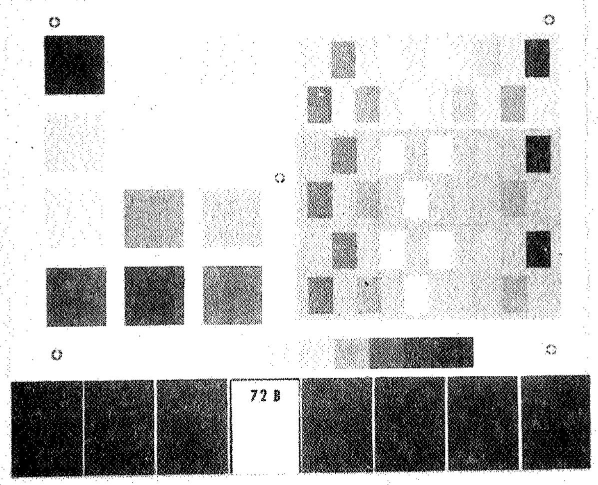
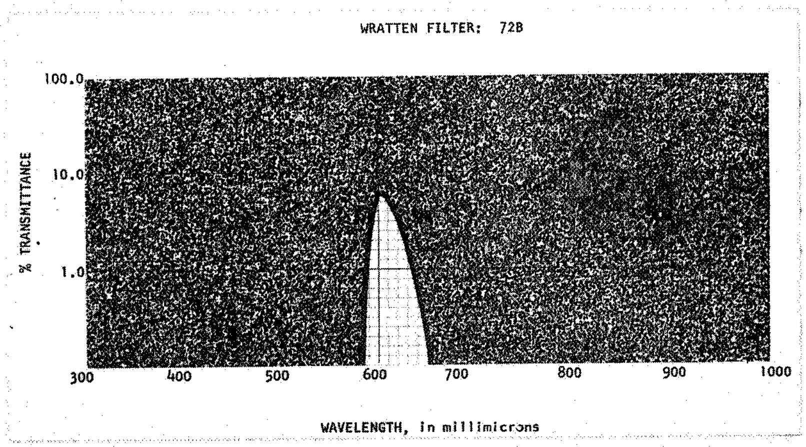
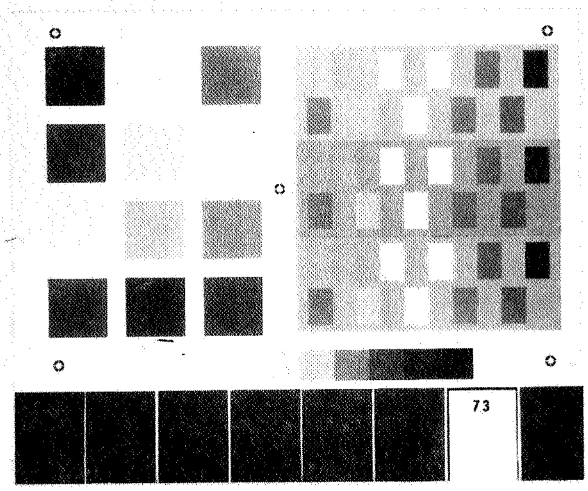
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons

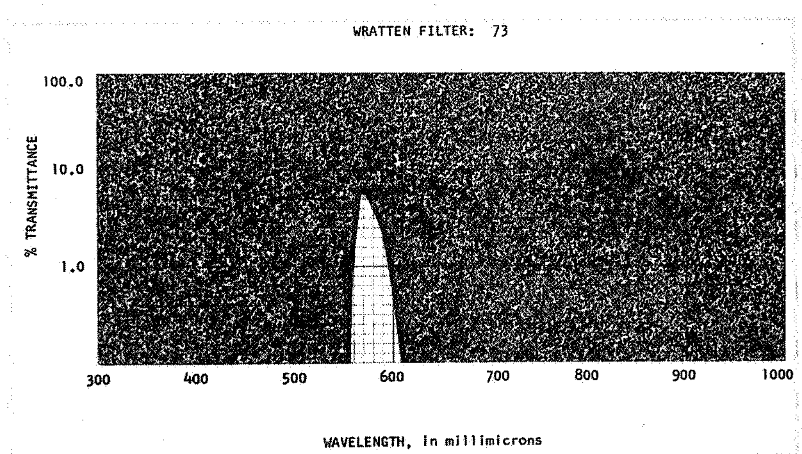

70

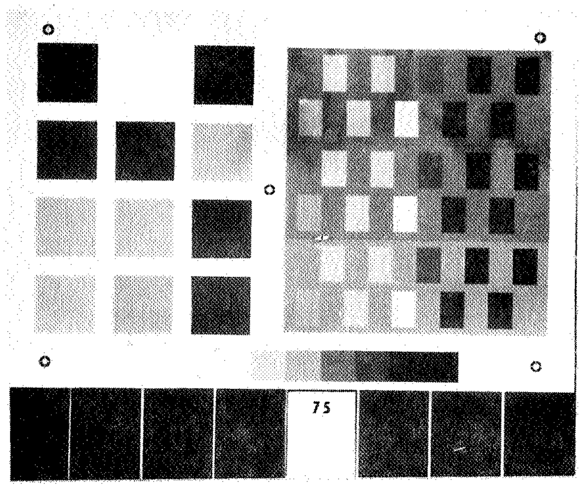

WRATTEN FILTER: 70
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000

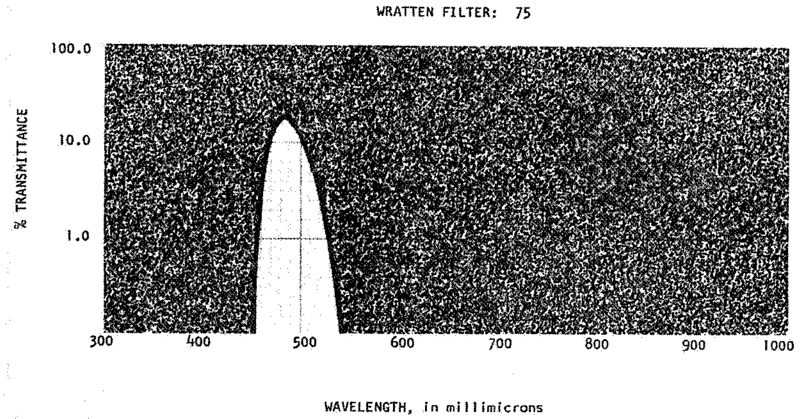

72 B

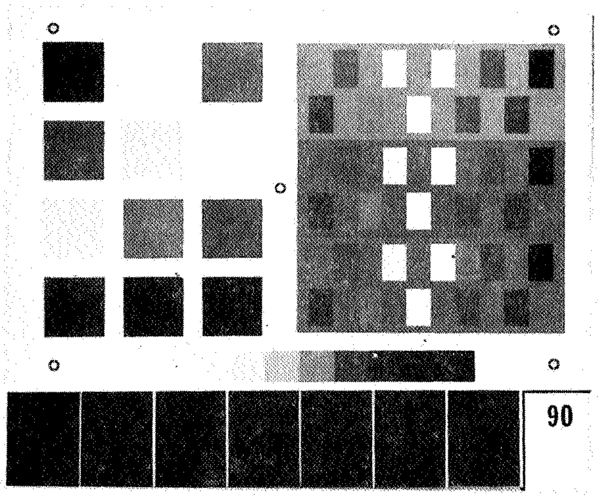

WRATTEN FILTER: 72B
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons

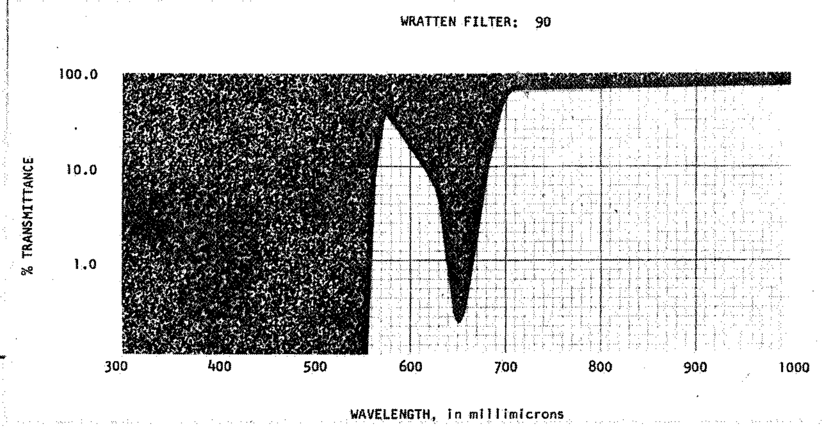

73

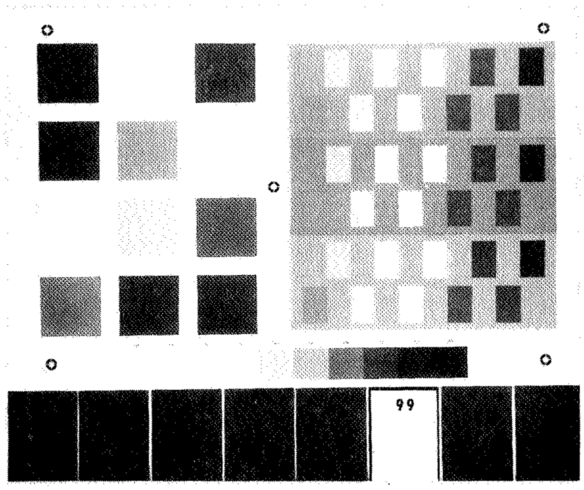

WRATTEN FILTER: 73
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons

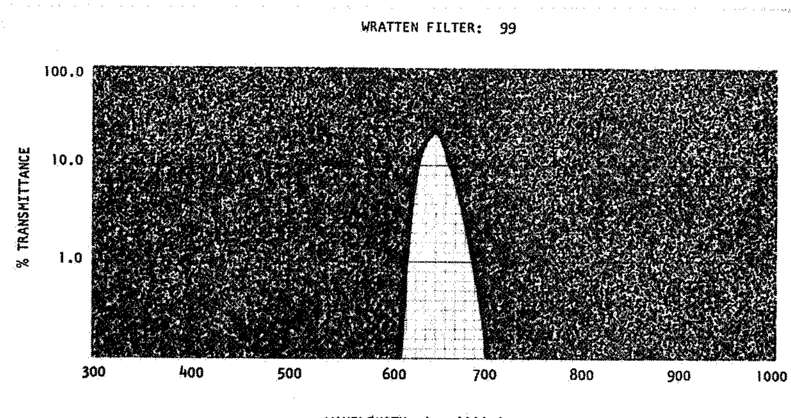

75


WRATTEN FILTER: 75
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


90


WRATTEN FILTER: 90
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons


99


WRATTEN FILTER: 99
100.0
10.0
1.0
% TRANSMITTANCE
300
400
500
600
700
800
900
1000
WAVELENGTH, in millimicrons

are listed in Table 2. The resultant filter array for each has been tabulated to facilitate comparison, percentage-wise,of the densities obtained on a negative that was produced without the use of a filter. It is seen by examining the data in Table, 2, for example, that the Wratten filter #70 (dark red) influences more colors of the spectrum by yielding lighter negative optical densities than any of the other combinations, including the one that employs no filter.

This type of information can be useful for selecting film-filter combinations which would contrast between two targets of visually similar color. For instance, notice, for the red and magenta squares, how the contrasts might be exaggerated by the use of either a Wratten 35 or Wratten 47B filter. The Wratten 35 filter would yield nearly a 50% contrast (magenta darker than red in positive mode) while the Wratten 47B filter would yield greater than 50% contrast for these two colors. The Wratten 61 filter, however, would yield a tone signature barely discernible to the eye. Other similar examples exist and they serve to emphasize the earlier statement concerning the need to know the target reflectance characteristics and the need to properly select the spectral bandwidths that will enhance the tone signatures of objects that are to be identified.

The data exhibited in Table 2 can also be used to determine the spectral bandwidths which yield the greatest number of unique tone signatures for various reconnaissance systems having multiple bandwidth capability. Using the color panel data as an example, a type of analysis which might be performed to determine spectral bandwidths for a multiband system can now be described. As shown in the following paragraphs, this analysis is relatively simple to perform following densitometric measurements. Consistent with our work plan such an analysis is first made for a 2-band system. Then additional bands are considered, up to a total of six.

Two-band reconnaissance system employing black-and-white panchromatic film. Table 2 illustrates contrasting tone signatures for each color square. The two filters yielding maximum contrast, hence the greatest probability that a distinction is possible, are tabulated below for each color. Then, as listed at the bottom of the table, the overall film-filter combination is selected giving the maximum number of unique tone signatures from the list; a choice of filters is indicated where alternatives seem feasible. Filters in the following lists are tabulated with lightest negative density to the left, increasing to the right.

Two-Band Reconnaissance System; Color Panel Array Data

Target	Wratten Filter on Which Target Exhibits Lightest Tone	Wratten Filter on Which Target Exhibits Darkest Tone
Black	70	73
White	70	73
Red	61	25A
Magenta	61	25A
Orange	75	25A/72B
Yellow	35	73
Chartreuse	70	73/99
Green	70	99/65A
Brown	70	73/72B
Turquoise	70	47B
Blue	70	47B
Violet	2C/90	47B

Optimum Film-Filter Combination; Overall: 70-73

Three-band reconnaissance system. The three filters yielding maximum contrast, one from the other, are selected by the two endpoint filters and one filter in the middle of the range, equidistant, percentage-wise, from the other two.

Three-Band Reconnaissance System; Color Panel Array Data

Target	Wratten Filter on Which Target Exhibits Lightest Tone	Wratten Filter on Which Target Exhibits Darkest Tone	Filter Giving Best Intermediate Tone
Black	70	73	12/30
White	70	73	35
Red	61	25A	73
Magenta	61	25A	8
Orange	75	25A/72B	8/70
Yellow	35/47B	73	2C
Chartreuse	70	73/99	30
Green	70	65A	8
Brown	70	73/72B	8/47B
Turquoise	70	47B	73
Blue	70	47B	30/75
Violet	2C/90	47B	65A/73

Optimum Film-Filter Combination; Overall: 70-8-73

Four-band reconnaissance system. The same technique of selection--equidistantly spaced filters as measured from Table 2--gives the following selections.

Four-Band Reconnaissance System; Color Panel Array Data

Target	Wratten Filter on Which Target Exhibits Lightest Tone	Wratten Filter on Which Target Exhibits Darkest Tone	Filters Giving Best Intermediate Tones
Black	70	73	2C/90, 25A/75
White	70	73	2C, 61
Red	61	25A	90, 30
Magenta	61	25A	65A/73, 70
Orange	75	72B/25A	2C, 90
Yellow	35/47B	73	75, 61/65A
Chartreuse	70	73/99	75, 72B
Green	70	65A/99	72B/25A, 75
Brown	70	72B/73	90, 65A
Turquoise	70	47B	30, 61
Blue	70	47B	30, 65A
Violet	2C/90	47B	99, 35

Optimum Film-Filter Combination; Overall: 70-2C/90 - 65A-73

Five-Band Reconnaissance System; Color Panel Array Data

Target	Wratten Filter on Which Target Exhibits Lightest Tone	Wratten Filter on Which Target Exhibits Darkest Tone	Filters Giving Best Intermediate Tones
Black	70	73	2C, 61, 35
White	70	73	2C, 35, 72B
Red	61	25A	35, 8, 70
Magenta	61	25A	2C/90, 12, 35
Orange	75	25A/72B	61, 2C/99, 30
Yellow	35/47B	73	74, 70/2C, 25A
Chartreuse	70	73/99	47B, 30, 25A/12
Green	70	65A	30, 8, 75
Brown	70	73	75, 8/47B, 65A
Turquoise	70	47B	90, 73, 35
Blue	70	47B	61, 75, 35
Violet	2C/90	47B	70, 65A, 35

Optimum Film-Filter Combination; Overall: 70-2C-8-35-73

Six-Band Reconnaissance System; Color Panel Array

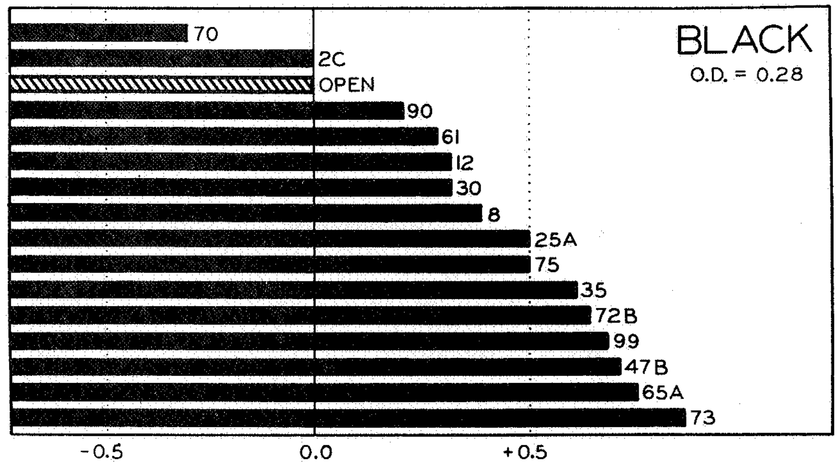
Target	Wratten Filter on Which Target Exhibits Lightest Tone	Wratten Filter on Which Target Exhibits Darkest Tone	Filters Giving Best Intermediate Tones
Black	70	73	2C, 90, 8, 72B/35
White	70	73	2C, 8/30/90, 12/61/75/35
Red	61	25A	65A, 73, 30, 72B
Magenta	61	25A	99, 8, 30, 72B
Orange	75	72B/25A	61, 99, 70/8, 30
Yellow	35	73	75, 70, 8/30, 25A
Chartreuse	70	73/99	47B, 75, 8/90, 65A
Green	70	65A	30, 35, 47B, 73
Brown	70	72B	61, 90, 30/99, 25A
Turquoise	70	47B	90, 12, 61, 75
Blue	70	47	2C, 30, 75, 35
Violet	2C/90	47B	8, 99/25A, 30/75, 65A/73

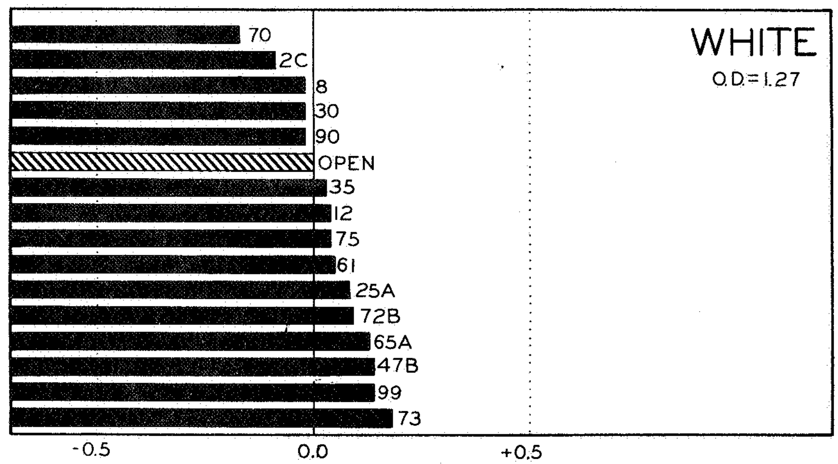
Optimum Film-Filter Combination; 70-2C-90-30-72B-73

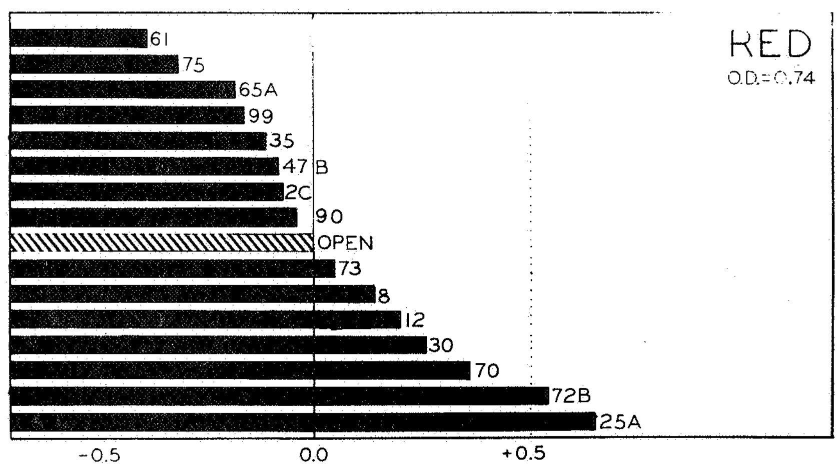
It is not so simple when the analysis of tone signatures is applied to natural terrain features since several complicating factors prevail. One such factor would be attempting to distinguish between objects having very subtle color differences. In the controlled color panel array example, twelve very distinct color values were used. In a natural scene, however, there may be many targets for which positive identification would be desired though they possess only subtle color differences. A forested area of different tree types would be such an example. The variability of subtle color changes coupled with the variability of exposure and densitometer readings only serves to reduce the chance for positive identifications. That is, the tone signature becomes obscured or poorly defined. One has to be careful about the degree of interpretability desired versus the degree of remote sensing attempted. It is probable that in many instances, narrower band filters would tend to reduce the variability mentioned above and help define tone signatures.

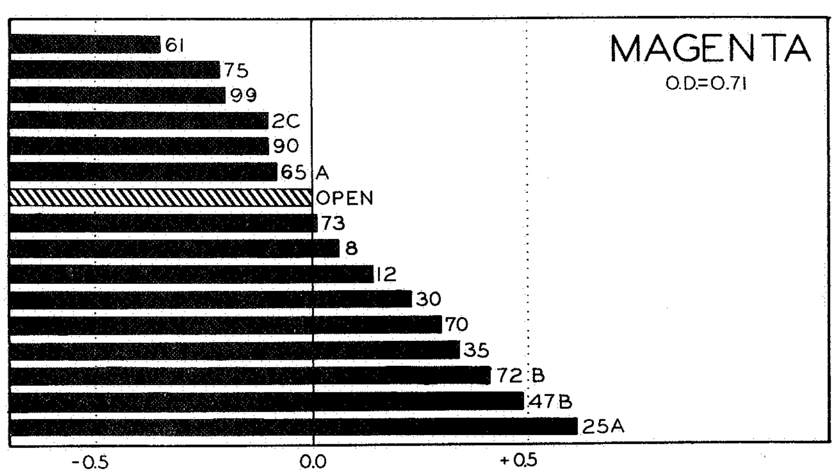
Table 2

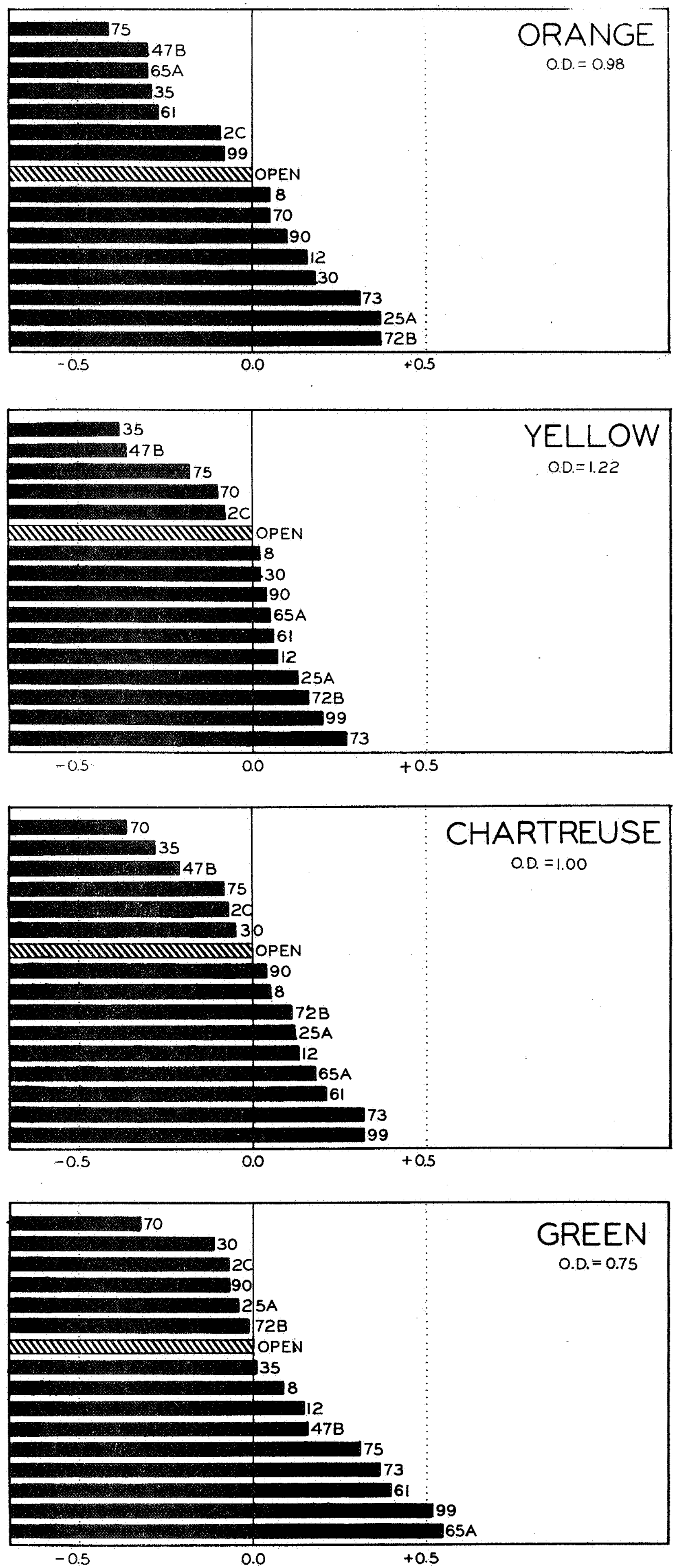
On the following three pages are listed the comparative data--by color panel square--of the fifteen Wratten gelatin filters used in this study. Each histogram relates the negative optical densities of each filter to that from an exposure obtained without a filter ("OPEN"). Hence, for each color square is listed an array of the filter numbers, <u>increasing</u> in negative optical density to the right. The absolute negative optical density for the "OPEN" exposure is listed in the upper right hand corner beneath each color chip label.


BLACK
O.D. = 0.28
70
2C
OPEN
90
61
12
30
8
25A
75
35
72B
99
47B
65A
73
-0.5
0.0
+0.5

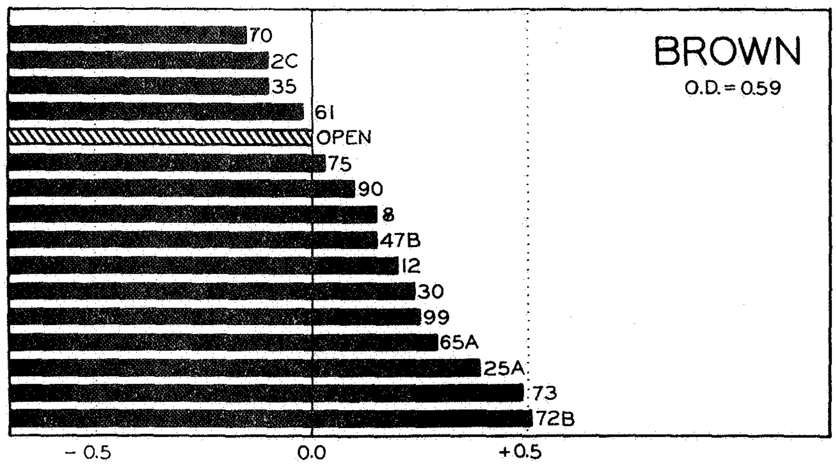

WHITE
O.D.=1.27
70
2C
8
30
90
OPEN
35
12
75
61
25A
72B
65A
47B
99
73
-0.5
0.0
+0.5

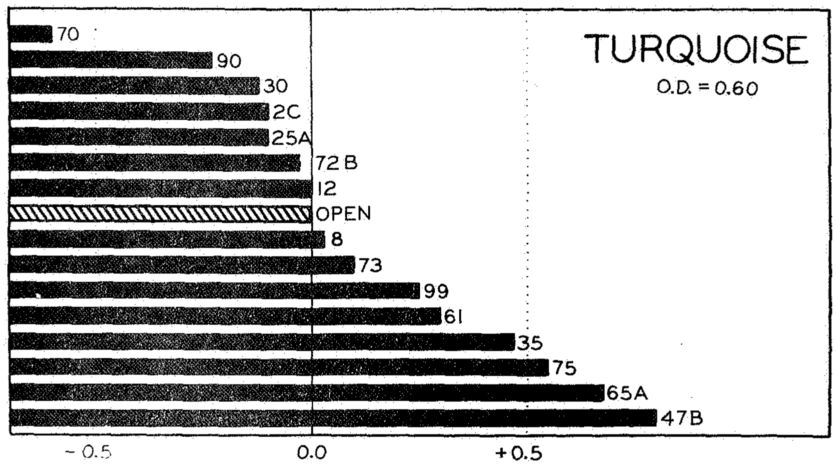

RED
61
75
65A
99
35
47B
2C
90
OPEN
73
8
12
30
70
72B
25A
-0.5
0.0
+0.5

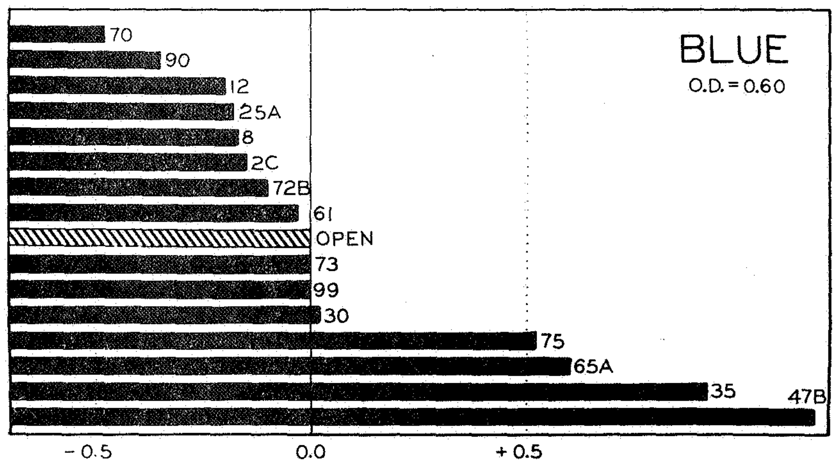

MAGENTA
O.D.=0.71
61
75
99
2C
90
65A
OPEN
73
8
12
30
70
35
72B
47B
25A
-0.5
0.0
+0.5

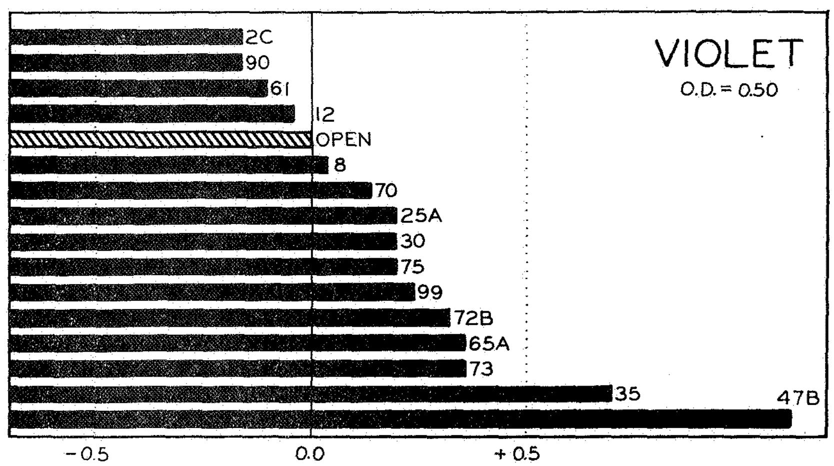


ORANGE
O.D. = 0.98
75
47B
65A
35
61
2C
99
OPEN
8
70
90
12
30
73
25A
72B
-0.5
0.0
+0.5
YELLOW
O.D.= 1.22
35
47B
75
70
2C
OPEN
8
30
90
65A
61
12
25A
72B
99
73
-0.5
0.0
+0.5
CHARTREUSE
O.D. = 1.00
70
35
47B
75
2C
30
OPEN
90
8
72B
25A
12
65A
61
73
99
-0.5
0.0
+0.5
GREEN
O.D.= 0.75
70
30
2C
90
25A
72B
OPEN
35
8
12
47B
75
73
61
99
65A
-0.5
0.0
+0.5


BROWN
O.D. = 0.59
70
2C
35
61
OPEN
75
90
8
47B
12
30
99
65A
25A
73
72B
- 0.5
0.0
+ 0.5


TURQUOISE
O.D. = 0.60
70
90
30
2C
25A
72 B
12
OPEN
8
73
99
61
35
75
65A
47B
- 0.5
0.0
+ 0.5


BLUE
O.D. = 0.60
70
90
12
25A
8
2C
72B
61
OPEN
73
99
30
75
65A
35
47B
- 0.5
0.0
+ 0.5


VIOLET
O.D. = 0.50
2C
90
61
12
OPEN
8
70
25A
30
75
99
72B
65A
73
35
47B
- 0.5
0.0
+ 0.5

C. Image Enhancement by Color Additive Techniques

When several black-and-white aerial photos have been obtained of the same area, each in a different spectral band, the photo interpreter may find it highly advantageous to combine these photos by projecting them on a screen in common registration. By so doing, he can employ a separate filter color for the projection of each photo. Then, when viewing the composite color image, he can use color as an aid to object identification. It should be noted that such color additive techniques and tone signature analyses are intimately related and are appropriately discussed in this report in terms of facilitating the interpretative task of the image analyst.

Figure 6 shows a basic color additive experiment whereby three light beams--each projected through a different colored filter--are partially overlapped to reveal color addition combinations.

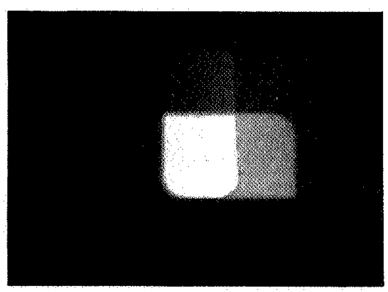


Figure 6. Color addition experiment using three overlapped colored light beams. By means of three projectors, the three light beams were simultaneously projected through red, green and blue filters, respectively, onto a screen. They were allowed to overlap and blend with each other, as the illustration shows. The overlapped areas exhibit different hues, due to the phenomenon of color addition: red with green produces yellow, red with blue produces magenta and green with blue produces cyan. Where all three of the light beams overlap, white light is produced. Similarly, as the illustration clearly shows, yellow light and cyan light produce white when overlapped, as does yellow with magenta and cyan with magenta.

This simplified experiment, when related to the previously mentioned concept of tone signature analysis, provides the basis for introducing a color variable into the regime of black-and-white photographic interpretation. As might be inferred from Figure 6, the interpreter need not be confined to any given combination of colors, as he would be if he depended on the standard available color film emulsions. "False color" renditions, some of which provide very useful color enhancements, merely require the use of different colored light filters. False color film emulsions, on the other hand, are difficult to manufacture, expensive to purchase, inherently hard to handle and process and almost completely inflexible in terms of the colors with which they are able to present various objects and conditions to the photo interpreter.

The color additive method for image enhancement employed by the principal investigators was performed using equipment already at their disposal. Up to six lantern slide projectors for $3\frac{1}{4}$" x 4" slides were mounted in tandem in such a way that "color wheels" containing an assortment of Wratten filters could be attached in front of each projector. Multiple images of the same scene, obtained in each of several parts of the electromagnetic spectrum, were then made into lantern slide positive transparencies and projected in common register onto a translucent rear viewing screen. A translucent screen was used to facilitate both the viewing of composite color images and the photographing of them. The latter was done for the purpose of illustrating examples of particular interest, as in this report. Once the images (up to six) had been projected in common register onto the screen, it was a simple matter to dial in the desired colored filter for each image. Where necessary, the filters in any of the wheels could be changed to produce other color renditions.

The number of possible color combinations is almost limitless when a wide variety of filters is available through which to project the black-and-white lantern slide transparencies. The principle investigators selected fifteen such filters to cover representative portions of the entire visible spectrum. These same filters were the ones used in photographing the color panel array in Table 1.

Figure 7 is a chromaticity diagram for a standard source tungsten

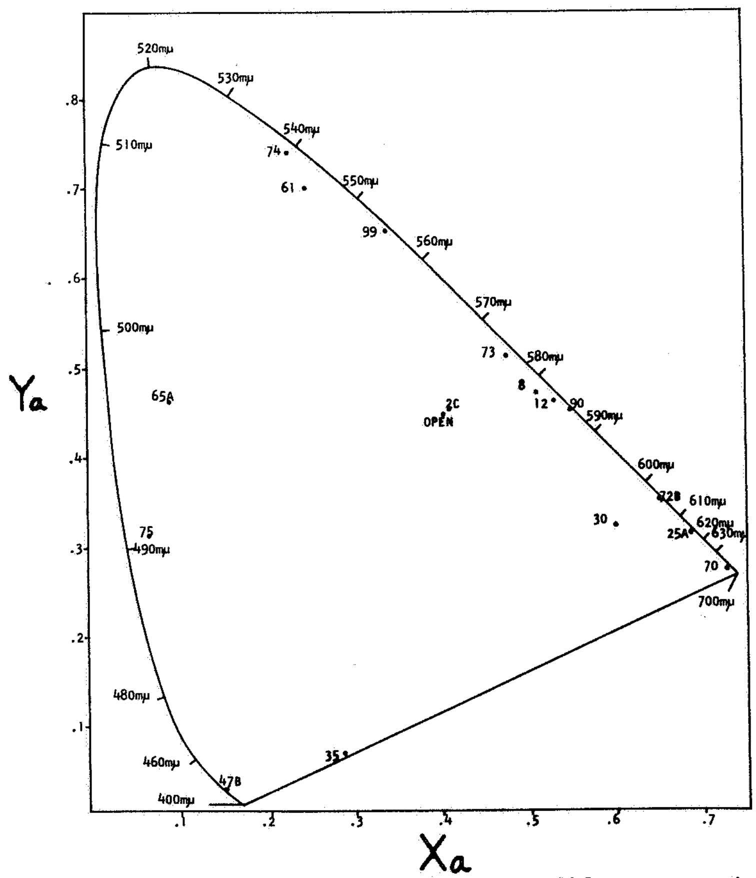


Figure 7. Chromaticity diagram of fifteen filters used in this study. The "OPEN" coordinate has a color temperature of 2854° K, equivalent to the tungsten light source of each $3\frac{1}{4}$" x 4" lantern slide projector. The color coordinate for Wratten 73, as seen above, is $y_a = 0.5134$ and $x_a = 0.4853$.

light of the type used in projecting the slide transparencies. In this diagram are listed the Wratten filters used in this study and their "x" and "y" coordinates. The "OPEN" designation denotes no filter; the fifteen filters were selected on the basis of stability and transmittance characteristics, as shown in Table 1.

In order to demonstrate the versatility of this technique as an aid to interpretation, an attempt was made to reproduce as closely as possible the "true color" rendition of Figure 4 (color panel array) by the color additive process. The result of this experiment is shown in Figure 8. When viewed directly on the screen, this composite color image had great brilliance and color fidelity and all colors could be distinguished with great ease. However, the principal investigators and several other people have agreed that the photo illustration, as reproduced in this report, does not do justice to the original composite image that was projected, even though this Figure compares adequately with Figure 4. Apparently there is greater color saturation in the image that is exhibited on the viewing screen than can be reproduced in a color photo of it.

As seen in the following illustration, the ability to combine the various optical densities of the four lantern slides into <u>one</u> image with the addition of color greatly improves its interpretability over the four respective black-and-white illustrations seen in Table 1. Whereas the normal human eye can perceive approximately two hundred shades of grey, this capability is extended, according to Crowell (Opt. Soc. of Am., 1953), to more than seven million <u>color differences</u> which can be perceived. This obviously gives the image analyst much greater flexibility and ease of interpretation when using color as an aid to his task.

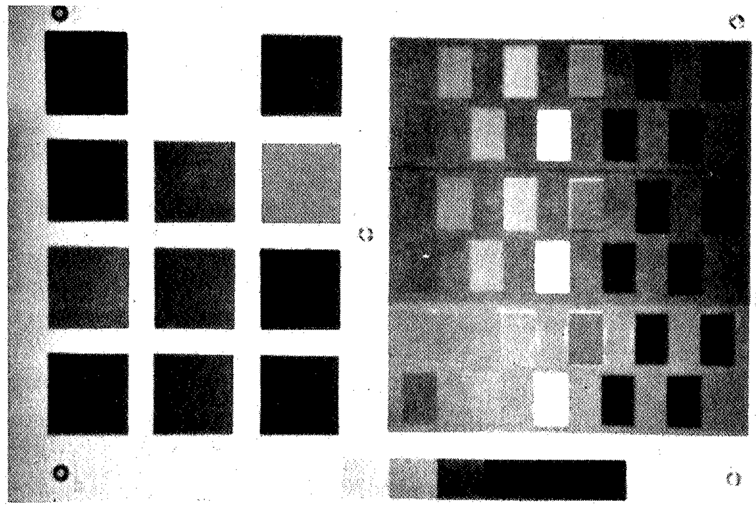


Figure 8. Color enhanced illustration of color panel array. This illustration is the result of an experiment designed to reproduce, by color additive techniques, the "true" colors of the target shown in Figure 4. This particular photograph was obtained by projecting four black-and-white lantern slides. The filters through which the lantern slide images were taken, as well as the filters through which they were projected, are as follows:

Slide No.	Film-Filter Combination Used in Obtaining the Black-and-White Image	Wratten Filter Through Which the Image Was Projected
1	Pan-No Filter	#12 (yellow)
2	Pan-25A	#25A (red)
3	Pan-47B	#47B (blue)
4	Pan-65A	#61 (green)

Figure 9 shows more of the color additive process whereby light beams of various hues and saturations are allowed to overlap forming new resultant colors. When black-and-white lantern slides of various densities are interposed between light source and color filter, these color beams undergo changes in saturation and brightness which alter the appearance and interpretability of the resultant composite color image.

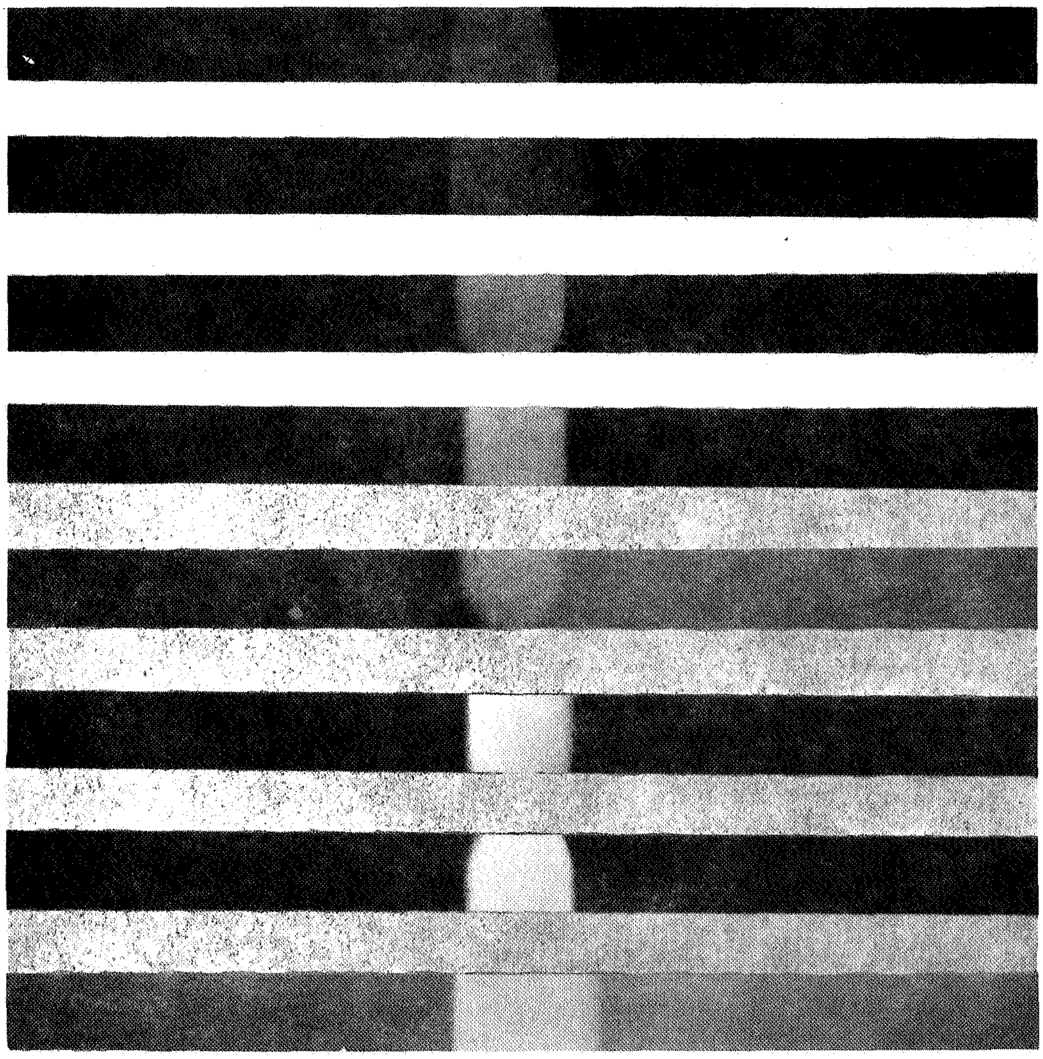
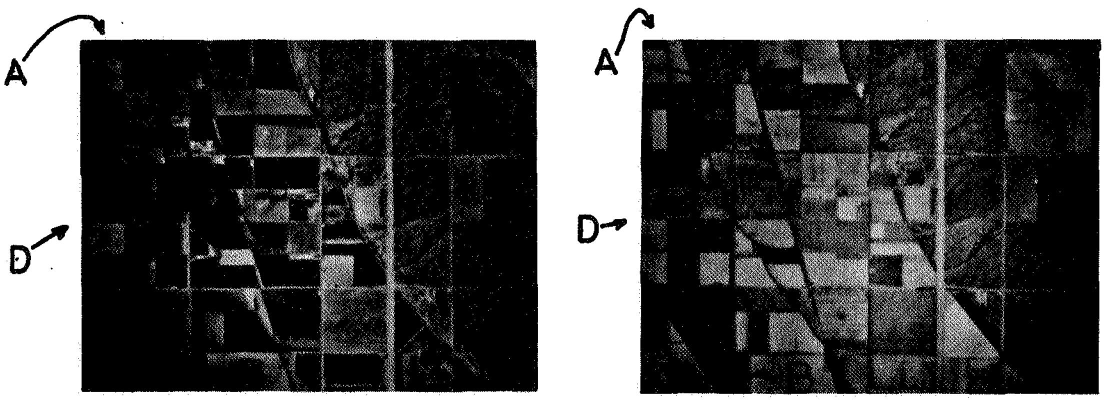


Figure 9. The colors appearing in the central portions of the above strips were obtained by overlapping light beams projected through various pairs of Wratten filters, without density interference. From top to bottom the filter pairs are as follows:

Pair No.	Left Filter	Right Filter	Resultant Color
1	Wratten 61 (green)	Wratten 25A (red)	Yellow
2	" 47B (blue)	" 25A (red)	Magenta
3	" 61 (green)	" 47B (blue)	Cyan
4	" 73 (green)	" 47B (blue)	Cyan
5	" 73 (green)	" 65A (blue)	Cyan
6	" 73 (green)	" 30 (magenta)	White
7	" 61 (green)	" 30 (magenta)	White
8	" 65A (blue)	" 30 (magenta)	White

An example of the employment of this technique in providing more interpretable imagery from multiband black-and-white aerial photographs appears in Figure 10 and 11. Those figures illustrate the extent to which enhancement can be obtained when using only two photographic bands. The area shown is near Tucson, Arizona. It was selected by the Color Committee of the American Society of Photogrammetry as one in which to conduct a color evaluation experiment in June, 1966.

In order to facilitate the separation of vegetated from non-vegetated areas, two black-and-white films were used, a black-and-white panchromatic film and a black-and-white infrared-sensitive film (see Fig. 10 below). Use of these two films, properly filtered during exposure, produced wide tone contrasts between the vegetated and non-vegetated areas, as shown below:



(a) Panchromatic 25A (b) Infrared 89B

Figure 10. Two properly filtered photographic bands for use in differentiating vegetated from non-vegetated areas. The Panchromatic 25A film-filter combination on the left yields <u>dark</u> tones where healthy green vegetation exists (refer to the "Green" histogram of Table 2). Not all dark tones in that photo denote healthy green vegetation, however, (See, for example, areas "A" and "B"). The Infrared 89B photo on the right similarly yields <u>light</u> tones where healthy vegetation exists, but again, not all light tones denote healthy vegetation. (See, for example, areas "C" and "D"). However, where there is both a dark tone on the panchromatic photo and a light tone on the infrared photo, healthy vegetation almost certainly exists. Light tones on <u>both</u> photos probably are indicative of fallow fields and roadways. It is fairly easy for an interpreter to scan back and forth between these photos and, by noting tone values on each, locate the areas of healthy vegetation. For objects which have more complicated tone signatures, however, a larger number of multiband images is required and the photo interpreter's task becomes much more difficult, frustrating and time consuming. It is in such instances that the color enhancement techniques described in the text can be of great benefit to the photo interpreter.

Figure 11. Some color enhanced composites of the two photographic bands which were illustrated in Figure 10. These examples are presented to demonstrate various color renditions which combine the information found in both photos of Figure 10. Note that, in each of these examples, the dominant color of the living vegetation is determined by the Wratten filter through which the Infrared 89B slide is projected, owing to the relatively light tones exhibited by live, green vegetation; the complementary Wratten color filter (through which the Panchromatic 25A slide is projected) is suppressed by those areas where darker tones are exhibited by the same healthy vegetation. Thus, the living vegetation is made to exhibit a unique color, and such areas are readily differentiated from other areas with which they might have been confused (e.g., areas "A" thru "D"). It sometimes is a matter of personal preference as to which might be the best rendition for interpretation. The following pairs of filters were used to produce these color photo illustrations from top to bottom:

Composite Color Photo Number	Wratten Filter Through Which Pan 25A Slide Was Projected	Wratten Filter Through Which IR 89B Slide Was Projected
1	#12 (yellow)	#50 (dark blue)
2	# 12 (yellow)	#65A (light blue)
3	#12 (yellow)	#61 (green)
4	#12 (yellow)	#25A (red)
5	#65A (light blue)	#25A (red)

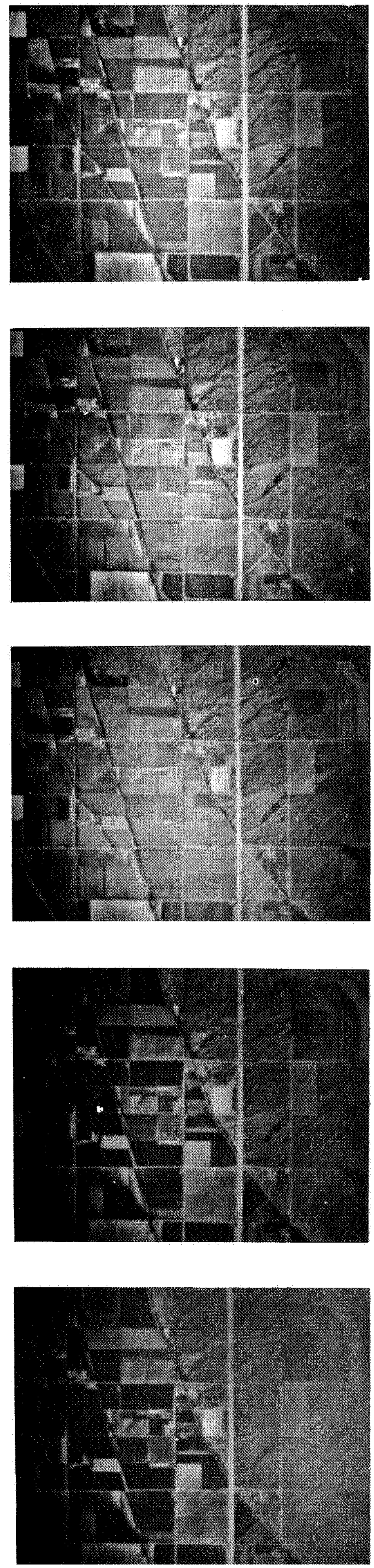
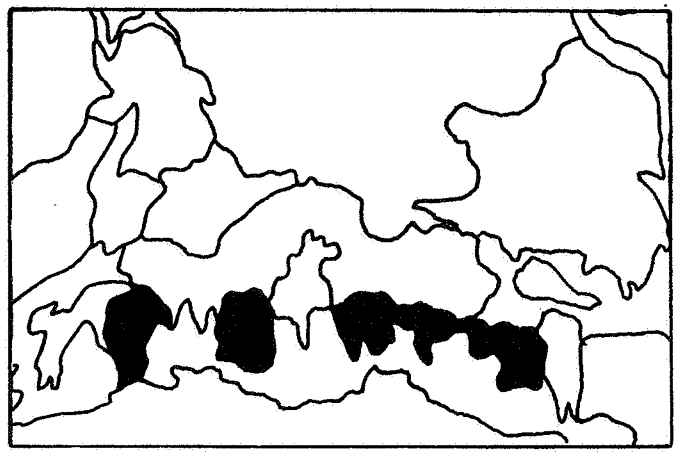


Figure 12. Color enhanced illustration of multispectral data. The above illustrations were obtained by superimposing in common registration several channels of imagery through selected Wratten filters. The lower illustration is "delineated" to aid in its interpretation by using color differences seen in the composite rendition. The following interpretations can be made with the aid of ground truth information:

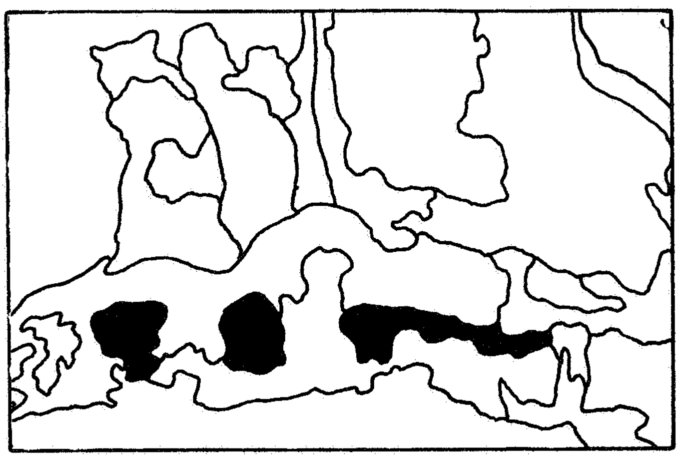
1. Light blue areas: low <u>sagebrush</u> type.
2. Green areas: wet <u>meadow</u> type dominated by rushes (<u>Juncus</u> <u>sp</u>.)
3. Red-orange areas: wet <u>meadow</u> sites dominated by sedges, gr grasses and forbs; very high in IR reflectance.
4. Dark brown areas: standing water from adjacent springs.

Densitometric Interpretation of Line Scan Imagery

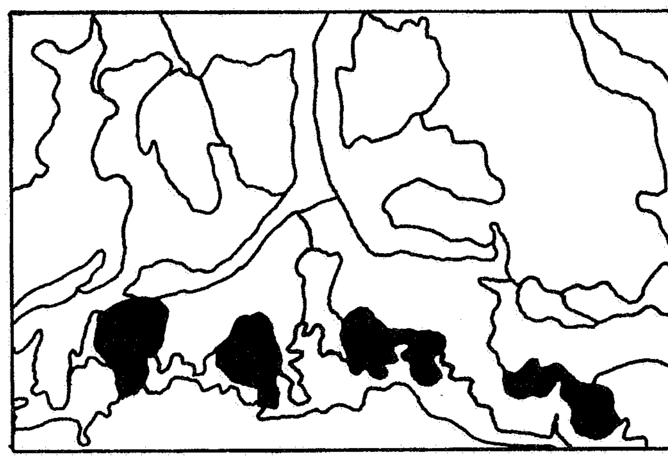
The following five diagrams are derived from optical mechanical scanner imagery. Each diagram is "stratified" according to densitometric measurements made of the strip film negative for the indicated channels of data. The optical mechanical scanner approach to multispectral imagery provides many channels (or spectral bandwidths) with which tone signatures might be related directly to recorded energy levels. The darkened areas in each diagram enable comparisons with the color enhanced composites appearing on the preceding page.



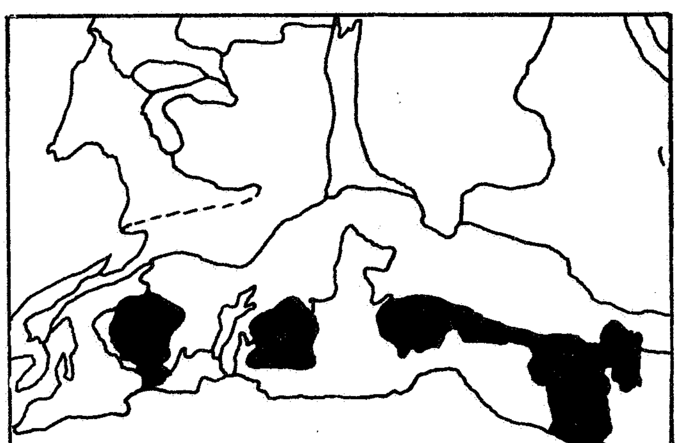
0.32 - 0.38 microns



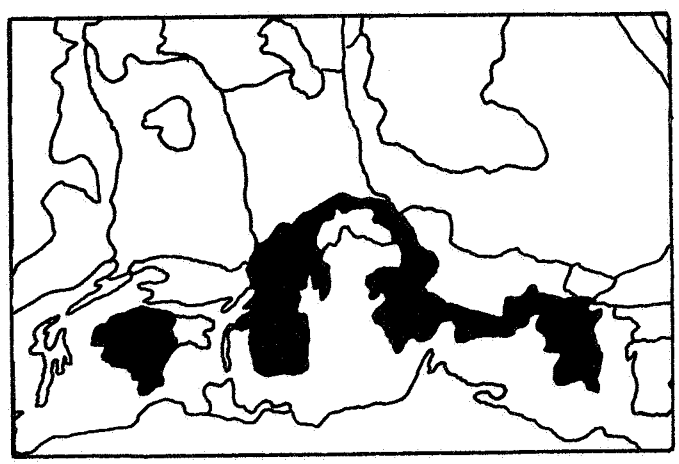
0.62 - 0.68 microns



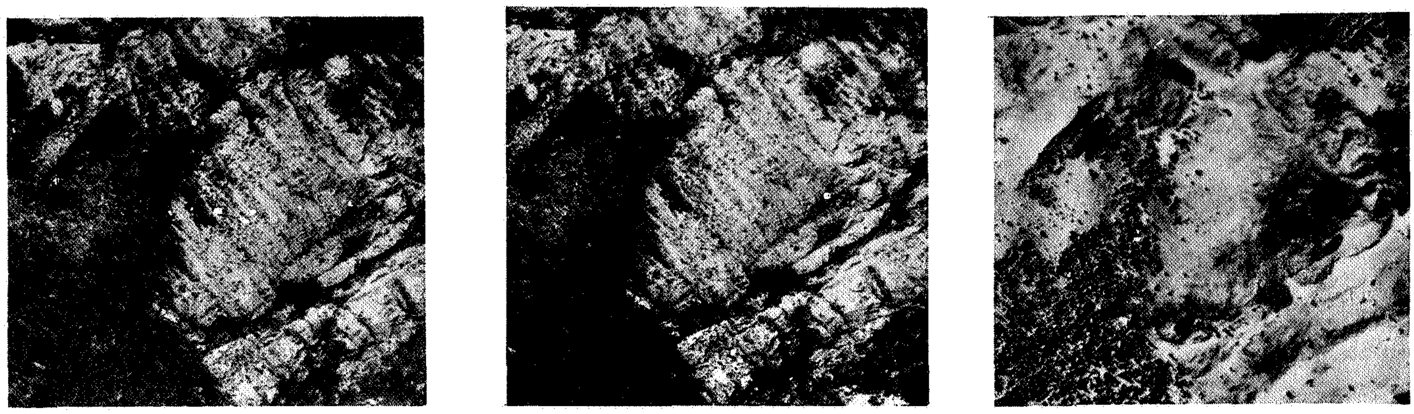
0.80 - 1.0 microns



1.5 - 1.8 microns

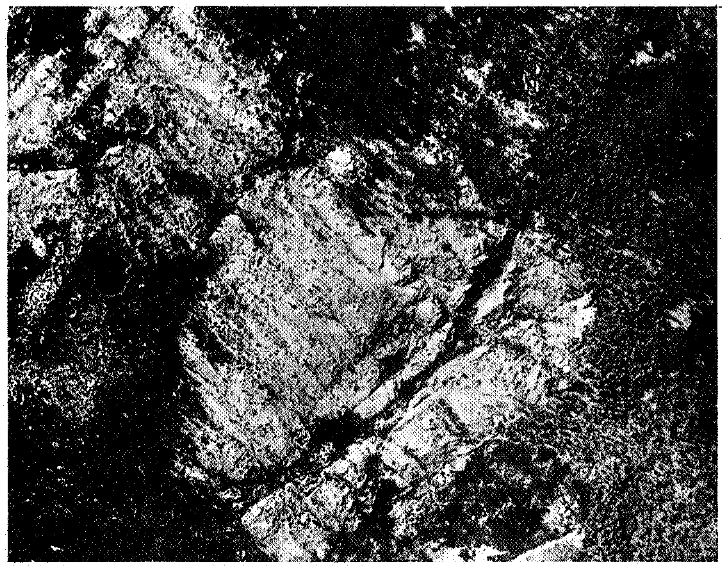


8.0 - 14.0 microns

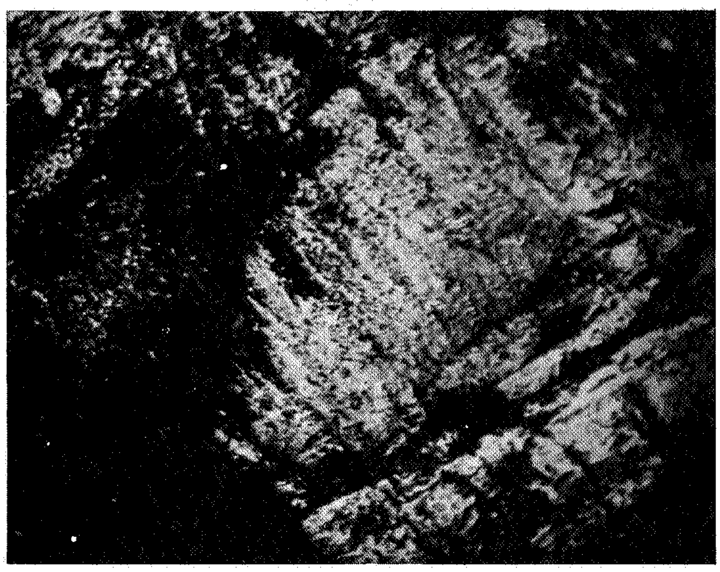


Panchromatic (.52-.58 u)　　Panchromatic (.66-.72 u)　　Infrared (.75-.95 u)

Figure 13. Multispectral photography of natural terrain features in the Bucks Lake Test Site. The above representative illustrations were reproduced from three narrow-filter photographic examples (see bandwidths above), simultaneously exposed, using a sixteen-lens camera. These particular illustrations were then made into positive lantern slide transparencies and projected in common register thru colored filters to produce the color composite seen in Figure 14. The ability to obtain multispectral photography and other imagery having identical geometric relationships greatly facilitates the color enhancing procedure. Multi-lens cameras provide this capability for film emulsions, such as the two film types seen above (i.e., Panchromatic and Infrared).



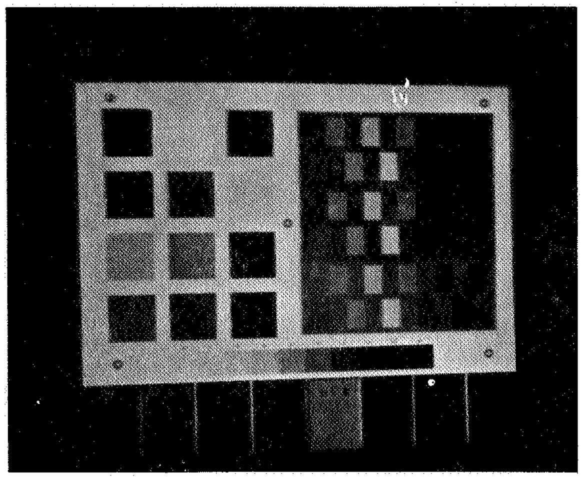
Ekta Aero Infrared



Color Composite

Figure 14. The upper photo shows standard false-color photography taken with Infrared Ektachrome film and a Wratten 12 filter. The lower photo is a color-enhanced illustration derived from the three black-and-white multispectral photographs seen in Figure 13. The following combination of colored filters was used in producing the lower photo:

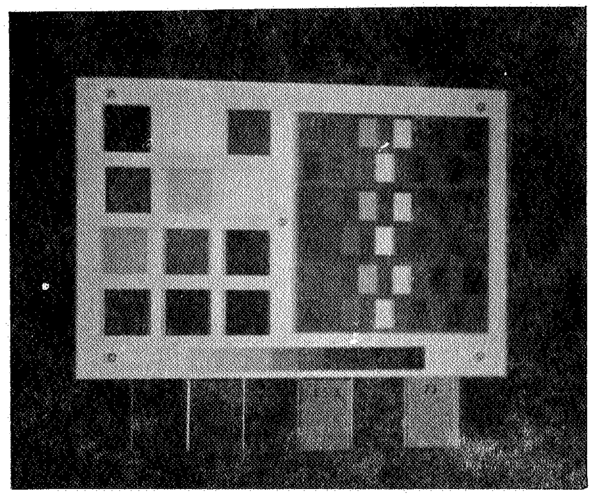
Slide Number	Exposure Bandwidth	Projection Filter
1	Panchromatic (.52-.58 u)	65A (light blue)
2	Panchromatic (.66-.72 u)	99 (green)
3	Infrared (.75-.95 u)	25A (red)



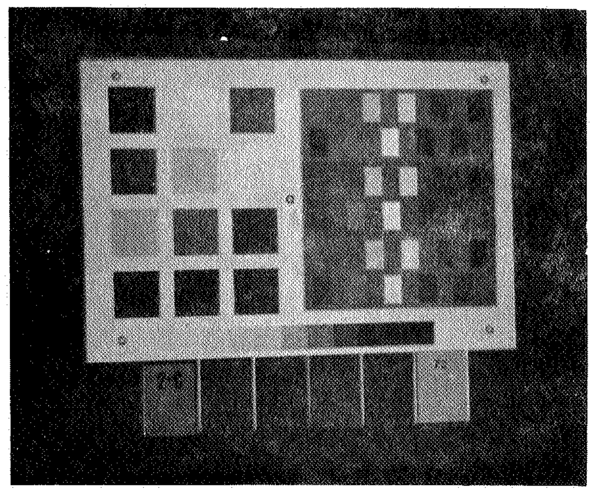
Slide Number	Exposure Filter	Projection Filter
1	2C	47B (blue)
2	65A	12 (yellow)
3	73	25A (red)

Figure 13. "False color" renditions of color panel array. The above illustration is obtained by color enhancement techniques using three different lantern slide transparencies. The particular sequence of slides used in this experiment comprises three of the four film-filter combinations suggested as optimum for a 4-band reconnaissance system (see page 22). It can be seen by comparing the above illustration with the color composites appearing on the following two pages (each example of which includes all four of the film-filter combinations suggested on page 22), that greater color separations are obtained when maximum contrasting slides are used. The above illustration was produced without including the transparency made from the Panchromatic-Wratten 70 film-filter combination.

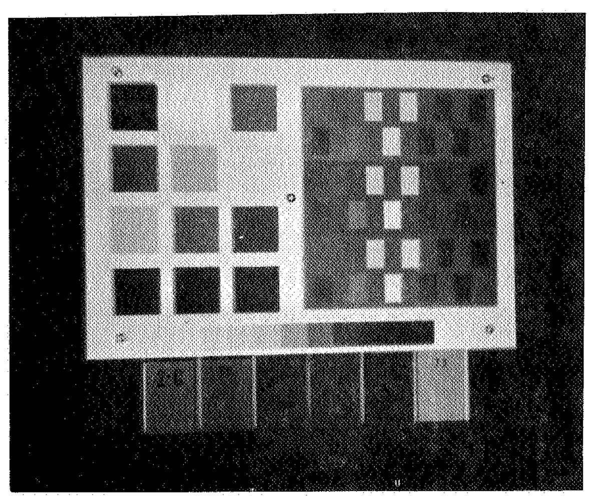
Slide Number	Exposure Filter	Projection Filter
1	2C	25A (red)
2	70	47B (blue)
3	65A	73 (olive)
4	72	61 (green)



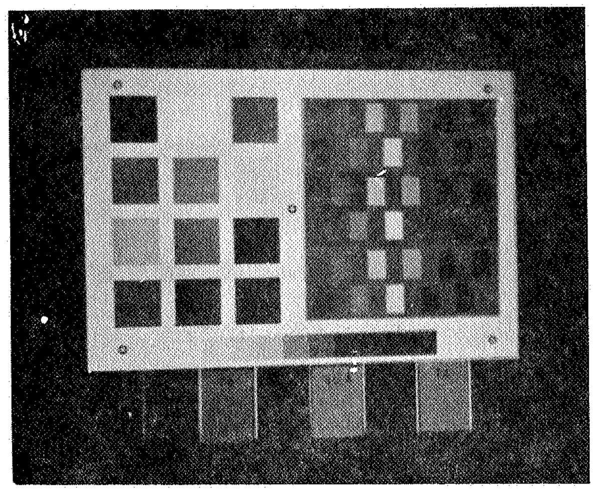
1	2C	73 (olive)
2	70	47B (blue)
3	65A	25A (red)
4	73	61 (green)



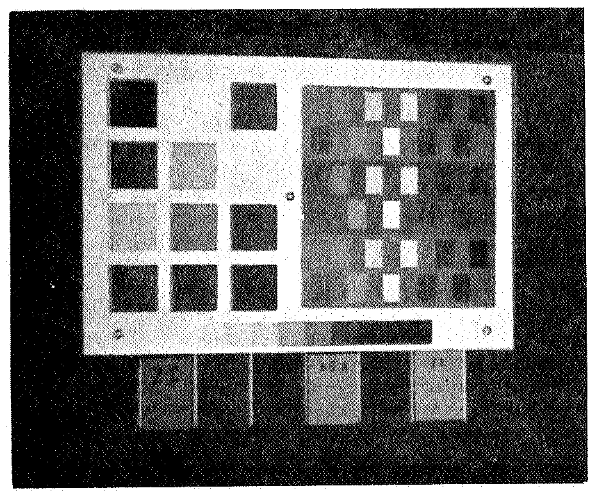
1	2C	47B (blue)
2	70	99 (green)
3	65A	25A (red)
4	73	12 (yellow)



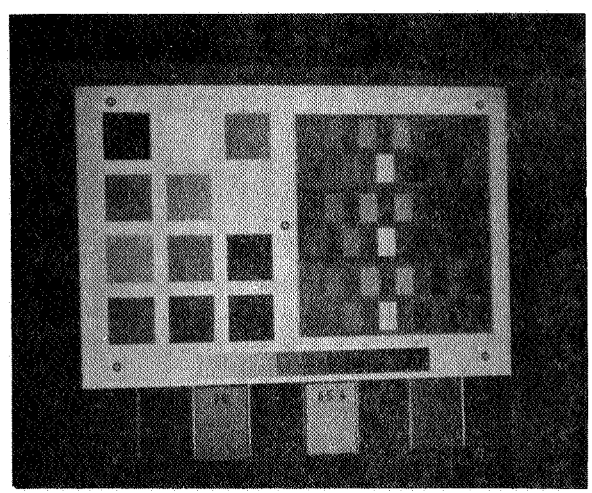
Slide Number	Exposure Filter	Projection Filter
1	2C	72B (dark orange)
2	70	61 (green)
3	65A	47B (blue)
4	73	90 (gold)

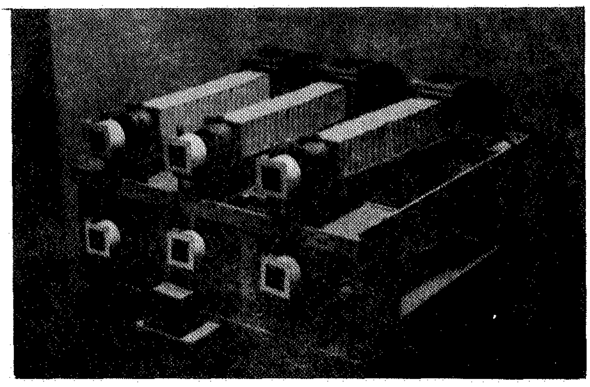


1	2C	35 (violet)
2	70	25A (red)
3	65A	90 (gold)
4	73	61 (green)



1	2C	73B (dark orange)
2	70	65A (light blue)
3	65A	90 (gold)
4	73	73 (olive)





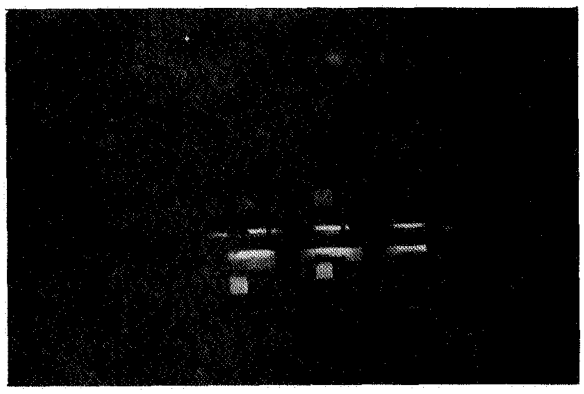


Figure 16. Color enhancement projection system, showing 26" focal length projectors (upper photo) and the same projectors in operation with various colored filters (lower photo). Up to six projectors may be used to project black-and-white multispectral images that have been made into $3\frac{1}{4}$ X 4 inch lantern slide transparencies. All color enhanced examples used in this report were obtained by photographing the resultant color composite through a translucent viewing screen in order to illustrate useful applications of this technique.

THERMOGRAMS OF YOSEMITE TEST AREA ILLUSTRATING VARYING TONE SIGNATURE DUE TO IMAGING AT VARIOUS TIMES OF DAY

Figure 17. Photo (1), taken at 1830 hours, is a thermogram filtered to image in the 3.5 - 5.5 micron range; it clearly shows campfires as bright spots.

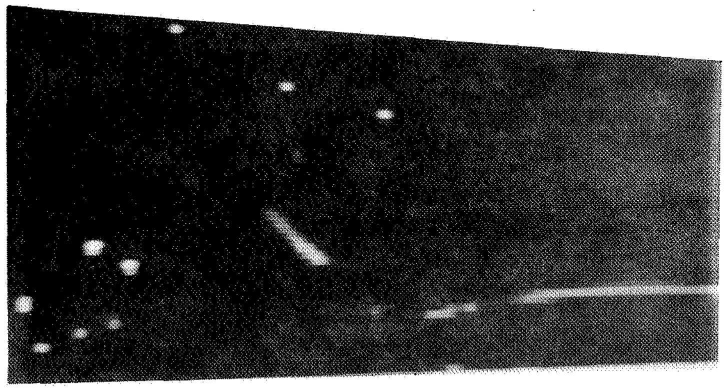
Photo (2), taken at 0830 hours in the 8 - 13 micron range, was exposed so as to highlight subtle differences of emitted radiation within the meadow at the right hand side of the field of view (see Appendix, Figure c).

Photo (3), taken at midnight in the 8 - 13 micron range, shows the asphalt roadway clearly and the relatively "cold" nature of the meadow area.

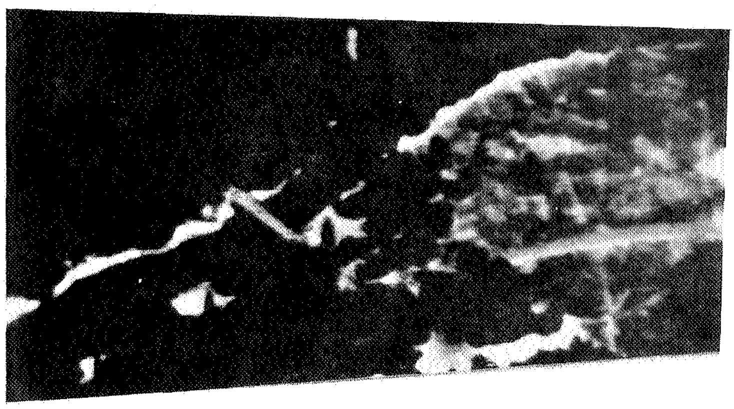
Photo (4), taken at 1030 hours in the 8 - 13 micron range, shows detail in the forested area better than any of the other examples.

Multiband color enhancement is able to provide, in one color composite image, all of the desirable features from each of these separate black-and-white thermograms (see next page).

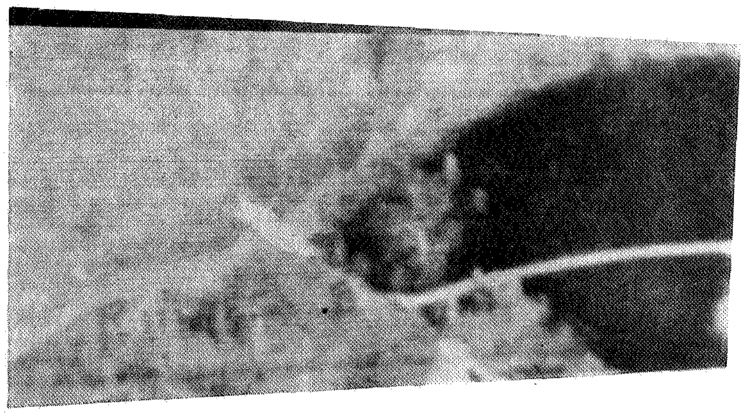
(1)



(2)



(3)



(4)

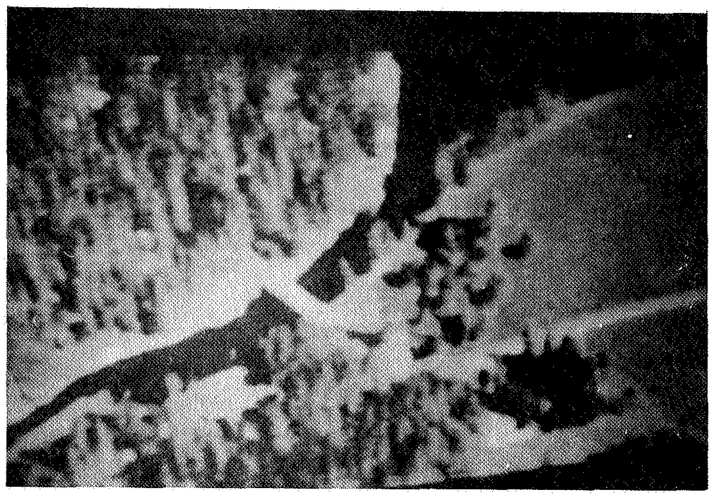


Figure 18. Color enhanced examples obtained by using images included in Figure 17 on the preceding page. The above illustrations depict the extent to which color composites facilitate the viewing and interpreting of multiple black-and-white images by superimposing them in common register on a translucent viewing screen. Note how the bright spots of the campfires (seen in Photo (1) of the preceding illustration) contrast with the surrounding colors. Both illustrations above were obtained by projecting three of the four images shown in Figure 17 through red, green and blue colored filters, respectively.

Consistent with the title of this report, it is appropriate to analyze at least one set of reconstituted color photos in relation to the practical applications of information derivable therefrom. For this purpose the four reconstituted color photos shown in Figure 19 will be used since they show a representative area of interest to wildland managers (vis., part of the Bucks Lake Test Site in the Sierra Nevada Mountains of California).

The forester seeking to improve management practices on the land shown in Figure 19 needs detailed, accurate and timely information regarding (1) the species composition of the timber, forage and other vegetation resources; (2) the vigor of each component of this vegetation, particularly with reference to his locating "high risk" areas, so called because of their susceptibility to attack by various insects and pathogens; and (3) the density of various vegetation components including (a) commercially valuable conifers that are of merchantable size, (b) commercially valuable conifers that are of less than merchantable size at present, usually confined to the forest understory and constituting a valuable "residual stand" after logging, (c) hardwoods which, in this area, are not merchantable and are considered as troublesome "weed species" and (d) total woody vegetation, including all of the above, together with shrubs, some of which may have forage value for both livestock and wild game animals. The factor known as "total woody vegetation" is of importance in assessing the watershed values of an area; it also is of importance in relation to problems of fire suppression, fire hazard reduction and trafficability (the ease with which personnel and mechanized equipment might traverse the area).

In addition to the above, the manager of an area such as that shown in Figure 19 would like to have information regarding soil moisture conditions. In an alpine meadow, for example, soil moisture conditions govern in large measure (1) the time when the area can be grazed by livestock without their trampling the annual grasses into the mud, (2) the time when attempts at reseeding the area would be most likely to succeed, (3) the time when trafficability conditions are likely to be most favorable, and (4) the times when the meadow vegetation is wet enough to retard a wild fire or dry enough to facilitate its spread.

A comparison of the reconstituted color photos shown in Figure 19b with the black-and-white photos from which they were derived (Figure 19a) reveals that much of the information desired in each of the above mentioned categories is far better determined through the color reconstitution process. An example or two from each of these categories should suffice for illustrating this fact:

1. Species Composition: If the photo interpreter were asked, from a study of the black-and-white photos shown in Figure 19a to locate all California Black Oaks (*Quercus kelloggii*) he would experience considerable difficulty, even after field checking several representative portions of the area to determine the characteristic appearance of such trees on the various types of black-and-white photography. On the other hand, once he knows the color signature for a few trees of this species, as exhibited on a reconstituted color photo such as the top left photo of Figure 19b he is readily able to locate virtually all remaining trees of this species within the entire area. The interested reader can acquire

some appreciation of the validity of this statement by first noting the yellow appearance of black oaks in Area A and then extending his observations to other parts of the photo where trees of the same species have essentially the same image appearance. He also will note that this particular distinction is not as well made on some of the other reconstituted color photos in Figure 19b. This is true even though exactly the same black-and-white lantern slides were used in all instances and only the filters used in color projection were changed. This example serves to emphasize the importance of using color filters that will yield maximum color contrasts between objects of interest.

2. Tree Vigor: In the area labelled "C" on one of the reconstituted color photos of Figure 19b, numerous lodgepole pines (*Pinus contorta*) are exhibiting a marked loss of vigor. Field checking indicates that beavers have recently invaded the area and, through the construction of dams, have flooded much of it. This drastic change of habitat has caused a loss of vigor to occur in the lodgepole pine stand that previously was thriving in the area. Once a few of these unhealthy trees have been located during the course of field checking the area, and the appearance of such trees has been noted on the reconstituted multiband color photography, virtually all other such trees can be detected merely by their characteristic color signature (a grey tone on the color composite for which the area "C" has been labelled). As in the previous instance, however, some of the color composites do not show these unhealthy trees acceptably well.

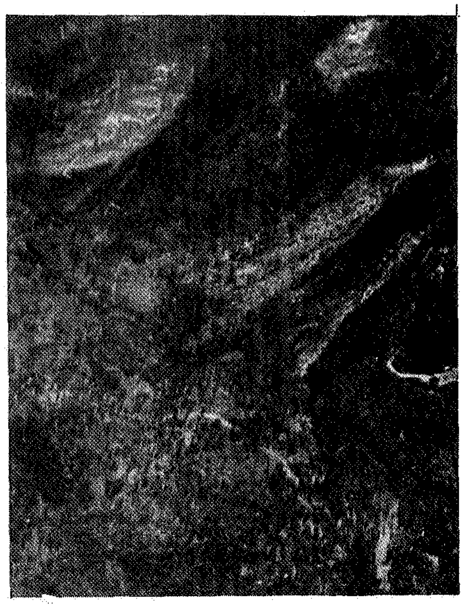
3. Vegetation Density: A comparison of the three black-and-white multiband photos of Figure 19a reveals that a somewhat different im-

pression of vegetation density might be obtained from each of them, at least for certain portions of the area shown. This is because of the varying tones exhibited not only by the different species of vegetation, but also by the background of soil and rock on these black-and-white photos. However, the additive color technique preserves whatever is good about each of the black-and-white photos for purposes of making vegetation density estimates. As a result, the color composite photos, despite the limited resolution exhibited by them because of the crude projection equipment that had to be used, permit a far more accurate estimate to be made of vegetation density than could be made on any one of the black-and-white photos. As previously mentioned, with projection equipment that provides better image registration, the color composites can show an even higher resolution than that exhibited by the black-and-white photos, since, through the use of multiple exposures the signal-to-noise ratio is improved.

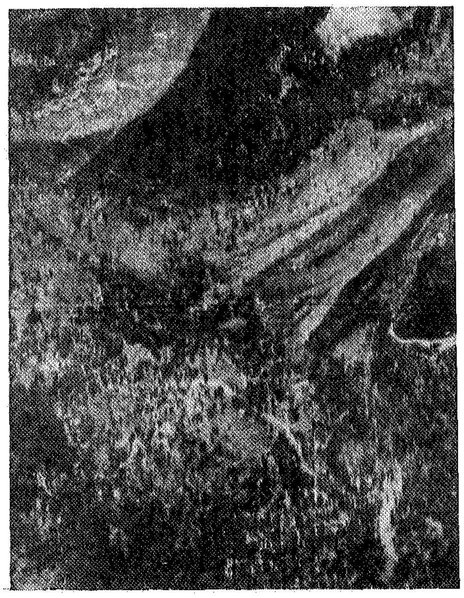
4. Soil Moisture Conditions: In some instances areas of wet soil can be perceived directly on aerial photos. Usually, however, some form of vegetation will thrive on areas where the soil is wet, and where the soil is dry the vegetation commonly will be sparse and chlorotic. Consequently, inferences as to soil moisture conditions usually must be drawn from the appearance of the vegetation. This fact is well illustrated in the color composites within the vicinity of point "B" of the alpine meadow. Field checking showed that all of the meadow area shown here was vegetated. Most of the tone and color differences seen there on the color composites were found to be attributable to differences in the vigor,

stand density and species composition of the meadow vegetation and these differences were, in turn, highly correlated with soil moisture conditions. After a limited amount of field checking has been done, therefore, significant soil moisture conditions could be mapped and more completely so when interpreting several color composites instead of just one of them.

The few specific examples of practical applications that have just been considered would seem to provide compelling evidence of the advantages of multiband imagery, once it has been reconstituted in color. It would be wrong to infer, however, that all inventory problems are solved merely through the use of this technique. Based on these examples, and several others which the principal investigators have considered in significant detail during the course of this study, one primary conclusion emerges. Multiband photography, when reconstituted in color, greatly facilitates image analysis as one seeks to acquire inventory data that will lead to better management of the earth's resources.



Film-Filter: Panchromatic 47B



Film-Filter: Panchromatic 25A

Film-Filter: Infrared 89B

Figure 19a. Multispectral black-and-white photographs of a portion of the Bucks Lake Test Site in the Sierra Nevada Mountains of California. Certain information can be derived from each of the examples shown here. Greater amounts of information can be derived from these illustrations by the color additive technique described in the text (page 45) and illustrated in Figure 166.

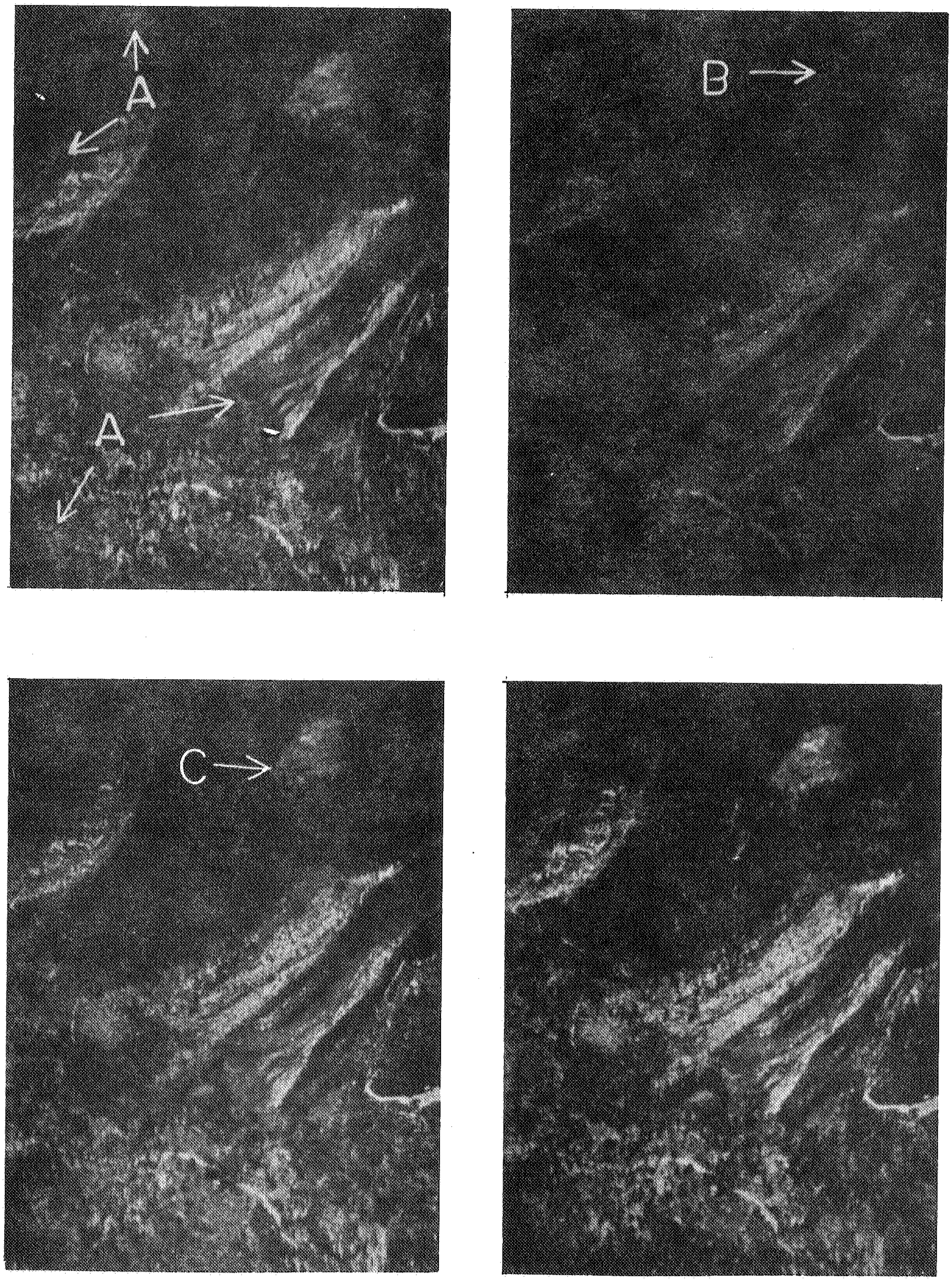


Figure 19b. Color composites obtained by using the multispectral black-and-white photos appearing in Figure 19a. For a detailed analysis of the usefulness and merit of reconstituted color composites such as these, see text (page 45).

IV. LIMITATIONS OF MULTIBAND REMOTE SENSING

It is deemed necessary to include in this report some comments relating to the limitations which exist in the realm of multiband remote sensing so that many of the concepts discussed herein can be kept in proper perspective.

In order to assess the usefulness and limitations of multispectral reconnaissance, several relevant factors must be analyzed. These include (1) the informational needs of the user, (2) the attainable quality of the remote sensing imagery or other data record, and (3) the available means of extracting from it the desired information. The importance of these three considerations will become apparent in the following discussion of factors which impose limitations when one seeks to make practical applications of the multiband remote sensing concept.

1. Natural terrain features tend to be more complex than artificial target arrays. It is much easier to demonstrate the success of multiband reconnaissance through the use of well-oriented artificial target arrays than through the use of natural terrain features. In nature there are many intergradations and subtle color changes which complicate the problem of distinguishing significant features and boundaries from a study of multiband imagery. For this reason it is important that research seeking to evaluate the concept of multiband reconnaissance be conducted, in part, on naturally-occurring features.

2. Serious difficulties are sometimes experienced when attempting to select the optimum wavelength bands for use in achieving various objectives. The selection of wavelength bands which will provide the most

meaningful tone signatures must be made with a view to both the number of distinct categories or conditions to be identified and the accuracy of identification required. For example, in an agricultural area the analysis required to isolate one particular crop type and condition class, e.g., "healthy wheat from everything else", is much simpler than that required to differentiate each item of the "everything else" complex. The problem of band selection is only partly one of locating the wavelength peaks and troughs wherein the amount of energy emanating from each type of feature differs most from that of its associates. In addition, there is the problem of determining the optimum band width to use when exploiting these peaks and troughs. If too narrow a band is used, too little energy will strike the sensor even when the maximum allowable exposure period is used. On the other hand, if too broad a band is used, the identifying tone signatures are likely to become less distinctive.

3. There are problems in attempting to achieve the required spatial resolution on multiband imagery. Most of the proponents for multiband reconnaissance advocate its being obtained either from high flying aircraft or from earth-orbiting spacecraft so that synoptic views can be obtained of vast areas. However, the information needs of a user often require greater ground resolution than is currently obtainable when sensors are operated from such great altitudes. Even if the individual images are of suitably high resolution, there can be a serious problem of image registration when one attempts to produce color composites. All multiband images of the same scene should have a common geometry so that they can be superimposed in proper register for purposes of color enhance-

ment. However, when several sensors are used, each designed for sensing in one particular region of the electromagnetic spectrum, geometric compatibility usually is lost. When this is the case, efforts at superimposing the resultant images can be both time-consuming and fruitless. In such instances, the resultant color-enhanced images obtained from transparencies having incompatible geometrical relationships may be no more interpretable than the original data. Theoretically, through improvement of the signal-to-noise ratio, the greater the number of transparencies used to form a composite image the better the resolution.

4. There are problems occasioned by limitations of the image analyst. As the number of photographs and related imagery is increased, the human interpreter's capacity to handle tone differences as seen on various film-filter combinations soon becomes a limiting factor. Without special equipment, the interpretation of these multiband images necessitates laborious cross-referencing of tone values, area-by-area and feature-by-feature. As greater numbers of conjugate images are used, the interpreter's task becomes more demanding and his speed and accuracy can deteriorate drastically.

A sophisticated partial remedy to this limitation is the use of automated techniques of analysis which do not weary under the task. These techniques rely primarily on matching tone signatures to previously determined standards. As such they are subject to sizable errors unless the image analyst himself carefully monitors the results.

A related problem arises when a very large interpretation task is to be performed, hopefully to a uniformly high standard of accuracy, but requiring the services of several photo interpreters. Limited tests have shown that there can be great variability between photo interpreters in terms of such factors as visual acuity, mental acuity, attitude toward the job and susceptibility to fatique. It follows that there can be significant differences in the results obtained by two or more photo interpreters as they attempt to extract a particular type of information from multiband aerial photographs and related imagery. There also can be differences in the results obtained from time to time by an individual photo interpreter attributable to variations in fatigue and in attitude toward the job. These variability factors can create serious problems during the analysis stage when there is a desire to treat all of the photo interpretation results as a single uniform sample. Three possible solutions to this problem are suggested on pages 12 and 13 of the present report.

V SUMMARY AND CONCLUSIONS

In any rapidly developing field, there is a tendency for its adherents to generalize about the potential applications which that field offers them. These generalizations usually take the form of either overstating or understating both the uses and the limitations. Such tendencies have been especially pronounced for the rapidly developing field of multiband reconnaissance. An objective of this report has been to provide a critical evaluation of that field.

The first part of this evaluation entailed the use of an artificial target array containing variously colored panels of recordable reflectance characteristics. In these tests multiband black-and-white photographs were obtained and densitometric measurements were made on the resulting negatives. From an analysis of the densitometric data it was possible to derive exposure specifications, feature-by-feature, which would yield maximum image tone contrasts (between feature and background and also between one feature and another) on the various film-filter combinations tested. Determinations of this type were done for hypothetical reconnaissance systems that might record as few as two, or as many as six spectral bands simultaneously.

In an intermediate stage, extrapolations of information obtained by the foregoing means were made by taking multiband photography of semi-artificial target arrays which contained not only color panels (for maximum control in testing various concepts of color reconstitution) but also natural terrain features.

One such array containing various naturally-grown crop types and naturally occuring soil and rock types was established beneath a water tower on the Davis campus of the University of California. Simulated aerial photographs were then obtained of the target array with multiband cameras. The stationary camera platform so desirable in this phase of multiband reconnaissance research, was provided by a catwalk around the water tower, 150 feet above the target array.

Another such array, containing various naturally occuring tree species, meadow grassland types and soil and rock conditions, was established on the floor of Yosemite Valley in Yosemite National Park, California. Simulated aerial photographs were then obtained of this target array also and with the same multiband cameras. In this instance the stationary camera platform consisted of an overlook at Glacier Point, nearly one mile distant from the target array, so that the photographic effects of a longer column of air could be studied.

Comparison of the Davis imagery with the Yosemite imagery, and with actual aerial photographic imagery that concurrently had been obtained of both arrays from photographic aircraft, clearly established the applicability of such tests to problems of aerial and space reconnaissance. In the developmental stage, important advantages of economy and degree of experimental control over the various multiband exposures accrue through use of fixed camera platforms such as the ones used at Davis and Yosemite.

Finally, the same multiband techniques as had been used in the two earlier phases of research (which by this time had shown considerable promise), were applied to various natural terrain features found at the

NASA Forestry Test Site near Bucks Lake, California.

On both the artificial targets and the naturally-occurring ones, techniques of additive color enhancement were used. In this phase of the research, color was introduced under controlled conditions while projecting multiband black-and-white imagery onto a screen. Such techniques were conclusively shown to yield more interpretable data and thereby to greatly facilitate the image analysis task. This task becomes more and more arduous as greater and greater quantities of multiband imagery are obtained to help solve an ever-increasing number of the world's problems of resource inventory.

Because of the encouraging results obtained with multiband techniques in the above tests, measures were taken with NASA support to have various test areas in California photographed with a multiband reconnaissance system that had been developed by Yost and Wenderoth when they were on the staff of Fairchild Camera and Instrument Corporation. This system consists of (1) a camera that obtains multispectral photography in four bands in the .36 to .98 micron wavelength region of the electromagnetic spectrum and (2) a companion viewer which presents a composite color rendition of the four photographs by additive color techniques. This camera-viewer system provides a far more sophisticated means of evaluating the concept of multiband reconnaissance than would otherwise have been available to the present investigators. By careful control of registration it greatly improves the <u>spatial resolution</u> of composite multiband images; and by careful control of illumination (including control over color saturation through the introduction of specified amounts of white light for each projected image) it greatly improves the <u>color quality</u> of composite images. Because imagery of our various California test sites was not flown with this equipment until very near the end of the reporting period, it is not possible to include examples of it in this report. However, preliminary indications are that excellent results were obtained. A special supplement to the present report, therefore, will be prepared in the near future in which numerous examples of composite color images formed by the Yost-Wenderoth system will be included.

A most important requirement for the successful implementation of multiband reconnaissance lies in the user's ability to define specific objectives and to recognize where limitations might affect the results. Once the objectives have been clearly set forth, use should be made of both artificial and naturally-occuring test areas that contain numerous examples of the objects and conditions that are to be identified. By such means the deriving of specifications for multiband photography will be greatly facilitated.

It cannot be hoped that a panacea of bandwidth combinations will be found that will be useful to all investigators in all disciplines. Therefore, when a single multiband system, containing perhaps no more than four to six bands, must be employed by investigators in each of several disciplines compromises must be made in the choice of bands. For each potential user, the question thereupon becomes not only one of selecting the optimum bands for his own special purposes, but of determining the relative usefulness of each of several proposed <u>compromised</u> systems, one of which he may be obliged to accept. It is believed that the techniques discussed in this report are fully as useful for this second purpose as for the first and that herein may lie their greatest ultimate value to workers in each of several disciplines as they jointly seek to employ multiband reconnaissance techniques.

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APPENDIX

Yosemite/Davis Multispectral Project, September, 1967

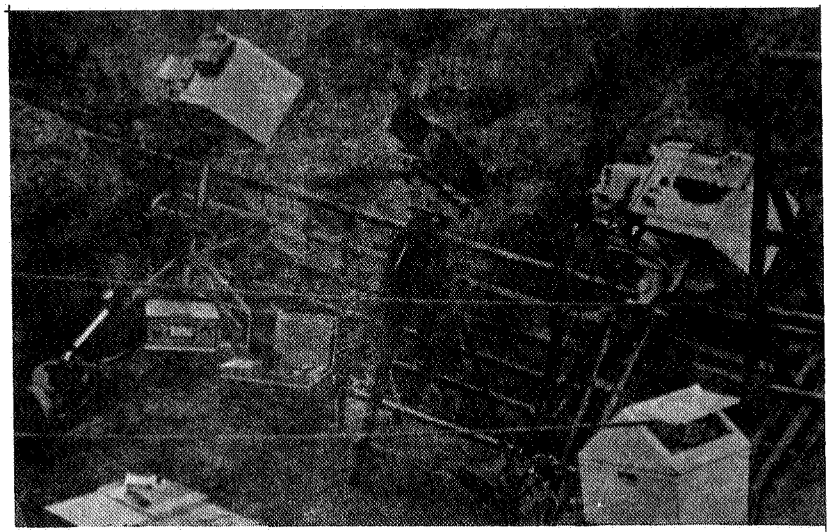


Figure a) Camera Station at Glacier Point in Yosemite National Park with two thermal infrared cameras and one long focal length light sensitive camera.

Figure b) The Davis Campus water tower and environs showing thermal IR cameras mounted on catwalk and orientated towards target array 150 feet below. Camera station is indicated by arrow; note target array below it.

Yosemite Test Site

On September 7 of this year, a multispectral project involving two thermal infrared cameras and many light sensitive cameras was conducted in Yosemite National Park for a period of several days. Complete cooperation by Park Service personnel enable the ground instrument monitoring crew and the camera crew to carry out their respective jobs with a minimum of difficulty. The purpose of this project was to obtain multispectral photography and other imagery from a number of specific electromagnetic bandwidths and draw some conclusions regarding its interpretability and usefulness for specific objectives. This project therefore served as the basis for a practical application of some of the concepts discussed in this report.

Figure a) on the preceding page shows the camera station at Glacier Point in Yosemite National Park with the camera apparatus in place. Each camera is oriented in such a way as to image the exact area of interest in the valley below, as delineated on Figure c.

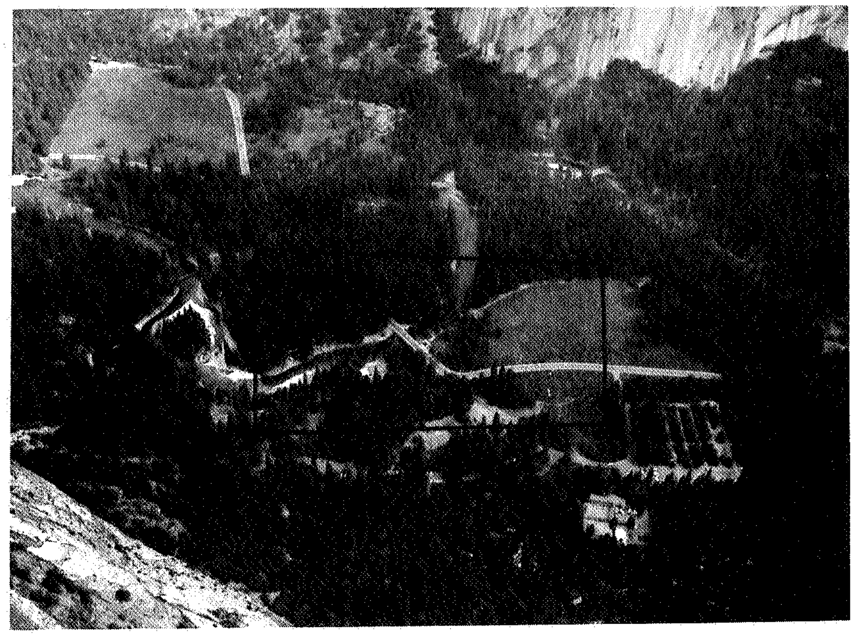


Figure c) Yosemite Valley test site and environs. The area of interest is outlined in the above illustration, as imaged by the Thermal Infrared cameras. This area contains a variety of natural and man-made features and a suitable locale for emplacement of a specially constructed target array which can be seen west of the bridge (Stoneman Bridge) approximately 150 yards. This special target array contained six colored panels 20 feet by 20 feet on a side (red, blue, green, yellow, black and white), a grey scale of five steps from white to black, three large soil moisture plots subjected to different degrees of moisture application, and a small resolution target (see Figure d). In addition, special thermal targets were laid out along the south side of the river bank in the next opening seen above, west of the target array. These consisted of impounded pools of river water which were allowed to heat up due to solar insolation, and three alumimum reflecting squares of diminishing size (144 sq. ft., 36 sq. ft., and 9 sq. ft. (which are barely resolvable in the above photo).

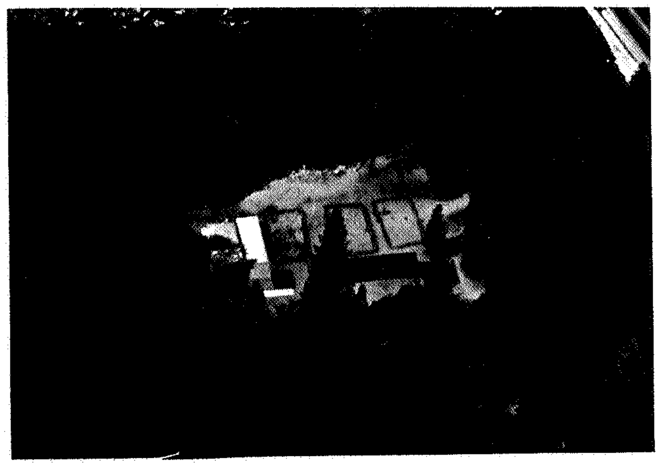
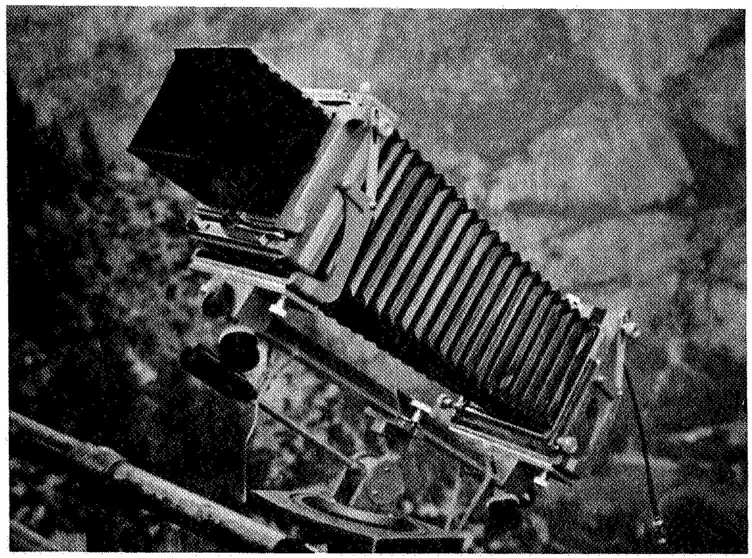
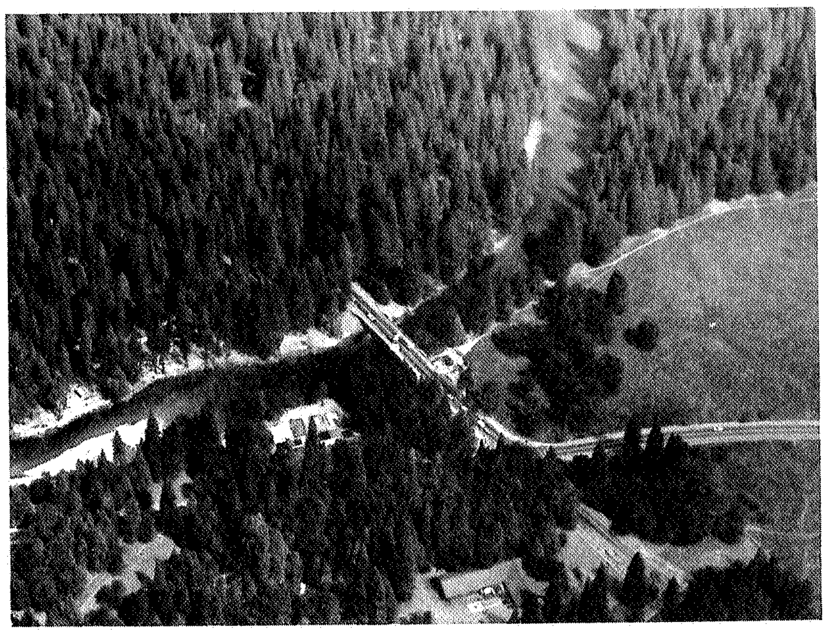


Figure d) Enlarged color photo of a portion of the target array showing the layout of the various color panels and the three large rectangular soil moisture plots. The soil moisture plot farthest to the left was maintained at saturated conditions; the middle plot was moistened periodically and allowed to surface dry; while the plot farthest to the right was initially moistened and allowed to dry to a much greater depth. The photo illustrations appearing on the following three pages include representative examples of multi-spectral photography taken with a special 20'' focal length camera using 4'' x 5'' film format which allows photo scales approximating that obtained from the thermal infrared cameras. Note the appearance (tone signature) of the color panels from one example to the next. Microdensitometer readings of their negatives clearly distinguish each of the six color panels.



20" focal length camera with which multispectral photography was obtained from Glacier Point camera station. Note cable release for the shutter and also ropes used to secure camera tripod to the railing.

Panchromatic exposure (no filter) of target area as viewed from Glacier Point camera station approximately 4000 feet away.



Panchromatic film and Wratten 12 (yellow or "minus-blue") filter.

Panchromatic film and Wratten 61 (green) filter.

Panchromatic film and Wratten 70 (dark red) filter.

Infrared film and Wratten 89B filter; poor shadow penetration is one of the drawbacks in using this film-filter combination. The light tone with which vegetation registers makes this film-filter combination a good one to include in multiband photography that seeks to provide unique tone or color signatures for various objects and conditions.

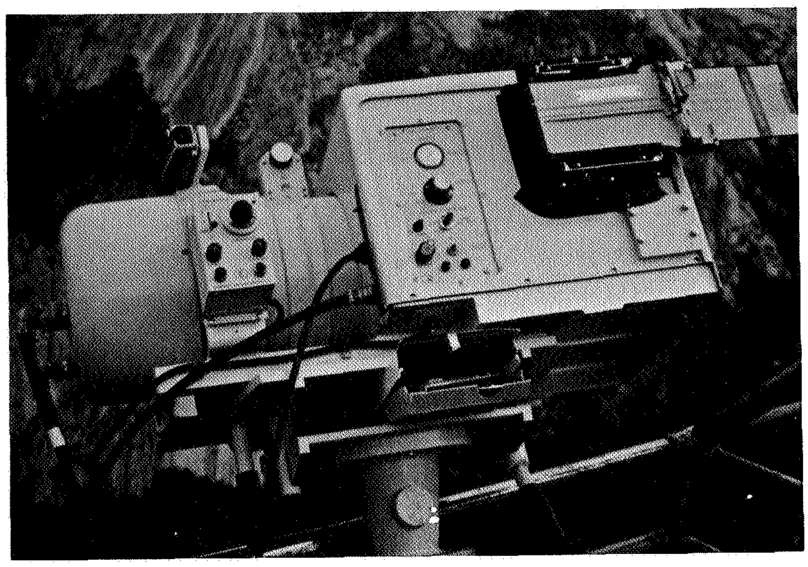
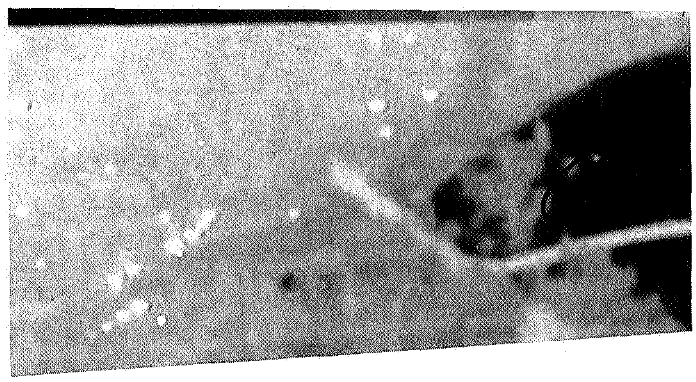


Figure e) Close-up of one of the Barnes Engineering Company's Thermal Infrared cameras (8 - 13 micron band) imaging radiated energy levels from the valley floor below.

Two thermal infrared sensing cameras were pressed into service at Glacier Point. One was filtered so as to provide exposures only in the 8 - 13 micron band and the other only in the 3.5 - 5.5 micron band. Through the use of these two cameras, a great many thermograms were obtained at various times of the day, including those illustrated on the next two pages. The 3.5 - 5.5 micron thermal infrared camera is most sensitive to peak energy levels around 1200° Kelvin-- such as might be measured from campfires. The 8 - 13 micron thermal infrared camera is most sensitive to energy levels of 300° Kelvin, corresponding roughly to the temperatures exhibited by most terrestrial terrain features. In the following thermograms, light tones denote relatively warm areas and dark tones denote cooler sites.

3.5 - 5.5 micron band; this thermogram was recorded at 8:40 p.m. and clearly shows a cooling down of the meadow compared to other features, including the river water. The bright "spots" seen scattered around are campfires of park visitors; two such bricquet fires were placed on the river bank near the water pools and aluminum reflecting panels and are clearly seen above. The dark tone observed in the target array area is the result of the saturated, cool soil moisture plot. Compare the above thermogram with the following one.



3.5.- 5.5 micron band; this thermogram was recorded at 9:25 p.m., three-quarters of an hour after the above thermogram. Differences in quantity and size of campfires are readily observable. Two smaller bricquet fires were added to those already present along the river bank test site mentioned earlier. In order to determine the resolving power of this camera, three very small bricquet fires of diminishing size were placed in the encircled area. The largest of these forming the apex of a triangle consisted of three burning bricquets. To the south a few yards, and forming the other two corners of the triangle, the other two bricquet fires containing one and two burning bricquets respectively, can be faintly seen. Each bricquet was less than a one inch cube.

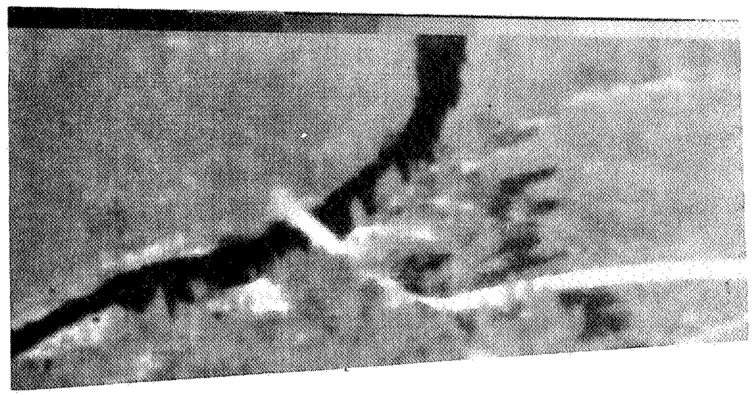
These four thermograms were all recorded in the 8-13 micron band. They are presented to show diurnal temperature fluctuations. The mid-morning recording (1) shows considerable detail within the tree canopy, owing to temperature differences which are separable, using the Barnes camera.

The mid-day recording (2) shows a nearly uniform radiation from vegetated sites, although the asphalt roadway still contrasts with the river water; some areas shaded or cooled by nearby trees are beginning to show up in the meadow.

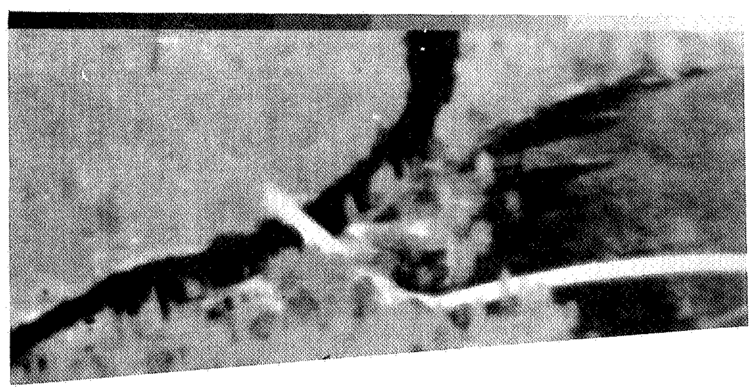
In (3) tree shadows have become greatly extended. By this time (6p.m.) the west end of the meadow is no longer receiving direct rays from the sun, but radiation from objects on the valley floor is continuing. Consequently, the area is cooling down at a fairly rapid rapid rate (4).

Notice how the aluminum reflecting panels (only two are resolvable and appear in the circle in the middle two thermograms) appear as dark spots. Refer to the multispectral photography on pages and to make comparisons and to determine the nature of the tiny black spot directly across the river from the aluminum reflecting panels.

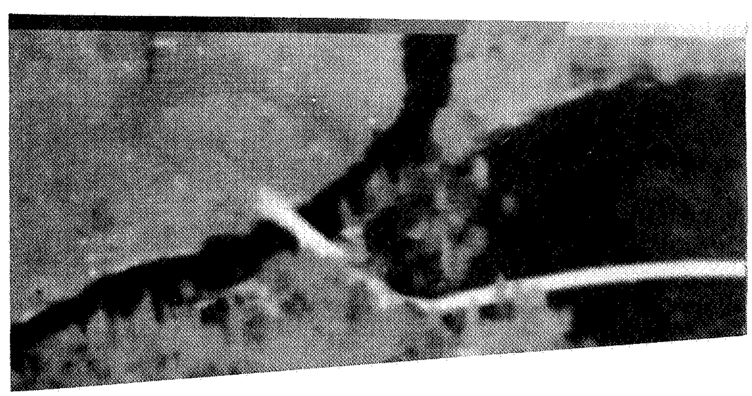
1) 9:50 a.m.



2) 2:40 p.m.



3) 5:40 p.m.

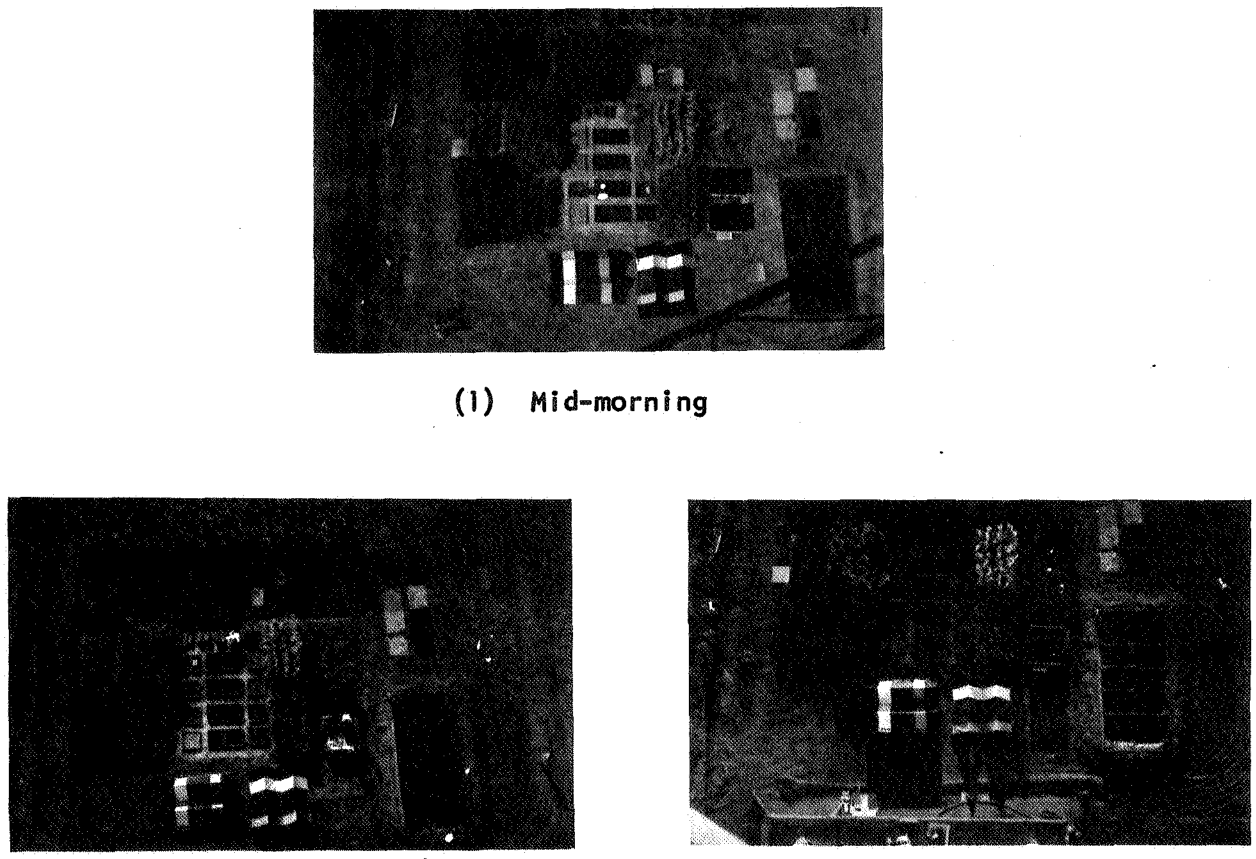


4) 6:10 p.m.

Davis Water Tower Test Site

Following the completion of tests at Yosemite, the principal investigators conducted extensive experiments from a water tower at Davis, using similar sensing equipment. The camera platform was provided by a catwalk, 150 feet above the ground, which surrounded the water tank. Figure (b) at the front of this Appendix illustrates the use of this stationary camera platform, and also shows the target array on the ground below. Many types of targets were assembled to enable multispectral photography and thermal infrared imagery to be obtained. These included various kinds of agricultural crops that were grown specifically for this test and various types of livestock which were moved into the target area on occasion. The entire target array can be seen in Figure (b) and selected portions of it are imaged in the following illustrations. Thermograms from both of the Barnes cameras (3.5 to 5.5 microns and 8.0 to 13.0 microns) were recorded beginning before sunrise and extending well into the evening until unchanging temperatures were once again measured. A special mount was constructed for the two thermal infrared cameras in order that the entire array could be periodically recorded merely by adjusting the tilt angle of the mount. Three different positionings of the mount were required to cover all elements comprising the target.

Included in the target array was a goniometric display of canvas panels of various colors as seen in Figure (f); Figure (g) is the thermal representation of these same targets at various times of the day.

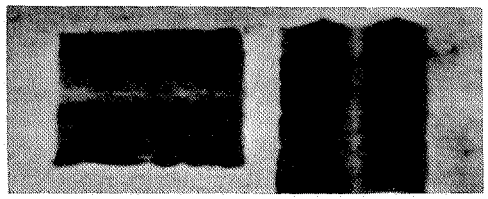


(1) Mid-morning

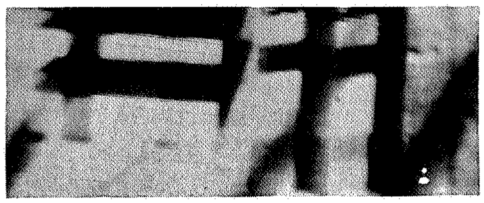
(2) Mid-afternoon

(3) Late-afternoon

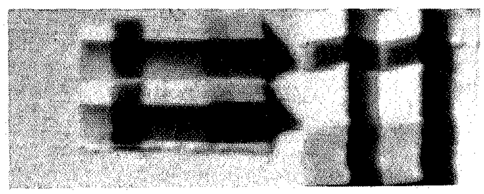
Figure f) Color illustrations of a portion of the target array at Davis, including the highly-colored panels which served as a goniometric target. Note the different appearances of various elements of the target array when illuminated at different sun angles (times of day). The green and blue panels (which were purposely placed side by side in this target) are illustrative of the subtle changes in color signatures which can be produced by the varying angles of illumination and of panel orientation.



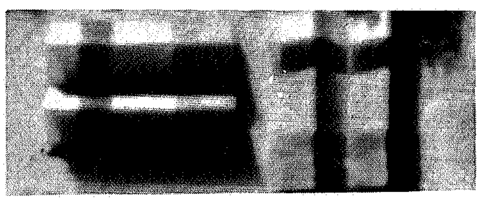
(1) Time: 0045



(2) Time: 0945

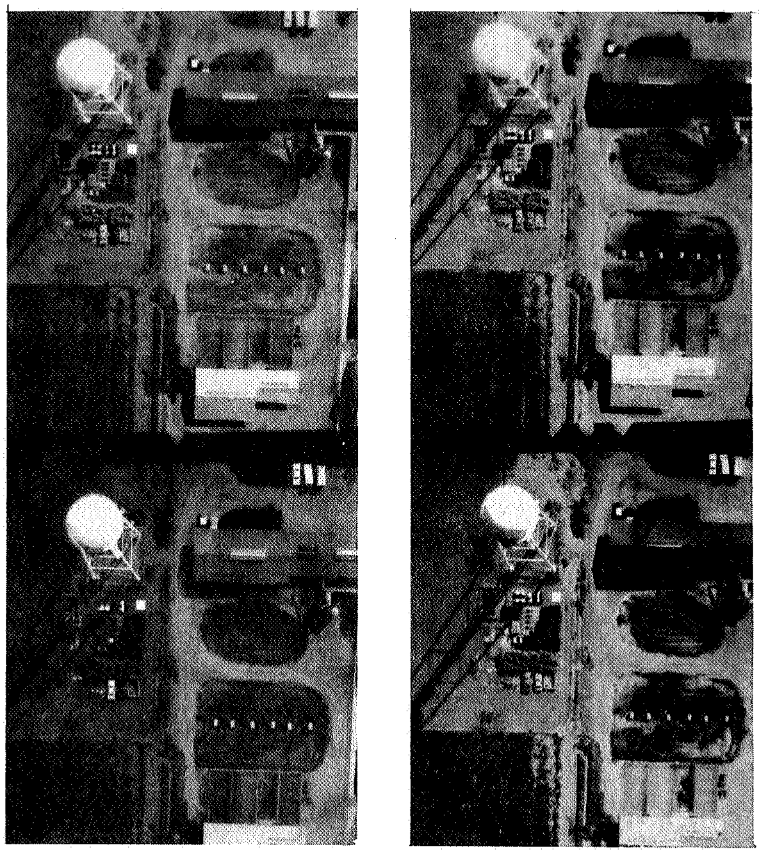


(3) Time: 1430



(4) Time: 1645

Figure g) **Thermograms** (8.0 - 13.0 microns) of the goniometric target array showing how the tone signature of each color panel changes with time of day and panel orientation. (Reference to Figure (f) will reveal the color of each panel). The white panel, for instance, shows a marked tendency to remain cooler than ony of the other panels during the daylight hours because most of the solar energy striking it is reflected instead of being absorbed and then emitted. Thermogram #1 indicates that there is very little temperature difference between any of the panels at this time of day (0045 hours). Apparently neither the color of a panel nor its orientation has a lasting effect on the temperature equilibrium which it reaches at night time. Note in thermogram (2) that the shadows cast by legs of the water tower can be seen falling diagonally across the panels. Thermograms (3) and (4) show the maximum tone differences associated with panel colors.



Wratten filters used (all in conjunction with Panchromatic film):

8	61
47B	25A

Note the target array set beneath the water tower in this view. The two autos seen farthest away from the tower (the larger one is blue, the smaller one red) exhibit interesting tone signature reversals on these film-filter combinations. The same is true for various soil types, crop types and moisture conditions displayed within the target array.

Figure h) Multispectral photography obtained of the Davis Water Tower Test Site using a recently constructed 4-lens camera system. The multi-lens camera approach helps to insure the greatest degree of registration capability because of common geometric relationships which exist between the simultaneous exposures. It is relatively easy, therefore, to combine positive lantern slide transparencies of these photos and project them through selected colored filters to enhance their interpretability beyond that which might be possible on the original black-and-white prints. Because the above photos were taken in late summer of 1967, time did not permit the inclusion in this report of composite color illustrations made from them. However, such illustrations will be included in a supplemental report in the near future.