PHOTOGRAPHY FOR THE MINERALOGIST

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INTRODUCTION

It has been said that one good illustration reveals more information than a page of description. It is important, therefore, for a mineralogist to be able to photograph geologic scenes, specimens showing structure or texture, or microscopic detail in a manner that will clearly illustrate the actual condition. To do this he must have at his command a knowledge of the photography of colored objects. He must be able to use light filters and color sensitive emulsions correctly.

The use of light filters, of various types of films or plates, of cameras, and of artificial illumination often causes considerable trouble in the minds of inexperienced operators. It is hoped that the following paper will be helpful in clarifying some of the difficulties so commonly encountered.

Publications of the Eastman Kodak Company will be referred to freely in this article. Appreciation is also expressed to Dr. G. M. Schwartz, Dr. Hans Froberg, and other members of the Geological Department of the University of Minnesota for many helpful suggestions.

LIGHT. In photography a few fundamental facts regarding light are important and must be kept in mind. The color of a light ray is determined by its wave length. The blue-violet rays have the shortest wave length, ranging from 400 and 500 $\mu\mu$ (millionths of a millimeter), while green varies between 500 and 600, and red between 600 and 700 $\mu\mu$.

The velocity of light depends upon the medium through which it travels. Light travels at the rate of about 186,000 miles per second in air and about one-third slower in glass. On passing through a triangular prism the short waves are retarded more than the longer ones; hence they are refracted to a greater extent, and white light is spread into its components forming the visible spectrum.

All of the rays contained in white light are not visible to the naked eye. The ultra-violet rays, beyond the blue portion of the visible spectrum, are short rays which are highly effective chemically. The x-rays, although not thought to be present in ordinary white light, are still shorter than the ultra-violet rays and are also invisible to the human eye. Rays extending beyond the red end of the spectrum are known as infra-red or heat rays. These also are invisible.

Color as Recorded by the Eye

A point to be considered is the comparative sensitivity of the eye and the photographic plate. One should keep in mind the fact that nearly all of the photographic emulsions used are most sensitive to the blue rays, while the human eye seems to be most sensitive to the yellow green rays, with the color sensitiveness diminishing towards the red and the blue ends of the spectrum. If in a dark room the colors of the spectrum are increased in intensity from total darkness to visibility of the entire range, the eye would first recognize light without color, then yellow-green followed by orange and blue, then red and finally blue-violet.

Objects may appear colored in white light if they absorb any of the three principal components of the spectrum. That is, if an object is blue, it absorbs the green and red rays in white light and reflects the blue; if green, it absorbs blue and red and reflects the green; and if red, it absorbs the blue and green and reflects the red.

In general, red objects seem to be brighter to the eye than any other color. This is because red objects generally reflect a greater amount of light than the blue or green. Eastman gives the results of measurements of the light transmission of a number of colored gelatine filters as follows:

Red filters transmit about 75%–80% of red light.
Green filters transmit about 33% of green light.
Blue filters transmit about 12% of blue light.
Yellow filters transmit about 85% of yellow light.

Light Filters

It is possible by the use of transmitting or absorbing media to control the color of light. Light filters which are either colored solutions or gelatin films are used for this purpose. Such filters absorb certain colors and transmit the remaining colors of the spectrum.

The red filter when placed across the path of a beam of white light will absorb the blue and green rays allowing only the red rays to pass through. A blue filter will transmit blue and will absorb the red and green rays, while a green filter absorbs both red and blue.

In the study of light, red, green, and blue are spoken of as the primary colors.

If one of the primary colors is transmitted and the other colors absorbed, then the absorbed colors are said to be complimentary to the transmitted one. To illustrate, if blue light is absorbed, mixtures of green and red light (yellow colored light) are transmitted. The K series of filters and the G filter, of the Wratten series, absorb blue rays and give forth yellow light. The yellow is said to be complimentary to the blue. Red, therefore, is complimentary to the blue and green, and green is complimentary to red and blue, a color known as magenta.

Sensitive Emulsions

There are various types of films and plates used in photography. The ordinary film or plate has an emulsion that is sensitive only to the ultra-violet, violet, and blue rays, and does not react to red or green light. It is, so to speak, color blind. If an object which is red or green is photographed, it will appear black or dark gray on the print. Ordinary materials, such as Eastman Commercial Films, give the same monochrome rendering of colored objects that we see when we look through the deep blue C filter.

The orthochromatic film, commonly used in a photomicrograph, is not as color blind as the ordinary film. The ortho film is similar to the ordinary film but is more sensitive, or color-corrected, towards the green portion of the spectrum. As the film is still most sensitive to the blue rays, a filter will be necessary to absorb some of the blue light and allow time for the green light to react upon the emulsion. When a yellow filter is used, the film reproduces the yellows and greens, and the various colors are recorded in nearly the same monochrome values that we see when looking through the green (B) filter. If red is photographed, it will appear black or dark gray on the print.

The panchromatic emulsion is sensitive to the entire visible spectrum; thus, even red objects may be photographed in intensities as recorded by the eye. Also, this emulsion is still supersensitive to the blue portion of the spectrum; therefore a filter of the K series is used to subdue the blue rays.

If the color sensitiveness of the three types of emulsions are plotted, they would appear about as shown in figure 1.

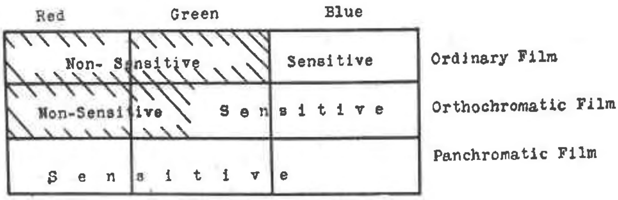

Fig. 1

Use of Filters

Filters are used for three main purposes; (*a*) to make corrections for the blue super-sensitiveness of the emulsions, thus rendering color in shades of gray equal to the intensity of the color as seen by the eye; (*b*) to photograph detail on a colored object; and (*c*) to record contrast between colored surfaces.

If panchromatic films or plates are used to photograph colored surfaces or outdoor pictures, a K_3 filter will give full color correction. A K_2 filter will give good results with ortho films. Blackwelder[1] has used a dark blue filter for photographing sand dunes and white formations. A G filter is used when the field is excessive in yellow and contrast is desired, or when thick aerial haze must be penetrated. As yellow filters absorb the ultra-violet and portions of the blue rays, longer exposures can be given to allow the green and red rays to react upon the emulsion.

In microphotography contrast or detail in the photograph is usually more desired than true color rendering. A colored object will appear white upon the print if it is photographed in light of its own color, and any detail upon the photographed surface will show up at its maximum. That is, if yellow chalcopyrite is to be reproduced as a light colored mineral, then a K_3 or G filter should be used. If contrast is desired, such as is necessary when photographing intergrowths of two minerals, one of the minerals should be photographed in light which it reflects and at the same time the other should be photographed in light which it absorbs. This will make a white and black print which, obviously, will show maximum contrast. To do this it is necessary to pick a filter which has an absorption band in the range of color of one of the members of the intergrowth. Detail, however, is destroyed, and, if it is neces-

[1] Blackwelder, Eliot, Hint for Better Geologic Photographs: *Science*, Feb. 27, 1931, vol. **73,** No. 1887, p. 241.

sary to get contrast yet preserve detail, it may be necessary to use a different procedure. A rule which seems to be of practical value when photographing two objects of different colors is to use a filter the color of which is between the colors of the two objects on the spectrum. That is, if a blue covellite grain is next to a pink bornite area, a green filter will give contrast yet preserve any detail which may be exhibited. This procedure is known as over-correcting. When doing this it is best to illuminate the object by light towards the red end of the spectrum, because of the super-sensitiveness of the emulsions towards the blue rays. Thus, when photographing for detail, it is advisable to expose the material to rays of its own color, but for contrast, use light which it absorbs.

It is suggested that the best guide to the filter or combination of filters to be used in any particular case is the visual inspection of the objects through the filters, keeping in mind the color sensitiveness of the films to be used (red reproduces as black on ordinary films, etc.).

By following these few rules it will be possible to control the action of the photographic plates or films and obtain the desired results.

A few mineral combinations are listed below giving the required filter to be used in their photography when using ortho double-coated films or plates. One of four filters, namely the K_3 (yellow), G (dark yellow), B (green) and H (blue), should be employed.

Bornite and chalcocite	B, G is good
Bornite, chalcopyrite, and gangue	K_3 is best, G and B good
Chalcocite and pyrite	H or B
Chalcocite and galena	B
Chalcopyrite and cubanite	H
Cobaltite, niccolite, silver and gangue	H
Detail in chalcocite	B
Detail in thin sections	B
Detail on sand grains	B
Domeykite and arsenic	A (with panchromatic film)
Domeykite and arsenic	H
Pyrrhotite and gangue	H or B
Pyrrhotite and magnetite	K_3 or G

Short[2] uses five color filters with panchromatic plates—the A (red), B, (K_3), G, and H. He gives a partial list of filters used for mineral combinations.

[2] Short, M. N., Microscopic Determination of Ore Minerals: *U.S.G.S. Bull.* **825,** p. 25, 1931.

Argentite and galena, B.
Bornite and covellite, H best; B gives little contrast.
Bornite and tennantite, B.
Bornite and chalcocite, any filter will do; none required.
Bornite, chalcocite, and chalcopyrite, B.
Chalcocite and chalcopyrite, B.
Chalcocite and covellite, H.(Covellite prints dark,and constrast should be reduced.)
Mottled chalcocite, B needed.
Chalcopyrite and galena, H best; B very good.
Chalcopyrite and pyrite, H.
Gangue minerals, K_3 or G is best; with other filters transparent minerals too dark.
Specularite and magnetite, H.
Sphalerite, K_3; with other filters this mineral appears too dark.

In general, deep colored filters increase contrast. A deep yellow G filter or red A filter will give a high degree of contrast.

For general outdoor work it is desirable to have a green, a blue, a yellow, and a red filter. For ordinary and orthochromatic films, the K_3 probably is the most useful. A green Wratten B or No. 58, a blue H or No. 45, a K_2 or No. 8, and a red A or No. 25 can also be recommended.

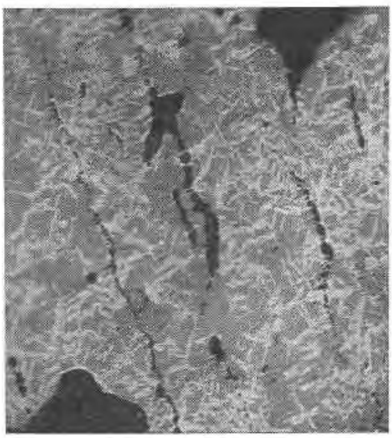

Fig. 2. Chalcopyrite (white) and Bornite (gray) intergrowth, photographed on a metallographic microscope. A K_3 filter was used with ortho cut film, also arc light illumination with a 6 second exposure through a 1 mm. opening in the iris diaphragm. Mag. 100×.

Often the expense of good filters is beyond the average pocketbook. It is easy, however, to make a series of fairly good filters by cementing pieces of colored cellophane between glass squares.

Glass from old photographic plates can be cleaned with hot water or by the use of a 4% solution of sodium fluoride, 60 grams, and 40% solution of formaldehyde, 30 cc.

The glass should be cut 2 in. by 2 in. so as to fit into standard filter holders. Some clear lacquer should be poured on a clean surface of one of the squares. Next, place a piece of cellophane on the wet lacquer and press all air bubbles and wrinkles out of the cellophane with another square. When perfectly smooth, remove the top glass square and place a few drops of clear lacquer on the cellophane. Then put the top square into place, being sure that there are no wrinkles or bubbles. It is advisable to bind the edges of the filter with thread and cover the thread and edges of the glass with lacquer. This will make the filters more permanent.

Another method for making home-made filters is to cement the colored cellophane between the two layers of cardboard leaving a hole in the center equal to the aperture desired.

A fairly complete series can be made by varying the number of layers of cellophane between the glass squares. A sky filter can be made by cementing only half of the square with yellow cellophane.

A series of home-made filters found useful are listed below. These were spectroscopically compared with Wratten filters.

4 layers of yellow cellophane	about Wratten 16, near G
2 layers of yellow cellophane	about Wratten 12, near K_3
1 layer of yellow cellophane	about Wratten 17, near K_2
1 layer of yellow and 1 of green	about Wratten 57, near B
2 layers of blue cellophane	about Wratten 41, near H
3 layers of blue cellophane	for sand dunes, grains, etc.
2 layers of green cellophane	about Wratten 66, near P

Cameras for the Mineralogist

In selecting a camera for field and general use the following points should be kept in mind: (*a*) the general cost and upkeep, (*b*) the size or bulk of the camera, (*c*) the size of the picture, and (*d*) the quality of the picture.

For general work a camera taking pictures $3\frac{1}{4}\times4\frac{1}{4}$ inches, or larger, with a 4.5, 5.6, or 6.3 anastigmatic lens, is to be recommended. In general, pictures in publications are about this size; thus, no enlarging or reducing is necessary. The camera should be focusable by a ground glass screen. A camera should be adapted to handle cut films, plates, or film pack, thus permitting the use of higher grade emulsions. The shutter arrangement on almost every camera is suitable for geologic work, although the better class of shutters make the camera more versatile.

If pictures are to be taken in the field where equipment has to be packed for considerable distances, a small camera undoubtedly should be considered. Small cameras with high grade and extremely fast lenses, taking from sixteen, to forty pictures on a single film, are very popular for this type of work. The high grade lens produces a critically sharp negative which can be enlarged to any desirable size. Another attractive feature of a small camera is its economy. The films are inexpensive and the best pictures of a roll can be enlarged at a small cost. These cameras are also very compact and are easy to handle. The small pictures also make excellent illustrations for the field notebook.

The individual geologist has little use for motion picture cameras except to take pictures for illustrated lectures. There are times when it is desirable to have motion pictures of geologic processes in action, field trips, field methods or localities. Where a group of geologists are working together, especially at a university, there should be a motion picture camera and projector in the equipment.

Exposure of the Emulsions

The length of exposure depends upon the type of film used, the speed of the lens, and the amount of light on the object. Generally, distant scenes require less time than close subjects, while nearby shaded objects require a longer exposure than objects fully lighted by the sun. An exposure table for rectilinear and anastigmat lenses is given below.

Exposure Table for Outdoors

For $2\frac{1}{2}$ hours after sunrise until $2\frac{1}{2}$ hours before sunset on days when the sun is shining.

	Shutter Speed	Rect. US	Anast. f
Group 1—Snow, marine, beach scenes. Extremely distant landscapes	1/25	32	22
Group 2—Ordinary landscapes showing sky, with a principal object in the foreground.	1/25	16	16
Group 3—Nearby landscapes showing little or no sky-groups, street scenes	1/25	8	11
Group 4—Portraits in the open shade not under trees or the roof of a porch, shaded nearby scenes	1/25	4	7.7, 7.9

The table shows that the exposure varies with the size of aperture of the lens, otherwise known as the lens stop. Two different systems are used in naming the stops, both being based upon the ratio between the diameter of the lens opening to the focal length of the lens. The one is the Uniform System (US), and the other the F System. In the latter the stop is expressed as a fraction of the focal length (F/22 or *f*.22 etc.). That is, the aperture is 1/22 of the focal length. In the US system the numbers are proportional to the exposure required, with *f*.4 being taken as unity. A table showing a comparison of the two systems is as follows:

F	*f*.4	*f*.5.6	*f*.6.3	*f*.8	*f*.11	*f*.16	*f*.22	*f*.32	*f*.45
U.S.	1	2	2.5	4	8	16	32	64	128

This table shows the relative exposure that is required with the *f*. system stops, the exposure varying as the square of the *f*. value, so that *f*.11 requires twice the exposure of *f*.8; *f*.16 twice that of *f*.11, and so on. US 2 requires twice the exposure of US 1; US 8, 8 times that of 1.

If a filter is used, then it is necessary to give a longer exposure because a portion of the light is removed. Commercial filters are marked with a certain factor. This is the number of times it is necessary to multiply the exposure time without a filter. That is, if a filter has a factor of 7 and a picture to be taken requires 1 second without a filter, then 7 seconds would be necessary if the filter is used.

In photomicrography the time of exposure is dependent upon the numerical aperture of the lens and the magnification. The N.A. of the lens usually is marked on its side. Short[3] states that the exposure of the negative varies inversely as the square of the numerical aperture, and directly with the square of the magnification. Generally, however, the calculated exposures are too short for low magnifications and too long for high magnifications. A few trial pictures, as suggested by Short, will aid in determining the correct exposure time. If a filter is used, the filter factor should not be forgotten, otherwise the negative will be underexposed.

[3] Short, M. N. *op. cit.*, p. 27.

Artificial Light

It is often necessary to photograph objects, such as hand specimens, sand grains, polished sections, thin sections, and fossils in artificial light.

One photographing a specimen should adjust a strong light, about 200 or 500 watts, so as to illuminate one side of the object at about a 45° angle from a line between camera and subject. A light about half as strong should be placed so as to throw its light on the other side. The angle between the lights should not be over 90°. The structure and texture of a specimen must be brought out by controlling the shadows. Lights shining directly opposite each other tend to deaden the reproduction. Generally a color filter is not necessary when using incandescent lamps because the yellow lights are about the same color as light through a K_1 filter.

An arc light is an excellent illuminator. It is best used in microphotography but often comes in handy for photographing sand grains, fossils, and small objects, especially when a vertical camera is to be used. Detail in sand grains can be shown by adjusting the concentrated arc light beam to strike the grains at an angle of about 15°–25°. No other light is necessary. A blue filter or green filter will help bring out detail and control highlights.

Thin sections can be illuminated by allowing the arc light beam to strike the mirror of the petrographic microscope. A green filter or yellow filter must be used, except when the section is predominantly red.

Polished surfaces can be photographed by directing the arc light beam on to the reflecting prism in the microscope. Here again a filter must be used.

Often a projection machine can be adjusted to give a light beam like the above mentioned arc light.

Special Hints

When photographing a specimen it should be perfectly clean and free from dust. A photomicrograph of a polished surface should be made only after the surface is entirely free from deep scratches, or the polish is as perfect as can be obtained with the equipment available.

Sand grains should be thoroughly washed and dried to remove all dust particles. If a dark background is desired use a piece of dark red celluloid. See Figs. 3 and 4.

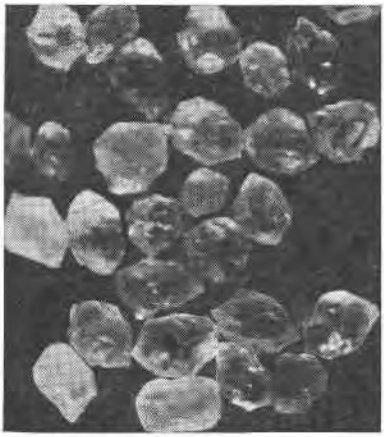

FIG. 3. These angular sand grains were photographed on a dark red celluloid sheet, giving a black background. An arc light beam strikes the grains at an angle of 15° from the horizontal. No filter is used. Enlarged 10× by use of a special lens on a vertical copy camera.

FIG. 4. Transparent sand grains photographed on a red celluloid background. The arc light strikes the grains at a low angle. Reflection of the light from the polished surfaces of the grains illuminated all sides of the grains. A green filter may be used to soften the high lights. Mag. 10×.

Dark fossils or rock specimens often need a thin white coating of ammonium chloride in order to make the features stand out.

If a banded structure does not show up as desired, the negative can be retouched by lightly building up the bands with a pencil. Remember, however, that dark areas on the negative become light areas on the print.

Processing the Negatives and Prints

Complete information on formulas can be taken from the sheet of directions inclosed in each package of films. The main points to be remembered are that panchromatic films should be developed in total darkness or in weak green light; red light of low intensity can be used for ordinary and orthochromatic films; printing out papers also can be used in red light.

The grade of paper to be used, the length of exposure, and the amount of time used in developing the print can best be learned by a few trials.

If the prints are made on glossy paper they are dried upon a ferrotype tin which has been coated and polished with paraffin and benzine to prevent the prints from sticking.

Bibliography

Eastman Kodak Co.: How to Make Good Pictures, Fifth Edition.
The Photography of Colored Objects, 1928. Tenth Edition.
About Lenses, 1929.
Photomicrography, 1931. Eleventh Edition.
Reproduction Work with Dry Plates and Films, 1929.
Color Films, Plates, and Filters for Commercial Photography, 1930.
Tennant and Ward: The Photo Miniature—Panchromatic Photography, Dec. 1930, Number 203.
Geo. Routledge and Sons: Handbook of Photography, by Lloyd, Hind and Randles, 1927.
U.S.G.S.: Bulletin **825,** Microscopic Determination of the Ore Minerals, M. N. Short, 1931.