Use of Aerial Color Photography In Materials Surveys

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•THIS PAPER summarizes the significant findings in the use of aerial color transparencies in construction materials surveys conducted by the Federal Highway Projects Office, Region 9 (Colorado, New Mexico, Utah, and Wyoming), U. S. Bureau of Public Roads, presents selected data and costs of aerial films and processing, as well as trends in aerial color films, and suggests areas in which research is needed.

The evaluation of aerial color photographs reported was a secondary objective of a comprehensive survey of construction materials. The project was not designed as a controlled research experiment and the results are representative of fairly restrictive climatic conditions, geographic area, and number of geologic materials. Aerial color transparencies (Kodak Ektachrome Aero Film) at a scale of 1:6,000 (500 ft to 1 in.), in single flight strips, were taken along the major road system and in other selected locations in Yellowstone National Park. The photographs were taken with a 6-in. focal length Pleogon lens from an average flight height of 3,000 feet. Over 400 flight-strip mi of color film were taken during the summers of 1961 and 1962. Selected segments totaling about 100 lin mi were taken with conventional panchromatic film at the same scale.

The color transparencies were examined in three dimensions by means of a mirror stereoscope and portable light source. Potential construction materials sources were annotated on transparent plastic envelopes containing the aerial photographs. Each source was then verified by ground inspection. Potential sources appearing to have the best construction materials were further investigated in the field with a backhoe after administrative approval for each potential site had been obtained. Representative samples were taken from each source investigated and laboratory soil tests were performed for engineering evaluation.

FINDINGS

As a primary result of the Yellowstone Park study and other materials surveys in which aerial color photography was used it was found that color photography had many advantages over black-and-white photography for use in materials surveys. Some of these advantages have been previously reported (1).

Use of black-and-white aerial photographs for interpretation of specific ground conditions, soils, or geologic materials involves the interpretation of various photographic tones. The number of such tones or shades of gray that can be differentiated is extremely limited, and many different types of soils or geologic materials may have about the same tonal expression. Inasmuch as the human eye can perceive about 20,000 shades and hues of color, interpretation of color photographs is considerably easier than that of black-and-white photographs. Identification of materials deposits can be based partially on the color of the deposits instead of relying on photographic tones as is done with the black-and-white photographs. Neither color nor photographic tone is used alone in identifying materials, but they do represent one of the most important elements used in photographic interpretation.

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An extreme example illustrating the deficiency of black-and-white photographic tones for use in photographic interpretation was noted in the Yellowstone Park study. Occasionally, it was extremely difficult to differentiate between certain low-growing types of vegetation and soil or rock on black-and-white photographs because both produced identical gray photographic tones. Differentiation was, of course, very simple on the color transparencies. This is an extreme example but it was paralleled by attempts to differentiate between types of materials.

Minard and Owens (2) in mapping soils and geology of the Atlantic Coastal Plain in New Jersey noted that certain rock and mineral types can be identified much more readily from aerial color photographs than from black-and-white photography. This also was found to be true in the Yellowstone Park study where it was possible to differentiate by using aerial color photography sands and gravels containing large percentages of obsidian or siliceous sinter from sands and gravels composed of the more common rock assemblages. Such a distinction was not as obvious on black-and-white photographs of the same areas.

Color differentiation also has proved superior to the use of black-and-white photographic tones for identification of engineering materials and geologic features on other projects undertaken in Region 9. For example, a comparison of color positive transparencies with black-and-white prints at a scale of 1:6,000 taken in Dinosaur National Monument, Colorado-Utah, where geologic formations are well exposed and of variegated coloring, showed the following: (a) differentiating between strata of sandstone and shale is easier on color than on black-and-white photographs, (b) flat erosional remnants of granular mountain outwash overlying dipping sedimentary formations are easier and more positively identified on color than on black-and-white photographs, (c) highly fractured light-colored limestone strata can be identified and differentiated about equally well on either type of photography, and (d) river terrace remnants are more reliably identifiable on color photographs.

Because of the distinctive greens and browns of organic soils, wet soils, boggy ground, and seepage zones, these features can also be more readily identified on color photographs than on black-and-white. Minor drainageways, poorly drained depressions and swales, and seepage areas in landslides show up quite clearly on color photographs. On black-and-white photographs such areas display generally darker photographic tones, but identification or delineation is not as positive and in some cases the conditions are not apparent even to an experienced interpreter.

Various vegetative types can also be recognized more readily on color than on black-and-white photographs. In some cases correlation can be made between type of vegetation and specific types of materials or ground conditions. In such cases the color photography proves superior to black-and-white.

Image identification is easier on color aerial transparencies than on black-and-white prints because of the color contrasts provided by the transparencies. Color transparencies are especially helpful in identification of cultural features such as trails and aerial targets.

While aerial color photography generally has been found superior to aerial black-and-white photography in terms of ease of interpretation and quality of results obtained, it does have certain disadvantages as compared to black-and-white photography.

The first, and most obvious, is cost. As a general rule, aerial color photography costs approximately two to four times as much as conventional black-and-white photography.

Another disadvantage of color photography is the difficulty in obtaining proper film exposure especially in areas where extreme lighting contrasts occur within the area of a single photograph. For example, in the Yellowstone Park study, hot spring deposits that were light in color and devoid of vegetation provided such sharp contrast with the surrounding dark vegetation that they often exceeded the exposure latitude of the color film. In such light-colored areas any colors present were often "washed out" in the photograph, and in general, images were not well-defined.

In the Yellowstone study considerable differences in quality of color reproduction were sometimes noted between flight strips of the same areas taken at different times.

Comparison of certain overlapping flight strips of aerial color photographs taken during the summer of 1961 with those taken during the summer of 1962 revealed that the latter had generally better color reproduction. This improvement was particularly noticeable in areas of dense vegetation where green hues were predominant. In these areas there was a tendency for the nongreen colors in the landscape to take on a more natural color in the 1962 photography than in the 1961 photography. This was particularly helpful in mapping old gray sandy beach deposits in heavily forested areas. In the 1961 photography the gray colors tended to be obscured by an over-all greenish cast making the detection of these deposits difficult. The improvement in the 1962 photography was attributed to more accurate film exposure.

Another deficiency of color transparencies as compared to black-and-white photographs is that production of duplicate transparencies is rather expensive; furthermore, color reproduction of the originals is difficult to attain without considerable experience. Therefore, if a color transparency is lost or damaged it cannot be replaced as easily as a black-and-white print. As a result, in working with color transparencies, considerable care in handling must be exercised.

Because color transparencies must be viewed by transmitted light, a suitable illuminating source is necessary if they are to be used successfully for materials surveys. This has not generally handicapped office use but can prove somewhat of a problem when used in the field. In the Yellowstone study, special portable light boxes provided with vibrator power supply which could be connected to an automobile electrical system were used for this purpose. They were fairly successful, but were awkward to work with in the field vehicle and of course were of no value when away from the vehicle.

The necessity for transmitted light when viewing color transparencies also means that a mirror stereoscope must be used because individual transparencies cannot be easily overlapped as black-and-white prints. In the field, a mirror stereoscope is relatively awkward as compared to the commonly used smaller lens stereoscope.

The Yellowstone study primarily utilized aerial color transparencies, and the comparisons have been with black-and-white photographs. If color prints are compared to black-and-white prints, it is obvious that some of the findings and conclusions from the Yellowstone study are no longer valid. For example, transmitted light would not be needed for viewing the color prints, and adequate duplicates of color originals would be available, thus eliminating the danger of loss or damage to the originals during interpretive work.

In one area of Yellowstone Park a number of short flight strips were taken using Agfacolor Negative Film CN17. Because these photographs were taken in conjunction with another project, only cursory examination was made. Contact color prints tended to have an excess of green, but had good resolution. It was later found that these photographs had been printed with a light source that did not provide a full spectrum. Contact prints subsequently made with an appropriate printing light source showed a great improvement in color balance. Black-and-white prints made from the same color film negative were of excellent quality.

PROCUREMENT OF AERIAL COLOR PHOTOGRAPHS

The distance between the project to be photographed and the airfield at which the photographic aircraft is based is extremely important in either a black-and-white or color photographic mission. Some delay in procuring color photography for the Yellowstone study was experienced because the aircraft and crew were based several hundred miles from the project area and could not take advantage of short periods of excellent photographic weather during prolonged cloudy and rainy periods.

Because the exposure latitude of most color film is narrower than for conventional black-and-white film, exposure difficulties are encountered where there is extreme contrast in the light reflectance within a photographed area. There is a tendency for the light-colored areas to be overexposed with a consequent "washing out" of colors and at times images are not registered distinctly. In flying over areas that are either light or dark, the photographer can properly adjust the exposure for the given scene.

In this connection, the ability of the photographer to think and use good judgment in photographing under varying conditions of light, haze, clouds, and changing subject matter is important in the procurement of quality color photographs.

Haze, which tends to cause color photographs to have an over-all bluish cast and thus subdues original ground colors recorded on the film, becomes an important factor as flight heights are increased, particularly in certain geographic areas and at certain times of the year. The effects of haze are less noticeable for relatively large scale photographs taken at fairly low flight heights. Various color films also have greater or lesser sensitivities to haze. Haze filters and compensation in the printing process are other ways in which the effects of haze are minimized. The tendency is toward the use of high quality shorter-focal-length lenses that permit lower flight heights for a given photographic scale. In addition to reducing the haze problem, such high quality short-focal-length lenses sharply reduce the amount of darkening of corners of photographs, a common problem with color aerial photography taken with inferior lenses. Antivignetting filters on the aerial cameras and automatic-dodging printers also can minimize corner darkening.

The use of filters reduces the amount of light reaching the film and sometimes may be a source of difficulty. For example, it was observed that in a number of flight strips on the Yellowstone project the images in the corners of the aerial photographs were blurred. It was later determined that this blurring was caused by a faulty color balancing filter that had inadvertently been exposed to excess heat. Fortunately, the blurring was not sufficiently serious to affect the utility of the photographs.

Color balance of an aerial photograph depends on the geographic latitude, season of the year, time of day, haze conditions, amount of cloud cover, film exposure, type and variation of emulsion, type of filters used, and film processing and printing.

TRENDS IN AERIAL COLOR FILMS

Through continued research by film manufacturers improvements in aerial color films have steadily been made. Many former objections and criticisms of color films are no longer valid. Significant trends, particularly within the last five years or so have been (a) a great increase in emulsion speed or light sensitivity, (b) reduction in granularity with consequent increase in resolution, (c) improvements in dye formulas resulting in a greater degree of color fidelity, (d) greater latitude of exposure, and (e) decreasing costs.

Film sensitivities and resolution have reached standards today that were hardly thought attainable by many only ten years ago. Costs of color film have been on the decrease, and this trend will continue as aerial color film comes into more general use.

Aerial color negative films of both domestic and foreign manufacture have recently been introduced in the United States. The advantages of aerial color negative film over color positive transparencies make it appear that negative film will come into greater use, particularly as improvements are made in emulsion speed and exposure latitude and as costs decrease. Color negatives afford greater flexibility in that both black-and-white prints and color prints can be made from the same negatives. The negatives can be saved and additional prints made as required. Compensation for incorrect exposure, haze, vignetting, and color balance can all be done in the photographic laboratory. Color balancing filters are not required on the aerial camera as they are with reversal-type film.

As a rule the paper base material on which color photographs are printed has many of the same characteristics as the base material used to print black-and-white photographs. At least one film company produces color print material which is tough, waterproof, and dimensionally stable (3).

SUMMARY OF SELECTED AERIAL COLOR FILM DATA AND CHARACTERISTICS

The following aerial color films are commercially available at this time and only selected characteristics are included.

1. Kodak Ektachrome Aero Film, Process E-3. —This is a color reversal film from which positive transparencies are obtained. This replaces Kodak Ektachrome Aero Film, High Contrast. This film has an "Aerial Exposure Index" (4) of 25, which is about three times as fast as the previous film with a speed index of ASA 40 daylight. Haze filters are recommended and color balance filters are used when necessary with particular emulsions.

2. Kodak Ektachrome Infrared Aero Film Process E-3. —This replaces Kodak Ektachrome Aero Film (Camouflage Detection). The new film is a false-color reversal film that has three layers sensitive to green, red, and infrared radiation, rather than blue, green, and red as in conventional color film. A yellow Kodak Wratten Filter No. 12 is used to absorb blue radiation to which all three layers are sensitive. Color compensation filters may be used for color improvement of transparencies as necessary. This film has an Aerial Exposure Index of 10 which takes into account the use of the yellow filter.

3. Kodak Ektacolor Professional Film, Type S. —This is a recently available color negative film with a speed index of ASA 80 daylight. Use of a haze filter is recommended. Color balancing is accomplished in the printing process. A recent experimental trial showed that good quality aerial color prints can be produced. This film appears to have reasonably wide exposure latitude without objectionable shifts in color balance. Although not designed for aerial photography, it has fairly high contrast and good haze penetration without the use of a haze filter.

4. Ultra-Speed Anscochrome.—A color reversal film from which positive transparencies are obtained. The speed index for this film is ASA 200 daylight. By forced processing the speed can be pushed to ASA 400-800. This film has a temperature-color balance of 6,000 K and has high resolution when exposed under normal conditions. The latitude of exposure is about plus or minus one-half lens stop for accurate reproduction and good color saturation. Color positive prints (Printon) can be made from this film.

5. Super Anscochrome. —This film is a color reversal film having a speed index of ASA 100. Exposure latitude and color balance are similar to Ultra-Speed Anscochrome. It has slightly higher resolution and provides somewhat less contrast than the latter.

6. Agfacolor Negative Film CN17. —This is a negative color film with a speed index of ASA 40 daylight. Typical exposures are 1/250 to 1/450 sec at f4 to f5.6 under average conditions of brightness. Satisfactory results can be obtained at one to two lens stops lower than for optimum exposure. Ultraviolet and light yellow filters can be used. Color balancing is accomplished in the printing process.

COST OF AERIAL COLOR PHOTOGRAPHY

As a general rule, aerial color photography costs about two to four times the cost of conventional black-and-white photography. This is not surprising since color films have three emulsions while panchromatic films have only one. Raw aerial color film costs approximately three to four times as much as panchromatic film. Chemical kits used for processing both types of film are about the same price.

One commercial aerial color processing photographic firm quotes a price of $90.00 for processing negative color film (9½-in. by 100-ft roll) and $115.00 for color reversal film of the same dimensions. Color paper prints that are not color balanced can be obtained for about $0.90 a print. Prints that have been color corrected and dodged for lens vignetting cost $3.00 each.

A price quotation obtained for 1:6,000-scale photography from a commercial photogrammetric firm was $55.00 per flight-strip mile. This includes one set of contact color prints, one set of black-and-white prints, and one photographic index. Additional color prints were obtainable at $15.00 per flight-strip mile and additional black-and-white prints at $1.00 each.

SELECTED ASPECTS OF COLOR FILM PROCESSING AND PRINTING

One of the more important phases, and often neglected, is the extreme care that is necessary in the photographic laboratory regarding general cleanliness and prevention

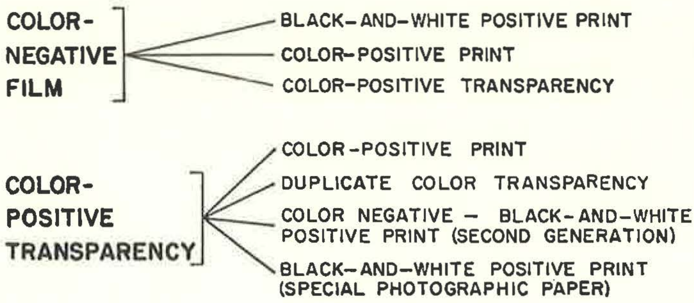

Figure 1. Possible products from color-negative and reversal-type film.

of contamination of chemical solutions. In addition, processing procedures must be rigidly controlled. The general attitudes, habits, and procedures followed in most black-and-white photographic laboratories are not good enough.

One phase of color processing that is often misunderstood is the time required in the photographic laboratory. For the most part, the total time required to process a roll of exposed aerial color film is only slightly longer than that required for black-and-white photography if the proper equipment is available. Color reversal film takes slightly longer to process than color negative film. Although color processing time does not differ significantly from the time for black-and-white, the complete attention of the laboratory technician is required throughout the color processing operation. This is not the case with black-and-white photography.

Two governmental agencies report that their production capacity for black-and-white prints is from two to two and one-half times greater than that for color prints. This comparison illustrates the additional time required to make color prints with the equipment used in these particular photographic laboratories. The type of aerial color film processing equipment used by most laboratories is of the so-called "wind and rewind" type. Continuous processing, as is used in the motion-picture industry, is not made to accommodate aerial color film. Continuous processing equipment is quite expensive, and at the present time is not justified by the quantity of aerial color film processed.

Contact printers, either conventional or automatic-dodging type, equipped with full spectrum tubes enable color prints to be made from either positive transparencies or color-film negatives. By means of special filters or by adjustment of the printing light source, the color balance of each photograph, can be regulated. Compensation for haze can also be made in the printing process by removal of some of the blue color by means of filters. Differences in film exposure and light quality (time of day) can also be compensated for in printing. Automatic-dodging printers enable a more uniform density to be obtained throughout a given photograph and tend to made the photographs in a flight strip more nearly uniform. Some objection has been voiced regarding the use of automatic-dodging printers that, with some films, cause serious color balance shifts due to reciprocity failure (longer exposure time in printing required). Attainment of perfect color balance in each print is still a costly and time-consuming process.

Figure 1 shows the possible products (contact size) that may be obtained from color-negative and reversal-type films. Enlargements from both types of film can also be made.

VIEWING AERIAL COLOR PHOTOGRAPHS

Optimum stereoscopic viewing of aerial color photographs presents a few special requirements. For optimum color perception it is necessary to have a light source that radiates energy over the entire color spectrum. Some modern fluorescent and incandescent lights and combinations of fluorescent and incandescent lights meet this requirement. Most of the light sources used for photographic interpretation of aerial color photography in the past have been of the "home brew" variety. Recently, special fluorescent tubes coated with selected phosphorus providing energy in the entire color spectrum have been made available. This light source is color balanced at 3,900 K and has intensities of 400 and 600 ft lamberts. The higher intensity is used for viewing dense transparencies. Diffusers provide an even distribution of light. This special light source has the added advantage of maintaining its color balance and intensity of output for long periods of time, something ordinary fluorescent light cannot do. As with other fluorescent light sources, heat dissipation is not a problem as it is with incandescent bulbs.

Double projection photogrammetric instruments currently in use have not been designed for use on aerial color photographs. Use of color aerial photography in these instruments, both qualitatively and quantitatively, has up to this time been experimental in nature. Color positive transparencies sandwiched between glass plates have been used in the Kelsh stereoscopic plotter by means of polarized light and a special platen with a surface of anodized aluminum. Despite its limitations, this approach appears to have considerable merit, particularly for interpretation purposes (5). Color transparencies have also been experimentally employed in optical-train photogrammetric instruments. Because these instruments do not depend on the anaglyphic principle for their operation, polarized light is not required for stereoscopic viewing. This approach has proved successful for qualitative use.

Predictions have been made, perhaps optimistically, that color diapositives for use in photogrammetric plotting instruments will be available within the next five years. Color diapositives would eliminate the dimensional instability problem of positive transparencies. However, there is still the problem of either coating or laminating color emulsions on glass plates. The latter procedure appears more promising. Although the commercial film companies and others have not seriously tackled this problem in the past, some token progress has been made and the results offer some encouragement. A breakthrough on this problem should result in more extensive use of color photographs in photogrammetric instruments both quantitatively and qualitatively.

Although not specifically designed for the 9- by 9-in. format used extensively in highway work, a stereoscopic-viewing instrument of interest to the military and others has recently been developed. This instrument permits the viewing of projected 70-mm strip color and conventional photography in three dimensions without the aid of polarized light or colored lenses. This is accomplished by a special projection system and viewing lens. Magnification is also provided.

RELATIONSHIP BETWEEN QUALITY OF COLOR REPRODUCTION AND PHOTOGRAPHIC INTERPRETATION

Establishment of a set of rigid criteria for evaluating the acceptability or nonacceptability of aerial color photographs for use in materials surveys is nearly impossible and at best not practical. General requirements applying to black-and-white photography procured for interpretation purposes are applicable to color photographs. The value of true color reproduction in interpretation of soils, locating sources of construction materials, and mapping geologic formations is questionable when considered in terms of the effort and cost of attaining this objective. Although it would probably be aesthetically desirable to obtain true color reproduction, the effort and cost is at present too great to warrant it. Actually, color distinctions and differences are of paramount importance, and it may sometimes be necessary to disturb good color balance to attain certain color contrasts.

Proper film exposure enhances color differences, and is particularly important with color reversal film because there is little leeway in the photographic laboratory to compensate for errors. Overexposure generally tends to "wash out" colors. Latitude of exposure varies considerably with various color films and with some films it may be desirable to underexpose rather than overexpose. The reverse may also be true for other films. For critical work, test exposures should be made with the same film (same emulsion number) as is to be used on the project. Laboratory procedures should be standardized.

Resolution in an aerial photograph is an important consideration. It may, however, be less important on a color than on a black-and-white photograph because color rendition and contrasts are probably more important in differentiating images. Aerial color films generally have much greater contrast than color films produced for ground photography. Aerial color photographs with high image resolution are certainly desirable, but other considerations may be more important for photographic interpretation. Where photographs are to be viewed under magnification or where enlargements are to be made, resolution assumes greater importance.

RESEARCH NEEDS

The available knowledge related to use of aerial color photographs for interpretive purposes is still relatively small. Because most state highway departments do not have the time, trained specialists, facilities, or funds to undertake comprehensive research projects of a basic nature, most research in this area has been conducted by universities and agencies of the Federal Government. Though considerable research in this field has been conducted by the military, the results of this work have not generally been made available to civilian engineers and scientists because of security restrictions.

The selection of the proper film and/or filter for use on specific projects having unique color combinations needs to be investigated. Some research of this type has been done on a trial-and-error basis using various film-filter combinations and film exposures. A limited amount of work has been done by an approach that eliminates most of the guesswork, by using spectral reflectance measurements (spectro-photometric studies) of the soils and rocks to be photographed. The results of these measurements show the dominant wave lengths of reflected light thereby enabling the photographer to select an appropriate filter that will give optimum color contrasts (6, 7).

Aerial photographic interpretation has in the past been largely qualitative and subjective in nature. Although the amount of information that can be obtained is quite large, the quantitative approach to interpretation may possibly be the approach that really "pays off." This approach has long been neglected and is in need of further study. By use of a densitometer or microdensitometer, color transparencies or prints can be scanned and the intensity of specific wave lengths of light either transmitted (transparencies) or reflected (prints) can be measured and recorded. Normally, measurements of the amounts of red, blue, and green light are made. Particular rock types, soils, and landforms can then be identified and differentiated. In this manner, distinctions can often be made among geologic formations and soils that are impossible to make visually (6, 7, 8).

Experimentation is needed with all types of aerial color film to determine the latitude of film exposure in relation to the value of the resulting photographs for interpretive purposes.

Research involving the use of various combinations of light sources, reflectors, filters, and light intensities in color-viewing systems for interpretation is needed. This phase of enhancing color differences for interpretation has been neglected.

The potential of false-color films for interpretive purposes needs to be evaluated. False-color films differ from ordinary color films in that one of the three emulsion layers is sensitive to infrared. Colors produced by this film after processing are not those of the objects (soil or rock) photographed. Color contrasts and differences depend to a large extent on the differences in infrared reflectivities of the scene photographed. This film has an advantage over conventional infrared film in which the record is in shades of gray (4, 9).

Controlled experiments in aerial color film deterioration are needed to ascertain the degree of stability of dyes under ideal storage conditions and in routine office and field use. The effect of certain chemicals used on color prints to retard the bleaching of colors should be ascertained. Normally, color prints are soaked in these solutions. When dried, the then invisible coating reduces the penetration of ultraviolet rays which cause bleaching of dyes.

Particular types of vegetation have been correlated with specific soils and ground conditions and can be used by trained interpreters to identify these conditions on aerial photographs. Recognition of vegetative types is greatly facilitated by means of aerial color photographs. Research to correlate identifiable vegetation on aerial photographs with specific conditions and materials on the ground is needed. False-color films may have some application and potential use. It is probable that this approach to interpretation will have its greatest success in semi-arid and subarctic regions. There is need for more test flights and use of aerial color photographs over a broader range of climate, topography, and geologic materials.

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REFERENCES

1. Chaves, J. R., Schuster, R. L., and Warren, R. J., "A Preliminary Evaluation of Color Aerial Photography for Use in Materials Surveys." HRB Proc. 41:611-620 (1962).
2. Minard, J. P., and Owens, J. P., "Application of Color Aerial Photography to Geologic and Engineering Soil Mapping." HRB Bull. 316, pp. 12-22 (1962).
3. Nagel, W. J., "Aerial Color Film." Presented at Annual Meeting of American Society of Photogrammetry, Amer. Cong. on Surveying and Mapping, Washington, D. C. (1962).
4. Eastman Kodak Company, "Kodak Data for Aerial Photography." Kodak Pub. M-125, Rochester, N. Y. (1961).
5. Petterson, H. D., "Use of Polaroid Filters on Kelsh Plotters." Photogrammetric Engineering 29(5), pp. 882-887 (Sept. 1963).
6. Fischer, W. A., "Spectral Reflectance Measurements as a Basis for Film-Filter Selection for Photographic Defferentiation of Rock Units." Professional Paper, U. S. Geol. Sur. 400-B, pp. 136-138 (1960).
7. Ray, R. C., and Fischer, W. A., "Quantitative Photography—A Geologic Research Tool." Photogrammetric Engineering 26(1), pp. 143-150 (Mar. 1960).
8. Derr, A. J., "Application of a Microdensitometer to Photo Data Assessment." Presented at Fifth Annual Symposium of Society of Photographic Instrumentation Engineers (Aug. 1960).
9. Tarkington, R. G., and Sorem, A. L., "Color and False-Color Films for Aerial Photography." Photogrammetric Engineering 29(1), pp. 88-95 (Jan. 1963).
10. Fischer, W. A., "Color Aerial Photography in Geologic Investigations." Photogrammetric Engineering 28(1), pp. 133-139 (Mar. 1962).
11. Heller, R. C., Doverspike, G. E., and Aldrich, R. C., "Identification of Tree Species on Large-Scale Panchromatic and Color Photographs." Presented at Annual Meeting of American Society of Photogrammetry, Amer. Cong. on Surveying and Mapping, Washington, D. C. (1963).
12. Maruyasu, T., and Nishio, M., "Experimental Studies on Color Aerial Photographs in Japan. " Institute of Industrial Science 8(6), p. 32, Univ. of Tokyo (Mar. 1960).
13. Bergmans, J., "Seeing Colors." Macmillan Co., New York (1960).