formal and informal training has been established on a permanent basis.

Discussion of Dr. Ray's Paper

MR. EARL ROGERS: You mentioned a training program, quite a formal one, as I understand it. I didn't understand about the length of time.

DR. RAY: It is a two-week training period, ten days of intensive training.

MR. FRANCIS ORTIZ: Is the training available to any geologist?

DR. RAY: I am pleased to answer in the affirmative, with reservations. The courses have to be limited in the number of participants. Other than a Geological Survey geologist is permitted to participate in the course, provided this does not interfere with the programmed training of Survey geologists. In other words, if there is room at a particular time, because the number of participants is less than the allowable number, we are very happy to let someone else participate.

MR. HENRY BUTHMAN: You spoke of using a Kelsh plotter. Have you found from its use that it has more or less replaced the use of contact prints in the larger scale photography?

DR. RAY: At present, finite limitations concerning accuracy of geologic maps have been disseminated among the geologists of the Survey. Just as there are standard accuracy limitations of topographic mapping, we now have certain limitations to be met in compiling a Grade A, let's call it, geologic map.

Where such accuracy standards have to be met, the Kelsh plotter, of course is a very fine instrument to give the accuracy required. Undoubtedly there are a great many jobs where simpler, less precise, photogrammetric instruments would be adequate for the problem at hand, and I expect that is particularly true of some of your own work. In our own work, although we have encouraged the use of the Kelsh plotter, the use of contact prints has by no means been replaced.

A Performance Estimate Comparing Conventional Geologic Mapping with that Accomplished with the Aid of Color Photographs

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A COMPARISON between a color photogeological map of one area and geologic maps of the same area produced by other methods was originally scheduled for this panel. However, it was believed that such a limited presentation might miss the broader interests of a large part of those attending this meeting. So I have taken the liberty of broadening the scope of the presentation on an informal basis.

As Mr. Fischer has stated my experience in the past nine years has included a study of perhaps 40,000 large-scale, vertical, stereoscopic, color, aerial photographs covering a large number of mining districts in the Basin Range Province, and several on the Colorado Plateau. This basically was a research project in the use of the color photographs in mineral exploration.

Mineral exploration for the future requires geological analysis of regions and districts, resulting in predicting ore deposits several hundred feet below the surface of the ground. In the past nearly all outcrops of mineralization have been located by ground work; this requires the largest number of the best possible geologic maps. The color photographs function as such geologic maps with great detail; maps for reproduction can be produced quite efficiently from the photographs by simple procedures.

During past studies, color photographs and photogeologic maps produced therefrom, have been compared with many geologic maps of much of the 500,000 sq. mi. of the Basin Range Province and Colorado Plateau. These maps include State, District, and detailed maps of local areas. The color photographs show that there are many errors and omissions and that these seriously limit the use and value of those maps for exploration purposes.

Recent geologic maps produced by the U. S. Geological Survey are much better than the average. The personnel of U. S. G. S. includes many geologists with much experience and skill in mapping and with considerable understanding of the regions in which mapping has been conducted. It is possible however that such high-calibre mapping might have been materially aided by using color aerial photographs.

Successful mineral exploration requires a sound theoretical framework by which geological facts from many sources can be related and permit prediction of buried ore deposits.

There is a vast literature on ore deposits and the general geology of regions and contained mining districts from which the generally accepted theories concerning ore deposit genesis have been derived. The conventional theory concerning the hydrothermal type of ore deposits in the Basin Range Province regards them as originating in molten bodies of rock invading the crust of the earth. The final solutions given off after the common rock-forming minerals crystallize contain dilute concentrations of ore forming elements. The solutions migrate into the rocks overlying the "stock," and form deposits of several types depending upon the rock and structural situation.

The theories suggested by the thousands of colored photographs of many mining districts are that there is little evidence of invading granitic rocks. They suggest a general streaming-off of heated ore-bearing solutions—called by many European workers "metasomatism." Many of the described "intrusives" in the region have been found to be metasomatically recrystallized rocks, or fault blocks of basement-complex granitic rocks. This requires a different approach to ore search in the region. This finding has been probably the most valuable result of the use of the color photographs in the study of the region.

The mechanics of the production and use of the color aerial photographs may be of interest. A light single-engine airplane with fixed vertical-camera installation operated with an intervalometer has been used in photography. Good quality mapping photography with 60 per cent endlap and 25 per cent sidelap is possible with such equipment.

The color film may be processed with simple equipment and laboratory facilities. A fluorescent light table with diffusing plexiglass top has been found most satisfactory for viewing the color transparencies.

The first study of the photographs is in the roll form. The different rock units and structural patterns can be determined, and the nature and scope of the photogeologic map to be compiled is estimated.

Photogeologic mapping is done on acetate strips for each flight line or part thereof, with center-line control. A mirror stereoscope is used for the detailed study and map drafting. The photogeologic strips can be compiled into a single sheet or reproduced and used separately. For reconnaissance studies and field checking, the separate strips are most convenient; they can be aligned approximately for viewing the complete area. A large magnifying glass is most useful for examining detail. Since it produces a pseudostereoscopic effect, it is useful in examining rock textures, changes in which are often important in ore study.

The rock units on the acetate strips are usually colored as mapped. An ink tracing of the sheet is used for ozalid prints, which are colored with printing ink washes.

The principal advantage of the color photographs for mineral exploration or general geologic mapping is that they allow a very detailed and complete premapping of an area before field work. The concept of as thorough as possible premapping of an area before ground studies has been slow in attaining general acceptance. This is probably due in part to the limitations of the black and white photographs, and perhaps to disinclination of the geologists to do the amount of "estimating" necessary in such work. But it provides much greater efficiency in the mapping work—particularly in remote and inaccessible areas.

In mineral exploration, it is possible to make a quite thorough analysis of an area and a selection of the critical spots—the situations in which ore can be expected. This is difficult for geologists to accept as being possible if their approach has been primarily a detailed ground and minerologic study of areas as a basis of ore analysis. However, the advantages of the color photo-view has been demonstrated in many areas in which an opportunity for comparison has been possible.

Another advantage of thorough pre-mapping and study in mineral exploration is in selecting the areas for ground acquisition before entering an area. At times detailed ground studies of an area before ground acquisition attract others to acquire the ground on speculation. This might be very costly in an important area. By having advanced to the point where the first field activity is taking up the ground, such trouble from speculation can be avoided.

An exploration activity of the type suggested was carried out this past Spring. The study of a district indicated a favorable area. The ground was staked with 64 claims. Subsequent ground study of the mineralization details (scattered copper mineralization in this instance), more than adequately substantiated the photogeologic findings.

The selection of favorable areas in a region, analysis of the areas, and selection of ore targets by aerogeologic and color photo methods can be done many times faster than by ground methods. Time is probably the most critical element in such activities.

The development of airborne geophysical methods will contribute to the speed of exploration activities. Such activities will be more effective if concentrated on limited areas analyzed by means of the color photographs than by using broad reconnaissance. The photogeological study and mapping will also greatly facilitate the interpretation of the geophysical data. A limited research project of such nature has been initiated with Hycon Aerial Surveys this year.

A general article describing color photogeologic studies was presented in the June 1952 *Mining World Journal.* Another article will be published by that journal soon. Reprints of the articles will be supplied upon request.

Discussion of Mr. Laylander's Paper

MR. LANDEN: Would not the use of modern stereoplotting equipment be an advantage in photogeologic mapping?

MR. LAYLANDER: Stereoplotting equipment such as the Kelsh plotter would be valuable in making detailed topographic-geologic maps. For reconnaissance planimetric mapping in connection with photogeologic studies in ore search, the table stereoscope with binocular and large magnifying glass are sufficient for most purposes.

MR. BUTHMAN: Do you find that color photography is helpful in recognizing mineral deposits, and has it advantages over black and white photography?

MR. LAYLANDER: In the study of dozens of mineralized areas it has been found that there are essentially none which do not have changes of color in the surrounding rocks reflecting the ore zones. For example, in the Pioche, Nevada district which has important bedded lead-zinc deposits near the base of the Cambrian section, the color photographs show areas of dark manganosiderite bloom and pyritic alteration along fractures 1,700 feet higher in the section. Those alterations are confined to the ore zones. Also, distinctive types of gossans reflecting copper porphyry deposits can be seen on the color photographs. In both types, the distinctive alterations and intensity of the zoning are very difficult to see by black and white photography, or by ground observation. The generalization can be that there are essentially no important ore deposits which do not have both broad alterations and specific local alterations, fairly readily seen on the color photographs, which cannot be distinguished on the black and white photographs.

On the Colorado Plateau a color photogeologic study of about 2,000 sq. mi. of the uranium producing areas indicated that there were usually subtle alterations of the rocks reflecting ore zones which were largely overlooked by ground studies. In the Big Indian area, for example, infrared-color film with a special filter combination showed a change from a reddish to a yellowish color in the Chinle formation near ore zones, which could not be seen either on black and white film or visually. There is a great field of potential research in study of areas by means of special color films and filter combinations, in determining non-visible changes in rock colors, related either to hydrothermal alteration or facies changes.

DR. H. T. U. SMITH: What type of color film do you find more satisfactory, and what is the maximum altitude from which good color rendition can be obtained?

MR. LAYLANDER: The only color film for aerial cameras generally available has been the Eastman Aero-Ektachrome. The altitude problem is complex. In general, by using stronger anti-haze filters for increased altitude, the same approximate color rendition can be obtained. However, shades and tones of colors, even with corrective filters often appear different on different scales, as between 15,000 and 5,000 ft. elevation above the ground photography. This is often important in making comparisons of hydrothermal alteration phenomena. It might be related to grain of the photographic emulsion, transmission of the reflected light, etc.

A set of color photos with a monochromatic effect resulting from film age, incorrect filters for light conditions, or processing, still provides a great deal more geologic information than black and white film. Correction filters on the viewing table can largely compensate for such monochromatic effect. There is also an automatic visual and psychological compensation for the monochromatic photographs, even without the correcting filters on the viewing table.

DR. SMITH: Two other questions: Have you used color film in areas having a great deal of vegetative cover? Will you give more information about the use of infrared-color film and filter combinations?

MR. LAYLANDER: Plant patterns in many areas are quite sensitive to minor element concentrations, and such plant pattern anomalies are an aid in determining ore deposits at some distance below the surface of the ground. For example, within perhaps a mile radius of a lead-zinc deposit, where either hydrothermal or ground water has carried small amounts of zinc or manganese, there may be considerable change in the plant patterns. Those plant patterns may be picked up to some extent with the black and white photographs, but the infrared-color film will usually give much greater distinction. As far as has been observed there is little perceptible specific change in the colors of particular plants due to minor element concentrations.

The plant patterns also reflect the rock patterns. Considerable photogeological mapping can be done on that basis, where correlation between plant types and rocks on which they grow has been established. The correlation can be determined in less densely covered areas, and projected into heavily covered areas.

The infrared-color film was designed to distinguish between dead vegetation or paint used for camouflage and live vegetation, on the basis of the chlorophyll reflectivity. It is a rather peculiar emulsion for geologic purposes in which colors are not the same as viewed directly. Not enough work has been done to make many generalizations. The film will sometimes show marked changes in rock colors due to hydrothermal alteration which are either very subtle or are not observable with regular color film or direct observation.

MR. ISAACS: Have you used color photography in conjunction with black and white; that is, making one color photo to five or six black and white on a flight line?

MR. LAYLANDER: There would seem to be little economic advantage to such a procedure. For geologic purposes overlapping color is most advantageous. There might be some advantages, but that has not been determined.

MR. R. J. HUGHES: What is the comparison between color photography and black and white photography, with respect to cost?

MR. LAYLANDER: The color film with filters and processing chemicals might cost $120 per 75 ft. roll as against $60 for black and white. There are also fewer flying days annually for color photography than for black and white. Accordingly the overall cost of color might be about 50% higher than black and white. However, the value of color film for geologic studies and mapping ordinarily would be considerably greater than the difference in cost of the photography.

MR. ROGERS: Can you give an estimate of the savings in cost in exploration work using color photography, over techniques not using photography?

MR. LAYLANDER: With enough experience in a region so that rock units can be recognized, it is possible to produce a good geologic map of a district in about a month's time, that is, an area of about 30 sq. mi. and on a scale of about 1:6,000. In some districts compared, which had had years of ground mapping, many important features were not observed or mapped by ground methods which were readily observed with the color photographs. In general, the relative efficiency of color photogeological mapping would be at least four to one when compared to ground methods. For complex, remote and inaccessible areas, the relative efficiency would be much greater than that.

MR. ROBERT COLWELL: I'd like to make a comment regarding the relative cost of color photography when compared to black and white. It was mentioned that a number of factors make it difficult to make a blanket comparison. However, in a recent test, in which considerable effort was made to take a typical mission and figure the cost of purchasing the film, flying the photography, and processing the material and getting it ready for viewing, first in black and white and then in color, the cost figures came out roughly as follows:

For panchromatic photographs, the cost would be around $650, and for aero-ektachrome, the color photography, the same mission would be $850. Either figure is surprisingly low, compared with the overall values attained.

*"Eagles of Geology"**

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ABSTRACT: *This paper briefly describes the historical development of aerial photography as a component part of the exploration teams in one segment of the petroleum industry. Progressing from early limited use of aerial photographs through the birth and present application of photogeology, many advantages and values are demonstrated by illustrations. It is pointed out that basic principles of good management are essential in the application of photogeology to an exploration program, if maximum results are to be expected. Well-trained personnel and adequate tools are of utmost importance. Some limitations may be removed through developments now in progress.*

DURING my many years of being closely related to the search for petroleum, I have learned of the trials and tribulations of the field geologist. Often, they have brought to mind the story of the tiny lad wandering frantically through a densely-packed circus crowd. A thoughtful man asked if he were lost. The lad bravely anwered, "I'm not lost; my mother is lost." The man then raised the lad high upon his shoulders, from which point of vantage he was quickly able to identify his mother.

Similarly, aerial photography has, to a large degree, lifted the field geologist out of the swamps, out of the jungles, over trackless deserts, frozen waste lands, and the tallest mountain ranges. Along with speed, it has given him the wings of an eagle, the ability to stalk, study and swoop down upon his prey—the elusive petroleum trap.

From infancy to maturity the art of adapting aerial photography to exploration for petroleum and mineral deposits, now commonly called photogeology, has passed through many phases. The "Eagles of Geology," equipped with the vastly improved air photos and highly developed instruments and techniques, can "soar" over large areas while seated in comfortable offices.

Efforts of earlier-day geologists were slowed by painstaking measures necessary

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