SOME OBSERVATIONS ON PHOTOGRAPHIC INTERPRETATION

What is Photographic Interpretation?

by

Charles E. Olson, Jr.
School of Natural Resources
The University of Michigan

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WHAT IS PHOTOGRAPHIC INTERPRETATION?

Photographic interpretation is defined by the American Society of Photogrammetry (1) as: "The act of examining photographic images for the purpose of identifying objects and judging their significance."

Almost every individual engages in photographic interpretation. Books, newspapers, magazines, billboards, and television all offer photographs to look at; and with each look the observer gains ideas or impressions about something. These ideas or impressions are actually photographic interpretations. Such interpretations may be conscious or unconscious, accurate or inaccurate, complete or partial; but interpretation is an essential part of the process through which information is obtained from photographic images.

A photographic interpreter, or photointerpreter, is an individual specially trained or skilled in photographic interpretation. Because of his training or skill, the photointerpreter is better able to identify objects from their photographic images and can more accurately and completely judge the significance of these objects than can an unskilled or untrained observer.

Photographs as Graphic Records

Civilization and man's ability to communicate developed together. People may argue about the order in which communication media developed, but all agree that drawings came early. Man's first drawings may have been finger markings in the dirt which approximated the shape of things that he had seen. When some indication of size, or scale, was added, his drawings became more meaningful. Color and indications of fur, hide, or texture have been found in early drawings of the cave man, indicating that the importance of these qualities was recognized at an early date. As man and man's civilization advanced, his ability to communicate improved. Languages became more expressive and drawings more detailed. Such things as shading and shadows, repetition of patterns, and combinations of related features were added. These additions improved his graphics, but man was not satisfied. He wanted a complete picture of what he had seen, and he kept searching for some way to record what his eye actually saw.

The search for better graphic records led to the photographic process, but the road was a long one and progress was neither direct nor steady. Aristotle's concern with the nature of light (approximate 384-322 B.C.) was an early prelude to photography. Actually, the word photography was derived from Greek and means "to draw with light."

A photograph is nothing more nor less than a graphic record of energy intensities.

Today, and increasingly in the years to come, photographic interpreters should not limit their consideration to images or records produced with visible light. A photograph records the intensity of energy received at the focal plane of the taking camera. By varying the characteristics of the recording system, we can obtain records representing wavelengths of energy in many parts of the electromagnetic spectrum. Each part of the electromagnetic spectrum can provide useful information, and most photographic interpreters will have to work with graphic records from several parts of the spectrum. Their field of interest includes the entire electromagnetic spectrum and the images that can be produced with many sensors. Unfortunately, the mechanics involved in obtaining the photographic, or just graphic, images from several sensors causes us to lose sight of the basic situation that brought these sensors into existence. Man's search for better graphic records led to photography, and <u>any photograph, regardless of its origin or the type of images displayed, is nothing more nor less than a graphic record</u>.

Elements of Photographic Interpretation

Photographic records come in many shapes and sizes and represent energy in many parts of the spectrum. Photographic interpretation is essential to the effective use of these records, and interpreters should be prepared to handle them. Interpretation of these varied records is not as difficult as it may appear, for the elements of photographic interpretation apply to all graphic records regardless of the nature of the sensing system that produced them or the portion of the electromagnetic spectrum represented. While a thorough knowledge of the characteristics of the sensing system is of immense value, interpretations of graphic records are always based on one or more specific properties of the images making up the record at hand. These properties are sometimes called <u>elements of photographic interpretation</u>, for interpretation of photographic records requires either conscious or unconscious consideration of one or more of them, and preferably of all of them (10).

Nine elements of photographic interpretation are described in the following paragraphs. The discussion is not intended to be exhaustive, for a separate book could be written about each of them. Appreciation of the importance of these elements grows with experience and practice.

1. <u>Shape</u>. The shape or form of some objects is so distinctive that their images may be identified solely from this criterion. The Pentagon Building near Washington, D. C. is a classic example.

2. <u>Size</u>. In many cases, length, width, height, area, or volume are essential to accurate and complete interpretation. The volume of wood which could be cut from the stand in Figure 1 is dependent upon tree-size, stand density, and size (or area) of the stand.

3. <u>Tone</u>. Different objects reflect and emit different amounts and wavelengths of energy. These differences are recorded as tonal, color, or density variations in the record. The stand of mixed hardwoods shown in Figure 1 was photographed in late October at the peak of the fall color

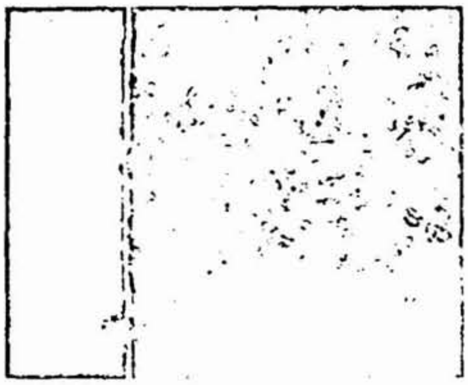


FIG. 1. Panchromatic-minus blue photograph of mixed hardwood stand at the peak of the fall color change. Lightest toned tree crowns are sugar maple; dark-toned crowns are generally oak. (University of Illinois photograph.)

FIG. 2. The shadow of this building shows the steeple more clearly than does the image of the steeple itself. (University of Illinois photograph.)

FIG. 3. Land-use pattern on loess in Calhoun County, Illinois. (U.S.D.A. photograph.)

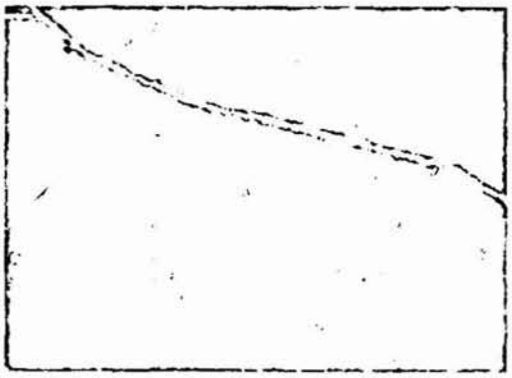


FIG. 4. Black spruce, northern white cedar, and balsam fir in swampy area in Leelanau County, Michigan. (University of Illinois photograph.)

FIG. 5. Thermal power plant at the University of Illinois. (University of Illinois phograph.)

FIG. 6. Shallow water revealed by tonal contrast, although exact shoreline is not resolved; Leelanau County, Michigan. (University of Illinois photograph.)

change. Species differences show clearly in different tones or shades of gray.

4. Shadow. Shadows can help or hinder the interpreter, for they reveal invisible silhouettes but hide some detail. Shadows in Figure 2 provide information on the size and shape of this building which is not apparent from the image of the building alone. These same shadows obscure detail in the lawn and sidewalk areas in front of the building.

5. Pattern. Pattern, or repetition, is characteristic of many man-made objects and of some natural features. The land-use pattern shown in Figure 3 is typical of areas of deep, wind-blown soils. Orchards and strip cropping are particularly conspicuous because of pattern.

6. Texture. The visual impressions of roughness or smoothness created by some images is often a valuable clue in interpretation. Tree size is often interpretered on the basis of apparent texture. Smooth, velvety textures are commonly associate with young saplings, while rougher, cobbled textures usually indicate older trees of sawtimber size.

7. Site. The location of objects with respect to terrain features or other objects is often helpful. The open pond and the flatness of the area of dark-toned vegetation in Figure 4 both indicate a coniferous swamp. In this area of Michigan, northern white cedar, balsam fir, and black spruce are the predominant swamp conifers. The stand shown here is actually a mixture of these species.

8. Association. Some objects are so commonly associated with other objects that one tends to indicate or confirm the other. In Figure 5, the two tall smokestacks, large building, coal piles, conveyors, and cooling towers are obviously related. This combination and arrangement of features identifies the installation as a thermal power plant.

9. Resolution. Resolution depends on many things, but it always places a practical limit on interpretation. Some objects are too small, or otherwise lacking, to form a distinct image on the photograph. The lake in Figure 6 shows some interesting tonal patterns, but the exact location of the shoreline is not visible along much of the boundary of the lake. The shore-line failed to resolve because of insufficient tonal contrast between adjacent land and water surfaces.

Note that seven items on this list are qualities that man developed in his early drawings. The last three items are important to interpretation because they tend to integrate or set limits on the others. In 1954, Colwell presented a concise statement showing how integration of interpretations of several photographic images could lead to accurate interpretation of conditions not directly visible in the photograph (3). He called this approach the "convergence of evidence." Integration of several of the elements of photographic interpretation is essential to any interpretation and contributes to the "convergence of evidence" frame of mind. Association, in particular, is closely related to this "convergence of evidence" concept.

The Philosophy of Photographic Interpretation

In recent years, photographic interpretation has been called a new natural science (8, 9). An increasing volume of literature has appeared, and is appearing, that attempts to establish rules or procedures for photointerpretation (7, 8, 13). However, no single, best method of procedure has evolved which is acceptable to even a majority of photointerpreters. It is generally agreed that the interpreter should work methodically, should proceed from general considerations to specific details, and should proceed from known to unknown features (13). Methodical work and interpretation of known features before evaluating the new and unknown features are almost axiomatic in scientific endeavors. Proceeding from general to specific considerations is also desirable as long as the considerations of general (sometimes called regional) features do not bias the interpretation of the specifics. Specific, local considerations often provide the evidence needed to complete or confirm the broader regional pattern. In most cases, general and specific features must be considered together. To say that one must come before the other can be misleading. To go further than this and propose that interpretation should proceed from one specific group of features to another is an unwarranted channelization of the infinite variation that the photointerpreter encounters.

Drainage, landform, vegetation, and man's activities are thoroughly scrambled in most photographs, and each feature may be indicative of the nature of the others. For this reason, the photointerpreter should be terrain-conscious in the broad sense of terrain. He should understand that the images he interprets make up a terrain and that the terrain he deals with is a complex series of interrelated features academically catalogued as agriculture, botany, geology, engineering, etc. The importance of these interrelationships was clearly expressed by C. H. Summerson (14) when he said:

> "The subject matter of the photo interpreter is as broad as the earth itself; ...upon the earth's surface is a tremendously varied pattern of natural features, upon which man has superimposed an equally varied cultural pattern. .... Where there are so many varied objects to be considered, our first inclination is to classify. Classification is indeed necessary, but it must always be remembered that groupings are man-made and not natural. .... Conclusions based on empirical identifications of isolated elements in a terrain may often be very inaccurate. .... The knowledge that no region is a static thing greatly aids the interpreter in his understanding of the terrain."

Because aerial photographs record images of all types of terrain features, photointerpretation has become a valuable tool in each of the earth sciences, and in several other fields as well. However, photointerpretation cannot be confined to geology, forestry, soils, or any single field and remain effective. The photointerpreter must consider all of the factors making up any terrain, even when his special interest may be directed solely to geology, forestry, agronomy, or engineering. Failure to give adequate consideration to all aspects of a terrain is a major cause of misinterpretations. Belcher put it this way during a discussion of correlations between man's activity and his environment (2):

> "...the average interpreter does not know many things and he doesn't realize his lack of knowledge. If he places two elements of the environment together and pulls a boner, it isn't because the environment is wrong; instead it's because there were three other elements that he ignored or didn't know were there."

The Photographic Interpretation Process

Photographic interpretation is a deductive process and features that can be recognized and identified directly lead the photointerpreter to the identification and location of other features in the terrain under consideration. Even though all aspects of a terrain are irreversibly intertwined, the photointerpreter must start some place. He can't consider drainage, landform, vegetation, and man-made features simultaneously. He must start with one feature or group of features and then go on to the others, integrating each of the facets of the terrain as he goes. In all probability, no one starting point will satisfy, or be best for, all interpreters or for any one interpreter all of the time. For each terrain, the interpreter must find his own point of beginning and then consider each of the various aspects of the terrain in logical fashion.

The deductive process which is photographic interpretation, requires conscious or unconscious consideration of the elements of photographic interpretation listed earlier. The completeness and accuracy of photointerpretation are proportional to the interpreter's understanding of how and why photographic images show shape, size, tone, shadow, pattern, and texture, while an understanding of site, association, and resolution strengthens the interpreter's ability to integrate the different features making up a terrain. For the beginning interpreter, systematic consideration of the elements of photographic interpretation should precede integrated terrain interpretation. Mastery of the elements of photographic interpretation is seldom possible, however, before the interpreter gains considerable experience in terrain interpretation.

Photographic Interpretation and Photogrammetry

Interest in photointerpretation has been stimulated during the last 15 years, or more, by outstanding successes achieved through photointerpretation of aerial photography for military and civilian purposes. Without question, early and continuing development of instruments permitting precise measurement and mapping from aerial photographs contributed to these photointerpretation successes. Since these instruments are usually considered tools of photogrammetry, it is sometimes difficult to distinguish between photogrammetry and photographic interpretation.

Photogrammetry is defined by the American Society of Photogrammetry (1) as: "The science or art of obtaining reliable measurements by means of photographs."

Photographic interpretation was defined at the beginning of these notes as: "The act of examining photographic images for the purpose of identifying objects and judging their significance" (1).

From these definitions, it is clear that the photogrammetrist (as the specialist in photogrammetry is called) is primarily concerned with measuring and the photointerpreter with identifying and judging significance. It should also be clear that the photogrammetrist cannot make a measurement unless he first identifies what he is going to measure, and that the photointerpreter must often measure to arrive at a final identification and his judgment of signficance.

INTERPRETATION OF AERIAL PHOTOGRAPHS

Vertical aerial photographs--those taken with the optical axis of the camera pointed vertically downwards towards the earth--are the most common graphic records encountered by photointerpreters. This does not mean that vertical photographs are always best for interpretation purposes, for oblique photographs can provide tremendous amounts of information. It just happens that the advantages of vertical photographs for photogrammetric mapping purposes are so great, and the amount of mapping photography so plentiful, that vertical photographs are more readily available than all other types of aerial imagery.

Interpretation of vertical aerial photographs is sometimes difficult for the beginner. Everyone is used to the oblique perspective that we see every day with our own eyeballs, but the plan view observed when looking down on the tops of objects is much less familiar. Being less familiar, in plan view, many objects are more difficult to identify from vertical, than from oblique, air photos. Despite this, correct integration of clues gained from an assessment of the nine "elements of interpretation" mentioned earlier can lead to consistently accurate results. Brief looks at how each of the elements of interpretation can contribute to correct interpretations follow. The discussion is not intended to be exhaustive, and some elements are treated at greater length than others. Taken together, however, they provide a starting point from which interpretation of the complex interrelationships portrayed in aerial photographs can begin.

Shape

One of the most outstanding examples of shape as a factor in interpretation is found in the almost instantaneous recognition of the Pentagon Building in Washington, D. C., because of its shape. All shapes are not this diagnostic, but every shape is of significance to the photographic interpreter. Stated another way: The shape of any image is a factor that the interpreter should consider when interpreting that image.

Consideration of shape should include consideration of total form. Relative proportions of length to width, height to length or width, etc., are just as important as generalized outlines seen in plan or profile view.

When geometric shapes are present, man's activity is almost always indicated. Symmetric, straight, or perpendicular forms are rare in nature, but do occur in geologic features such as domes, faults, and bedding planes. Also, old fire scars and storm damage can give rise to straight and/or angular boundaries between vegetative types. In any case, the presence or absence of definite shapes should be observed and noted by the interpreter.

Linear Features

Linear features--those that are exceptionally long compared to their width--are some of the most obvious images in photographs. Roads, railroads, power lines, and streams are some of the most important of these, but the interpreter needs to be alert to even the less obvious linear elements in the terrain he is interpreting. Even distinguishing between the more obvious linear elements presents some difficulties, but the following observations may be helpful.

Railroads are characterized by broad sweeping curves and the complete absence of sharp corners, except at crossovers which are relatively rare. Grades are relatively flat, when compared with highways, and cuts and fills are common. The roadbed is continuous and bridges will be present where the railroad crosses streams and significant ravines.

Highways and roads resemble railroads, but have sharp corners and right-angle intersections. Grades are steeper than with railroads, and highways tend to follow the contour of the ground with fewer cuts and fills. Bridges are common (where needed), but many small streams have earth-fill over culverts instead of bridges. When side-by-side, highways often swing away from the railroad going through small towns, but the railroad usually goes straight through. While it is true that the newer super-highways have grade and alignment characteristics resembling railroads, the dual lanes with wide median strips, and the presence of cloverleaf interchanges, permit ready interpretation in almost all cases.

Electric transmission lines are straight, or composed of straight segments, and tend to cross the terrain with no reference to topography. Trees are cleared from rights-of-way and this leaves a narrow, but distinctive, scar through forested areas. Sometimes poles or pylons are visible, but not at the smaller scales often encountered by the photointerpreter. Pole locations can sometimes be identified from the mound of subsoil left after digging the postholes. In some cases, the wires themselves can be seen, even at scales as small as 1:20,000. Electric transmission lines cross streams and ravines without bridges, but maintenance roads may be visible along the otherwise clear pole line.

Gas pipelines resemble electric transmission lines, but seldom have maintenance roads along them, and are less oblivious to topography. A continuous line of subsoil, left after digging the ditch for the pipe, persists as a distinctive feature for years. In some areas, pipelines can be seen in aerial photographs as light-toned streaks crossing corn fields even though the photographs were taken more than ten years after the pipeline was constructed. Even where cropping is continuous, the soil disturbance associated with the pipeline produces different light reflectances than the undisturbed areas adjacent to it, and these may well persist for more than ten years. To simplify tunnelling under existing roads, pipelines often bend sharply towards the road just before the point where the tunnelling begins. This jog in the path of the linear feature is rare with power lines.

Fence lines are difficult to identify except when land use is different on the two sides of the fence. Once land use has been established for a long period of time, the fence lines may be quite obvious in aerial photographs even decades after the land use pattern has been abandoned. This is particularly true of old farms that have been planted to trees or allowed to reseed naturally.

Streams are seldom confused with other linear features because of their irregular shape, varying width, and complete dependence on topography.

Drainage ditches are common in flat lands and are usually easy to separate from natural streams because of their distinct tendency to be straight and have uniform width. A trail of dredged material may be visible on one, or both, banks of the ditch. Some confusion may arise where existing stream channels are improved to facilitate drainage, with or without a realignment of the channel, but careful consideration of the total drainage pattern usually indicates the true situation. In some areas, ditches are used to transport irrigation water from mountain reservoirs to dryer valleys and plains. In these valleys, irrigation ditches may resemble the drainage ditches of other areas. Once again, complete consideration of the drainage system (or irrigation system) will clear the air.

Geologic faults are linear features that can be quite obvious when prominent rock structures are truncated or roads displaced. In other cases, and especially after extensive weathering, faults may be very difficult to recognize.

Dams are shorter than the features discussed above, but may well be mentioned at this point. Straight, or smoothly curving, sections of shoreline should be studied carefully to be sure that that piece of beach isn't actually the dam that indicates an artificial lake as opposed to a natural one. The presence of the dam may indicate the work of man and suggest other man-made features in the same area. However, all dams are not man-made and beaver dams more than a mile in length are known.

Tree Species

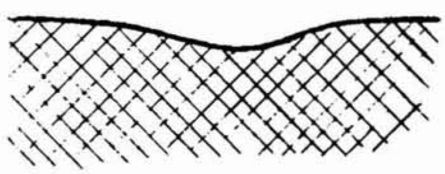
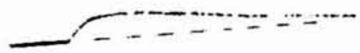
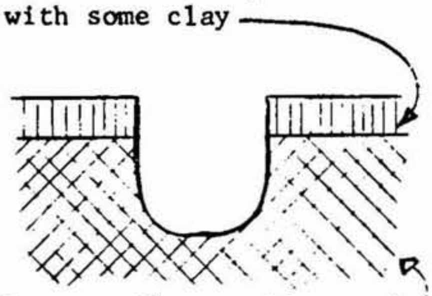
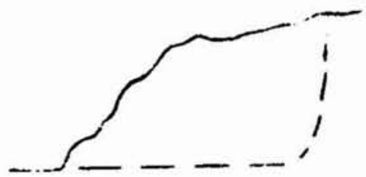
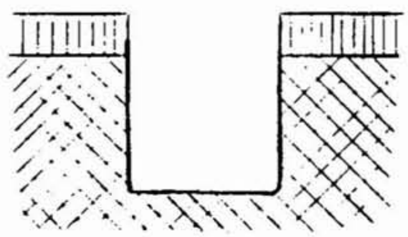
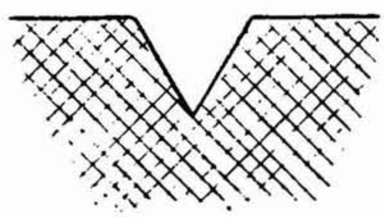
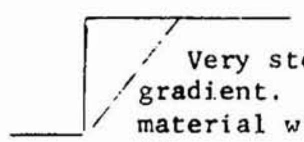
Shape is often an aid in interpreting tree species, for branching habits and total form vary from genus to genus, and in some cases between species within a genus. Shadows often provide a profile view which helps in tree identification.

Soil Texture

Soil texture can often be determined from aerial photographs if careful attention is paid to the cross-sectional shape of the small gullies that are present. Several factors have to be considered and it is easy to make errors, especially when hardpans or abrupt changes in soil texture with depth produce compound gully shapes. An example of one over-generalized, but still useful, treatment of gully shape is attached.

Gully Shape as an Indicator of Soil Texture

Adapted from: A photo-analysis key for the determination of ground conditions: Land form reports, Volume I - General Analysis. Cornell University and the Office of Naval Research, 1951.

Soil description	Cross section	Longitudinal profile
Cohesive soils Clays and silty clays (common old lake beds, marine terraces, and clay-shale areas).		 Low, uniform gradient
Moderately cohesive soils Weakly cemented sand-clays (common in coastal plains and many bed-rock areas).	Weathered soil profile with some clay  Loose soil or rotten rock	 Compound gradient
Moderately cohesive soils Silts (primarily loose and alluvial silt deposits. Also fine volcanic ash falls).		 Fins and pinnacles near head-end. Compound gradient.
Non-cohesive soils Sands (common in terraces and outwash plains).		 Very steep gradient. Coarse material with few fines  Short, steep, uniform gradient. Well-graded mixtures

Size

The fact that some objects are bigger than others should need no special mention, but beginning interpreters often forget that relative sizes of different objects in a single photograph can provide valuable clues. Some objects are readily identifiable and can be used as guides to the approximate sizes of other objects that are not so easily recognized. In many cases, however, relative size is not enough and the interpreter must use some of the techniques of the photogrammetrist. These will not be discussed in detail, but some indication of the possibilities seems in order.

Distance

The distance between two points, or the length of an object, can be determined from an aerial photograph. The accuracy of such measurements is a function of photo scale and the accuracy of the photo measurement. On standard USDA photography at a scale of 1:20,000, a careful interpreter can usually determine distances to an accuracy of approximately ± 5 feet. When the ends of the distance(s) measured are at significantly different ground elevations, accuracy usually decreases.

Height

The heights of objects, or differences in elevation between ground points can be determined from air photographs. Several methods are available, but the best is that based upon differences in parallax between two vertical photographs of an object taken from different points in space. Stereoscopic photography is required. Careful work can provide spot height data (i.e., height of a tree or building) accurate to within ± 1/2000 of the flying height. Topographic mapping or contouring can be performed to somewhat lower accuracy. Contouring requires continuous determination of spot elevations and is more difficult than determining the height of a single small object.

Area

Determination of the area of irregular parcels is more easily accomplished from vertical photographs than with ground methods. Accuracy is limited by scale and slope, but has been found acceptable for most natural resource purposes. In rough terrain, it is often easiest to transfer boundaries from the photographs to a planimetric map, and then determine the area of the parcels of interest from the map boundaries.

Volume

Many organizations with large quantities of raw materials routinely use aerial photographs to determine the volume of material in open piles. Photogrammetrically determined volumes have proven accurate enough to permit useful estimations of the quantity of the finished product produced by the plant.

Tone

Tone, whether the shade of gray in a black and white photograph or the combination of hue, chroma and saturation in a color photograph, conveys more information to an alert, knowledgeable interpreter than any other single element of interpretation. In almost all cases, however, it is the difference in tone between objects, or between an object and its background which is important. In fact, without a difference in tone between the background and the edge of an object, there can be no detectable image.

Relative tone can be quantified by measuring the amount of light transmitted through a photographic negative or other transparency. As the amount of silver present increases, the amount of light transmitted decreases and we say that we have a denser, or darker-toned, image. Microdensitometers exist that can scan photographs at reasonably high rates of speed. If the output of such an instrument were plotted for single scans across a photograph, we might get plots such as those shown in Figure 7. The total range of density is greater in trace A than in B; but, due to the uniform change in density across the photograph, no images would be detectable in the strip of the photograph represented by trace A. The second trace (B) shows two distinct images. Notice, however, that the slope of the trace indicates that there is a much sharper change in density at the edges of image one than at the edges of image two. The slope of the microdensitometer trace, or the edge gradient (5), indicates that image one will be sharper, and easier to resolve, than image two. The second image may blend with its background and appear as a small blob rather than an object of distinct shape.

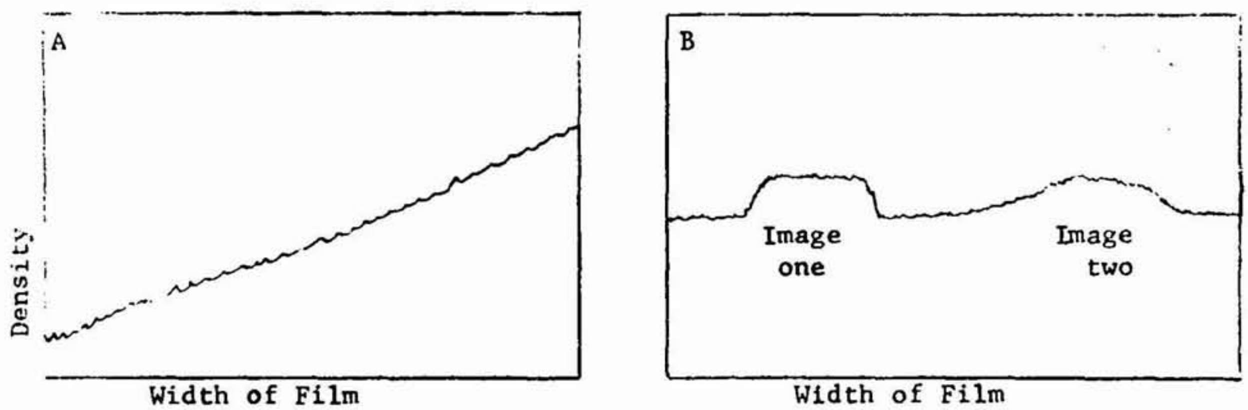


Figure 7: Potential microdensitometer traces at two different locations.

Colwell (4) described the significance of tone and edge gradient in much the same fashion when he listed three "primary characteristics governing the quality of photographic images" for photointerpretation. These were:

1. Tone contrast, or "the difference in brightness between an image and its background."

2. Image sharpness, or "the abruptness with which the tone or color contrast appears to take place on the photograph."

3. Stereoscopic parallax, or "the displacement of the apparent position of a body with respect to a reference point or system caused by a shift in the point of observation."

Colwell's first two characteristics have just been discussed, and the third was mentioned in the remarks under SIZE-HEIGHT.

The importance of tone, and tone contrast, justifies a closer look at the factors controlling tone in aerial photographs. Earlier in these notes it was stated that "a photograph is nothing more nor less than a graphic record of energy intensities." Thus, differences in tone in a photograph must be related to differences in energy intensities. How do such differences come about?

The Energy Flow Profile for a Camera System

The term energy flow profile was coined in 1962 to describe the sum of the complex factors affecting the energy reaching the focal plane of any camera (11). A schematic representation of the generalized energy flow profile for a camera mounted in an orbiting satellite is shown in Figure 8. The energy source is assumed to be the sun. Solar energy must pass through space and the atmosphere before reaching an object on the earth. Gases, clouds, and other media reduce the total amount and alter the spectral distribution of energy reaching the object. The object reflects some energy back into space, and some of this reflected energy may reach the camera, but not before passing through the atmosphere again. Some of the energy scattered by the atmosphere along the incoming path from the sun also reaches the camera and the image formed is the result of the sum of the energy from the object and the scattered energy component. The scattered energy component is nearly constant for all parts of a single photograph and produces a general increase in exposure, or fogging, of the photographic emulsion.

Up to this point in the profile, man can exert no direct influence except to decide if he will, or will not, take pictures. Once the energy reaches the camera, man can exert controls. Proper choice of filter lets us almost eliminate the effect of scattered energy, but at the expense of eliminating the blue and ultraviolet energy reflected by the object. Filters can block certain wavelengths and permit us to work with energy in specific spectral bands, but filters can never add anything to the profile that isn't already there.

Inside the camera, the energy reacts with the photographic emulsion on the focal plane of the camera to form an invisible, or latent, image. The nature of this image is controlled by the amount of energy hitting each part of the emulsion (the energy differences previously mentioned) and the spectral sensitivity of the emulsion. Since all emulsions are not alike (Figure 9), dif-

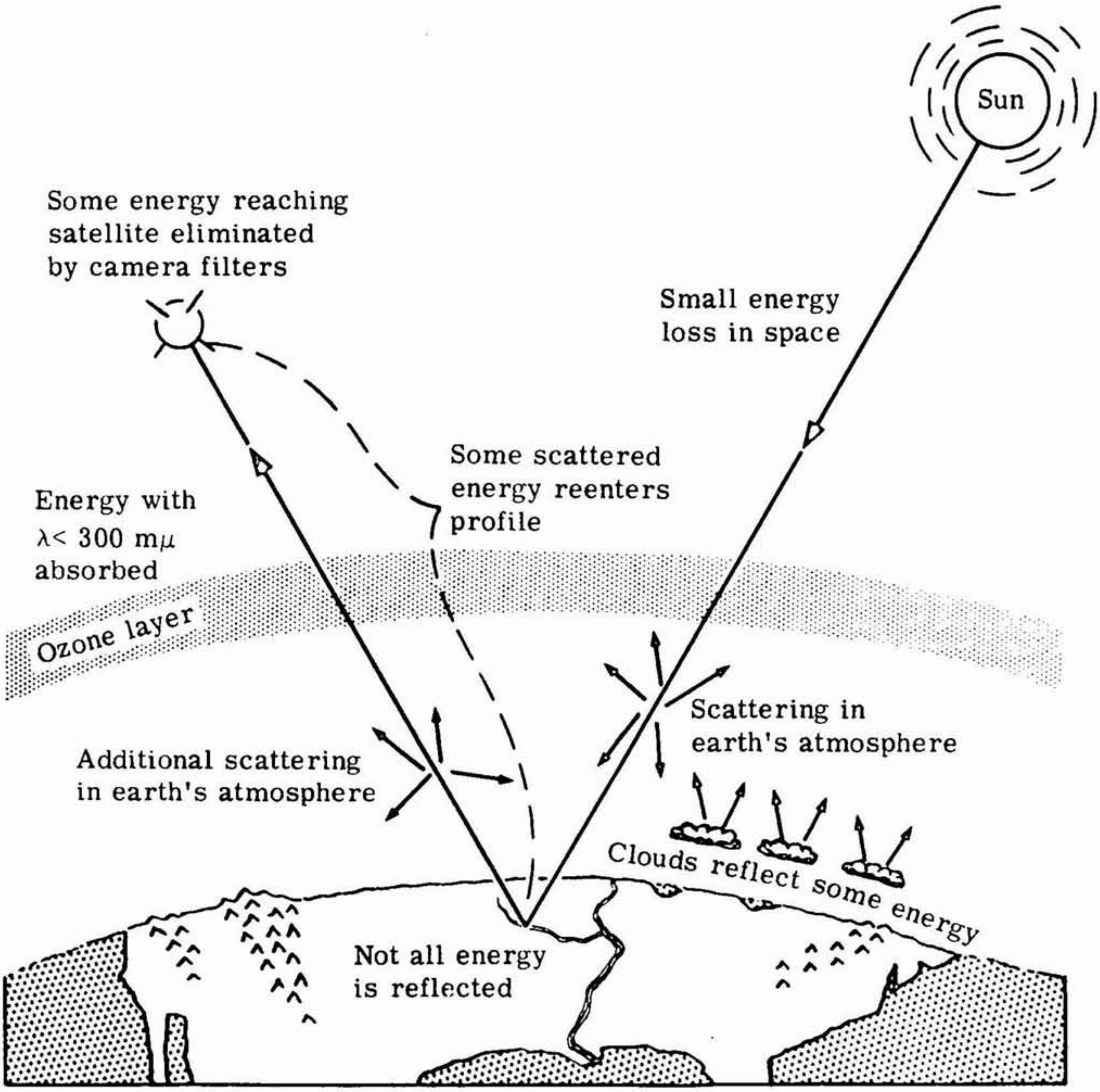


Figure 8: The energy flow profile for a camera system in an orbiting satellite.

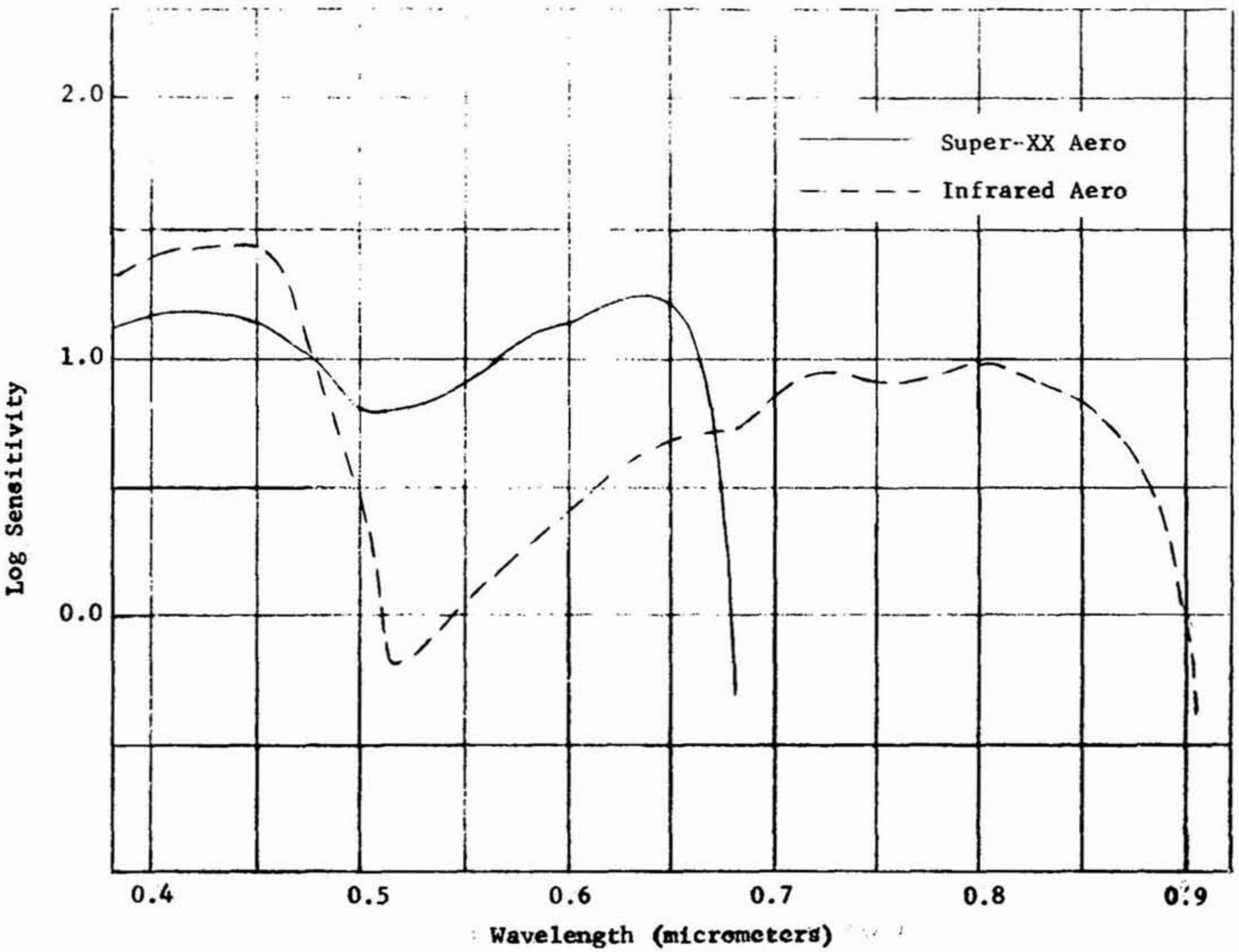


Figure 9. Approximate sensitivity curves for two aerial emulsions.

ferences in spectral disttibution, as well as total amount of energy reaching the focal plane, are important.

If we back off, for a moment, and look at the profile for a single photograph, we can see that the camera could be mounted in an airplane, or even hand-held on the ground, without changing the basic profile. Moving the camera location simply changes the length of the path of reflected energy from object to camera.

For a single photograph from nominal altitude, the primary variable in the entire energy flow profile can be proven to be the reflectance from the object. Differences in tone of the photograph require differences in reflectance from the different objects and backgrounds. Because of this, it is important for the interpreter to appreciate the various factors which can cause differences in light reflectance between different objects at one point in time, or from one object at different points in time. Data for forest trees will be used to illustrate the significance of this.

<u>Light Reflectance Properties of Forest Trees</u>

Light reflectance from tree leaves varies spectrally. As shown in Figure 10, a subdued maximum occurs near 0.55 micrometers, a distinct minimum near 0.65 micrometers, and a broad plateau of high reflectance is found between 0.8 and 1.2 micrometers. Reflectance at longer wavelengths is of little concern at the moment, for no practical photographic emulsion is sensitive at wavelengths longer than this.

While the shape of the curve in Figure 10 is representative of healthy green foliage from many species, the absolute reflectance can vary considerably. Seasonal changes in reflectance in the visible spectrum (0.4 to 0.7 micrometers) of considerable magnitude are apparent in Figure 11, but are more significant in broad-leaved species than in pine. In the spring when pine foliage is dark and new leaves on broad-leaved species are relatively light, aerial photographs show distinct tonal contrasts. Similar contrasts are not observed later in the year ~~(Figure 12)~~.

Sharp differences in tone can be obtained in different photographs taken simultaneously if the wavelength bands recorded are not the same. The two photographs shown in Figure 12 were taken simultaneously by two cameras in one airplane. One photo was recorded on a panchromatic film through a Wratten 12 filter while the second was recorded on an infrared sensitive emulsion through a Wratten 89B filter. The resulting wavelength bands recorded were approximately 0.50 to 0.68, and 0.70 to 0.98 micrometers, respectively.

All of the reasons for the differences in foliar reflectance are not understood, but moisture is an important factor. Leaves that develop under drought conditions tend to be less reflective than leaves that unfold with ample moisture (Figure 13). Yet leaves that unfold under ample moisture conditions show little change in reflectance if drought conditions are subsequently imposed upon the plant.

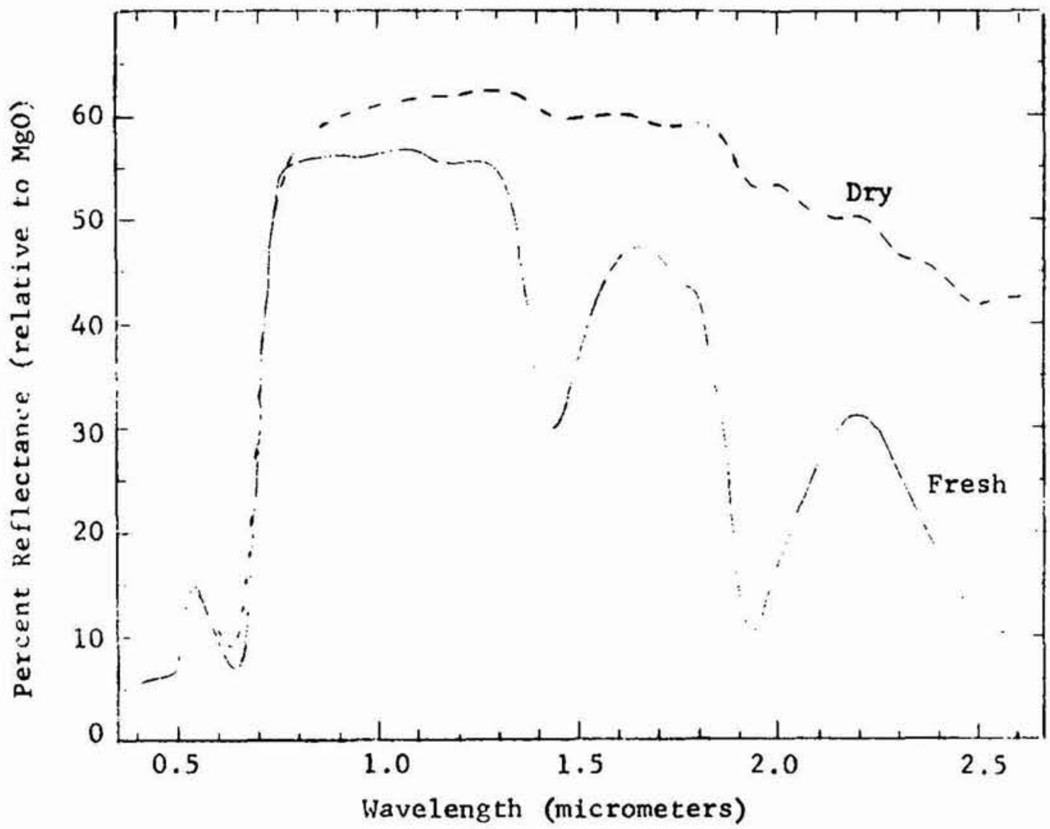
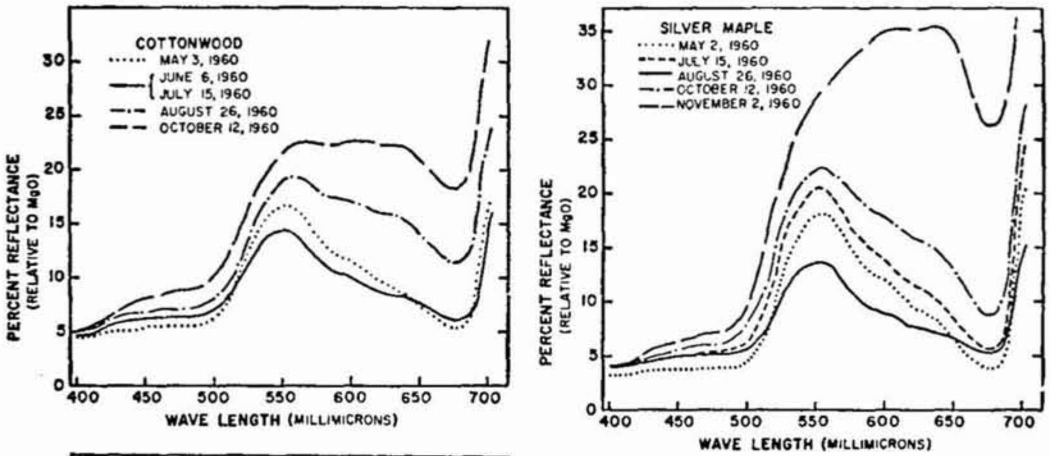


Figure 10: Spectral reflectance of the upper surface of a freshly picked sycamore leaf and the same leaf after air-drying for seven hours. Moisture content of the leaf decreased from 301 percent of its oven-dry weight when fresh, to 16 percent of its oven-dry weight after air-drying.

The general pattern of reflectance over wavelength shown here is typical of reflectance curves for most live, green, healthy vegetation.



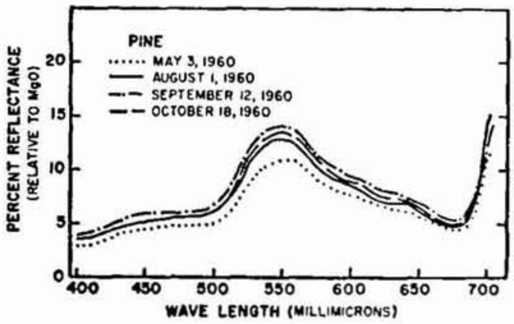


Figure 11: Spectral reflectance of tree foliage on several dates during a single year.

Figure 12: Panchromatic air photos of an area in Ogle County, Illinois, in May (right) and September (left). A minus-blue filter was used in both cases. (USDA photos)

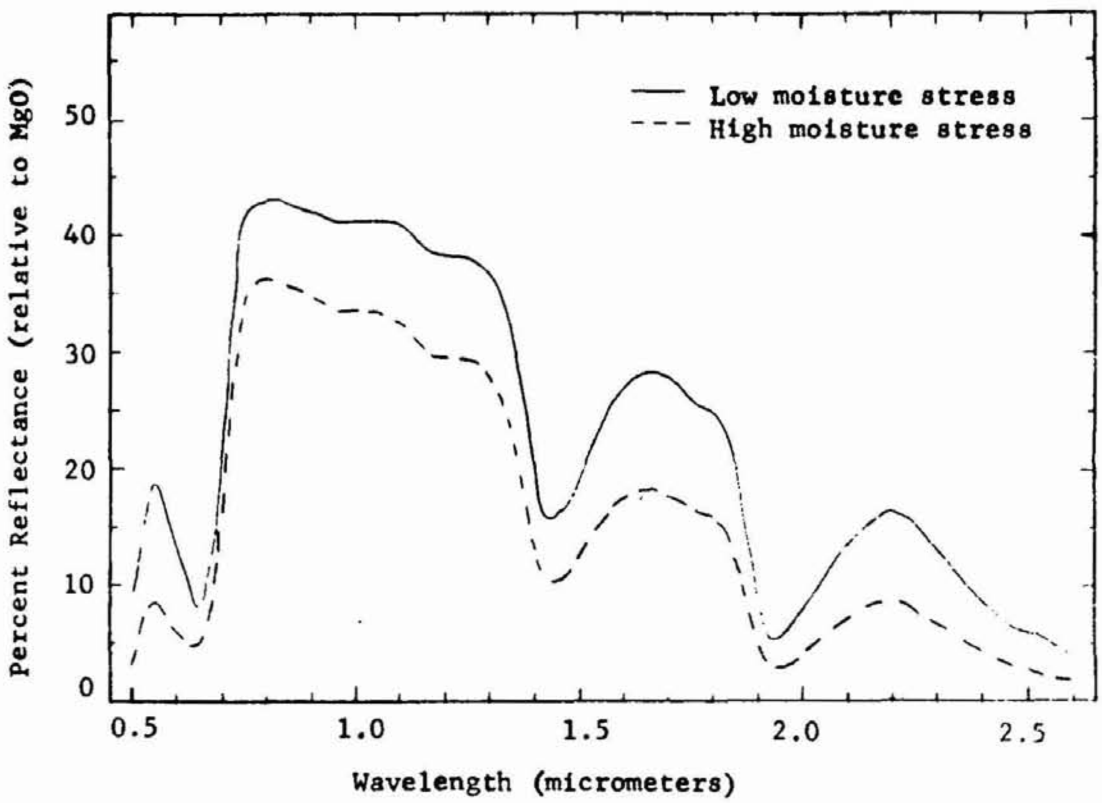


Figure 13: Spectral reflectance of the upper surface of immature leaves on two yellow poplar seedlings. One plant had been watered regularly and was under low moisture stress, while the second plant had not been watered for four weeks and was under high moisture stress. (Both curves were obtained without removing the leaves from the plants.)

A decrease in reflectance for leaves unfolding under high moisture stress, as compared with reflectance for leaves unfolding under low stress, has not been observed with all species.

Photographic Tone of Tree Foliage

Although reflectance from tree foliage is imperfectly understood, we can draw some general rules for the tonal rendition of trees imaged in positive prints from aerial photographs.

Broad-leaved trees photographed with a panchromatic emulsion tend to be light-toned in early spring, dark-toned during the summer, and turn lighter-toned at the onset of fall coloration. If an infrared emulsion is used, the trees are very light-toned, almost white, in the spring and summer, and become somewhat less light-toned at the onset of fall coloration.

Needled trees photographed with a panchromatic emulsion are dark-toned all year long, except for the deciduous conifers such as bald cypress and larch. If infrared emulsions are used, the conifers are usually dark-toned, and contrast sharply with the broad-leaved species.

Photographic Tone in Water Areas

Water tends to photograph in dark tones in all photographs, for specular reflections from smooth water surfaces are seldom reflected in the right direction to reach the camera. When the camera is in the right place to record these specular reflections, a bright spot appears in the water. Rough water, or boat wakes, often seem to glitter because of specular reflectance from some parts of the wave surfaces.

In many cases, panchromatic photographs will image water in light-tones. In shallow water, enough light may reflect from the bottom to form an image (Figure 6). In like manner, suspended sediment may also result in a light-tone of water areas. Chemical effluents, and even heated coolant water can often be detected in panchromatic photographs.

Black and white infrared aerial photographs have not been shown to be of significant value in detecting water pollutants. Color infrared emulsions seem to offer considerable promise, however.

Shadow

In addition to providing a silhouette, the presence or absence of shadows--and shadow length--provides an immediate index of the relative height of different objects in a photograph. Shadows are often the best indication of relative heights of objects when looking at a single photograph where the advantages of the stereoscopic view provided by overlapping photos are not obtainable. Compare the shadow lengths of the smokestacks and various buildings in Figure 5, as an example.

Pattern

Land-use patterns are often distinctive. Agricultural practices, in particular, leave clues as to what has taken place that can provide positive indication of the crop present. Row patterns in corn and soybean fields separate them from wheat fields and pastures that lack such patterns. Wave patterns along coastlines often reveal the presence of submerged obstacles, such as sandbars and reefs, even though the obstacle cannot be imaged directly.

Texture

Texture, like pattern, is often related to land-use. Planted vegetation usually appears in smoother textures than natural vegetation. As abandoned agricultural areas revert to forest, encroachment by woody species results in a rougher texture of fields that may or may not be accompanied by obvious tonal differences. Eventually, this encroachment produces a mottling which is a distinctive disruption of the previous uniform texture of the active fields.

Site

Just as some tree species grow in swamps and others on dry upland ridges (Figure 14), so some man-made objects are found along rivers and others on hill tops. Thermal power plants need an abundant supply of coolant water and are often (but not always) found near major streams. Hydroelectric plants must have water under pressure and are always associated with a natural or man-made water supply. Early warning radar stations, on the other hand, are usually placed on high promontories to minimize terrain interference with the line of sight of the radars.

Association

Association is often one of the most helpful clues to the identity of man-made installations. The manufacture of aluminum requires large quantities of electric power. Absence of the power supply rules out this industry. Schools usually have associated playgrounds and athletic fields while churchs do not. Large farm silos are an indication that livestock are (or were) present. Unexpectedly large culverts or bridge spans across small streams indicate that heavy runoff occurs frequently enough to require the engineering works necessary to cope with the water when it comes.

To the military interpreter, the presence of antiaircraft guns is almost positive proof of the presence of a target worth defending. If he hasn't found it, he had best look again.

Resolution

The ability of a photographic system (including lens, filter, emulsion, exposure, and processing, as well as other factors) to record fine detail in a distinguishable manner is referred to as the <u>resolution</u>, or <u>resolving power</u> of the system. Unfortunately, resolution is one of the most misunderstood and misused qualities of the photographic system--at least by most photographic interpreters.

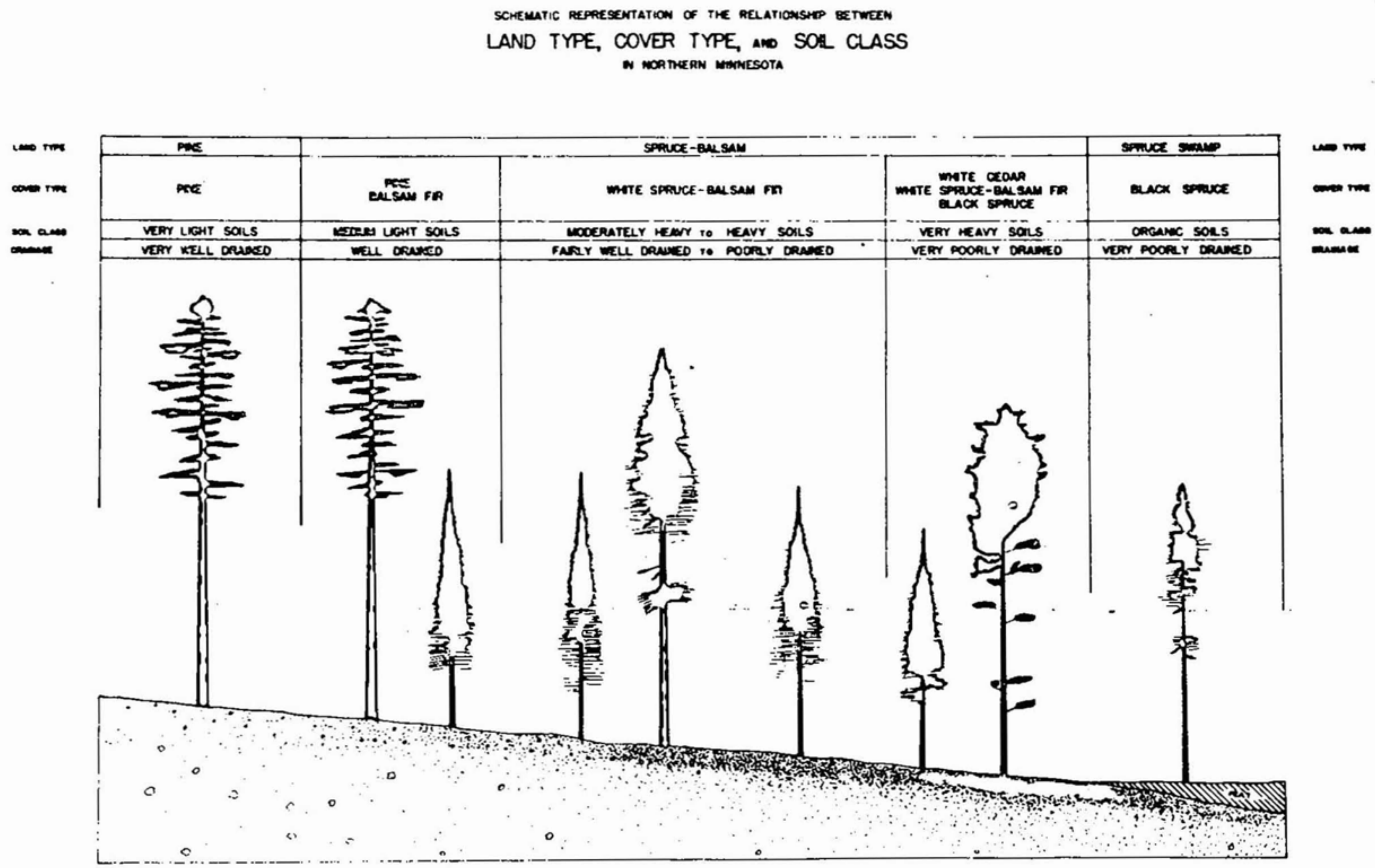


Figure 14: Relationship between species distribution and site for an area at the edge of the former Lake Agissiz in North-central Minnesota.

Resolving power depends on many factors. The first, and often overlooked, requirement is that a difference exist in the energy reaching the focal plane from the object and its background. If there is no such difference, then nothing that the recording system can do will create a discernible image.

The importance of tone contrast and edge gradient were included in the discussion of Tone. It should be clear that resolution is related to edge gradient. If the difference in density across an edge is great enough to be detectable, then the steeper the edge gradient, the greater the probability that the density change will be detectable as a visible change in the tone of the photograph.

Edge gradients are influenced by the total photographic exposure, or the total energy involved in producing a particular image. Steep gradients are usually associated with intermediate exposures, and lower gradients occur at both extremes. Thus, resolution falls off at high or low exposure levels, compared to the maximum resolution achieved at some intermediate exposure. This loss in resolution is one of the major reasons why significant over or underexposures are undesirable, and is a major problem encountered by the interpreter who must work with imagery containing both very-light and very-dark images in the same photograph. The washed-out appearance of broad-leaved trees imaged in infrared photographs is partially due to the loss of resolution that accompanies the overexposure of the trees when the overall photographic exposure is set to record less reflective objects occurring in the same terrain. Also, the loss of resolution observed in shadowed areas is due to the fact that objects in the shaded areas reflect so little light to the camera that they are underexposed.

Describing Resolution

It is customary to describe resolution in terms of the results obtained when photographing a target containing a series of parallel lines. The most common target contains a series of black lines on a white background with the spaces between lines being the same width as the lines themselves. Usually, these targets contain several sets of lines having different spacings (and line widths). Resolving power is then expressed as the number of lines resolved per millimeter of distance across the photograph.

Resolution of Some Common Aerial Emulsions

As shown below in Table 1, resolving power varies widely from one emulsion to another. The difference is particularly noticeable at low contrast, where contrast refers to the difference in light reflectance from the black and the white portions of the test target. Within the range of photographic problems encountered by the photographic interpreter, low-contrast resolution is usually more important than high-contrast resolution. In fact, a contrast ratio of 2:1 is considerably higher than is often encountered with the small objects, or parts of objects, that are of so much concern to the interpreter.

Table 1: Film speed and resolving power of four photographic emulsions frequently used in aerial photography.

Emulsion	Film Speed (ASA)	Target Contrast 1,000:1	2:1	1.26:1
		----lines per mm ----		
Plus - X	80	94	50	27
Super - XX	100	80	30	15
Tri - X	200	72	25	15
Infrared Aero	125	70	35	*

* Data not available; probably 20 lines per mm.

Photographic interpreters are often confused by errors in assessing resolution. When telephone wires resolve, it does not necessarily follow that any object the thickness of a telephone wire will resolve. The wire (or a paint line on a parking lot) is detectable because its length results in exposure to several silver halide grains, rather than because the camera system can resolve very small images. Resolution of the familiar USDA photography at a scale of 1:20,000 is such that round or square objects less than 2.5 feet across are seldom discernible. When measuring tree heights, interpreters usually do quite well with round-topped trees like large oak and maple, but poorly with trees having sharp-pointed crowns like balsam-fir or spruce. The crown of a balsam-fir may extend ten or fifteen feet higher than the point where its diameter narrows to 2.5 feet.

The tone of the background affects resolution of small objects. Photographic emulsions can act as a scattering media and some of the energy from highly reflective (bright) objects may cause exposure of silver halide grains adjacent to those at the geometric location of the object. Bright objects against a dark background will appear larger than they actually are, but dark objects against a bright background will appear smaller than they actually are. Small bushes on a white sand beach often fail to resolve because lateral irradiation of adjacent grains results in exposure of the grains that should have remained unexposed to mark the location of the bush.

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THE IMPORTANCE OF LIGHT REFLECTANCE IN PHOTOGRAPHY

The energy flow profile concept provides a basis for modelling the photographic process. One simple model used to predict relative tone values in vertical aerial photography is shown below. Although developed for a target on the optical axis, relative tone ranking values for an object and its background are preserved when off axis in position. The model does not guarantee that tone differences will be recorded in a photo, but indicates the relative probability of obtaining such a tone difference.

It can be shown that:

$$RN = k \int_0^{\infty} \frac{S(\lambda)}{S(\lambda max)} \times \tau_f(\lambda) \left(E(\lambda) \times R(\lambda) \times \tau_a(\lambda) + L(\lambda) \right) d\lambda$$

where

RN = Tone Ranking Number (no units)

k = a proportionality constant to put RN into an appropriate range of magnitudes

$S(\lambda)$ = Spectral sensitivity of the photo emulsion at wavelength λ

$S(\lambda max)$ = Spectral sensitivity of the photo emulsion at the wavelength where sensitivity is maximum

$\tau_f(\lambda)$ = Filter transmission (percent) of the filter on the camera (can include transmission of lens also) at wavelength λ

$E(\lambda)$ = Incident radiation (total) on the object at wavelength λ

$R(\lambda)$ = Reflectance (percent) of the object at wavelength λ

$\tau_a(\lambda)$ = Transmission (percent) of the atmosphere along the path from object to target, at wavelength λ

$L(\lambda)$ = scattered light reaching the camera at wavelength λ

For any single air photo the sensitivity of the film and the transmission of the filter are the same for all objects in the picture. As long as the objects are in full sunlight, the incident energy (E) will be the same for all targets. Atmospheric transmission (τ_a) will be essentially constant for all targets clustered around the optical axis. The scattered light (L) will also be constant for all targets. Thus, the only term that can vary radically from target to target is the reflectance of the object. We know that different objects do vary radically in their reflectance at given wavelengths.

From this brief discussion, it should be apparent that differences in light reflectance between targets is the **major** source of tone variations between the images of these same targets. Also, if there is no reflectance difference, there can be no tone difference.

SPECTRAL SENSITIVITY OF FILM/FILTER COMBINATIONS

The common photo emulsions and filters used in aerial photography have spectral limits approximately as follows:

Panchromatic film Plus-X Super-XX Tri-X	Sensitive to ~ 680 millimicrons
Infrared film (B & W)	Sensitive to ~ 980 millimicrons (virtually insensitive between 510 and 540 millimicrons)
Normal color film	Sensitive to visible spectrum
Infrared color film	Sensitive out to ~950 millimicrons
Wratten 8 filter	Absorbs all shorter than ~485 millimicrons
Wratten 12 filter (minus-blue)	Absorbs all shorter than ~500 "
Wratten 25a filter	Absorbs all shorter than ~595 "
Wratten 89B filter	Absorbs all shorter than ~695 "

In general, the emulsion determines the spectral limit on the long wavelength end, while the filter sets the short wavelength limit.