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ADVANTAGES OF OBLIQUE ILLUMINATION IN MINERAGRAPHY[1]

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Mineragraphy, the study of minerals in polished section with the metallographic microscope for the purpose of determining their identity and paragenesis, has generally been carried on under vertical illumination. Vertical illumination is commonly produced by reflecting a horizontal beam of light downward by means of a prism or mirror so that the light impinges on the mineral section at an angle of ninety degrees and is reflected back into the eye of the observer.

Oblique illumination may be produced by using a parabolic reflector; by shifting the source of vertical illumination so that the rays of light strike the mineral section at an oblique angle; or by using ordinary daylight. That these methods are unsatisfactory and little used is shown by the fact that in the literature of mineragraphy there is a marked lack of reference to oblique illumination of any kind and the great benefits which may be derived from its use have apparently been overlooked.

The only texts which have been published on mineragraphy contain a small amount of information concerning oblique illumination or how it may be produced. Murdoch's tables[2] give the characteristic colors of certain transparent minerals under oblique illumination, and Davy and Farnham[3] mention the change in color produced by inclined light and give a table containing the characteristic colors of several minerals. Other references to oblique illumination in the literature on mineragraphy are very few and indefinite in character, and this type of illumination seems to be considered of little value.

[1] This investigation was carried on while enrolled as a graduate student in the Department of Mineralogy, University of Michigan, Ann Arbor, Michigan.

[2] Murdoch, Joseph. Microscopical Determination of the Opaque Minerals. John Wiley and Sons. **1916.**

[3] Davy and Farnham. Microscopic Examination of the Ore Minerals. McGraw-Hill Book Co. **1920.**

This is undoubtedly due to the fact that no easily manipulated and thoroughly satisfactory means of illuminating a polished mineral section with light impinging at an oblique angle has been used until the *Silverman Illuminator* was devised and adapted to the metallographic microscope.

The Silverman Illuminator consists of a glass tube, bent to form a nearly complete circle. This tube is provided with a tungsten filament and exhausted and sealed forming a small electric lamp which is mounted on an aluminum ring base and provided with a three armed spring clasp. This clasp is so arranged that a slight pressure of the fingers is sufficient to draw in the arms so that the lamp may be slipped over the nose of the objective where it is firmly held by the arms upon releasing the clasp. This makes it possible to attach or remove the illuminator from the microscope in a few seconds and is a great convenience and time saver.

The illuminator is connected by means of a small flexible cord with a rheostat which in turn is connected with the standard one hundred and ten volt circuit, alternating current, commonly used for lighting purposes. The rheostat is provided with a short-circuit so that the intensity may be increased if necessary. The standard lamp with normal resistance connected with a one hundred and ten volt circuit furnishes a light of twelve watt intensity which has been found to be perfectly satisfactory for all ordinary purposes.

When the illuminator is in place and the current turned on, a ring of light is produced surrounding the objective. This light is reflected downward and impinges on the polished surface of the mineral section at an oblique angle. The light is again reflected by this polished surface and part of it passing outside of the field of the objective is lost. Sufficient light is reflected directly into the objective and to the observer's eye to furnish satisfactory illumination.

In carrying on this investigation the microscope was provided with vertical illumination by properly focusing a beam of light from a small arc lamp upon the mirror in the microscope tube. Without interfering with the arc lamp connection, the Silverman Illuminator was connected with an ordinary electric light socket and the rheostat and switches so arranged on the table beside the microscope that the illumination could be changed from vertical to oblique by operating the switches controlling the electrical connections which did not require any change in the observer's position.

None of the polished mineral specimens used had been permanently mounted and for examination it was found very convenient to temporarily mount them by placing them, polished side up, in a small crystallizing dish nearly filled with small bird shot. By placing a glass slide upon the polished section and forcing the mineral down into the shot until the glass slide touched the walls of the crystallizing dish, it was found possible to arrange the the polished section in very nearly a horizontal plane. A crystallizing dish was carefully chosen in which the height of the walls was the same at all points.

The advantages of oblique illumination over vertical illumination for the examination of polished mineral sections with the metallographic microscope will be discussed under the following headings:

(1) Observation of the normal color of minerals.
(2) Illumination of cavities.
(3) Differentiation of gangue minerals from ore minerals.
(4) Disclosure of internal structure and observation of minerals below the surface of a polished section
(5) Indication of relative hardness of minerals by emphasized relief.
(6) Observation of the action of reagents.

In order to illustrate the difference in the appearance of the field of the microscope when the illumination is changed from vertical to oblique several characteristic fields were photographed, which accompany the following discussion.

(1). *Observation of the normal color of minerals.* In general the normal colors of minerals are not revealed by vertical illumination. This is due to the fact that rays of light impinging on the polished suface of a mineral section at ninety degrees are reflected back without entering the opaque minerals and are therefore unaffected by their inherent color. This makes the identification of minerals with characteristic colors difficult and their presence is sometimes not even suspected and very erroneous results are reported.

Oblique illumination, however, reveals the mineral in its normal color. This is due to the fact that the rays of light impinging at an oblique angle on the mineral surface enter the mineral if it is transparent, or are reflected by slight irregularities on the surface, which exist on the most perfectly polished section and which cause the emergent or reflected ray to display the inherent color of the mineral.

Brilliant blue and green minerals, as azurite, malachite, or chrysocolla, appear in their normal colors and are instantaneously recognized when examined with oblique illumination. With vertical illumination they all assume various shades of gray and cannot be distinguished from the gangue minerals, nor would their existence be even suspected unless they were present in sufficient amounts to be visible to the naked eye. The red minerals like cuprite and proustite, and brown sphalerite are revealed in their normal colors, which makes their recognition extremely easy. The phenomenon is sometimes observed that vertical illumination reveals the complementary color. This is illustrated by the crimson ruby proustite which often appears to be blue when examined by vertical light.

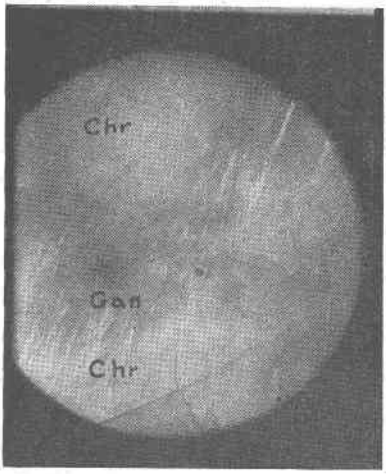
The observation of the normal color is illustrated by the accompanying photomicrographs of chrysocolla. These photomicrographs were made with the standard Bausch and Lomb microcamera and the greatest care was taken to maintain identical conditions, the only change being from vertical to oblique illumination with the Silverman Illuminator.

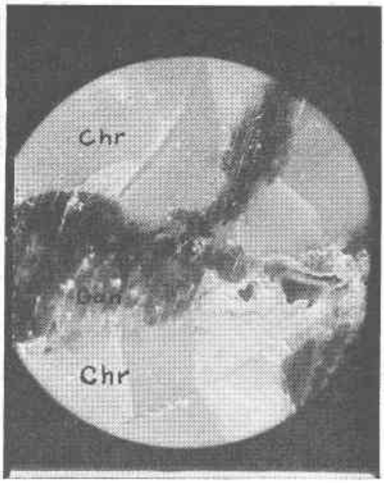
The specimen consisted of brilliant blue chrysocolla, a silicate of copper, in a dark brown siliceous gangue. Figure 1 shows the mineral photographed with vertical illumination in almost the same colors as it appeared to the eye. The whole field is an even gray color and apparently homogeneous and there is practically nothing to lead the observer to suspect the presence of so highly colored a mineral as chrysocolla.

Figure 2 shows the same field under oblique illumination. The chrysocolla shows its characteristic blue color, which photographed white, and the enamel-like appearance of the polished chrysocolla is revealed, so that the observer is able to identify the mineral and distinguish it from the siliceous material with which it is associated.

The same may be noticed with many colored minerals and as color is one of the most helpful physical properties by which minerals may be recognized, this revelation of normal color becomes an invaluable asset in the identification of minerals under the microscope.

(2) *Illumination of Cavities.* Microscopic cavities exist in nearly all polished mineral sections. They may be formed by fragments being torn from the section by the action of the abrasive





CHRYSOCOLLA FROM SEVEN DEVILS, IDAHO

FIG. 1. Vertical Illumination. Magnification 50 X.

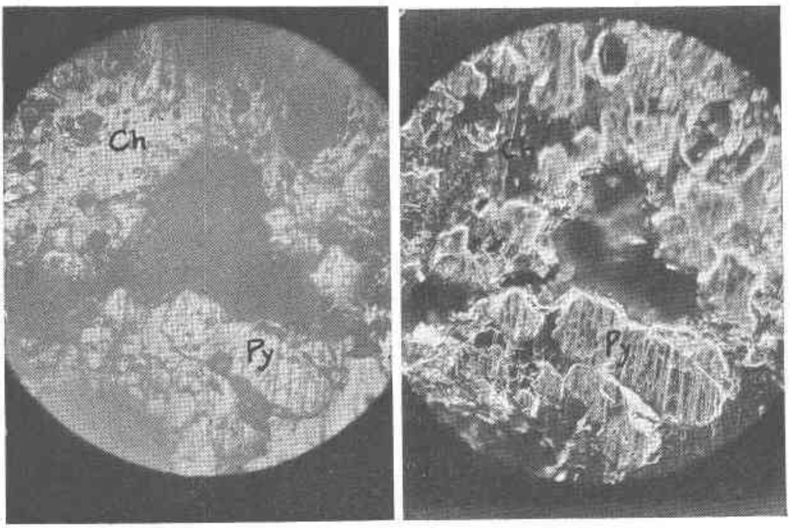
FIG. 2. Oblique Illumination. Magnification 50 X.

Chr. = Chrysocolla; Gan. = Gangue.

on a brittle mineral. These cavities seldom exhibit any phenomenon of interest altho they may sometimes disclose the typical cleavage of a mineral which is an aid in its identification. Due to the existence of voids in practically all mineral aggregates, cavities are produced when they are intersected by the plane surface of the polished section. These are of great interest as the walls are often coated with beautiful microscopic crystals and they may contain inclusions of minerals other than those exposed at the surface.

A cavity when viewed by vertical illumination is generally not recognized as such. The rays of vertical light impinge on the bottom of the cavity and are only faintly reflected to the eye. As there is no illumination of the walls, the cavity only appears as a slight irregularity on the surface and its true significance is lost and no hint is obtained concerning its contents. On the contrary, with oblique illumination the light impinging at an oblique angle is reflected from the walls so that every corner is visible, and the walls and floor of the cavity are brilliantly illuminated. By changing the focus of the microscope the whole depth of the depression may be examined and the observer often obtains a very unusual and beautiful effect of gazing down into an opening of apparently great depth, the walls of which may be lined with very small and brilliant crystals.

The illustration shows an intergrowth of pyrite and chalcopyrite. Figure 3 shows the section illuminated with vertical illumination and little evidence of a cavity or its contents is visible Only a black spot is shown proving that nearly all the vertical rays are absorbed and very little light is reflected. Figure 4 photographed with oblique illumination discloses the outline of the



PYRITE AND CHALCOPYRITE FROM SIEGEN, PRUSSIA

FIG. 3. Vertical Illumination. Magnification 50 X.

FIG. 4. Oblique Illumination Magnification 50 X.

Py=Pyrite; Ch=Chalcopyrite.

cavity and the mineral crystals composing its walls and floor. As it is possible to photograph with only a small amount of the depression in focus the photograph does not disclose the whole depth of the depression, which can be readily revealed to the observer by gradually lowering the objective of the microscope. The sharpness of the focus of the surface of the section has been sacrificed to bring the walls of the cavity into view.

(3) *Differentiation of gangue minerals from ore minerals.* In general the great difference between gangue and ore minerals lies

in their transparency. The common gangue minerals, as calcite, quartz and the silicates, are fairly transparent while the ore minerals vary from semi-transparent to absolutely opaque. The transparent minerals when viewed by vertical illumination appear in various shades of gray which may approach dense blackness. This is due to the fact that the vertical incident light is largely absorbed by the transparent mineral and very little light is re flected back to the eye of the observer. This makes the distinction of gangue from ore minerals nearly impossible and the identification and significance of the presence of gangue minerals is often not noted.

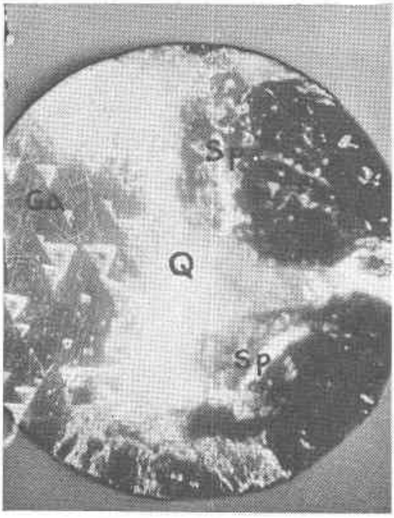
Oblique illumination, on the contrary, instantly reveals the gangue in its true transparent or translucent state. The oblique rays of light impinging at an angle enter the mineral and are reflected by cleavage and fracture planes, as well as by the contact surfaces of other minerals, so that the transparent minerals are brilliantly illuminated and their detection and identification is greatly facilitated. This also aids in making a rough quantitative estimation of the amount of ore minerals present, as well as revealing evidence concerning the intergrowth and formation of gangue and ore which is of great value in determining the paragenesis of the mineral aggregate.

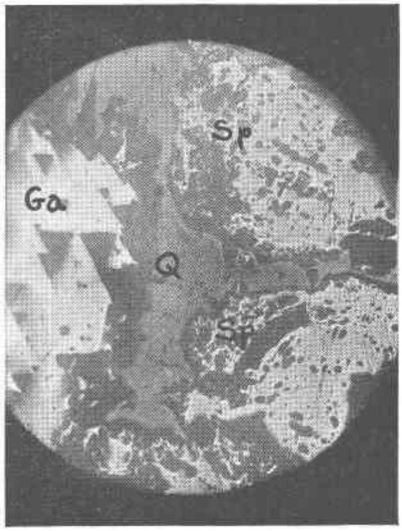
The illustration was made from a polished section containing galena and sphalerite in a siliceous gangue. Figure 5 shows the field photographed by vertical illumination. Galena is easily recognized by its characteristic triangular pitting. The identification of the sphalerite is not so positive as it appears as a medium gray. The dark mineral separating the two may be any one of many minerals which show the same color under similar conditions and its identity is very uncertain.

Figure 6 photographed by oblique illumination reveals the sphalerite with its charactristic brown color and the unknown mineral is instantly recognized as being the quartz gangue which separates the two ore minerals.

(4) *Disclosure of internal structure and observation of mineral below the surface of a polished section.*

This is closely associated with the differentiation of gangue minerals from ore minerals as the underlying principle is the illumination of the transparent gangue. As the internal structure is revealed by oblique illumination, cleavage lines are disclosed





GALENA, SPHALERITE AND QUARTZ FROM CASAPALCA, PERU

FIG. 5. Vertical Illumination. Magnification 50 X.

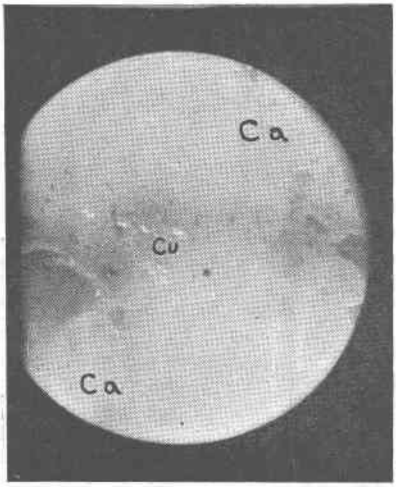
FIG. 6. Oblique Illumination. Magnification 50 X.

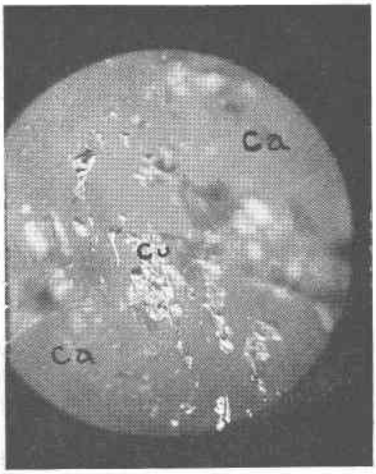
Ga = Galena; Sp = Sphalerite; Q = Quartz.

which are often typical of the mineral and become a valuable clue to its identification. This is very marked in minerals with a conspicuous and characteristic cleavage, as calcite or the feldspars. Particles of mineral lying below the surface which are invisible with vertical illumination become immediately visible with oblique illumination and the presence of minerals otherwise unsuspected is revealed and a more accurate estimate of the amount present may be made.

The illustration shows native copper in calcite. Figure 7 shows the polished section photographed with vertical illumination, only a few small specks of copper are visible. The field is exceptionally well illuminated as the calcite was very clear and the black ground of the mounting caused the calcite to act as a mirror and a large amount of light was reflected.

Figure 8 photographed with oblique illumination discloses the large amount of native copper actually present.





NATIVE COPPER IN CALCITE FROM CRYSTAL FALLS, MICHIGAN

FIG. 7. Vertical Illumination. Magnification 50 X.

FIG. 8. Oblique Illumination. Magnification 50 X.

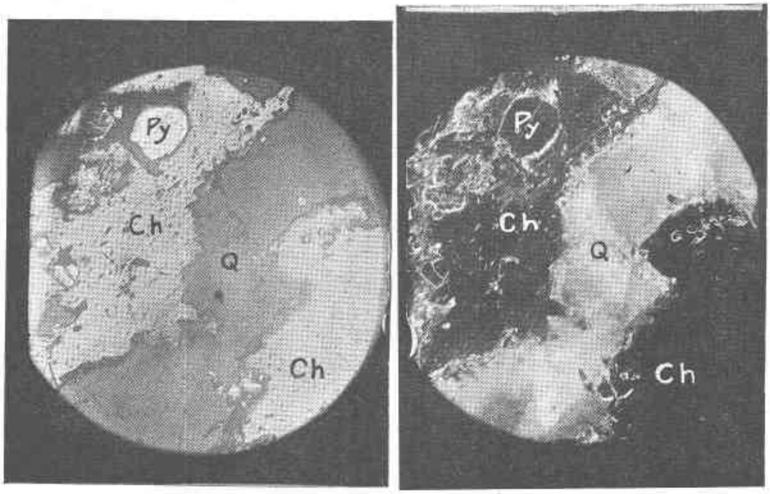
Ca = Calcite; Cu = Copper.

(5) *Indication of relative hardness by emphasized relief.* It is well known that a mineral aggregate containing two or more minerals of different hardness cannot be polished to a perfectly plane surface. The action of abrasive powders is naturally more rapid on the softer minerals and a surface is produced from which the harder minerals project in slight relief. As hardness is one of the physical properties by which minerals are identified, the recognition of relief in the polished section becomes a great aid in the identification of the minerals present. Vertical illumination illuminates the harder projecting minerals evenly, so that recognition of relief is very difficult.

Oblique illumination, on the contrary, illuminates the sides of the projecting minerals so that relief is emphasized and the difference in hardness is immediately noted. This relief may be increased by shading one side of the illuminator so that one side of the projecting mineral is brilliantly lighted and the other is in shadow.

The illustration was made from a polished section containing pyrite, chalcopyrite and quartz. Figure 9, photographed with vertical illumination, shows the pyrite entirely surrounded by chalcopyrite and so evenly illuminated that the surface appears nearly plane.

Figure 10, photographed with oblique illumination, shows the pyrite standing out in relief with one side of the crystal brilliantly illuminated and its superior hardness over chalcopyrite is instantly noted.



PYRITE, CHALCOPYRITE AND QUARTZ, FROM HOMESTEAD, OREGON
FIG. 9. Vertical Illumination. Magnification 50 X.
FIG. 10. Oblique Illumination. Magnification 50 X.
Ch = Chalcopyrite; Py = Pyrite; Q = Quartz.

(6) *Observation of the action of reagents.* Chemical reagents, principally the common acids and the few solutions used in the laboratory determination of minerals, may be applied to the polished section and their action observed under the microscope. By adding the reagents in proper sequence quite complicated reactions may be carried out by which positive identification of minute amounts of mineral may be made.

The action of reagents is generally marked by; (a) the evolution of gas, (b) tarnishing of the polished section, (c) etching of the mineral, or (d) formation of a precipitate. All these phenomena may best be observed by oblique illumination as the gas which accompanies nearly all reactions collects on the surface of the specimen as well as on the droplet of reagent and forms a film of bubbles in which vertical illumination is absorbed and lost. The relief produced by etching and the colors of precipitates are disclosed by oblique illumination which aids in making a correct interpretation of the reaction.

The Use of the Silverman Illuminator in Photomicrography. There has been some question concerning the suitability of the Silverman Illuminator as a source of light for photomicrography. By actual use it has been found to be very satisfactory. In one respect it is a great improvement over vertical illumination in that the light is evenly distributed over the whole field so that few negatives of uneven density are produced by its use. The greatest care must be observed in using vertical illumination to obtain even distribution of light as the slightest disarrangement of the mirror used to reflect the horizontal beam of light downward results in uneven illumination of the field and the production of a poor negative.

The length of exposure necessary to produce good negatives with oblique illumination will of course depend upon local conditions, as the voltage of the circuit, the magnification used, and the character of the minerals in the field. In general the exposure with oblique illumination must be from three to six times as long as that required for vertical illumination. In exceptional cases where a mineral of great transparency is being photographed, the exposure may be less due to the fact that the absorption of vertical light is so great that little light is reflected to the photographic plate.

No positive statement as to exposures may be made until standardized equipment is universally used, as the system of vertical illumination commonly employed may vary greatly depending upon the experience of each individual investigator. Slight differences in the type of lamp used, the distance removed from the microscope, and the system of condensing lens employed, will produce such great differences in the intensity of illumination of the field that no two observers will obtain concordant results.

Oblique illumination can be used with magnifications as high as 400X. Beyond this point it is difficult to obtain satisfactory illumination as the rays of light cannot pass around the nose of the objective sufficiently to illuminate the field. This is not a serious objection as most investigations are carried on at comparatively low magnifications.

It is not the intention of this paper to maintain that vertical illumination has no value and should be discarded, but to attract the attention of students of mineragraphy to the advantages which may be derived from oblique illumination and to suggest that this type of illumination may be frequently used with profit to supplement observations made with vertical illumination.

NEW OPTICAL DATA FOR ANALYZED SUSSEXITE*

E. Poitevin and H. V. Ellsworth, *Canada Geological Survey and University of Toronto*

On comparing the indices given for sussexite,[1] $2Mn(Mg)O_2$ $B_2O_3H_2O$, with those of Camsellite,[2] $2MgO.B_2O_3.H_2O$, there is a marked discrepancy evident when one considers the specific refractivity of the constituent radicals. Manganese oxide has a higher specific refractivity than magnesium oxide and therefore, sussexite should have the higher indices, contrary to the published values as indicated below.

	α	β	γ	Elongation
Sussexite	1.541±0.003	1.545±0.003	1.554±0.003	+
Camsellite	1.575±0.005	————	1.649±0.005	−

Having recently obtained a good specimen of sussexite from Franklin Furnace, New Jersey, U. S. A., the original locality, we have determined the indices of refraction of this mineral on a sample of known chemical composition.

The specimen consists chiefly of willemite, franklinite and zincite with a coating of white, fibrous sussexite on what appears to be a slickensided surface. A sample 0.4 g. in weight was obtained by scratching the fibres with a steel point. Half of this was used for the general analysis and half for a direct water determination. Microscopic examination of the sample showed that only a few minute grains of the associated minerals were present.

* Published with the permission of the Director, Geological Survey, Canada.

[1] Larsen: Microscopic Determination of the Non-opaque Minerals, *U. S. Geol. Survey, Bull.* **679.**

[2] Ellsworth and Poitevin: Camsellite, a New Borate Mineral from British Columbia, Canada. *Trans. Royal Soc. Canada,* **May,** 1921.