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Critical Terrain Analysis

Parameters influencing the photo interpretation elements of tone and texture on color and color infrared aerial films.

THE INCREASING COMMERCIAL utilization of color and infrared color photography has added a new dimension to the realm of the aerial image analyst. These films offer significant advantage for terrain data acquisition especially in engineering and resource applications.

The use of color and color infrared versus panchromatic film is predicted on the premise that the photo interpretation elements, tone and texture may be improved. Color films result in greater ease of identification of shapes and forms in photo interpretation studies. Thus a saving in costs of field checking may be realized. This saving more than alleviates the extra expense associated with color. Practical experience has illustrated that a greater degree of confidence and increased accuracy result with their use in interpretation of vegatative and cultural features.

ABSTRACT: *Very often, only marginal results in the analysis of color and color infrared aerial photographs have been achieved due to the inability of the user to optimize the parameters affecting the final recorded terrain image. A qualitative analysis of the solar spectrum, films, filters, processing, camera lens, focusing, exposure, and terrain characteristics is presented together with the selection of proper color balance for both color and color infrared photography. The earth's surface is considered under five basic categories*; (*a*) *vegetation*, (b) *exposed soils and rocks*, (c) *water*, (d) *snow and ice and* (e) *urban areas. The variables, including reflectance characteristics, are considered in detail, and augmented by color photographic examples.*

Color and infrared photography are nearly always flown for studies having a particular purpose. However, the purpose may cover several disciplines. Therefore, the final prints or transparencies should provide sufficient contrast for the optimum discrimination between the feature of interest and the background. For example, in the terrain typical of the Laurentian Uplands, geologists may be interested in the surface configuration of exposed rock outcrops whereas the forester may be interested in the foliage adjacent to the outcrops. These two interests are not always compatible, as may be seen on Plate 1. A slightly different color balance or relative exposure of each film layer may be selected for each purpose. Unfortunately, this feature is not always appreciated by investigators in the field. As a consequence, considerable conflict occurs in the literature as to the suitability of color and color infrared photography for various aspects of terrain analysis.

The conflict in the literature seems to arise from the following causes:

- Unknowingly, researchers have not always had properly exposed or processed films and prints.
- Investigations have been conducted at various times of the year in widely scattered geolographical areas, having unique terrain characteristics.
- Investigators have had a tendency to generalize conclusions based on particular study areas.

It is imperative that the proper film and filter be selected and the exposure specified to attain the *color balance* for the purposes intended. Consideration must be given to the spectral composition of the incident solar

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energy and the terrain reflective characteristics. *Color balance* should not be chosen on the basis of aesthetics. A detailed examination and comparison of trial transparencies or prints must be conducted by the interpreter familiar with the purposes of the study. Densitometers may be useful in this regard. Unfortunately, a practical method for quantitative specification of the proper color balance for different terrestrial subjects eludes us due to the great number of subjects involved. This step must be based on a qualitative analysis of the physical factors affecting the photographic image contrasts, on experience and eventually on some trial and error. The physical factors that affect the final image recorded on the photography include.

- The spectral composition of the incident solar radiation.
- The film-filter combination and processing including the photographic printing if transparencies are not used.
- The camera lens, focuslng and exposure involved.
- The terrain characteristics and reflective properties with respect to season.
- The urgency or expediency necessary to complete the project.

These factors are discussed in detail together with case histories of practical applications in an attempt to outline the variables which control the image of the terrain recorded on the final photograph. An understanding of these variables will lead to the optimum film-filter and color balance for maximum discrimination of desired terrain characteristics.

The Solar Spectrum

The sun is the primary source of energy for photography. Radiation from the sun is attenuated by the earth's atmosphere and selectively reflected by terrestrial features. The spectral composition of sunlight, both direct and reflected, is illustrated for a number of conditions in Figure 1. It may be seen that wavelengths of importance in transfer-

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Captions for Plates on Opposite Page

Plate 1. Color prints prepared from the same negative. The color balance of the right print was determined for tree species interpretation. The color balance of the left print was determined in order to enhance surficial features on exposed bedrock. *Location:* Parry Island, Georgian Bay. *Purpose:* (*i*) town site selection; (*ii*) land inventory for archeological study. *Terrain*: Precambrian biotite gneiss with numerous post-pleistocene beach deposits. Vegetation consists of second growth Maple, Oak, Birch, with some Pine. *Scale:* 1 inch = 400 feet. *Film:* Ektachrome MS. *Filter:* No filter. *Exposure:* 1/500@*f*/5.6. *Date:* June 4, 1968.

Plate 2. Infrared color print developed from a transparency, color balance determined for maximum discrimination in Spruce terrain. *Location:* Fort Smith, Northwest Territories. *Purpose:* Slope stability and landslide investigation. *Terrain:* Lacustrine plain with surficial stabilized sand dunes (sand ± 40 inches over varved clays ± 100 feet). Vegetation consists of Black and White Spruce, Jackpine, Popular with Spagnum Moss and organic accumulation in low lying areas. *Scale:* 1 inch = 600 feet. *Film:* Ektachrome Infrared Aero. *Filter:* Wratten No. 12. *Exposure:* 1/500 @ *f*/4. *Date:* August 30, 1968.

Plates 3 and 4. Simultaneous exposures of color infrared and color photography. Color balance determined for predominant deciduous forest species. *Location:* Parry Island, Georgian Bay, *Purpose:* Tree species interpretation and inventory. *Terrain:* Reworked sandy till overlying precambrian gneiss. Vegetation consists of Maple, Oak, Beech and Birch. Plate 3.—*Scale:* 1 inch = 400 feet. *Film:* Ektachrome Infrared film. *Filter:* Wratten No. 12. *Exposure:* 1/500 @ *f*/4. *Date:* June 4, 1968. Plate 4.—*Scale:* 1 inch = 400 feet. *Film:* Ektachrome MS. *Filter:* none. *Exposure:* 1/500 @ *f*/5.6. *Date:* June 4, 1968.

Plate 5. Infrared color print developed from a transparency. The color balance was determined to emphasize snow drift patterns. *Location:* Orangeville, Ontario. *Purpose:* Evaluation of effect of prevailing winds and snow drifting for residential subdivision design. *Terrain:* Ground Moraine; ice accumulation in areas of poor drainage. Prevailing winds are from the Northwest with little directional variation. Note the streamline envelope around the bushes and pile-up of snow behind the houses. *Scale:* 1 inch = 400 feet. *Film:* Ektachrome Infrared Aero. *Filter:* Wratten No. 12. *Exposure:* 1/500 @ *f*/4 *Date:* February 23, 1968.

Plate 6. Color print prepared to maximize contrast of subaqueous features. *Location*: Giant's Tomb Island, Georgian Bay, Ontario. *Purposes:* Evaluation of recreational capability of shoreline. *Terrain:* Near horizontally bedded Ordovician limestone (Trenton Group) with mantle of lacustrine sands, stabilized dunes behind the beach, and interference patterns displayed by underwater sand bars. *Scale:* 1 inch = 500 feet. *Film:* Ektachrome MS. *Filter:* None *Exposure:* 1/500 @ *f*/5.6. *Date:* July 23, 1968.

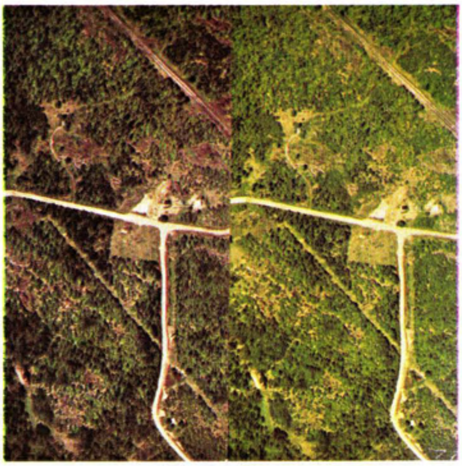

Plate 1

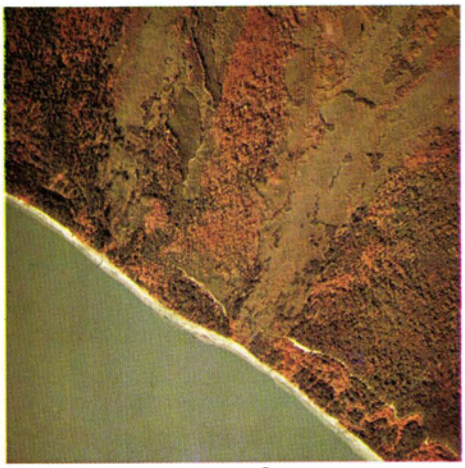

Plate 2

Plate 3

Plate 4

Plate 5

Plate 6

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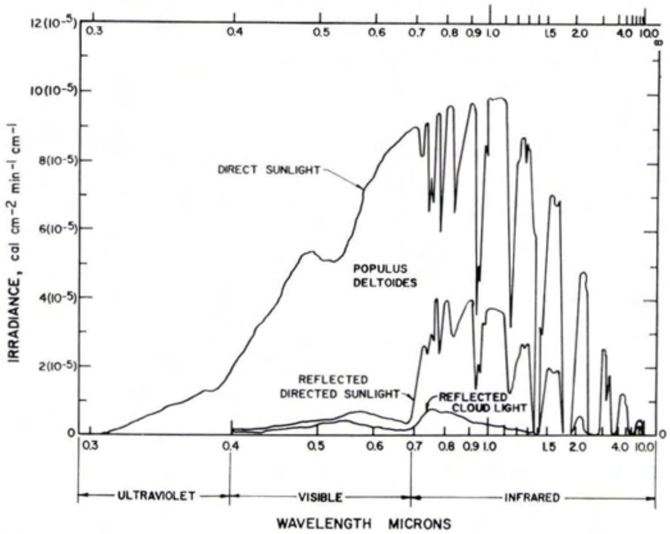

FIG. 1. The spectral distribution of direct sunlight incident on a horizontal surface. Also shown in the spectral distribution of reflected direct sunlight and of reflected cloudlight from a Populus deltoides leaf.[12]

ring energy from the sun to the earth's surface range from about 0.3 microns to 4.0 microns. This range sufficiently overlaps the color and infrared color film sensitivities of 0.4 microns to 0.7 microns and 0.5 to 0.9 microns (with a yellow filter) respectively. Certain salient features of these curves should be examined.

The curve for reflected direct sunlight from a leaf of Populus deltoides, peaks initially at a point slightly below 0.6 microns, in the green region of the spectrum (Figure 1). For photography sensitive to visible light, the leaf will appear green. In the near infrared portion of the spectrum, much more reflected energy is available. Infrared color films are sensitive to this portion of the spectrum. If uniform overcast conditions exist, most of the reflected light from a leaf will diffuse. The spectral distribution of this energy is shown by the curve for reflected cloud light in Figure 1. Note that the ratio of reflected energy in the photographic infrared (0.7 to 0.9 microns) to that in the 0.5 to 0.7 micron range of the visible is greater for reflected direct sunlight than for reflected cloud light. This feature indicates that insufficient energy is available to expose properly the photographic infrared relative to the visible sensitive portion of the film, unless some attempt is made to reduce the incident light in the green and red parts of the spectrum. Therefore, it will be more difficult to obtain the proper exposure of infrared film under overcast conditions.

For color photography, the curves for reflected direct sunlight and reflected cloud light are somewhat similar (Figure 1), although the peak in the visible is shifted slightly towards short wavelengths for the latter, resulting in a slightly more yellow positive image. This effect may be partially corrected by the use of suitable color compensating filters. However, color photography exposed under a high overcast will appear somewhat duller than exposed in direct sunlight.

If drifting clouds are prevalent, reflected direct sunlight will be subject to very great fluctuations with time; but with a limited number of cirrus clouds, the incident solar radiation will be a maximum.[8] If thin cirrus, and particularly cirrostratus clouds are present, some systematic spectral distortion of the incident solar radiation may be expected. These clouds are often difficult to discern visually and may cause concern to the aerial photographer. Their presence is indicated by sky with a white color cast often confused with haze.

The amount of diffuse solar radiation or skylight present is important for aerial photography. This light provides the illumination for detail normally in shadows. A typical spectral distribution curve for skylight is shown by Figure 2. Color photography is

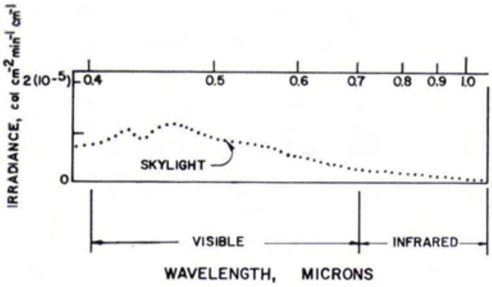

FIG. 2. Spectral distribution of skylight or diffuse solar radiation.[12]

sensitive in the portion of the spectrum where peak skylight occurs and will give the best record of features ordinarily in shade. The maximum shadow lighting will be obtained with a high cloud overcast. By the same reasoning, infrared photography may be used to enhance shadows—for the emphasis of microfeatures and textural details. This effect is beneficial for photography of snow surfaces (Plate 5). It is also helpful in interpretation of tree species when the interpreter uses the profile of the tree, as shown by its shadow, to assist in identification (Plate 3).

Diffuse solar radiation results when direct solar energy is scattered and reflected by water vapor and particulate matter in the atmosphere. Scattering depends on the particle radius of inhomogeneities in the medium relative to the wavelength of interest. For very small particles, scattering will vary inversely as the fourth power of the wavelength penetrating the medium (Rayleigh's Law). Thus, this type of scatterng is reduced with longer wavelengths. However, as the particle sizes increase to the order of 1/10 to 10 wavelengths, Mie scattering begins to predominate[5] with maximum scattering occurring when the wavelength is equal to the particle radius. Large solid particles (>10 wavelengths) result in non-selective scattering or reflection of light, all wavelengths being affected equally.

If the particles causing scattering in the atmosphere are submicron in size, such as smoke or haze, the use of infrared photography will result in greater image contrast than color photography. However, if the scattering agent is fog, little advantage will be gained by the use of the extended wavelength sensitivity of infrared photography. Poor results will be obtained with either type of photography. Temporal and spatial variations in scattering are prevalent. For example, desert atmospheres are usually much more transparent than atmospheres in humid environments. Less water vapor is in the air in winter than in summer, and increased turbulence at noon time on sunny days brings more dust into the tropospheric air.[13]

The energy received at the earth's surface, and thus the total energy available to expose the photographic medium, will depend on the solar altitude. As the solar beam forms a greater angle with the zenith, the pathlength through the atmosphere lengthens, the total available energy decreases, and the ratio of direct to diffuse solar radiation reaching the earth's surface increases. Thus, with greater geographic latitude, there will be a relative increase of diffuse solar radiation, and a decrease of direct solar radiation. Therefore, given the same terrain subject, total reflectivity will vary with geographic latitude. As a result, slightly different filtration and total camera exposure will be required in the Arctic versus a temperate climate, to compensate for the spectral difference in compostion of the incident solar radiation. To illustrate this effect, Figure 3 shows the variation in attenuation of the solar energy received at the earth's surface for a number of different path lengths of the solar beam through the atmosphere. M, the *optical air mass*, is a measure of the path length of the solar beam through the atmosphere, expressed as a multiple of the path length to sea level for a source of the zenith. Note that as the optical air mass increases, some spectral distortion of the incident energy occurs, and the wavelength of maximum incident energy increases from 0.47 to 0.69 microns for $M=0$ and $M=5$ respectively.

The above discussion indicates that filtra-

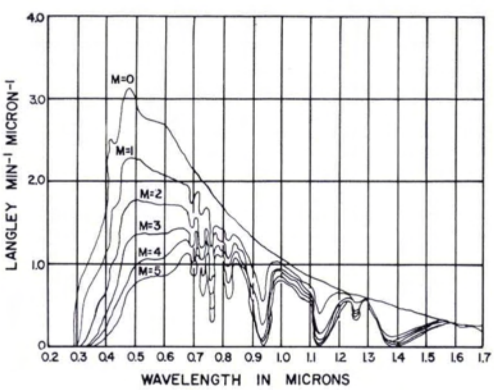

FIG. 3. Spectral distribution of solar radiation incident on a normal surface for six optical air masses.[7]

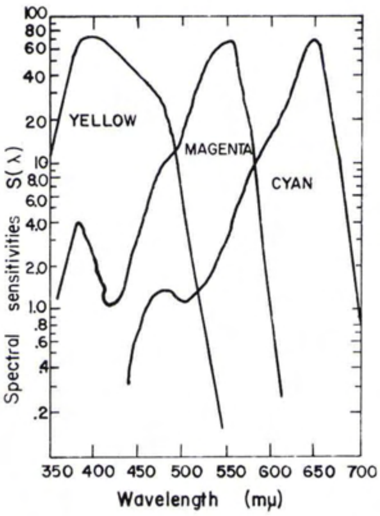

FIG. 4. Spectral sensitivity curves for Kodak Ektachrome Aero film.[10]

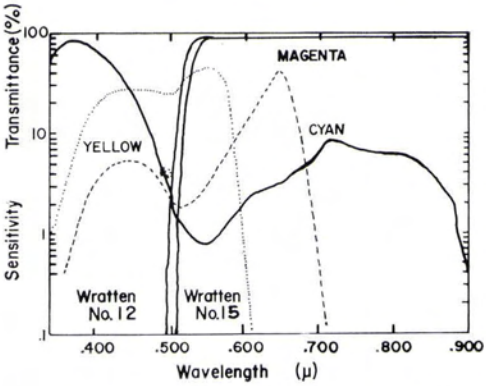

FIG. 6. Spectral sensitivity curves for Kodak Ektachrome Infrared Aero film and spectral transmittance of indicated Wratten Filters.[3]

tion either on the camera or during printing must be adjusted slightly for changes in the amount of incident solar energy, in the atmospheric conditions, and in the optical air mass as well as for changes in subject reflectivity. Variations in optical air mass will occcur both diurnally and seasonally for a given geographic latitude.

FILMS, FILTERS, AND PROCESSING

Color and color infrared films are used to display the spectral and spatial distribution of solar energy reflected from the terrain surface. These films have three sensitive layers consisting of yellow, magenta, and cyan, which are sensitive to blue, green and red; and green, red and infrared for color and color infrared film respectively. All the layers of infrared film are sensitive to blue light necessitating the use of a yellow filter. The characteristic curves, and the spectral sensitivities of the various layers for both films (reversal) are illustrated in Figures 4, 5, 6, and 7. For color films, these layers are all about the same speed and have similar characteristic curves. For infrared film, the speed of the cyan layer is considerably decreased to compensate for the increased spectral reflectivity of vegetated terrain beyond about 0.7 microns (Figure 7). Color films are available either as reversal or negative, and color infrared as a reversal film, although it may be developed

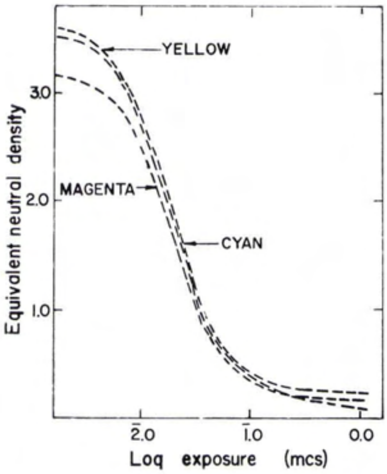

FIG. 5. Typical characteristic curves for Kodak Etachrome Aero film.[10]

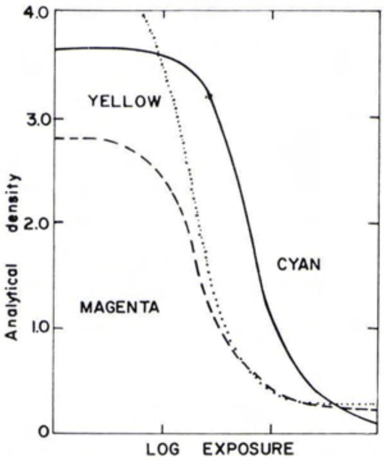

FIG. 7. Typical characteristic curves for Kodak Ektachrome Infrared Aero film.[3]

to a negative. The characteristic curves for color negative films are more nearly linear than those for reversal films. Reversal color film usually has a higher contrast and is normally processed for direct viewing whereas negative film is used to produce prints. The printing process permits greater flexibility in color and exposure correction. For these reasons, the exposure latitude for reversal film is more critical than for negative film. If the exposure is not in the correct range (within one-half an f/stop), it will be more difficult to obtain the proper color balance with the reversal material. Reversal films produce a slightly sharper image than negative color films of the same speed, and reduce the loss in image sharpness associated with printing.

The exposure of color films should be selected in order that variations in reflectivities from the terrain subject of interest may be recorded on the linear portion of the characteristic curves of the appropriate sensitive layers. This will give the maximum amplification of variations in terrain exposures and result in the greatest recorded contrast. The color balance of normal color films may be readily changed in any direction with gelatin color compensating filters. However, with infrared color film, a special glass filter (Corning 3966) is necessary if it is desired to decrease the speed of the cyan layer.[3] The speed of the cyan layer of infrared film may be increased by extending the time in the first developer during processing. A simultaneous increase of contrast and a slight color shift may result.[3] If the characteristic curves of the individual layers of the film are not conformal, color correction fitters will have different effects at different density levels. Lack of conformity may occur as a result of the developing process.

The optimum color balance for color films may depend on reproducing the natural scene for public relations purposes, or on differentiating between terrain objects. These two purposes may not always be compatible. The optimum balance for public relations will depend on aesthetics and on personal preference whereas the optimum balance for aerial analysis depends on the subject terrain and lies within narrow limits. The final color balance when printing is decided by densitometric measurements performed on the individual film layers and by trial and error. The ultimate selection should be chosen under the guidance of a person familiar with the terrain of interest and the ultimate use of the photographs. Faithful rendition of actual scene color is not necessary and may not even be desirable with color films, except where presentation to the uninitiated public is involved (Plate 1).

Infrared color films were designed to make camouflaged objects discernible within heavy foliage. The color balance of this film has been compensated for use with a Wratten No. 12 filter under normal conditions.[3] However, if excess haze and water vapor are present between the camera and the subject (e.g., at high altitudes), slightly more blue filtration may be required such as a Wratten No. 15 filter. Similarly, at low altitudes, the use of a Wratten No. 8 filter may be justified.

Experimentation involving the comparison of the No. 8 (1/500, f/4.5) and No. 12 (1/500, f/4.0) filters at altitudes of 2,600 and 4,400 feet was conducted over terrains consisting of agricultural forage crops, and deciduous (Maple, Poplar, Birch) and coniferous (White Pine, Spruce) trees in an area north of Lake Huron. The spruce terrain was flown for the purpose of delectation of spruce budworm damage. The film was exposed on a clear day with some drifting clouds in early July. The No. 8 filter gave superior contrasts within the foliage of individual deciduous species at the lower altitude and slightly better contrasts at the higher altitude. For these particular conditions, it seems evident that a No. 8 filter should be used for altitudes below about 5,000 feet.

The correct color balance for deciduous foliage applications with this film will appear as a vivid purplish red (Munsell 7.6 RP 4.9/13.6) (Plate 3). Coniferous trees will have a purplish cast with this color balance. Practical experience indicates that the color balance cannot provide optimum simultaneous amplification for minute variations within different subject terrains such as grass, deciduous trees, and coniferous trees. This effect may be observed in Plate 2, exposed at Fort Smith in the MacKenzie River Lowlands of Northern Canada. The autumn color change was just beginning in the deciduous trees. No variations within the poplar themselves has been recorded due to the necessity of determining the color balance to accomodate the poor reflectance from the spruce and Jack Pine terrain. As a result, separate color balances should be selected for each type of terrain. There is little justification for the use of infrared photography simply to discriminate between gross families of vegetative species, such as coniferous or deciduous tree species, although rather spectacular results may be obtained. These could be adequately identified on color or even black-and-white films by an experienced interpreter.

If foliage appears saturated by vivid red tones (e.g., Munsell 5.0 R 3.9/15.4), and little density variations are observed within the foliage on infrared photography, then the overall exposure is probably such that variations fall near the top of the characteristic curve for the cyan layer producing negligible changes in density. These vivid red tones should be avoided. They may be caused by the wrong filtration on the camera, by the use of an incorrect shutter speed or aperture opening on the camera, or by an incorrect processing time in the first developer. The film provided by the manufacturer may also vary unpredictably from batch to batch and result in a poor overall color balance.

From the previous discussion, it is obvious that the procurement of densitometric measurements on photographic films for the quantitative measurement of terrain reflectance is not warranted, unless measurements are compared to a control object in the actual scene. In this case, care must be taken that the exposures measured for the individual layers are included within the linear portions of their respective characteristic curves. Both very high and very low density regions of the photograph should be avoided.

Camera Lens, Focusing, Exposure

Many camera lenses were originally designed for use with panchromatic films and the *minus blue* Wratten No. 12 Filter. If these lenses were not fully achromatized, a slightly yellow effect may be observed and images in blue light may be of low quality on color films. This effect may be removed by the use of the appropriate color correction filters.[2] However, if too much blue light is removed by the lens, it may be difficult to achieve a satisfactory color balance. Often, the camera lens will have a greater filter effect than common haze filters.

If wide-angle lenses are used, especially with the standard 9-inch film, a decrease in light intensity towards the margins of the positive image is unavoidable. Because of their restricted exposure latitudes, in comparison to panchromatic films, this problem may be very serious with color films, although it may be alleviated by the use of graded density layer or antivignetting filter. The required gradation of density over this filter depends on the fiying height and haze present. Some difficulty is usually encountered in matching the gradation of this filter to the atmospheric conditions encountered at the time of exposure. Fall-off of light towards the margins of the picture format is less conspicuous with the smaller format 70-mm film.

With color infrared films, a slight adjustment in focusing is usually required, unless the camera lens has been properly designed for the extended wavelengths in the photographic infrared. Because infrared wavelengths are longer than visible wavelengths, an increase in lens to film distance will be required in order that the rays focus in the same plane.

Camera exposure is expressed in terms of an exposure time and a relative aperture or *f*-stop. Solar altitude and haze are primary determinants of the total exposure; solar altitude is the most important variable. Haze affects the apparent luminance of the darkest parts of the scene, resulting in reduced scene contrasts. Therefore, the camera exposure must be decreased with increasing haze. The greatest effects of haze are usually confined to altitudes below 6,000 feet in the Great Lakes region and remain constant thereafter.

The overall exposure should be selected so as to include the average terrain exposure and the small exposure variations near the toe and the steepest portions respectively of the characteristic curve for the particular film layer of interest. A common exposure setting for color films is an exposure time of 1/500 of a second and a relative aperture of *f*/5.6, although (*f*/4.0, 1/250 may be preferable with infrared color film. If a variation in total exposure is required, the aperture opening should be adjusted rather than the exposure time. However, for the best definition, the aperture opening should be kept as small as possible and a longer exposure time used (keeping within acceptable image motion limits).

Terrain Characteristics

The spectral reflectance curves for various terrestrial subjects are illustrated in Figure 8. It should be noted that a large number of the terrain features are tightly grouped with a low reflectance in the visible, but the reflectance curves are more evenly distributed with less overlap in the near infrared portion of the spectrum (0.7 to 0.9 microns). Thus, it will be easier to record these features with greater tonal differences on infrared than on color photographs. For the purposes of discussion of the applications of color and infrared color films to terrain data acquisition, the

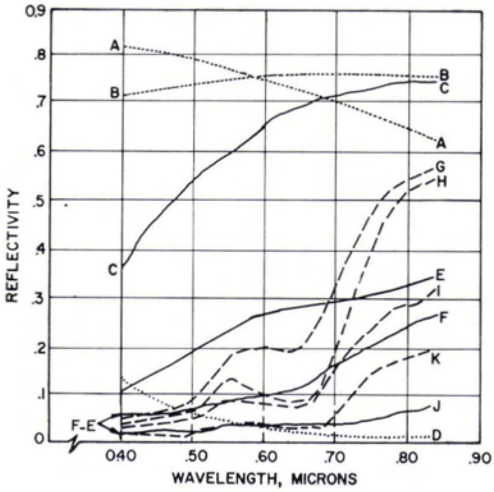

FIG. 8. Spectral reflectivity from forest cover, soils and other formations.[6] *A*—fresh snow. *B*—snow covered with ice. *C*—limestone, clay. *D*—water surface viewed obliquely. *E*—desert. *F*—podsols, clay loam, paved roads. *G*—deciduous forests, autumn. *H*—deciduous forests, summer. *I*—conifer forests, summer. *J*—Black earth, sandy loam, dirt roads. *K*—conifer forests, autumn.

earth's surface may be divided into a number of general categories which have similar scene characteristics. These categories include vegetated surfaces, bare soils and rocks, water, snow and ice, and urban areas.

VEGETATED SURFACES

A large percentage of the earth's surface is covered with vegetation for most of the year. Natural and cultural differences in species, vigor, and density of foliage is indicative of the changes in the soil profile. In bedrock regions foliage differences often occur on unique stratigraphic or lithologic units. Surficial, fractures, joints and bedding planes are often manifested in the vegetative pattern. As a consequence, an interpretation of structural detail may be performed (e.g., Plate 1 and Plate 6). Because greater reflectivity variations occur from foliage in the photographic infrared, infrared color film, if properly exposed and processed, will provide the optimum potential for recognition of foliage differences (see Plate 3 and Plate 4). If infrared film is not properly exposed and processed, little justification exists for its use over color films for vegetative studies. For mapping areas of field crops, or natural vegetation for studies dealing directly or indirectly with foliage, photography should be obtained just before maximum canopy cover (slightly before maturity). At this time the effect of underlying soils or loss of vigor in the plants themselves will have a maximum effect on the reflectance of the plant canopy. The effect of underlying soils rapidly becomes a minimum as the vegetation matures. Field experience indicates that infrared photography for vegetative studies in temperate climates is not particularly beneficial from late autumn to early spring. In early spring the plant canopy is not sufficiently developed to obscure the background whereas in the fall the reflectance of most vegetation except for coniferous trees (Figure 5) is increased due to the maturity of the leaves and individual differences are suppressed. Exceptions to the above may occur where the rate of leaf development in the spring may be used to separate species.

The following factors have been observed to affect reflectance in forests.[9] Young foliage of Spruce and Fir have three to four times greater reflectance than older foliage. For deciduous trees, old leaves reflect more than young leaves. The reflection from hardwood foliage decreases during the early weeks of the growing season, remains constant until mid or late summer, and rises rapidly during the autumn color change. At the same time, variations in reflectance from the foliage are minimized during autumn. However, the reflectance from conifers decreases significantly towards the end of the growing season. The drier the habitat, the greater the leaf reflection in the visible spectrum. A strong tendency has been observed for reflection of infrared to decrease with increase in altitude. Increased fertility of the soil reduces reflection in Ash and Oak. Climate and geographic latitude influences the properties of leaves. Arctic, temperate and tropical leaves are much different.

BARE SOILS AND ROCKS

Bare soils and rocks occur predominantly in arid environments. Typical examples are the Basin and Range Province of the southwestern United States or the Arctic Barren lands in the Keewatin District of Canada. A considerable percentage of the ground may be exposed during planting season in agricultural areas of intense use. These areas are usually developed on loess, till, lacustrine, alluvial or coastal plains where transported soils are involved. However, for most applications in humid climates, the presence of exposed soils or rocks represents an exceptional condition. But usually enough bare soil areas are imaged to aid in interpretation (except in the tropics).

Bare soils tend to have a maximum reflectance variation in the 0.6 to 0.7 micron portion of the spectrum. This range is included in the spectral sensitivity of color, color infrared, and panchromatic films. This explains why panchromatic films have proven quite satisfactory for general detail soil mapping. However, color films offer greater ease in identification of soil and rock features and consequently field checking may be reduced. Tanguay indicates that soil boundaries may be most easily and accurately delineated with color film.[10] Often a unique color may be associated with a particular stratigraphic unit or igneous complex, and used as a ready horizon marker in mapping bedrock. If field checks are performed on each unit, surficial geological maps may be prepared directly from the color aerial photographs. However, for the interpretation of landform-parent material relationships, scale is much more important than the type of photographic medium employed whether it be panchromatic, color or color infrared film. Usually, a small scale is desirable (e.g., 1 mile per inch). For detail, soils mapping and determination of soil boundaries, a larger scale is more useful (1,000 feet per inch).

Infrared photography gives increased contrast between wet and dry soil areas and thus is superior for the preparation of drainage maps. Similarly, infrared photography will emphasize the surface configuration and textural detail on exposed bedrock due to the presence of shadows and small amounts of moisture in bedrock depressions.

WATER

Photography of water bodies may be obtained for gaining information about the bottom materials or for ascertaining the spatial variations of certain physical properties near the surface of the water itself. Color photography of near shore environments will give much useful data related to subaqueous terrain (Plate 6). The actual recorded image detail will depend on the solar altitude, the presence or absence of clouds, the effects of the intervening atmosphere, interference from wave and wind action, the transparency of the water (turbidity, pollution etc.), the inherent reflections from the subaqueous terrain and the film-filter combination used. Photography of underwater landscapes should be conducted when the solar altitude is approximately between 30° and 60° as measured from the zenith. At these altitudes, sufficient solar illumination is available and specular reflection may be avoided unless the water surface exhibits extreme wave interference patterns or turbulence. Fairly low-altitude photography will yield greater water penetration than photography from high altitudes due to reduced atmospheric effects. Experience indicates that slightly better penetration is obtained with a high thin cloud overcast than for clear conditions. The actual transparency of water bodies varies greatly with the surrounding terrestrial environment. Usually, tropical waters transmit light much more readily than do northern waters. Fresh water lakes exhibit greater clarity in late summer after the effect of the influx of surface runoff from adjacent terrain has been dissipated. Similarly, coastal waters are clearer in the late summer after the passage of winter and spring storms. Heavy rainfalls or storms tend to increase the turbidity of shallow water bodies. The inherent contrast of subaqueous features affects their detectability. For example, organic sediments or mafic rocks are more poorly imaged than light colored sands in equal depths of water.

Color and color infrared films may be used for aqueous studies. These films each have characteristics which must be considered. In most instances, color film will give the optimum image of underwater terrain, whereas color infrared film will emphasize patterns related to the physical and chemical properties of the water and the suspended matter it may contain, particularly near the water's surface. This effect is caused by the increased light absorption of water at longer wavelengths.

The attenuation of radiation in water, as in most mediums, is approximately exponential and is dependent on wavelength.[8] This wavelength dependence is illustrated in Figure 9. Figure 9 shows the percentage of incident light at various depths in Lake Huron for a number of unique spectral bands. Maximum penetration occurs in the 0.44 to 0.49 spectral band. Plate 6 is an example of color photogra-

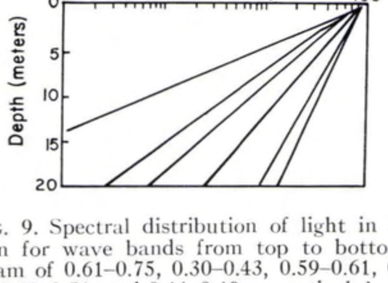

FIG. 9. Spectral distribution of light in Lake Huron for wave bands from top to bottom of diagram of 0.61–0.75, 0.30–0.43, 0.59–0.61, 0.54–0.59, 0.49–0.54, and 0.44–0.49 respectively[1].

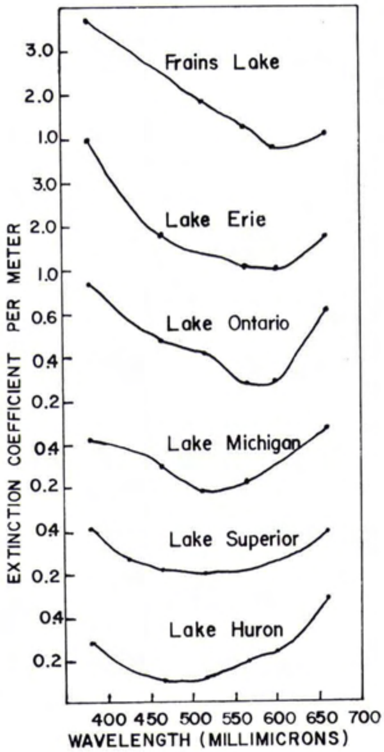

FIG. 10. Vertical extinction coefficients for various wavelengths in the Great Lakes and a small inland lake[1].

phy exposed in mid-summer to show offshore sand bars and the extent of the marginal shell in Georgian Bay, a part of Lake Huron.

Typical vertical extinction coefficients expressed as a function of wavelength are shown in Figure 10 for each of the Great Lakes and for a small inland lake. The extinction coefficient is a measure of the light absorbed per meter of depth by the water. Increased extinction coefficients indicate increased difficulty in obtaining images of the subsurface environment. It should be observed that as the extinction coefficient per metre of depth increases, so does the wavelength for greatest penetration. Thus, for turbid water, such as river water containing a great deal of suspended matter, wavelengths for optimum imaging are extended and are included within the sensitivity of infrared film. Thus, little difference is encountered in practice for imaging of subsurface features in turbid water on either color or color infrared photographs.

Experimentation to study the diffusion of a chemical dye in a sediment laden river, discharging into Lake Ontario, was conducted in early spring. Simultaneous exposures over the north shore of the lake were obtained with unfiltered color photography and infrared color photography using Wratten #29, #70, and #89B filters. The #29 filter used with infrared color film yielded the best results for imaging the surface diffusion patterns of the turbid water flowing into the lake. The spectral response of water recorded on photographic films is indicative of some of the physical properties of the water. For instance, the color of water recorded on aerial photographs is a complex function of bottom reflection and reflection from suspended particles in the water. If water appears black on color photography, it indicates that complete absorption of light has occurred. This may be caused by a number of factors, such as low reflectance from a stream or lake bottom or from areas of deep water (Plate 6), or perhaps if dissolved oxygen levels are low. It may be for this reason that plumes from sewage treatment plants are recorded as black on infrared photographs. In water with considerable sediment content reflection from the near surface, suspended sediments may emphasize this effect. Good results for rivers were obtained by comparing simultaneous exposures of infrared (Wratten #70 filter) and color photographs.

SNOW AND ICE

Snow has a very high reflectance for visible light, but the reflectance decreases rapidly with extended wavelengths (Figure 8). Textural patterns on snow and ice are enhanced to a considerable extent with the use of color infrared film (Plate 5). Color film exposed at the same time as Plate 5 showed a lack of detail. Patterns on snow and ice surfaces are caused by shadows from topographic irregularities, the presence of impurities in the snow and ice, and the presence of liquid water at the surface. Factors such as ice depth, snow thickness, density, and the surface configuration of the underlying terrain also contribute to the tone and texture of the winter scene. With color photography, it is difficult to obtain the proper film exposure due to the high scene reflectance. Color film exposed simultaneously with Plate 5 showed a lack of detail. At the same time, shadow detail and surface ice accumulations were not enhanced.

CITIES

Because infrared color film has a high contrast and is used with a yellow filter, it offers superior haze penetration as compared to color photography. This capability is particularly beneficial in urban and industrial areas where atmospheric pollution may be a problem. However, shadows from vertical features may cause problems with infrared photography. In conducting photographic missions over cities, it must be kept in mind that atmospheric pollution has spatial and temporal variations. For example, haze is usually less of a problem on weekends and in suburban areas.

TABLE 1. SUMMARY OF FILM CAPABILITIES FOR TERRAIN ANALYSIS

(ASSUMING OPTIMUM ATMOSPHERIC CONDITIONS)

	Panchromatic	*Color*	*Infrared Color*
1. Photographic			
(a) Image Definition	1	3	2
(b) Shadow Penetration	2	1	3
(c) Shadow Emphasis	2	3	1
(d) Haze Penetration	2	3	1
(e) Ease of Association by Non-Technical Observers	3	1	2
2. Vegetation			
(a) Species Identification	3	2	1
(b) Detection of Loss of Vigour	3	2	1
(c) Mapping	3	2	1
3. Exposed Soils and Rock			
(a) Topography	2	1	1
(b) Macro Drainage	3	2	1
(c) Micro Drainage	3	2	1
(d) Moisture Content	3	2	1
(e) Soils Mapping	2	1	2
(f) Soil Failures	3	2	1
(g) Fracture Patterns on Rocks	3	2	1
(h) Detection of Rock Outcrops	3	2	1
4. Water			
(a) Penetration	2	1	3
(b) Absorption	2	3	1
(c) Aquatic Vegetation (Surface)	3	2	1
(d) Aquatic Vegetation (Subsurface)	3	1	2
(e) Pollutants	3	2	1
5. Snow and Ice			
(a) Depth & Thickness	2	3	1
(b) Meltwater Accumulation	2	3	1
(c) Drift Patterns	2	3	1
6. Urban			
(a) Land Use	3	1	2
(b) Traffic Studies	3	1	2
(c) Pavement Studies	3	2	1

Color film exposed over urban areas under hazy conditions may result in a poor color balance due to the exclusion of blue light. When atmospheric conditions are good, the use of color photography will permit the interpreter to readily identify cultural micro features in the urban scene.

A summary of film capabilities for terrain analysis is provided in Table 1. The numbers indicate the relative suitability for each film (1 being the best) for a particular application assuming atmospheric conditions are ideal. These tabulations apply for professional interpreters with backgrounds in the particular discipline described. The tabulations do not necessarily apply for the layman. They are intended as a guide for a person planning the use of these media.

URGENCY

Special purpose projects, such as the acquisition of data for the location and design of engineering facilities, cannot afford the luxury of time lost for the optimization of the film-filter terrain interaction. Photographs must be obtained when the project has first approval by the client. This may require exposing the film under less than ideal atmospheric condition and/or at a time when terrain reflectance does not provide maximum contrast for objects of interest. However, much may be done to solve this problem by properly matching the recording medium to the scene. For example, if soils mapping is involved on a typical till plain with intense agricultural use, color photography might be used in the spring and autumn and infrared color photography might be used in the summer. Color photography might be used with overcast conditions. Thus, the use of color and infrared color photography may be used to extend the temporal conditions under which adequate, but perhaps not optimum photography for most purposes, may be obtained. The use of different film-filter combinations, exposed simultaneously, will result in the maximum available information to terrain analysis.

SUMMARY

The photo interpreter should be actively involved in the selection of the film-filter combination and the spectral balance of color films. The color balance should be selected to provide maximum contrast in the terrain of interest. An understanding of the physical parameters affecting the image recorded on color and color infrared film for given terrain conditions will enable the photo interpreter to increase both his accuracy and his efficiency.

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