A Preliminary Evaluation of Color Aerial Photography in Materials Surveys

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A recognized need has existed for evaluation of color aerial photographs as a tool for use in materials surveys. The opportunity to use color aerial photographs in a comprehensive materials survey presented itself in Yellowstone National Park (area about 3,472 sq mi), where a critical material shortage exists in certain portions of the area. This project was undertaken by the Federal Projects Office, Region 9, U. S. Bureau of Public Roads, and was sponsored by the U. S. National Park Service. Strip aerial photography flown along the major highway system at a scale of 1:6,000 was used for the most part. The color aerial transparencies obtained were studied stereoscopically.

Special considerations in the procurement of color aerial photography are presented, together with descriptions of field and office procedures. Comparisons are made between color and black-and-white aerial photographs. Tentative conclusions drawn from the results of the project are given.

• BLACK-AND-WHITE aerial photographs have been used by a number of State highway departments in conducting materials surveys and inventories. Private organizations and consultants engaged in mapping studies or exploration for construction materials have also used aerial photographs in the United States and in many other parts of the world. The Bureau of Public Roads, in addition to sponsoring projects in some States where aerial photographs are used for materials exploration, has conducted materials searches in Alaska and in several national forests and parks. The aerial photographs employed in these studies have been black-and-white prints available from various governmental agencies generally at scales of 1:20,000 or smaller. In some cases larger scale photographs have been used.

Although it has been considered for several years that color aerial photographs might be useful in materials surveys, their use has been delayed largely because of high cost, slow film speeds, and poor quality of color reproduction. The U. S. Geological Survey has for a number of years used color aerial transparencies for some of their geologic mapping and mineral exploration studies. The U. S. Coast and Geodetic Survey has used them for coastal mapping; the U. S. Army Corps of Engineers and other military organizations, for military intelligence studies, camouflage detection, and special terrain studies; and the U. S. Department of Agriculture, for detection of diseased crops and trees. Private commercial organizations and universities have experimented with color aerial photographs for other specialized uses.

In 1958, the Federal Highway Projects Office, Region 9 (Colorado, Utah, New Mexico, and Wyoming), Bureau of Public Roads, contracted to have some experimental color aerial photographs taken in Dinosaur National Park in Colorado and Utah. The results of this trial were promising, and possible advantages of using such photography for soil and materials surveys were recognized. Various color projects were later flown in Colorado, New Mexico, Utah, and Wyoming.

In 1961, the Bureau of Public Roads entered into an agreement with the U. S. National Park Service whereby Region 9, would conduct a comprehensive inventory of construction materials along the major highway system in Yellowstone National Park. This work was sponsored by funds provided by the Park Service. While accomplishing the objectives of the agreement for conducting a construction materials search, it was also planned to make a preliminary evaluation of the color photography in Yellowstone Park for use in materials surveys. Photography from other areas was also evaluated. Reconnaissance mapping of significant geologic units normally of concern in preliminary highway location and design was also to be done in conjunction with the materials search. Aerial photographic interpretation of special ground conditions was also to be performed in various areas.

PROCUREMENT OF AERIAL PHOTOGRAPHS

During the summer of 1961, the Bureau of Public Roads contracted to have 428 linear mi of color photography taken at a scale of 1:6,000 (1 in. to 500 ft) in single flight strips along the major road system in Yellowstone National Park. In addition, several segments were covered by two or more adjacent flight strips with standard sidelap to furnish adequate coverage. A number of side flights, mainly along minor rivers, were made where potential sources of material were suspected. Some oblique photographs were taken to supplement the vertical photographs. A small segment of the photography flown at 1:6,000 was also flown at 1:4,800 (1 in. to 400 ft) in order to make a comparison of the photographic detail. Black-and-white photographs (panchromatic) at a scale of 1:6,000 were taken for segments totaling 100 mi. Coverage in color at this same scale permitted comparison of the two types of photography. The black-and-white film used was Kodak Super XX Aerographic. Of the 428 linear mi contracted to be flown in color, 300 mi were flown during the summer of 1961. Difficulty in obtaining the required color film and inclement weather prevented the contract from being completed.

The aerial camera used to take these photographs was a Zeiss RMK 15/23 equipped with a Pleogon lens having a 6-in. focal length with a maximum aperture of f 5.6. The size of transparencies produced by this camera is 9 by 9 in. (23 by 23 cm). The average flight height above ground for 1:6,000 photography was 3,000 ft.

The color film used for this project had an exposure index of daylight-40. This is a reversal color film of the subtractive type which when processed gives a color positive transparency. Emulsion characteristics usually vary somewhat from roll to roll, as a result the exposure index as well as the color balance also varies. Because of this, it was necessary to make trial flights over the terrain for which photography was desired to determine the proper combination of shutter speed and lens opening that would give optimum exposure and color reproduction for a particular roll of film. A corrective color balancing filter was provided with each roll of film because of the variations in film characteristics.

Proper color balance must be obtained to insure relatively accurate color reproduction in the aerial transparency. To obtain this color balance and minimize shadows, aerial photographs were taken as near peak solar altitude as possible.

Haze filters are sometimes used in taking color pictures to prevent the over-all bluish hue that results from the dispersion of light by dust and water particles suspended in the atmosphere. Haze does not present a serious problem for low altitude photography, but its effect becomes increasingly apparent as the height of the aerial camera above ground is increased. The magnitude of haze also varies with time of day, season, and geographic location.

Because of the use of haze filters, the need for color balance and the slower speed of color film, aerial lenses that have larger apertures than those used in black-and-white photography must be used. Higher quality lenses having good resolution, little color or spherical distortion, and relatively even light distribution are required. It is expected with the development and use of faster color film that the lighting requirements and size of lens opening will be reduced.

Developing and processing of color film are far more exacting than for black-and-white and are extremely important in the production of acceptable color photographs. Composition of developing and fixing solutions and developing time must be carefully controlled. Temperature of developing solutions for example must be maintained within ±1 F. Considerable care must also be exercised while drying or handling the film. Special, rather costly equipment is needed for adequate processing.

Color film should be developed within 24 hr after exposing. Exposed undeveloped film should be refrigerated if it is impossible to develop it within 24 hr. Because of the tendency for the dyes in unexposed color film to change with time, particularly in hot humid climates, the film should be stored at temperatures ranging from 45 to 65 F.

The cost of color photographs should be considered not by itself, but in relation to actual savings in time, money, and increased information made available through their use. The added advantages and savings gained through the use of color are not always measurable. The costs involved in procuring either black-and-white or color aerial photographs are small, if not insignificant, compared to the final cost of constructing a highway. If a single good source of material is located for a project, or if the haul distance to a suitable source can be shortened appreciably, the cost of photography and the personnel involved may well be paid for many times. Similarly, the savings made by recognition and avoidance of unstable ground, hard bedrock, seepage areas, or other poor ground conditions in projecting a preliminary highway alignment are apparent.

The following average price ranges per linear mile for 9- by 9-in. color aerial transparencies are for photography obtained by negotiated contract. The prices include the cost of plastic envelopes in which the transparencies are placed.

Scale	*Cost ($)*
1:4,800	43.75-60.75
1:6,000	38.25-52.75
1:12,000	27.00-33.50

It has been the experience of the Federal Highway Projects Office, Region 9, that color photography may be obtained at somewhat lower prices through competitive bids, but the quality is often poor and not acceptable. Also, quoted prices are those charged for work in Region 9 and may not be the same elsewhere. Price quotations will also vary with the number of miles of photography required per job and the distances involved in getting a plane to the area to be photographed. Color photography in Region 9 has generally been taken at the same time as black-and-white photographs for photogrammetric mapping.

The cost of 1:6,000-scale black-and-white photographs printed on double weight paper having a semi-matte finish, is between $20.00 and $27.50 per linear mi. Two sets of prints and an uncontrolled photographic index are included in this price.

VIEWING EQUIPMENT

To view color aerial transparencies properly with a stereoscope, a suitable lighting system is required. Although almost any type of light box will permit viewing of transparencies, it is desirable to have a balanced light source that provides a spectrum comparable to that of natural sunlight. This is done by using fluorescent and incandescent lamps of about equal wattage. A means of varying the intensity of light is also desirable because the number of color distinctions the human eye can make varies with the light intensity. The eye can detect more color differences at lower levels of illumination. An appropriate translucent light diffuser is necessary to provide an even distribution of light throughout the transparency, to prevent "hot spots" while viewing. Ventilation holes are necessary and a small air blower is desirable to dissipate heat created by the lamps. Excessive heating of color transparencies causes them to curl and may permanently damage them. A small portable home-made light box equipped with fluorescent lights capable of being run by 115 volts ac or 12 volts dc was used on this project. It was therefore possible to view aerial photographs with a lense stereoscope in the field. A mirror stereoscope was used almost exclusively in the office.

Transparent plastic envelopes 10 by 11 in. in size were used so that annotations could be made on them with a grease pencil and to protect the aerial transparencies. The envelopes containing the transparencies were punched and placed in a three-ring notebook for convenient storage and use in the field.

PROCEDURE FOR CONDUCTING MATERIALS SURVEY

The procedure was similar to that used for black-and-white photographs. First, a search and review of published geological literature pertinent to the areas under study was made. Geologic maps, bulletins, folios, and other reports were studied. Information regarding known sources of construction materials was obtained from both Bureau of Public Roads and Park Service engineers familiar with these areas. Thus, as much background information as possible was obtained before the initial study of the aerial photographs was undertaken. The amount and value of this background information varied. Rather detailed, recently published geologic maps and reports were available for some areas and only old generalized reconnaissance-type geologic maps were available for others. This background orientation is considered an essential part of a materials investigation.

Following the literature review, a rather rapid preliminary examination of the aerial photographs, covering strips 4,500 ft wide, was made using a mirror stereoscope. This initial examination served to correlate the information obtained from the literature survey with the aerial photographic patterns observed. Specific geologic features and landforms were marked on the plastic envelopes for later investigation in the field. In this manner it was possible to plan and perform the field work more efficiently.

The ground examination consisted of examining rock outcrops, geologic materials in highway cuts, and river cut banks. Shallow holes were dug with shovels and mattock, and borings made with a hand auger to expose materials below the ground surface. Materials brought to the surface as a result of animal digging were also examined. Whenever possible, field notes taken included descriptions of soils and rocks and approximate depths of materials. Such ground examination is an essential part of this work and its importance cannot be overemphasized. Reference numbers for field observations made were placed on the aerial transparencies. Wherever possible, a stereoscopic examination was made in the field vehicle by means of a portable light box and pocket lens stereoscope. Color and black-and-white photographs were also taken from the ground during the course of the field investigation.

After the preliminary phase, the photographs were examined in greater detail, mapping units such as granite, glacial till, alluvial fans, and landslides were determined and their boundaries placed on the plastic envelopes for alternate photographs in each flight strip. Appropriate mapping symbols were developed for various rock types, landforms, and ground conditions. Boundaries or areas that were doubtful were noted and checked in the field. Mapping units were then described and the descriptions included as a part of a preliminary report for each of the segments studied. Potential material sources were noted and sites for sampling were marked on the photographs. Each of the indicated sources was examined with a stereoscope in the office by a Park Service official before any sampling or field investigation with mechanical excavation equipment was done. This insured the coordination of the work with Park Service policy and planning. All approved potential material sources were explored by means of either a truck- or a crawler-mounted backhoe, capable of excavating to a depth of about 12 ft, and representative samples were taken for laboratory testing. A brief description of the materials from the test pits was made and the approximate quantity in each potential source was determined by the field crew. Electrical resistivity equipment, although not used in this investigation, will be used in the future to help determine depths and quantities of materials. Final reports summarizing the results of the materials investigations were prepared for individual highway segments. These reports incorporate results of laboratory testing.

PRELIMINARY RESULTS AND FINDINGS

The purpose of this discussion is to point out some of the more important findings for this particular application of color aerial photographs. The findings of this study represent the result of only one summer's work using color aerial photographs for locating material sources and for generalized mapping. Undoubtedly new facts will come to light as color aerial photography is used by others.

Because the human eye is capable of distinguishing about 20,000 shades and hues of color, and color is perceived every day, it is not too surprising to find that color photographs are not only appealing but have many advantages over black and white. Persons using black-and-white aerial photographs must interpret specific ground conditions, soils, or geologic materials in terms 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 of various colors may have about the same tonal expression. It should be remembered that neither photographic tones nor color are used alone in identifying specific materials or determining ground conditions. In some instances, the type of landform, gully, or drainage pattern may be the basis for recognition rather than photographic tone or color.

When using color aerial photographs for materials surveys, relative rather than absolute colors are of primary importance. Thus, slightly "off-color" photographs are as usable as those showing exact or nearly exact ground colors. This statement should not be misinterpreted as an endorsement for marginal or poor quality work. Visually, it is only possible to tell if the color registered on the photograph approximates that on the ground. The quality of the illumination also determines what colors the eye perceives, although the true colors may be registered on the film. If the illuminating source is deficient in a portion of the visible light spectrum, then these colors are not perceivable to the eye.

The requirements for acceptable color photographs that are to be used for materials surveys are not as stringent as those that have been stipulated with respect to endlap, sidelap, crab, and tilt for mapping by photogrammetric methods. In general, acceptable color photography must have good definition of images, have even light distribution, be free of clouds, and have the proper exposure and color balance.

Color photography that is either considerably overexposed or underexposed, discolored in processing, or off the designated flight lines should be rejected. Overexposed color photographs have a "washed out" appearance whereby many of the ground colors do not register on the film. The problem is particularly serious in areas with little or no vegetative cover where there is more than ample reflected light available and where light meter readings are not always reliable. A greater percentage of the ground colors register on underexposed film than on overexposed; for this reason, slight underexposure is more desirable than slight overexposure. For the most part, color photographs were properly exposed and colors recorded on the film compared well with those observed on the ground.

One obvious advantage of color aerial photographs is that cultural features such as highways, trails, buildings, and aerial targets are more readily identifiable than on black-and-white photographs. Personnel appreciate the fact that it is easier to orient oneself in the field because the terrain and culture appear natural.

Image definition is better on color aerial transparencies than on black-and-white prints because use of prints results in some loss of detail.

Wet soils, organic soils, boggy ground, and seepage zones can be easily identified on color photographs because of the green grass and other vegetative growth in these wet areas. The brownish color of the organic soils is readily recognized. Minor drainageways, poorly drained depressions or swales, and seepage areas in landslides show up quite clearly. On black-and-white photographs these areas have generally darker photographic tones, but identification or delineation is not as positive and in some instances the conditions are not apparent.

The identification and delineation of such rock types as granite, rhyolite, basalt, limestone, shale, and sandstone are greatly facilitated by means of color photography, and large boulders in glacial till are easier to identify. In one instance, the fracture pattern for a granite was so distinctive that it appeared equally well on color as on black-and-white photographs. Color is particularly helpful in instances where the rock fracture pattern or other features are not distinctive and cannot be used as a means for identification.

Although the authors lacked training in forestry, it was recognized that various vegetative types can be identified more readily on color than on black-and-white photographs. It is not always possible to correlate a particular type of vegetation with a specific type of material or ground condition but color photography will be useful wherever reliable correlations can be made. For example, aspen growing on alluvial fans in southern Colorado clearly outlined the extent of these deposits. Dense timber cover that completely obscures ground detail is a liability in aerial photographic interpretation when using black-and-white or color photographs. As an example, the detection of local, thin deposits of glacial sand overlying volcanic flows in one area of Yellowstone National Park was impossible because of a dense cover of lodgepole pine.

In several cases, the colors of certain features were not of constant density in adjacent pictures. For example, vividly colored algae growing in hot springs appeared in almost true color on one photograph, but were almost completely "washed out" in the next. This condition apparently is the result of the difference in the angle of reflected light from the ground for successive plane positions. Although this change in color density may be obvious in comparing individual photographs, it is not generally apparent when pairs of photographs are viewed stereoscopically. A similar difference in photographic tones on black-and-white photographs was also noted on sand and gravel river bars.

Several scales of color photography were flown so that a comparison could be made relative to their use for materials surveys. The scales selected were 1:4,800, 1:6,000, and 1:12,000. Previous experience in Region 9, indicated that a scale of about 1:6,000 would be the most desirable for locating materials sources. The results of this study showed this to be true. The flight strip widths for 9- by 9-in. photographs of the three scales used are as follows: 1:4,800 (1 in. to 400 ft), 3,600 ft; 1:6,000 (1 in. to 500 ft), 4,500 ft; and 1:12,000 (1 in. to 1,000 ft), 9,000 ft. A scale of 1:4,800 permits more ground detail to be observed, but the flight strip width is one-fifth less than that for 1:6,000. The advantage of having the 900 ft in additional width in the 1:6,000-scale photography, more than offset any slight advantage gained by use of the larger scale. The additional detail obtained from the 1:4,800-scale photographs did not help appreciably in the detection of materials sources or in the determination of ground conditions. The 1:12,000-scale photographs show insufficient ground detail for optimum use, although the smaller scale does provide greater width of coverage and permits a broader overall view. Examination of photographs at this scale requires greater study time than at 1:6,000 and leaves many uncertainties in the interpreter's mind regarding actual ground conditions. Scales ranging from 1:6,000 to 1:8,000 should provide sufficient ground detail and width of coverage for optimum use in materials surveys.

If a color aerial transparency is either lost or damaged, there is no possibility of replacement as with prints made from black-and-white film negatives. This is an obvious disadvantage, and as a result, greater care is needed in handling and working with transparencies. Reproduction of color transparencies is rather costly and color reproduction of the originals is not reliable. A suitable illuminating source is also required for viewing color transparencies in the office. A special portable light box adapted for battery operation is needed if transparencies are to be viewed in the field. Field use of color aerial transparencies under extremely hot and dry climatic conditions results in curling of the transparencies. Under similar conditions black-and-white photographs printed on double weight paper also curl and become brittle.

CONSIDERATIONS AND RECOMMENDATIONS

The considerations and recommendations indicated are based primarily on the results and findings of the work done in Wyoming, Colorado, Utah, and New Mexico during summer 1961. Future work will undoubtedly uncover many new facts in the use of color photographs in engineering materials and soils surveys. Some of the present objections should be eliminated with improvements in faster color films having greater contrast and exposure latitude.

The type of camera and lens used to take aerial color pictures is highly important. The quality of such a camera should be equal to or exceed that of the Zeiss RMK 15/23 equipped with a Pleogon lens. There has been a tendency for commercial organizations to use lenses of longer focal length, such as 8¼-in. or 12-in. rather than 6-in. lens to obtain color photographs. Although use of longer focal-length lenses results in better light distribution, giving more uniform density in the photograph, the flying height required is greater to obtain a given scale. This increased height of the aerial camera above the ground increases the haze effect that gives the photographs an undesirable bluish hue. High quality lenses of shorter focal length do not produce noticeable vignetting. Haze is a lesser problem due to lower flying heights required.

Equipment used to process color film is rather expensive and some commercial organizations have neither the equipment nor experience in taking or processing color photographs necessary to produce a good quality job. For this reason, color photography has been secured in Region 9 by negotiated contract because the objective is to obtain a high quality product at a reasonable price. Unless a State highway department has had previous experience with a commercial organization, it is recommended that the organization concerned be required to submit in advance examples of color photographs at the desired scale of the area to be photographed. Examples of photographs at other scales, or the same scale, taken in other parts of the country should not be accepted as evidence that the organization is capable of producing acceptable photographs for the area in question.

The season and time of day are important in the procurement of color as well as black-and-white photography. Color photographs should be taken preferably during the time interval between complete snow disappearance and leafing of deciduous trees or from the time the trees are bare to the first snow. Photographs taken in the fall have longer shadows than spring or summer photography because of the lower sun angle. This is particularly apparent in photographs taken in the higher northern latitudes. The intensity and emitted wave lengths of light from sunlight also vary with latitude and time of day. For obtaining proper color balance and minimizing shadows, aerial photographs should be taken as close to peak solar altitude as possible.

The selection of Kodak Ektachrome Aero Film, used on this project, was based on the previous success attained by the commercial organization contracted to do the work in producing acceptable color aerial transparencies with this film. Because the evaluation of various types of color aerial films was not a part of this study, no attempt was made to use other commercial films for this materials investigation.

Color aerial prints, rather than color aerial transparencies, are not acceptable for use in materials surveys because of excessive cost and lack of good color reproduction. One price recently quoted was $4.00 to $5.00 per print, when ordering 50 prints or more at a time. The high cost of color prints is a direct reflection of the skill and experience required and the difficulty in producing color pictures of acceptable quality. Relatively large emulsion shrinkage of color prints causes them to curl with small changes in temperature and humidity.

This investigation did not include the use of color aerial photographs for conducting engineering soils surveys. Casual observations regarding the identification of soil differences by means of photographic interpretation appears encouraging. An evaluation of color photographs for a broad range of geologic materials and a variety of soil forming conditions is needed.

Both black-and-white and color aerial photographs can be used to economic advantage in conducting comprehensive materials surveys. Color photographs are particularly useful in this respect because they generally permit information to be obtained that cannot be seen on black-and-white photographs. Furthermore, color photographs permit the job to be done more efficiently and reliably.

An adequate job by trained personnel may take considerable time and effort in the office and field. The education, training, and experience of the aerial photographic interpreter is significant. A background in the earth sciences, training and experience in aerial photographic interpretation, and a knowledge of highway construction materials, photogrammetry, and highway engineering are highly desirable.

The possible application of color aerial photographs for mapping by photogrammetric methods appears encouraging. One problem is in obtaining a stable film base to which color emulsions will adhere. Once this technical problem is resolved, it is likely that color photographs will be worthy of consideration and evaluation for mapping by photogrammetric means.

Undoubtedly, black-and-white photographs will continue to be used in the search for construction materials. However, good quality color aerial photographs can be produced and employed advantageously in conducting material searches. About 700 linear mi have been photographed in color for the Federal Projects Office, Region 9, Bureau of Public Roads, since 1958. As a result of past experience and the findings of this study, an additional 250 linear mi of color photography are planned to be flown in 1962.

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