EFFECT OF LIGHT ON POLISHED SURFACES OF SILVER MINERALS

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INTRODUCTION

The fact that the polished surfaces of certain silver minerals are affected by the light rays from the carbon arc has been known for some time; however, little has been published concerning the details of the reactions.

Any change that occurs on the polished surface of a mineral, due to the action of light or heat from the light source, is called light or heat etching, respectively. The object of the present work was to collect data on light and heat etching and arrange it in a form that could be used in the identification of minerals, when they occur in such small quantities that the usual microchemical tests are unsatisfactory. The problem was suggested by Dr. G. M. Schwartz, of the University of Minnesota, under whose supervision the work was carried out.

The writer is greatly indebted to Dr. J. W. Gruner, Dr. Charles Park, and other members of the Geology Department of the University of Minnesota for help in checking the reactions and for many valuable suggestions. Dr. M. N. Short supplied specimens of pearceite and stromeyerite from the United States Geological Survey collection.

SUMMARY OF PREVIOUS WORK

In 1917 Dr. F. N. Guild[1] published a paper on the silver ores in which he stated that argentite and pyrargyrite were etched by the naked arc light. Proustite did not react. He found that the so-called brongniardite broke down into pyrargyrite as well as other constituents.

Dr. W. L. Whitehead[2] has studied the common silver minerals under the oil immersion lens, using the standard Leitz metallograph microscope, and has tabulated his results. He showed that argentite, polybasite, pearceite, stephanite, freibergite, and proust-

[1] Guild, F. N., A Microscopic Study of Silver Ores and Associated Minerals: *Econ. Geol.*, Vol. **12**, pp. 297–353, 1917.

[2] Whitehead, W. L., Technique of Mineralography: *Econ. Geol.*, Vol. **12**, pp. 697–716, 1917.

ite were etched by the rays from an arc light. Miargyrite, stromeyerite, cerargyrite, other halides, silver amalgam, dyscrasite and native silver were not altered in 10 minutes. He also stated that the reactions vary greatly in intensity with various specimens, but are, even when obscure, quite typical for each mineral.

Schneiderhöhn[3] mentioned that argentite darkens under the action of light and attributes the reaction to the effect of heat.

The halogen silver salts are most affected by the ultra violet, violet and blue rays.[4] This does not seem true for the silver sulphosalts studied in this problem as will be shown later.

The data concerning the action of light on the various salts are given in publications of Eder's *Jahrbuch für Photographie*, but they are not compiled into tabular form.

Methods and Equipment

Most of the microscopic work of this problem was done with a standard Leitz MM micro-metallograph microscope. The microscope was equipped with an iris diaphragm in the shield between the main condensing lens and the reflecting prism. The diaphragm was completely open for etching, and in some cases the entire shield was swung out of the path of the light beam. Minerals previously reported as negative were found to react when the full strength of the light was applied.

Some of the work was done on a polarizing microscope. This was an ordinary petrographic microscope equipped with a reflecting prism and a horizontal nicol prism. Light was supplied from a 1000 watt filament lamp. The reactions with this microscope took seven times as long as those observed on the metallograph.

Several specimens of each mineral were examined. These came from various parts of the world. In each case the identification of the mineral was checked by the use of the new tables supplied, in manuscript, by Dr. M. N. Short of the United States Geological Survey.

The reactions of the silver minerals to light were first studied under the oil immersion lens, but the changes were often obscured by bubbles forming in the oil. The bubbles probably were due to gas formed by the decomposition of the silver minerals. After working for several weeks with oil immersion lenses, it was decided to

[3] Schneiderhöhn, Hans, Untersuchung Von Erzen: *Selbstverlog der Gesellschaft, Berlin*, pp. 207, 1922.

[4] Communications from the Eastman Kodak Company.

use lower magnification. The 4 mm., 8 mm., and 14 mm. lenses were used but only a few active minerals can be satisfactorily etched with the 8 mm. and 14 mm. lenses. In general, the 4 mm. lens is most satisfactory.

Wratten filters were used to control the rays of the spectrum and a N/2 copper sulphate solution was used when it was desired to eliminate most of the heat. A nickel glass filter was used to absorb the light and transmit the heat rays.

Experimental Data

Light. The beam of light from the carbon arc may be divided into the heat rays and the rays of the visible spectrum. Schneiderhöhn[5] believes that the heat rays are more important in light etching while other writers believe the reactions are due to a photochemical effect. Evidence cited below shows that argentite, and most of the silver sulpho-salts seem to be affected by both groups of rays while stromeyerite, andorite, petzite, and probably coloradoite are affected only by the invisible heat rays.

The intensity of the arc light beam was not determined, but reactions occurred in about one-seventh of the time needed for those using the 1000 watt filament lamp as the light source. Thus, the arc light beam probably is equivalent to 6000–7000 watts when the shield is removed from the path of the beam.

The temperature of the arc light beam was not determined but potentiometer readings indicated that the copper sulphate solution absorbed more than five-sixths of the heat. While working on specimens mounted in sealing wax, it was found that the wax melted and appeared to boil when the diaphragm of the shield was wide open. Sealing wax softens in boiling water. Chalcocite, which has an inversion point at 91° C. recrystallized when the shield was removed from the path of the light.

The following Wratten filters were used to absorb the light of various wave lengths; number 76 blue transmitting a band from $\lambda 480\mu$ down, number 75 cyan blue filter transmitting a band from $\lambda 450$–520μ, number 74 green filter transmitting a band from $\lambda 520$–580μ, and number 70 red transmitting a band from $\lambda 680$–$720\mu+$. The width of the transmitted bands were checked by the use of a Zeiss model C hand spectroscope. The red filter, number 70, was found to transmit more heat than the others. A nickel glass filter was used to absorb the light rays but transmit the heat rays.

[5] Schneiderhöhn, Hans, *Op. cit.*

The results of tests upon several specimens of each mineral are tabulated below.

TIME NECESSARY TO PRODUCE A VISIBLE REACTION

Filter Number Wave Length	76 480–down	75 450–520	74 520–580	70 680–720	Heat Alone (after 1 minute); above 720
Mineral					
Argentite	15 sec.	10 sec.	5 sec.	15 sec.	Pits only
Stromeyerite	?	?	25	8	Slight etching
Polybasite	60	45	35	10	Very slight etching

The filters reduce the intensity of the light so much that it is difficult to determine the time of reaction of pyrargyrite, pearceite, or proustite, which are more inactive to light rays than those minerals given in the above table, but they seem to be affected more by light thru the red filter. Chalcocite, petzite, hessite and coloradoite are affected mainly by the heat rays.

The above work on the effect of various wave lengths of light is of a preliminary nature only and should be followed by detailed studies.

It is stated above that the silver haloid salts are most affected by the ultra violet, violet, and blue rays. The above experiments tend to show that the silver sulpho-salts are most affected by waves of a long wave length. The following relationship, therefore, is probably correct though with considerable overlapping.

Rays	Violet	Um. Blue	Cy. Blue	Green	Yellow	Orange	Red	Heat
Wave Lengths (in microns)	397	431	486	527	589	656	760	+
	Silver haloids most affected.				Silver sulpho-salts most affected.			
	Most specimens active ⟶			Most specimens inactive		⟵ Most specimens active		

In some cases argentite, polybasite, stephanite and pyrargyrite when exposed to light and heat deposit a sublimate on the objective lens. When the 4 mm. or objectives of lower magnification are used without oil a small yellow to brown ring is deposited after an exposure of about a minute. There is some doubt as to the identity of the sublimate but if the etching results in the formation of free silver, as is suggested by theories of photochemistry, then one would expect the sublimate to be free sulphur, antimony or arsenic trioxide, depending upon the composition of the mineral. This effect is not seen when oil immersion is used, as the sublimate probably goes into suspension in the oil.

Specimens of argentite, polybasite and sometimes stephanite decompose and give a sublimate on the objective lens even though three-fourths of the heat is removed from the light beam.[6] If the copper sulphate filter, which almost completely removes the heat, is placed across the light beam little or no sublimation occurs. Some decomposition is probably due to the effect of light but apparently the sublimation is caused mainly by the action of heat. The minerals etched by heat alone, however, do not give the deposit on the lens. Thus, it may be concluded that the combined action of light and heat is necessary for the formation of a sublimate under the action of the arc light beam.

The etching produced on the polished surface of a silver mineral is very delicate and any attempt to polish the surface removes the etching.

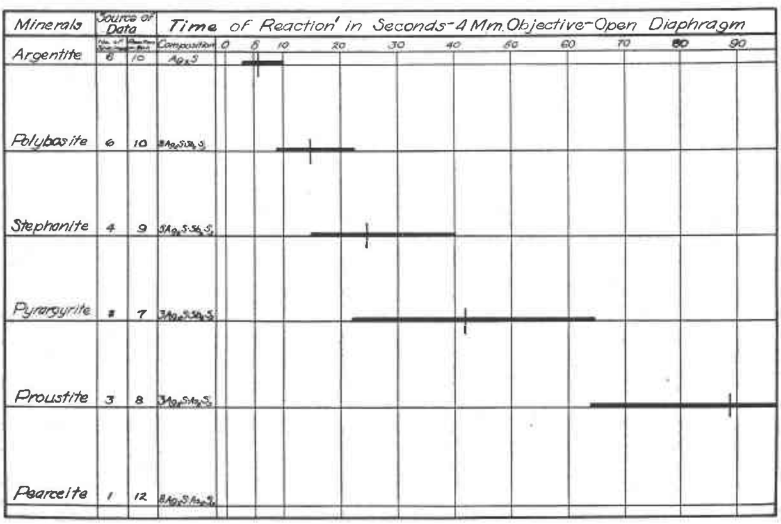

FIG. 1. Variations in reaction speeds of common silver minerals, showing also the range of the reaction speeds in the individual minerals.

[1] Refers to time necessary to produce a visible reaction.

[6] A 20 mm. water jar is placed across the light beam between the condensing lens and the reflecting prism. This removes three-fourths of the heat according to potentiometer readings.

SPEED OF REACTIONS. The silver minerals etch, or react, at different speeds depending upon the relative stability of the mineral in the presence of light. Fig. 1 shows how the speed of etching increases with the variations of chemical composition of the mineral. These reactions are best observed under the 4 mm. objective lens. The reaction speed of the individual mineral specimen varies considerably due to a difference in the reaction speeds with different orientations of the grains.

If a mineral is etched by light concentrated by an objective of lower magnification than the 4 mm. lens, the speed of the reaction will be less. The more active minerals such as argentite and polybasite will etch under light concentrated by low magnification objectives while pyrargyrite, pearceite, proustite, and other transparent silver minerals, will etch only by light concentrated by objectives giving high magnification. Thus, the speed of the reaction of a mineral seems to vary directly with: (1) the concentration of light, (2) the concentration of heat, (3) the stability of the mineral to these agents, (4) the transparency of the mineral, (5) the orientation of the mineral grains, and (6) the chemical composition of the mineral. See fig. 2. The following table gives the average time of reaction of many specimens.

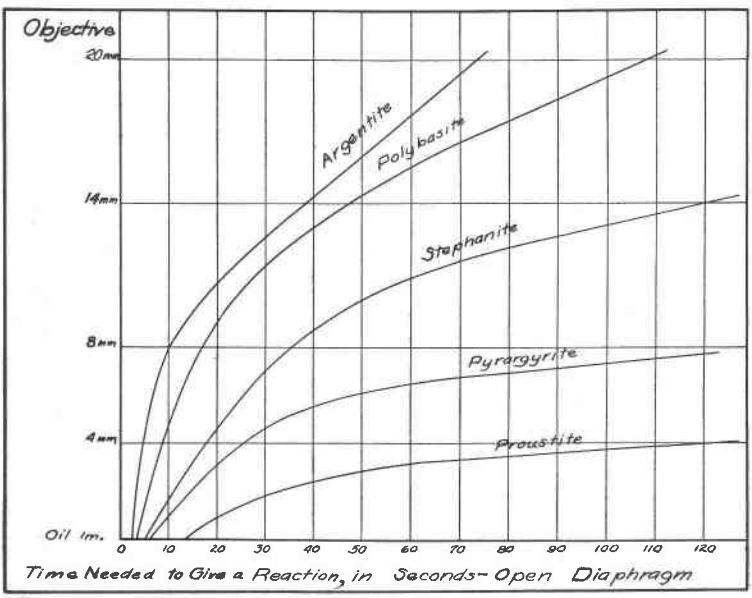

FIG. 2. Curves showing average reaction speeds with various objectives.

TIME IN SECONDS NECESSARY TO PRODUCE A VISIBLE ETCHING

OBJECTIVES	Oil Im.	4	8	14	22 mm.
MINERALS					
Argentite	2	5	10	40	80+
Polybasite	4	6	14	50	100+
Stephanite	6	18	35+		
Pyrargyrite	8	24+			
Proustite	15	120+			
Pearceite	18−	?			

It is impossible to rely on the speed of the reaction alone. This is shown by the fact that some specimens of polybasite react as rapidly as argentite. The etch pattern, however, is quite typical for the various minerals. By considering the speed of the reactions and the etch pattern one may usually identify a silver mineral. The patterns of the minerals are described in detail in the discussion of the individual minerals.

The color of the etch surface will vary in different minerals. The etch patterns of silver minerals are usually shades of gray, but in some cases yellow or silver patterns are obtained. These colors probably are due to the variations in density of the free silver deposited on the mineral surface during the reaction. See the following table.

COLOR OF THE ETCHED SURFACE AFTER EXPOSURE TO LIGHT

MINERAL	Color after 1 minute or less, 4 mm. lens	Color after 2.5 minutes, 4 mm. lens
Argentite	Gray to black	Blue black
Stromeyerite	Gray to yellow (Silver colored in hand specimen)	Same
Polybasite	Gray	Same
Stephanite	Yellow to gray	Light yellow to reddish brown
Pyrargyrite	Yellow gray	Gray
Proustite		Light gray
Pearceite	Sometimes gray, usually negative	Light gray
Andorite	Gray to black pitted	Iridescent to black
Petzite	Gold	Same but coarser particles
Unidentified galena enrichment	Brown	Blue to blue green
Coloradoite	Brown	Blue iridescent, brown edges, sometimes black

The following table shows approximately the action of various minerals under light. It is sometimes necessary to determine whether the etching is caused by heat or light. This is done by the use of the copper sulphate solution filter mentioned above. The speeds given represent averages of many reactions. One would expect variations as is shown in fig. 1.

Description of Minerals

Argentite. Argentite is very unstable in the presence of light and heat from the carbon arc. See figs. 1 and 2. The first appearance of the etch pattern is seen along the cracks and scratches of the specimen. The pattern seems to consist of small dashes oriented in two directions so as to form a very fine screen-like pattern. The etching, caused by light alone, usually appears, at first, in small dots over the surface. Shortly after the appearance of the dots a finer etching develops in the spaces between them. The etching grows dense after long exposure. Some specimens show no other action regardless of the amount of heat.

Sometimes when the heat rays are not removed more active specimens show a different pattern. The etching just described takes place very rapidly and in some specimens almost instantaneously. The heat then volatilizes the inner portion of the etched area, forms a group of pits in the center of the field, and causes a heavy sublimate to deposit on the objective lens. Around the pits a band is formed with less conspicuous effect, but on close examination it seems that a change has taken place in the structure of the mineral. This area is anisotropic after etching and shows a bladed intergrowth. Recrystallization occurs, but it is questionable if the inversion point at 175° C. is reached. Outside of this area a dense outer band is formed. See fig. 3. The entire surface exposed to the light beam thus gives a target shaped pattern.

If the center of light is moved so as to fall upon the outer portion of the etching, a volatilization occurs. A central group of pits will form if exposed long enough. Thus, the action of light is probably closely followed by the action of the heat rays. These two reactions take place so rapidly that they appear to occur simultaneously. It is necessary, however, to have the maximum amount of light possible, i.e., the unshielded arc, in order to get the heat reaction described above.

Argentite was also etched by the 1000 watt light. The etched pattern was the same as that formed by the action of the arc light,

TABLE SHOWING REACTION OF MINERALS TO LIGHT

Mineral	Polarized light	Time[1] of Reaction to Arc Light in Seconds, 4 mm. lens		General Appearance
		Heat and Light	Heat Removed	
Argentite	Slight to neg., anisot.	4	6	Dense etching, heavy sublimate on lens.
Stromeyerite	Strong, anisot.	4	15?	Intergrowth pattern, recrystallization, silver etching.
Polybasite	Fair-good, anisot.	5	5	Spotted surface.
Stephanite	Fair, anisot.	15	30	Brown screen like pattern, not dense.
Pyrargyrite	Fair, anisot.	20	45	Thin etching conc. at edge of field and along scratches.
Proustite	Fair, anisot.	90	Slight after long exposure	More transparent than pyrargyrite. Reactions same.
Pearceite	Strong, anisot.	15+	Slight after long exposure	Reactions same as proustite.
Andorite	Strong	10+ (On edge only)	Neg.	Black pitted center with bright iridescent band at edge of field.
Petzite	Isotropic	6 (When warm)	Neg.	Bright gold etching, expanding and contracting bands during exposure. Cubic cleavage.
Hessite	Fair, anisot.	10±	Neg.	Slight pale yellow film spreads over surface during exposure. Structure later develops.
Coloradoite	Isotropic	20–60	Neg.	Changes to blue, brown, to iridescent along edges only.
Unidentified galena enrichment. With lillianite.		20+	Neg.	Changes from pinkish brown to blue then brown or vice versa.

[1] Refers to the time necessary to produce a visible reaction.

PHOTOMICROGRAPHS OF THE REACTIONS*

FIG. 3. Argentite etched by both light and heat. The pattern is slightly off center to show the characteristic target shape. The inner and central portions show the effect of the heat rays while the outer portion is caused by the action of the light rays. 4 mm. objective. Mag. 178×.

FIG. 4. Stromeyerite showing the typical intergrowth pattern caused by exposing the mineral to the heat and light rays of the carbon arc. 4 mm. objective. Mag. 178×.

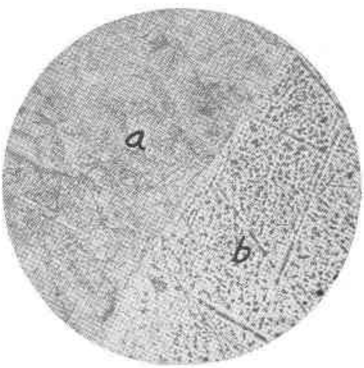

FIG. 5. Polybasite etched by both heat and light. This shows two orientations of the mineral and the patterns of each orientation. 4 mm. lens. Mag. 178×.

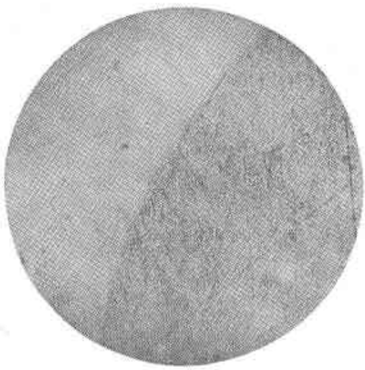

FIG. 6. Stephanite etched by both light and heat. The pattern resembles that of pyrargyrite, proustite, and pearceite, but it usually is coarser. 4 mm. lens. Mag. 178×.

* All of the etch patterns are moved off center to show the entire relationship.

FIG. 7. Pyrargyrite etched by heat and light. Note the concentration of the elongated dashes (etch marks) along the scratches. This pattern is finer than that of stephanite. 4 mm lens. mag. 178×.

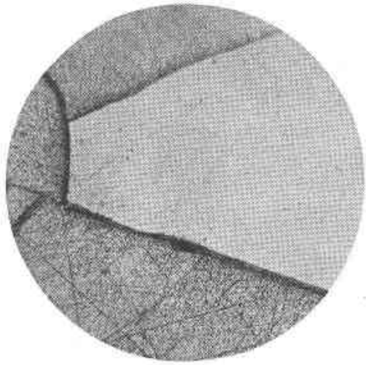

FIG. 8. Proustite in two orientations etched by the action of heat and light. The central grain is just beginning to etch after being exposed for two minutes. 4 mm. lens. Mag. 178×.

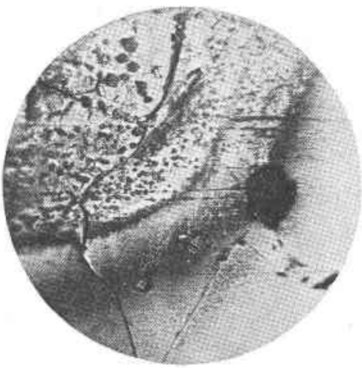

FIG. 9. Andorite etched by the rays from the carbon arc light. The central portion is deeply pitted and fractured, while around this there is a band of red to iridescent colored etching. 4 mm. lens. Mag. 178×.

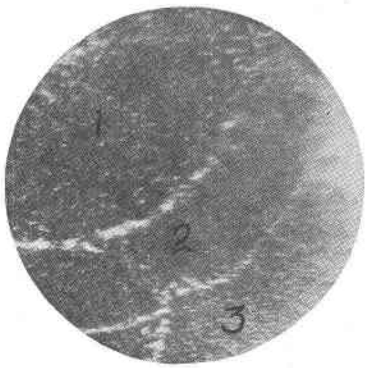

Fig. 10. Petzite after exposure to the heat rays of the arc light. Note the three advances of the etch pattern, and hazy appearance of the etching. 4 mm. lens. Mag. 178×.

but the time needed to produce a visible effect was seven times as great as that when the carbon arc is used. By using the oil immersion lens with unpolarized light the etching took place in 10 seconds, and with the polarized light in 18–20 seconds. Little change in the speed of the reaction was noticed when the heat rays were removed. This would indicate that the etching of argentite is not entirely a heat action as Schneiderhöhn[7] suggested.

A small amount of the sublimate, mentioned above, was collected on a cover glass and found to be soluble in carbon bi-sulphide. Upon evaporation small crystals which seem to be sulphur were formed. Thus, argentite probably decomposed into free silver, left on the surface as an etch pattern, and sulphur, deposited on the lens as a sublimate.

The characteristics of argentite are: the negative to slight anisotropism; the rapid appearance of dots; the development of the fine etching between dots; the target shaped pattern; and the heavy sublimation under the action of light and heat.

STROMEYERITE. Stromeyerite etches rapidly when exposed to the full beam of the arc light. The surface of the specimen turns yellow brown and seems to wrinkle. The etching, shown in fig. 4, resembles a wrinkled skum, but on close examination it shows a pattern suggestive of the intergrowth obtained by Guild[8] by etching stromeyerite with KCN. The light etched surface, however, looks silver colored in the hand specimen. If the surface is exposed to light for 15 seconds or longer small groups of black dots form suggestive of argentite. These seem to outline grains of stromeyerite. The specimens, however, show a complete absence of a granular structure under polarized light. Thus, the dots etched black are probably intimate mixtures of argentite and stromeyerite or a portion of stromeyerite partly breaking down to form argentite.

When five-sixths of the heat was removed by the copper sulphate solution the intergrowth etching did not form, but the small black dots appeared in 15 to 20 seconds. Thus, the intergrowth-like etching is due to the action of the heat rays, while the spotted etching is due to the action of the light rays.

Considerable change takes place in the specimen during its exposure to the light and heat of the carbon arc. A single large grain uniform under polarized light was observed after exposure to the

[7] Schneiderhöhn, Hans, *Op. cit.*

[8] Guild, F. N. Enrichment of Silver: *Lab. Investigation of Ores*, p. 227. McGraw-Hill, 1928.

light beam and found to have developed a fine granular, bladed, or interlocking structure. The small grains show no common orientation, but they do have about the same degree of anisotropism as that shown by the original stromeyerite. This grain structure is best seen if the silver etching is first removed by fine polishing. The granular structure is confined to the portion of the grain exposed to the arc light, and there is a sharp contact between the etched material and the solid unetched surface of the large grain.

The chemical composition of stromeyerite, $Ag_2S \cdot Cu_2S$, suggests the possibility of a breakdown into argentite and chalcocite. Argentite is unstable in the presence of light and heat while chalcocite has an inversion point at 91° C. a temperature easily reached by the rays from the arc light. Chalcocite, sometimes, shows a crystal rearrangement after short exposure to the light from an arc.

It is difficult to explain the changes that take place in the stromeyerite specimens during the exposure to the arc light. A breakdown of the mineral probably occurs forming a thin layer of chalcocite and argentite. The argentite, in turn, breaks down into free silver and sulphur. Recrystallization of stromeyerite by heat probably causes the development of the grain structure below the etching.

Summarizing, stromeyerite shows very high anisotropism under polarized light. Rapid wrinkling of the surface forming an intergrowth-like pattern, deposition of a bright silver coating on the surface, and the formation of the interlocking grain structure occur upon exposure of the mineral to the arc light beam.

POLYBASITE. Polybasite is rapidly etched by the light rays and may be mistaken for argentite. It is mentioned above that the time of visible etching of the two minerals overlaps, but, in general, polybasite is less sensitive to the arc light than argentite.

The interesting fact about polybasite is that it has two distinct etch patterns depending upon the orientation of the mineral grains. If two grains having different orientations are etched, one will start as fine elongated dashes very closely spaced but uniformly distributed, while the other grain will start as similar marks widely spaced. As the etching progresses the original finely etched surface becomes like that shown in fig. 5*a*, while the widely spaced etching becomes dotted like that shown in fig. 5*b*. On long exposure the patterns seem to interchange. The etch pattern shown in 5*a* will become similar to that of 5*b* and vice versa. In general, the dotted etched surface is most characteristic of the mineral.

The etching of this mineral seems to be due primarily to the action of the light rays, since the speed of the reaction is unchanged when the heat rays are largely removed. There is no evidence of crystal rearrangement as is seen in other minerals. Thus, the heat action is of little importance.

Polybasite may, therefore, be recognized by its pattern, by its reaction speed, and by its good anisotropism. The anisotropism serves as a criterion in distinguishing polybasite from argentite.

STEPHANITE. This mineral, like many others, can be etched very successfully by the use of objectives giving lower magnification than the oil immersion lens, but the speed of etching is reduced.

Stephanite shows considerable variation in the speed of etching. Some specimens examined etch with the speed of polybasite while others are comparable to pyrargyrite, but the mineral usually etches at a speed between the two.

Stephanite, like pyrargyrite, pearceite, and proustite starts to etch along minute scratches and fractures. The early concentration of the small elongated marks around the border of the field is plainly visible. The etching progresses across the field as small areas or groups of light brown to yellow gray marks. These marks usually outline small diamond shaped areas, but some specimens seem to show more or less rectangular shape. Then these etch marks join to form a screen-like pattern over the surface, visible only on close examination.

Stephanite, also, shows a different reaction speed with different orientations of the crystal grains. This fact was brought out when some grains of a specimen reacted as described above while others showed activity enough to give a thin sublimate on the objective lens. Heat rays cause sublimation and concentration of the screen-like pattern into small black to brown spots after long exposure. See fig. 6. The time of light etching is reduced about half when heat rays are present in the light beam.

Thus, stephanite may be recognized by its speed of reaction, its yellow to brown spotted etching, and its screen-like pattern.

PYRARGYRITE. Pyrargyrite, proustite, and pearceite react to light and give about the same etch pattern. Thus, only a few characteristics of each mineral will be given. In general, the etch pattern of these minerals is like stephanite, but it is slightly finer and concentrated more along scratches.

Pyrargyrite has a dark ruby color generally. The mineral reacts to the carbon arc in about 20 seconds, and gives a delicate etch pattern, when the 4 mm. lens is used. See fig. 7.

PROUSTITE. Proustite is lighter in color and is more transparent than pyrargyrite. The time needed to produce a visible etching under a 4 mm. lens is about 80 to 90 seconds. The mineral shows considerable variation in reaction speed depending upon the orientation of the grains. See fig. 8.

PEARCEITE. Pearceite is similar to proustite except that it seems to be less active. It is negative for two minutes and reacts only slightly after five minutes under the 4 mm. lens. Only one specimen of this mineral was obtainable so that a thorough investigation was impossible. Tests other than the light test probably will be necessary to identify the mineral.

ANDORITE. The first attempt to etch the surface of an andorite specimen was unsuccessful but during later experiments the following data were collected.

The specimen of andorite used in the experiments seems to be pure, and probably has the composition given by Dana for the mineral, i.e., $2\,PbS \cdot Ag_2S \cdot 3Sb_2S_3$. Tests were first made on the central portions of the mineral surface. These portions did not react to the light beam. Thus, the specimen was reported as negative to light reaction. When examining the sharp edges of the mineral, it was noticed that fracturing and decrepitation took place after a short exposure to the light and heat rays. Portions of the mineral surface sometimes seemed to fly off into space. Usually the reaction is not so violent.

After fracturing of the mineral a melting stage seems to occur. The mass yields as if plastic and turns red; then finally appears to boil. Seemingly large pits are formed; large bubbles of gas rise to the surface of a colorless liquid that is formed on the surface of the mineral. Small black particles are seen churning in the liquid, giving the appearance of a crater of an active volcano. Later examination of the specimen shows many gray to black pits with fused edges, at the point where the etching occurred. A bright red to iridescent band is formed around the outer edge of the pitted area.

Heat rays seem to be responsible for the reaction, since no action occurs with them removed. These rays cause the apparent boiling and decrepitation of the mineral surface. A sticky sublimate containing small fragments of the mineral is found on the lens. The identity of this substance is doubtful, but it is probably sulphur.

PETZITE. Considerable time was spent in determining the reactions of the telluride group. Generally the group is not active to light, but, petzite, hessite, and probably coloradoite show positive results. Petzite and hessite are identical as to their reactions according to Davy and Farnham's tables; Short's tables indicate that petzite is isotropic and has triangular cleavage pits.

By exposing the polished surface of petzite to the heat waves of the arc light beam a bright orange yellow pattern is produced on the surface of the specimen. The color and luster of the etching strongly suggests free gold, in contrast to hessite which does not give a gold etching.

A reaction occurs rather rapidly with either the oil immersion, 4 mm., or 8 mm. objective lens if the light adjustment is perfect. The reaction starts in the center of the field and spreads rapidly outward in waves. The etching spreads to a certain limit, halts momentarily, then it appears to retreat to the center of the field. The fine deposit of gold left on the surface by the advancing etch pattern melts into coarse gold particles and gives a retreating appearance. These particles seem to be suspended in a colorless liquid.

After the retreat there is a short halt, then a second advancement starts a short distance from the outer edge of the first advance. Thus, a narrow unetched space is left surrounding the portion first etched. Advancement followed by retreat occurs until the entire field is etched. See fig. 10.

Thus, petzite may be identified by its characteristic gold etch pattern, its triangular cleavage pits, and its isotropism. Hessite shows none of these properties.

HESSITE. When hessite is exposed to the heat rays a very pale yellow etching sweeps over the surface. The etching is so delicate and takes place so rapidly that often it is unobserved. After long etching, or exposure, the surface of hessite develops a structure that is suggestive of a rearrangement. No reaction takes place if the heat rays are removed from the arc light beam.

The faint yellow etching that rapidly sweeps across the surface and the later development of the structure are the most characteristic features of hessite.

COLORADOITE. This pink telluride is not very sensitive to the light rays. Along edges there is a change of color from pink to brown, blue, and sometimes iridescent, but only after long exposure to the light and heat rays. This mineral shows no very characteristic test in the presence of the arc light rays.

FREIBERGITE. Freibergite reacts to light rays under oil immersion but the use of lower magnification is too slow. Etching occurs only after long exposure when the 4 mm. lens is used.

Unidentified Galena Enrichment. During a study of the Leadville, Colorado, ores, a narrow band of material surrounding and replacing galena was found to turn from a light brownish white to a blue color in the presence of the heat rays from the arc light. Some areas in the galena were completely replaced by the unknown mineral. These areas upon exposure to the arc light turned brown then a distinct blue color.

Discussion

Schneiderhöhn[9] believes that the etching of argentite is due primarily to the action of the heat rays from the arc light, while Guild[10] suggests that the light etching, as seen in the silver sulpho-salts, is due to an actinic effect of the light. In general, in the silver sulpho-salts, the action of the light rays seems to be responsible for the formation of the etch pattern, but the heat rays undoubtedly have some effect. The light etching usually appears more rapidly if the heat rays are present. Heat, therefore, acts as an auxiliary agent rather than as the agent itself.

Heat, however, is more active upon minerals with low inversion points than those with high, and more active upon those minerals which are unstable than those which are stable. Such minerals as stromeyerite, andorite, petzite, and hessite are good examples of minerals etching primarily under the action of heat. The effect of light on this group is secondary, and in the case of petzite and hessite the light action is probably negligible.

The explanation of light etching probably lies in the basic principles of photochemistry. Meldola[11] stated that the action of light upon metallic compounds such as oxides and salts is, speaking in general terms, a reducing action, so that it is important to remember that the metallic compounds which show the most striking photochemical changes are generally those which are capable of being reduced from higher to lower state of oxidation. If the minerals are reduced by light it is quite probable that the etched pattern is due to an unequal deposition of free silver and is accompanied by the liberation of antimony, arsenic, and sulphur sublimates. Schneiderhöhn[12] suggested that SO_2 is given off from argentite when exposed to light.

[9] Schneiderhöhn, Hans, *Op. cit.*
[10] Guild, F. N., Personal Communication.
[11] Meldola, R., *Chemistry of Photography*, pp. 12, Macmillan & Co., 1889.
[12] Schneiderhöhn, Hans, *Op. cit.*

Light etching, perhaps, is not limited to the silver minerals. Mercury, uranium, iron, and chromium compounds show photochemical effects if an organic compound is present as a reducing agent.[13] Thus, by introducing the use of a few reducing reagents, harmless to the lens, it may be possible to extend the usefulness of light etching to non-silver minerals.

SUMMARY

In general, the problem of light etching may be summarized as follows:

1. Minerals can be identified by their characteristic reactions to the light and heat rays of the carbon arc.
2. The 4 mm. lens is the most practical objective to use in observing the reactions, but, some minerals will react with light concentrated by objectives giving lower magnification.
3. The polished surface of some silver minerals reacts at a certain speed with the light rays and an etch pattern forms that is typical for the mineral. The speed of the reaction varies, depending upon the orientation of the mineral grains, variations in chemical composition of the mineral, and the magnification of the objective lens used.
4. The pattern produced on the surface of silver minerals upon exposure to the arc light probably results from a deposit of free silver formed by the decomposition of the silver mineral; and some specimens of argentite, polybasite, andorite, and stephanite yield a sublimate thought to be sulphur, antimony or arsenic trioxide, depending upon the mineral composition.
5. The silver sulpho-salts are affected mainly by the light rays with wave lengths between $\lambda 520\mu$ and $\lambda 720+\mu$ of the visible spectra; argentite being most active in the presence of the green rays (520–580μ), while the other minerals are most active in the presence of the orange and red rays (680–$720+\mu$).
6. Heat rays usually speed up the action of the light rays; but, in specimens of petzite, hessite, andorite, and stromeyerite, the heat rays are almost entirely responsible for the reaction that takes place. The heat rays usually act as an auxiliary agent to the light rays.

[13] Meldola, R., *Op. cit.*