*Experiments in the Use of Color Aerial Photographs for Geologic Study**†

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ABSTRACT: *This report primarily concerns field evaluation studies of color aerial photographs for three test areas in arid parts of California and Nevada. Ground-to-photo color correlations were established; these correlations aided in: 1. Identification of stratigraphic sections by color sequences; 2. Interpretations of structural complexities from interruptions or offsets of color sequences; 3. Determination of marker beds by distinctive coloration; 4. Recognition of differences in age in similar rock types by color differences; 5. Recognition of highly altered zones by distinctive coloration; 6. Recognition of approximate degree of alteration within outcrop areas of a lithologic unit by color differences; 7. Recognition of shear zones and other structural features by sharp breaks in color pattern; and 8. Identification of stratigraphic units that have a characteristic over-all color.*

FREQUENT reports of preliminary photogeologic studies yielding significant amounts of valuable geologic information make it very evident that interpretation is a primary geologic use of aerial photographs. The "preliminary" character of such work only further emphasizes its value; for example, it may focus attention upon critical localities, or isolate localities that may become critical, or aid in directing the course and purpose of field investigations. But black-and-white photographs place definite limitations upon interpretive work.

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Colwell[1] designates elements such as tone, texture, size, shape, pattern, and mode of occurrence (site) as component recognition elements of a photo image. His analysis clearly emphasizes the value of new and additional photo recognition elements to photointerpretive work. "Color" is an added element on the color aerial photographs. The presence of the color element permits experimentation with new techniques that may yield additional geologic information. For example, various types of selective filters and color correction filters, when used in the viewing sys-

[1] Colwell, R. N., "Photographic Interpretation for Civil Purposes," Chapter XII of "MANUAL OF PHOTOGRAMMETRY," Second Ed. 1952, American Society of Photogrammetry, Washington, D. C.

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tem, will emphasize certain colors or change color balance in such a manner as to bring out specific geologic features. Care must be taken in evaluating the geologic significance of color, however, as color differences may be the result 1) of errors in exposure or processing, 2) haze or other environmental conditions at the time of exposure, or 3) defective or inadequate materials. Color aerial photography in geologic work is still experimental, although new experiments, techniques, and improvements are made daily.

Field evaluation studies have been made recently in two areas in western United States. This paper briefly describes these studies.

Field Evaluation Studies

The first field evaluation study of color aerial photography, a two-week study of an area near Furnace Creek, Death Valley, California, was made by the author in the fall of 1955. The second, of areas near Goldfield and Tonopah, Nevada, was made with W. A. Fischer and G. D. Eberlein in October 1956. Three days were spent in the Goldfield area and two in the Tonopah area. Color aerial photographs of all three test areas are 1:10,000 scale overlapping verticals taken from a flight altitude about 10,000 feet above mean terrain.

EQUIPMENT

In addition to standard field equipment, a portable light table and Old Delft scanning stereoscope were used at field bases and in all evaluation studies. Color transparencies were sealed in clear plastic envelopes for protection and to permit annotations.

Description of the Test Areas

Rock exposures in the Furnace Creek area consist mainly of a colorful steeply dipping, folded and faulted sequence of Tertiary strata. Layers of basalt are intercalated at several horizons throughout this sequence. Strata of Paleozoic Age, exposed along the eastern margin of the test area, are remarkably persistent in rock type, fossil content, thickness, and coloration. A linear pattern of ground color characterizes the test area, but structural complexities cause local anomalies in the pattern.

In marked contrast, the Goldfield and Tonopah test areas are characterized by exposures of altered volcanic rocks, including rhyolite, latite, dacite, andesite, and basalt. Locally, these rock types show different degrees and types of alteration. Random discontinuous complex patterns of ground color result, wherein some colors represent relatively unaltered rock types, others represent different degrees of alteration within each of several lithologic units, and still others represent zones of intensive alteration. The color patterns are complicated still further by shear zones, faults, and fracture patterns.

All test areas are in arid regions; vegetation is sparse, and bedrock is at or near the surface.

Study of the Furnace Creek Test Area

Six flight strips of color aerial photographs were taken parallel to the topographic and geologic grain of the Furnace Creek area. The photographs show the east flank of the Black Mountains, the intermountain valley, and a part of the west flank of the Funeral Mountains. Color photographs comprising the three flight strips over the intermountain valley area are overexposed and field-photo correlations could not be established on the basis of color alone.

In marked contrast, color photographs of mountainous and upland terrain are of exceptionally high quality. Photo images are sharply defined, color balance seems to be excellent, and correspondence of photocolor with ground color is well within the tolerances of matching by use of the rock-color chart.[2]

OBJECTIVES

Field evaluation studies in the Furnace Creek test area had a two-fold objective: (1) to outline specific geologic uses of color aerial photographs, and (2) to study the relationships of photo color to ground color, with regard to effects of variables such as atmospheric haze, type and altitude of terrain, sun angles, viewing distances, and flight altitudes. Data and observations recorded for this second objective are not presented in detail in this paper.

METHODS OF STUDY

To become familiar with the Furnace Creek area, ground colors in direct sun-

[2] Goddard, E. N., *et al.* (1948). "Rock Color Chart": National Research Council, Washington 4, D. C. (Also distributed by Geol. Soc. America.)

light were observed and evaluated from selected observation points. Traverses were made in all parts of the area to study the stratigraphic units; wherever possible ground color was then correlated with photo color, and characteristic colors and characteristic color sequences were established. Prior study of color photographs directed the course and purpose of many of these field traverses. Photo-interpretations made and checked in the field suggested specific geologic uses, and problems illustrating these uses were outlined and studied.

RESULTS OF STUDY

Preliminary results of this study suggest the following geologic uses of color aerial photographs:

(1) Photo-color sequences can be correlated with ground-color sequences that characterize undisturbed strata. For this purpose, colors may characterize stratigraphic units that may or may not have been previously established and described in the field.

(2) The absence of a specific color in an established photo- and ground-color sequence strongly suggests stratigraphic or structural complexity. This condition was used to detect the presence of a low-angle fault in the Funeral Mountains.

(3) Offsets or interruptions of established color sequences strongly suggest high-angle faulting. This principle can be illustrated in all parts of the field area.

(4) With respect to flight altitude and appropriate viewing distances, formations and stratigraphic units that show a characteristic over-all color can be identified and mapped.

(5) Distinctively colored strata within stratigraphic units can be used as marker beds.

(6) Strata different in age but similar in rock type can be recognized by color differences. This principle best applies in areas where such strata have been juxtaposed.

Preliminary results of more general studies of color made in the Furnace Creek test area indicate that:

Photo-color fidelity, with respect to ground color, is extremely difficult to evaluate. But, fidelity is not considered to be essential to the geologic use of photo color, provided that color *differences* are recorded. Additional low-altitude oblique color aerial photographs of the test area show that color differences are accentuated by slight underexposure and are minimized by overexposure; these photographs also indicate that optimum exposure settings are related to concentrations of particular colors. For instance: concentrations of ground color in the yellow range caused overexposure of color film; but in the same flight strip, concentrations of ground color in the red range caused underexposure.

For convenience, the three elements of a color are considered to be: (1) hue—such as "red"; (2) lightness value—such as dark or light in shades of gray; and (3) chroma—such as "pale" or "vivid." Impressions of colors, and of color differences, are related to edge gradients of colored images and to viewing distances; some loss of image sharpness, and some increase in lightness value at the expense of color chroma, take place as viewing distances increase. But atmospheric haze, not viewing distance, is considered to be the primary cause of these losses; also, haze affects impressions of color hue.

Atmospheric haze is usually not appreciable in mountainous and upland parts of the test area; distinct impressions of color can be obtained and recorded from viewing distances on the order of 11 miles. But haze is usually present over lowland areas, and color differences known to be present could *not* be detected from distances on the order of two miles. Different sun angles and different times of day also affected impressions of color hue.

STUDY OF THE GOLDFIELD AND TONOPAH TEST AREAS[3]

Field evaluation studies of the Goldfield and Tonopah test areas were based on two flight strips of color aerial photographs. Each flight strip covers a ground area approximately six miles long and $1\frac{1}{2}$ miles wide.

OBJECTIVES

Objectives of these studies were threefold:

(1) to evaluate the usefulness of color

[3] Basic geologic information of the Goldfield area was taken from U. S. Geol. Survey Prof. Paper 66 by F. L. Ransome (1909); basic information used in the Tonopah area was obtained primarily from field traverses.

aerial photographs in identifying and mapping lithologic units;

(2) to evaluate the usefulness of color photographs in recognizing and interpreting different degrees and kinds of alteration within these rock units; and

(3) to evaluate the correspondence of photo color to ground color, and the sensitivity of color film to changes in ground color. This third objective was undertaken primarily to improve specifications for future work.

METHOD OF STUDY

Parts of the Goldfield area shown on the geologic map and on color aerial photographs were first visited to become familiar with lithologic units mapped and described by Ransome. Lithologic information gained from field traverses in the Tonopah area was related directly to color aerial photographs, and a gross lithologic breakdown established in the field.

In both areas correlations were first established between lithologic units and their color and landform as shown on color aerial photographs. Margins of outcrop areas characterized on photographs by similar color and landform were visited in the field to determine their relationships to geologic contacts previously mapped or established. Zones of different coloration within each of several lithologic units were studied, hand specimens were collected, and preliminary photo-recognition criteria were established. Photogeologic identifications were made outside of areas covered by existing maps and then checked in the field. Thin sections made from the hand specimens were studied later by G. D. Eberlein in order (1) to identify rock type more precisely, and (2) to obtain data on types and degrees of alteration. Thin-section information was then related to photo color.

RESULTS OF STUDIES

Preliminary results of these field evaluation studies indicate that most of the lithologic units previously mapped or established in these two test areas can be recognized by color or groups of colors visible on the color aerial photographs. In both areas a general correspondence between coloration and alteration was observed. Zones of different coloration within a lithologic unit represent different stages of alteration. Colors of rocks in early stages of alteration are useful in recognizing lithology, but highly altered rocks have the same color within several different lithologic units. The colors associated with highly altered rocks are easily recognizable on color aerial photographs; thus their distribution and their relationship to structural features can be studied.

Thin-section study in general corroborated the findings based on field examination of rocks in the Goldfield and Tonopah areas. Lithologic units believed to be relatively unaltered, and characterized by a particular color, actually showed the least alteration in thin sections. Different colored zones within a lithologic unit showed definite differences in thin sections in either degree or in type of alteration. The most intense alteration was observed in zones having a diagnostic red color at the surface, but these zones are thought to be more closely related to structural features than to a particular lithologic unit. The results of this study suggest that the distribution of localities where one type of alteration predominates may be mapped be distinctive color, for example, alunitization in the Goldfield area.

In general, photo colors corresponded well with ground colors. However, all color aerial photographs of both test areas have a faint yellowish overtone. This overtone causes photo colors to be shifted toward the yellow part of the spectrum and detracts from the over-all appearance of the photograph; however, it was not believed to have significant effect upon color-correlation work. Yellowish overtones have been observed on 1:10,000 scale color photographs of other test areas, and bluish overtones have been observed on 1:20,000 scale color photographs. These overtones may be related in part to effects of differences in daylight characteristics at altitudes of 10,000 and 20,000 feet above ground upon color film at the time the film was exposed. Selection of an intermediate flight altitude between 12,000 and 14,000 feet might tend to counteract these overtones.