SOME APPLICATIONS OF NATURAL COLOR PHOTOGRAPHY IN MINERALOGY

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The use of natural color photographs or color transparencies[1] in mineralogy and petrography is still in the initial stage of application, although hand-colored lantern slides have, for a long time, been employed by teachers and lecturers on these subjects. During the past decade improvements have been made in the art of color photography, and at present there are several good color plates on the market. These are known as screen plates. In one type the color elements, red, green and blue-violet, are incorporated in an irregular mosaic forming a color screen, which is placed between the glass plate or film and the photographic emulsion. In another type the color screen involves a separate plate consisting of a regular pattern of square or other ruled elements having the same colors in a gelatin coating. The former is known as a combination screen plate, or film, of which the Lumiere Autochrome film and the Agfa color plate are examples; the latter are referred to as separate screen plates, and the well known Finlay color plate is the outstanding example.

The production of a positive picture on a combination plate involves a comparatively simple reversing process, during the finishing operations. With the separate screen plate a negative is made on a separate panchromatic plate which is exposed while pressed in contact, emulsion to emulsion, with a color screen known as the "taking screen." The glass side of the latter is held towards the lens. The photographic plate is developed, and from it prints are made as in printing ordinary lantern slides. The image consists of a pattern of minute squares of varying density corresponding to the color elements in the screen. "Taking screens" may be used any number of times unless they are damaged by careless handling. Colored positives are obtained by binding "viewing screens" in correct register with the positive prints. The viewing screen is essentially identical to the taking screen, consisting of red, green and blue-violet squares of the same size and arrangement.

The combination plates are made with a very thin and rather delicate emulsion which necessitates an exposure correctly timed within *very narrow limits* in order to reproduce the color faithfully. Incorrect exposures may be remedied to some extent by either reduction or intensification. However, when the error is too great, the plate is lost entirely. The separate plate method has a somewhat greater range of permissible

[1] Wolff, J. E., Lantern slides in natural colors for demonstrating geology and microscopical petrography: *Am. Mineral.*, vol. **15**, p. 117, 1930.

exposures and, if the error is too great in this case, the only loss in material is a panchromatic plate.

Making Duplicates

The combination screen plate may be reproduced in a copying and enlarging camera, but the duplicate always contains more black areas with correspondingly greater absorption and loss of brilliancy. The positive in the separate plate system is made from a negative, and hence any number of positive transparencies may be made and bound in correct register with viewing screens.

Absorption of Light by Color Transparencies

The brilliancy of the plates depends upon the amount of light transmitted. In the combination plate the absorption is over 90 per cent, whereas the separate plate absorbs about 75 per cent[2] of the light; hence the brilliancy of the latter is two and one-half times greater.

Projection Apparatus

A brilliant source of illumination is required for projection. However, a 500 watt projector is satisfactory for the normal class room, which can be properly darkened. The heat accompanying this amount of energy is considerable and must be dissipated by some means, otherwise any color plate having a low fusing material incorporated in the screen should not remain in the lantern more than one and one-half to two minutes. Projector manufacturers are now producing lanterns which cool the slides, but there are still opportunities for marked improvement in color plate projectors.

Photographic Apparatus

Many cameras, such as the various view and Graflex models or photomicrographic outfits, may already be adapted to the use of one or more of the various types of color plates after the ground glass is reversed. For some types of cameras special plate holders are required. The variations are too numerous to discuss here, and information concerning this matter may be obtained from the various pamphlets made available by the manufacturers of color plates.

A complete apparatus should be equipped with a series of corrected micro-lenses of, say, 16, 24, 48, 80 and 120 millimeters focal lengths in addition to a 7 or 8 inch lens. These will cover the range of specimens from those as small as 1/16 inch up to 18 inches or larger, depending upon the operating range of the camera.

[2] Wall, E. J., Practical color photography, p. 192. American Photographic Publishing Co., Boston, **1928**.

Filters

Since all lights have characteristic spectral values and daylight varies in this respect at different times of the day and year, special color filters are necessary, and those recommended by the manufacturers should be used if the type of lamp and voltage are the same as those specified. If the voltage is higher, however, blue will predominate, and if lower, the red will be too strong; hence the strength of the filter should vary if there is any appreciable difference in voltage or type of light from that recommended.

Illumination

Except for the exposure, the illumination and filter combination is the most important. One should aim to provide a uniform *soft* illumination with a minimum amount of contrast, for the objects are outlined on the plate by the color and not by strong contrast as in black and white photography. For the Agfa color plate photoflood bulbs have very good color values and intense illumination, but the intensity and spectral value of these vary greatly with ordinary voltage fluctuations, and also with the age of the bulb because of the condensation of the filament metal on the interior of the bulb. Projection bulbs of 500 watts capacity and nitrogen-filled Mazda lights produce good results. The latter, on account of their larger size, are more difficult to manipulate, especially for the illuminating of smaller objects. Probably the most reliable and satisfactory kind of illumination for photographing minerals, especially the smaller ones, is some form of arc light. Specimens up to 10 or 12 inches in diameter may be illuminated with two small arc lights by using a 50 mm. hand lens with holders designed to spread the light over the desired area. The same lens may be used to converge the light on small specimens when the latter are to be magnified a number of times. For many minerals a water cell is necessary to prevent overheating the specimen when the arc is focused on a small area. The small arc lamp which is generally used in connection with microscopic and photomicrographic work is not a white-flame arc and, after repeated trials with yellow objects, it was found that for the Finlay-Eastman plate their Wratten filter 4547 should be used with alternating current instead of their filter recommended for use with the white flame arc. Direct current would probably require a filter somewhat lower in density.

Determination of Correct Exposures

As the success in making a faithful reproduction of a colored object depends to so great an extent on the exposure, it would seem that a formula would be of great value in making this determination. The factors entering into such a formula,[3] however, cannot readily be determined within the permissible variation of the exposure, hence the formulated results are not within the required limits. The chief variables entering into the calculation of an exposure are: the numerical aperture or stop, the magnification, the intensity and kind of illumination, and the color intensity of the principal object to be photographed. Of these factors the numerical aperture and magnification may be accurately formulated. For large objects the light intensity may be determined with an electric photometer, which also includes the color intensity factor providing the colored object to be photographed occupies the major part of the field. For very small objects and photomicrographic subjects the ordinary electric photometer cannot be used on account of the usual design of the instrument.

The early meters for determining photographic exposures consisted essentially of a series of ground glasses having an interposed calibrated diaphragm which was used to vary the intensity of light reflected from the object to be photographed onto some comparison scale. If a camera is used in a dark room and the major part of the light shielded from the operators eyes, or if a focusing cloth is used long enough for the eyes to adjust themselves to darkness, the camera itself involves the essential principles of the early photometers. By closing the lens diaphragm until the most important objects are approaching the limit of being distinctly visible, one has a method which enables the experienced operator to determine the exposure with a fair degree of accuracy. This procedure involves all of the important factors including the color density. If an object is so densely colored that it does not show distinctly on the ground glass, a prolonged exposure is necessary for its reproduction. Considerable judgment is often required in prolonging the exposure so that the darker colored parts are not too greatly under-exposed, and at the same time the weaker colors are not too seriously over-exposed. It is an advantage to work with an intense source of illumination so that the image appears clear and brilliant on the ground glass at full diaphragm opening in order to compose the picture properly and subsequently to determine the exposure. When first starting to make color plates or introducing any marked change in the set-up, the photographer will find it desirable and profitable to make a seven strip test exposure plate of some object having a uniform color intensity over the entire field. To do this, one must start with some estimated exposure, which may be obtained by closing the diaphragm to a point where the ground-glass image is still clear and distinct but where further closing will render many of the parts nearly

[3] Whitehead, W. L., Notes on the technique of mineragraphy: *Econ. Geol.*, vol. **12,** p. 715, 1917.

invisible. One will soon become accustomed to the best working range in this respect. At the point where the image is still clear and distinct, a good first estimate for a Finlay-Eastman plate is approximately $\frac{3}{4}$ to 1 minute. This should be the exposure for the middle strip of the test plate and the other exposures calculated so the several strips vary by about 12% above and below each successive strip. One should calibrate the dark slide with white lines or use a spacing guide, Fig. 1, to indicate the spacing for the strips; that is, for each position of the slide as it is inserted for the several exposures. Special care is required to prevent

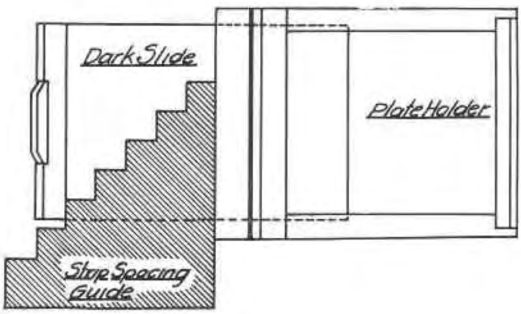


Fig. 1. Sketch of plateholder showing how spacing guide is used for making test exposures of color plates.

the shifting of the plate holder while inserting the slide, for any movement will give a blurred negative. When the test plate is correctly developed, the strip of the Finlay-Eastman negative which has the correct density for printing on No. 3 Azo paper will have the correct density for printing on an Ilford plate to reproduce the correct colors. If the test is made on a combination plate, the strip having the correct colors when developed, would, of course, represent the correct exposure.

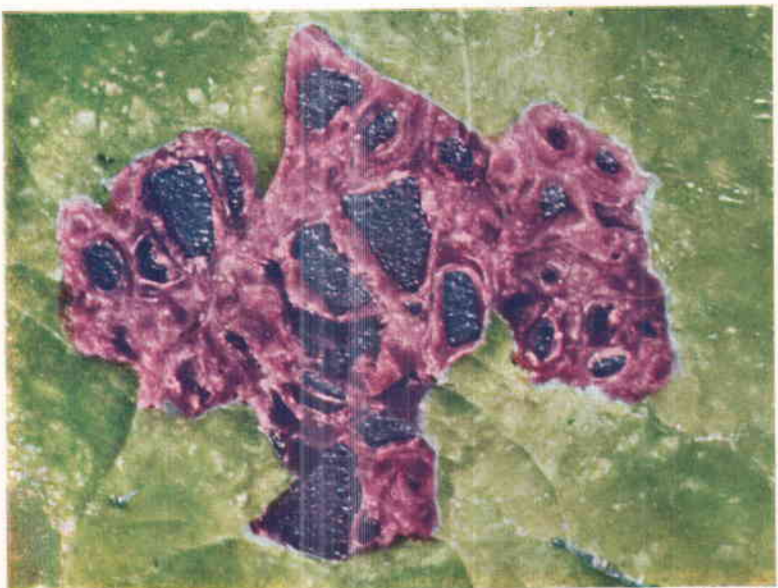
Printing and Transparencies

To make positive transparencies from the Finlay-Eastman negatives the writer uses a 15 watt Mazda bulb in a rectangular light house which is supported vertically. The light is diffused and reduced in intensity before leaving the house by passing through a combination of two pieces of flashopal glass which are separated two inches and each of which is covered by two pieces of twenty-pound bond paper. The bulb is 20 inches above an ordinary printing frame which rests in a horizontal position on a table. The average exposure is from 15 to 20 seconds for an Ilford positive plate. This allows sufficient time for shading underex-

PLATE I

A

Emerald from Colombia, South America. $\times = 10$



(Finlay Photographs)

B

Serpentine with stichtite surrounding chromite from near Dundas, Tasmania. $\times = 16$

posed parts of the negative, and thus makes a decided improvement in the color transparency.

The formulae and time of development recommended by the plate manufacturers should be carefully and conscientiously followed, for they are the result of consistent research and application.

Application to Mineralogy and Allied Subjects

One of the first subjects in this field to attract the attention of the color photographer is quite naturally the beautifully colored crystal aggregates, especially the crystals used for cutting gems and precious stones. When photographed these subjects should be so arranged as to show their distinguishing characters. Those who conduct lecture classes will find that natural color lantern slides of properly oriented specimens are, indeed, ideal. With illustrations of this kind the mineral can be described to the entire class simultaneously thus avoiding the mental and physical confusion created by passing around specimens. A series of slides may be made from selected material to cover the usual range of colors, occurrences, crystal forms and other structures of a given species. In this manner excellent museum specimens may be used to the best advantage for instruction, even though they could not be handled by students in either lectures or laboratory work.

With the Finlay color plate a very unexpected degree of perspective is obtained because of the combined effect of the screen and the color shading. The attention of the class is greatly increased, for it is quite the natural and instinctive thing to be inspired by color when our environment is one of color and not merely shades of gray.

One of the surprising advantages of color plates over black and white ones may be seen by comparing the natural color reproduction of a specimen of stichtite, chromite, and serpentine, Plate I, with a black and white reproduction, Fig. 2. In the latter the color tones blend one with the other and the outlines are indistinguishable, while in the color plate they are sharp and distinct. A small emerald crystal $\frac{3}{8}$ of an inch long from Colombia is shown reproduced in color at the top of Plate I and illustrates clearly how the crystallographic features and the color variations may be reproduced from specimen to color plate and then to text illustrations.

Optical mineralogy, which is a difficult subject to the beginning student, is replete with opportunities for the application of natural color illustrations. In the study of mineral fragments in crossed polarized light the student quickly grasps the significance of birefringence and other properties, for the instructor can cover in detail an entire microscope field. He can describe any individual grain or those of particular interest in regard to their optical orientation, as well as some of their physical properties. In the study of optical interference figures from oriented sections, the character of these and the dispersion of the optic axes can be readily and satisfactorily demonstrated with a set of slides which may be used in a projector or in the laboratory in connection with a viewscope. With the latter a number of slides may be simultaneously examined and compared.

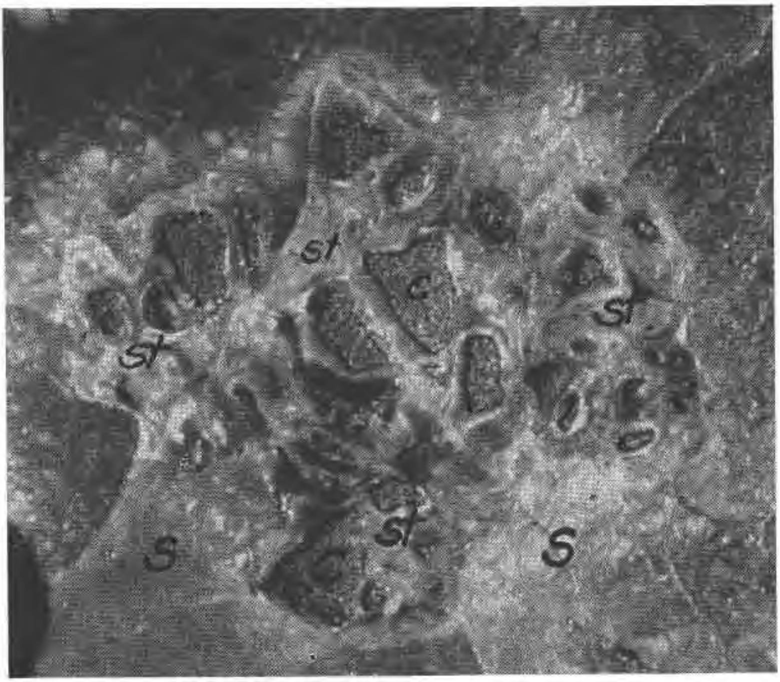


Fig. 2. Serpentine (S) containing stichtite (St) enclosing chromite (C), from near Dundas, Tasmania. Compare with natural color reproduction, B, Plate I.

In petrography, many kinds of structures, textures, mineral associations, alterations, pleochroic effects, and intergrowths may be demonstrated on the screen or viewscope. An advantage of the color plate over the projection microscope lies in the fact that the precise area desired is ready, hence the demonstration is continuous and follows smoothly according to the procedure outlined. A pronounced variation in colors may often be produced in intergrowths of substances having low birefringences by superimposing a gypsum plate. Two color plates of a subject of this nature taken at 90° positions make an excellent demonstration in compensation and retardation.

In mineragraphy, the application of these plates would be most useful in showing the characteristics of micro-crystals[4] corresponding to the element sought and other micro-crystals likely to occur in the same reactions because of other elements associated in the mineral or occurring as an impurity. A minor use would be in teaching the relationship of minerals in polished sections, but owing to the faint and indistinct colors of most of the metallic minerals in reflected light, one would probably not gain much in this field.

The photographing of very faintly colored, transparent cut-stones in natural color may be unsatisfactory on account of three factors: the first is due to their high luster, which is seldom reproducable to any degree because of the grain of the emulsion and texture of the projection screen; second, the reflection from the facets which produce either very high lights or dark spots; and third, the extremely faint color which is often difficult to reproduce from the rather dense tricolored elements of the color screen. The transparent gems with distinct color and those which are opaque make very beautiful color reproductions.

The writer can commend the use of natural color plates as an exceptionally satisfactory means of visual instruction for both the lecturer and the students; the laboratory teacher will likewise often find their use distinctly superior to other demonstration methods.

The public lecturer in mineralogy will discover in color plates of minerals a magic means of presenting to his audiences the beautiful forms and colors of minerals, as well as the entrancing and perplexing array of polarization colors produced by many petrographic sections. Some of the latter would be difficult for even the most vivid imaginations to overrate in delivering a popular lecture on these natural phenomena.

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[4] Putnam, P. C., Roberts, E. J., and Selchow, D. H., Contributions to determinative mineralogy: *Am. Jour. Sci.*, vol. **15** (5th Ser.), pp. 89–102, 253–261, 423–430, 455–460, 1928.