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Paragenesis of the minerals in the Einstein vein Madison County, Missouri

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PARAGENESIS OF THE MINERALS IN THE EINSTEIN VEIN

MADISON COUNTY, MISSOURI

BY

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A

THESIS

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Approved by O. R. Grawe
Professor of Geology

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INTRODUCTION

Selection of the Problem

The mineralogical problem of determining the paragenetic sequence of minerals in the Einstein vein, Madison County, Missouri, was suggested by Dr. O. R. Grawe, who previously had supervised a thesis by Joel Pomerene[1] dealing with the geology of the area. Although considerable attention has been given to the mineralization along the vein, a specific study of the paragenetic relations has not been made. Paragenesis has, however, been discussed by others in papers dealing with the geology of the area. Such a study is extremely important in the establishment of a hypothesis of origin, and hence, an essential aid in the search for other deposits of this type.

Acknowledgements

The writer wishes to express his sincere appreciation to Dr. O. R. Grawe, of the Missouri School of Mines, for his guidance, coordination, and general supervision of this work.

Mr. T. Ejima, Research Fellow, Department of Metallurgy, Missouri School of Mines, was kind enough to take the X-ray powder diffraction photographs used in the determination of the lattice constants of several minerals.

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[1] Pomerene, J. B., "Geology of the Einstein-Apex Tungsten Mine Area", Unpub. Master's Thesis, U. of Mo. Sch. of Mines & Met., 1947.

Thanks are also due Dr. P. D. Proctor, Chairman of the Geology Department, and R. Chico, Graduate Assistant, for their assistance in the preparation of the mine location and workings map.

Location and Mine Development

The Silvermine District is on the east flank of the St. Francois Mountains, Sec. 12, T. 33 N., R. 5 E., Madison County, Missouri, approximately nine miles west of Fredericktown. The area may be reached by paved all-weather roads, Missouri Highway No. 70 and County Road D. (Plate 1).

The Einstein Mine is the most extensively developed mine in the District. The property was first entered as mineral land in 1855. By 1879, the workings consisted of an adit (River Tunnel) and an inclined shaft from which three levels connected by winzes were developed. The lower levels were reported by Tolman[2] to be 75 and 150 feet from the collar of the shaft and to be 246 and 80 feet long, respectively. A map in the files of the Missouri Geological Survey based on information furnished by George O'Brien shows a third level at a distance of 275 feet from the collar of the incline. A masonry dam and a mill were constructed in 1879 to provide water and power for a mill in which argentiferous galena was recovered. Operations ceased a few years later after producing 50 tons of lead and 3,000 ounces of silver.

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[2] Tolman, Carl, "The Geology of the Silver Mine Area", Mo. Bureau of Geol. and Mines, 57th Bien. Rept., Append. I, 1933, p. 34.

According to Tolman[3], in 1916 the Madison Mining Corporation of New York began mining for tungsten. A mill was built to concentrate the ore. Eleven tons of tungsten ore were produced during a single month in 1917. Operations ceased with the end of World War I. A small amount of tungsten was produced about 1927 by the Ozark Tungsten Company. The Minerals Yearbook[4] lists the production of small tonnages of tungsten during 1937, 1938, and 1941. In 1947[5], the Apex Mine was reopened by the And-Mor Mining Company and about 1955[6] a new incline was sunk on the Einstein vein about 100 feet west of the New Discovery Incline.

At present the mines are not in operation. The lower levels of the Einstein Mine are inaccessible. The main level may be entered at considerable risk. Meager timbering is generally in fair condition, but some caving has occurred. The River Tunnel is connected with the Woodchute Adit by the Mittendorf Raise and the Woodchute is connected with the New Discovery workings, and the most recent incline by other raises. The Mittendorf Raise connecting the main level with the surface is inaccessible at present.

The Grigsby, or Preacher, Adit to the north and uphill from the

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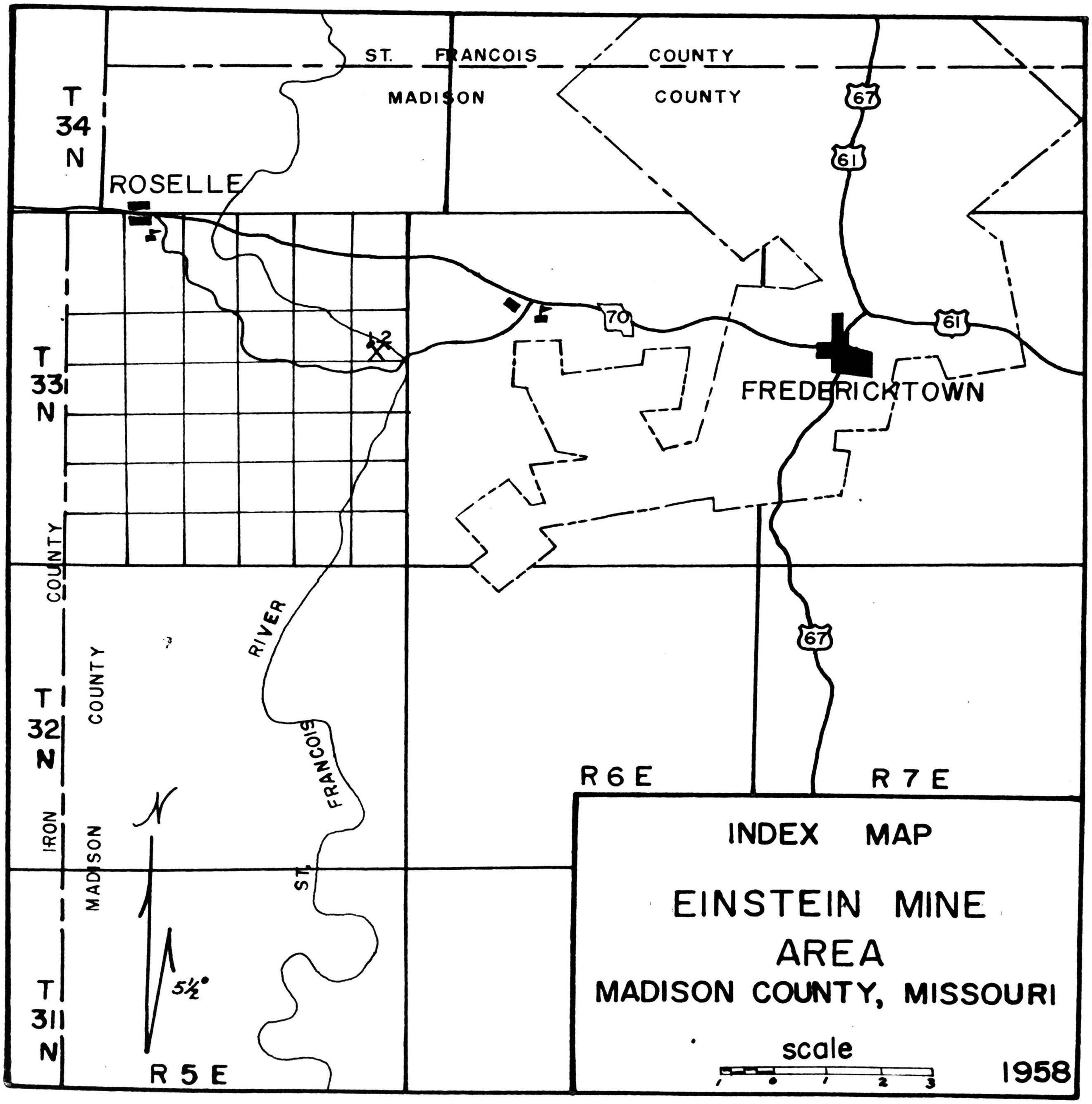
3 _Ibid._ p. 34.

4 U. S. Bureau of Mines, Minerals Yearbook for years 1929-43 inclusive.

5 Pomerene, _Op. cit._, p. 33.

6 Grawe, O. R., Personal Communication.

Plate I


ST. FRANCOIS COUNTY
MADISON COUNTY
T 34 N
ROSELLE
T 33 N
T 32 N
T 31 N
IRON COUNTY
MADISON COUNTY
ST. FRANCOIS RIVER
67
61
70
FREDERICKTOWN
R 5 E
R 6 E
R 7 E
5½°
INDEX MAP
EINSTEIN MINE
AREA
MADISON COUNTY, MISSOURI
scale
1958

Einstein main level, is not connected to the main level. The drift is approximately 50 feet long.

The Gabriel Adit, located 1/8 mile to the north of the Einstein workings, is approximately 100 feet long and connected to the surface by the Gabriel Shaft.

As a result of a brief reconnaissance of the mine workings, it is believed that the risk involved in entering the mine would far outweigh the value of any geologic information procured.

General Geology

The rocks exposed in the area are principally Pre-Cambrian rhyolite and rhyolite porphyry flows, a granite pluton, diabase dikes, and quartz veins. These are overlain by remnants of Upper Cambrian Lamotte sandstone, conglomerate, and arkose, and by small patches of Tertiary Lafayette gravel. Tarr[7] described the relationships of the igneous rocks to one another pointing out that the granite is intrusive into the rhyolites. The diabase dikes cut both the granite and rhyolites, and are in turn cut by the quartz veins. The Lamotte formation is exposed in a ravine 1/3 mile east of the Einstein Mine. It unconformably overlies the Pre-Cambrian igneous rocks. Younger Paleozoic and Mesozoic sedi-

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[7] Tarr, W. A., "Intrusive Relationship of the Granite to the Rhyolite (Porphyry) of Southeastern Missouri", G. S. A. Bull., vol. 43, 1932, pp. 965-992.

ments are not present in the area, but Hayes[8] mentions the occurrence of uncemented Lafayette gravels on several ridges. These are generally thought to be of Tertiary age and consist of quartzite and chert.

The Silvermine mineralization consists of quartz veins, varying from a fraction of an inch to two feet in width, intruded into a pinkish gray, medium-grained granite, and of quartz stringers intruded into rhyolite porphyry near the granite-rhyolite contact. A study of the joint pattern by Tolman[9] and by Pomerene[10] reveals three prominent joint trends in the granite. The nearly vertical N 25° E and N 65° E joints are paralleled by the diabase dikes, while the mineralized quartz veins occur as fillings of an east-west set of joints which dip 30-50° to the south. The emplacement of the veins was accompanied by greisenization of the granite wall rock. This introduced considerable topaz and greatly altered the feldspars. The extent of greisenization is directly proportional to the width of the vein at any particular point, and to the amount of brecciation and invasion of the wall rock by vein material. Greisenization is more extensive in the hanging walls of the veins than in the foot walls.

Faulting appears to have occurred during the emplacement and

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[8] Hayes, W. C., Jr., "Geology of the Ozark-Martin Mine Area, Madison County, Missouri", Unpub. Master's Thesis, U. of Mo. Sch. of Mines & Met., 1947.

[9] Tolman, Op. cit.

[10] Pomerene, Op. cit.

subsequent to the emplacement of the Einstein vein. Pomerene[11] mentions the existence of a thrust fault on the basis of slickensides exposed at the Einstein Mine and the Gabriel Adit 1200 feet to the north. This would mean that the vein as exposed at the Gabriel Adit is the down-thrown extension of the Einstein vein. He also cites the existence of a northeast trending shear zone:

> "It is believed that the Apex vein and the Einstein vein represent one vein that has been offset about 1050 feet by a fault. It is possible that the prospect pits which are arranged along a northeast striking line have been worked on portions of the vein offset in step fault pattern by the shear zone."

Grawe[12] believes that faulting accompanied the emplacement of the Einstein vein as evidenced by the presence of slickensides in the plane of the vein. This might further be substantiated by the occurrence of large, offset, quartz crystals at the New Discovery Mine which is on the Einstein vein, 850 feet west of the Einstein Mine portal.

Previous Work

The earliest reference to the mineralization at "Silver Mines" is that of Haworth[13] who noted the occurrence of topaz associated with

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[11] Ibid.

[12] Grawe, O. R., Personal Communication.

[13] Haworth, Erasmus, "A Contribution to the Archean Geology of Missouri", The American Geologist, vol. 1, no. 5, May, 1888, pp. 294-295.

the wall rock of the quartz vein, and attributed the formation of topaz to fumerolic activity. Haworth briefly compared the mineralization at "Silver Mines" to the tin mines of Cornwall, England and Zinnwald, Saxony, but he was unaware of the presence of cassiterite at "Silver Mines". Haworth described the vein at the "Apex shaft" as filled with quartz, argentiferous galena, fluorite, lepidolite, wolframite, and probably other minerals. The wall rock is stated to consist of quartz imbedded in a fine-grained mixture of mica scales with traces of iron oxide, leucoxene and zircon, with topaz and fluorite distributed in varying proportions throughout the fine-grained mass.

Buehler[14] noted the close association of pyrite, zinnwaldite, and huebnerite, and gave the results of a chemical analysis of huebnerite as:

Tungstic acid	76.50 %
Oxide of manganese	18.33
Oxide of iron	5.12
	99.95 %

He described the heubnerite as ranging in size from that of a pinhead to massive bunches weighing 100 pounds, distributed at intervals in the quartz vein and occurring as solid lenses 3 to 15 inches thick associated with a heavy clay gouge. Argentiferous galena and sphalerite also were reported as present in the vein and the number of ounces of

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[14] Buehler, H. A., Mo. Bureau of Geol. and Mines, Bien. Rept. of the State Geologist to the 50th General Assembly, 1919, pp. 97-98.

silver per ton was reported as equal to the percentage of lead prior to concentration.

The occurrence of crystals as well as masses of quartz is described by Tarr[15]. Huebnerite was described as occurring in large bladed masses associated with fluorite. Golden brown zinnwaldite rosettes occurring in bands a centimeter or more in width and 10 to 20 centimeters in length also were reported. Galena, pyrite, sphalerite, chalcopyrite, zinnwaldite, serpentine, and arsenopyrite were reported occurring in the vein and sericite in the wall rock. Tarr mentioned that topaz, tungstite, and stolzite had been reported to be present. Small quartz veins in the surrounding granite and rhyolite were noted to contain specularite, epidote, quartz, and garnet.

Ross and Henderson[16] presented optical data and a partial chemical analysis of topaz from the Einstein Mine. They stated:

> "The minerals that have been reported from the vein itself are quartz, fluorite, argentiferous galena, pyrite, sphalerite, huebnerite, and scheelite, the latter intimately intergrown with huebnerite. The wall rock on either side of the vein has been profoundly altered and the minerals topaz, quartz, fluorite, argentiferous galena, pyrite, sphalerite, huebnerite, and scheelite have developed through the replacement of granite.

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[15] Tarr, W. A., "The Minerals of Madison County, Missouri", Amer. Mineralogist, vol. 6, no. 1, Jan. 1921, pp. 7-10

[16] Ross, C. S., and Henderson, E. P., "Topaz and Associated Minerals from the Einstein Silver Mine, Madison County, Missouri", Amer. Mineralogist, vol. 10, no. 12, Dec. 1925, pp. 441-443.

"The feldspar in the granite of the wall rock has been completely replaced by muscovite and quartz partly replaced so that isolated island-like areas are all that remain of large quartz crystals. The fluorite (variety chlorophane) is colorless to blue, and on heating glows with a green color that soon changes to purple."

Perhaps the most comprehensive study to date of the mineralization at the Einstein Mine itself is the paper of Singewald and Milton[17] in which the greisenization of the wall rock is described. Sericite mica is stated to be later than the topaz which was derived from the quartz of the granite country rock. The "oily mottled-green appearange" of some of the greisen was noted by these writers. They suggested that the material is an alteration of the topaz rock to a soft material consisting of very fine scaly mica similar to sericite. The mineral was determined to be the damourite variety of muscovite. Optical properties and a partial analysis of Silver Mine mica (zinnwaldite) was given.

	Zinnwaldite	Silver Mine Mica
Fe	6.59%	6.91%
Li	1.99%	0.58%
2V	.35° ±	30° ± 10°
N_m	1.57 ±	1.57 ±

The marked deficiency in lithium suggested that the mica is not a member of the lepidolite system, but tends toward a lithian phlogophite. Singewald and Milton propose that some of the damourite may have been derived from the alteration of zinnwaldite.

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[17] Singewald, J. T., Jr., and Milton, C., "Greisen and Associated Mineralization at Silver Mine, Missouri", Econ. Geol. vol. XXIV, no. 6, Sept. 1929, pp. 569-591.

Zoned cassiterite was stated to occur in the greisen associated with fluorite and along topaz-zinnwaldite boundaries.

A description of the mode of occurrence of the sulphide minerals was given:

> "The sulphide ores consist of sphalerite, galena, pyrite, arsenopyrite, and chalcopyrite in a gangue of quartz and fluorite and a little sericitic mica. Wolframite also occurs in this ore. Included in the vein material is a great deal of topaz rock. Much of the ore consists of shattered topaz rock penetrated by stringers and veinlets which have not only filled the fractures in the topaz rock but also replaced it along their walls."

A table showing the paragenetic sequence of minerals in the Silver Mine area accompanies the paper. The sequence according to Singewald and Milton[18] is given in Table I and will serve for comparison with the sequence as determined by the present writer.

The mineral succession as determined by Tolman[19] does not essentially differ from that of Singewald and Milton. According to Tolman, considerable overlap and, in some cases, simultaneous deposition is shown by the mineralization. Chlorite (thuringite) is added to the sequence along with an unidentified phosphate, which precedes fluorite, and another unidentified mineral which encloses fluorite and is earlier than the associated mica.

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[18] Ibid. p. 591

[19] Tolman, Op. cit.

TABLE SHOWING PARAGENETIC SEQUENCE OF MINERALS

(After Singewald and Milton, Econ. Geol., vol. 24, 1929, p. 591)

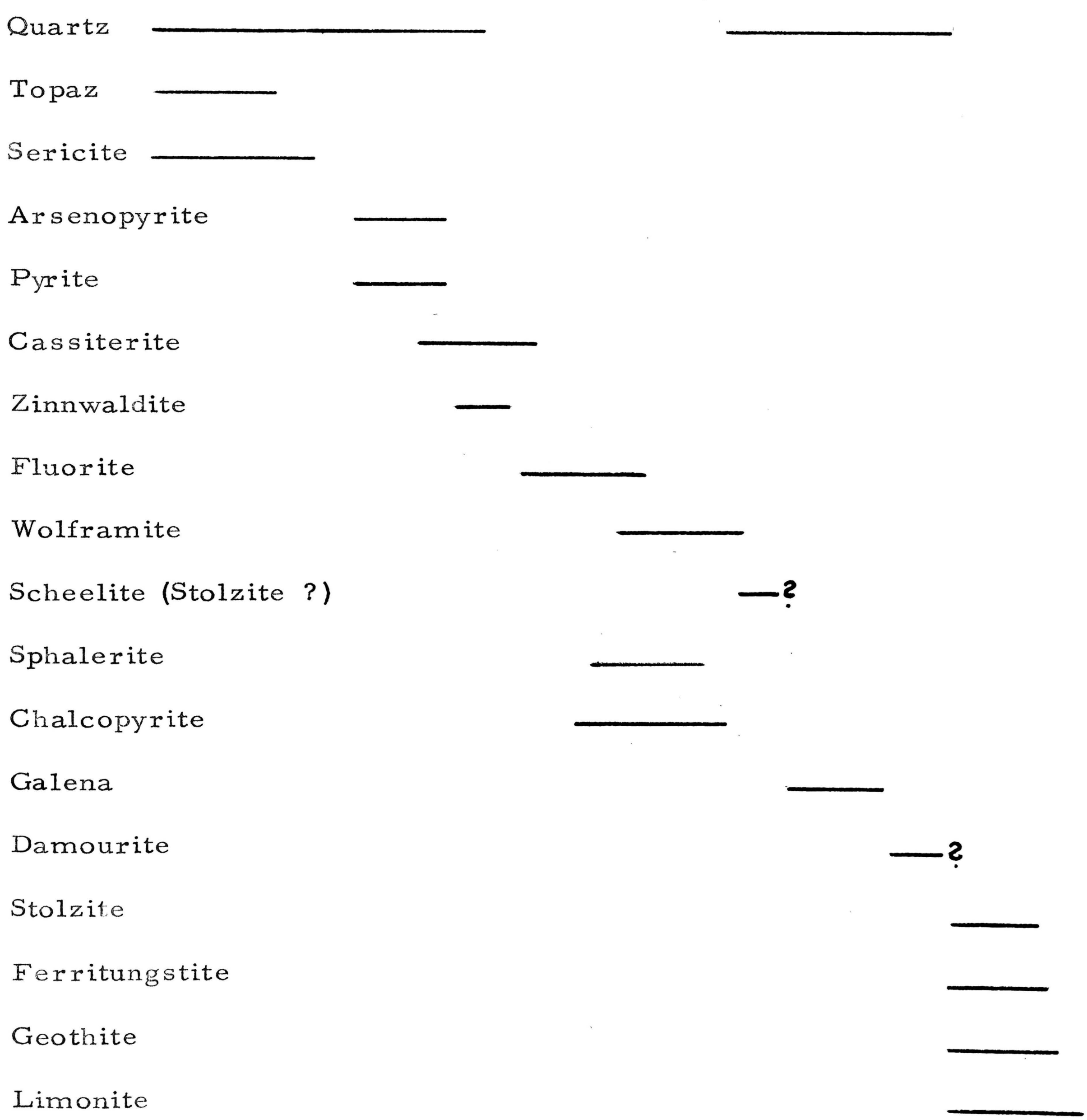

TABLE I

According to Pomerene[20], the same mineral sequence was not followed at all places. He states:

> "The mineralizing solutions which ascended along the thrust fault zones were dominantly siliceous and high temperature in character. These solutions altered the granite wall rock by bringing about solution and redeposition of the quartz, sericitization of the feldspars, and deposition of the topaz. This process probably continued throughout the mineralizing period. At the same time vein quartz was deposited. Some quartz deposition seems to have continued, at least locally, during the whole time of mineralization. However, after one phase of quartz deposition occurred zinnwaldite was formed, and then pyrite was deposited along with more quartz and galena and sphalerite. This succession seems to have been followed by the introduction of the tungsten-bearing mineral, wolframite.
>
> "At the Killian prospect this stage seems to have been followed by the deposition of a small amount of scheelite, francolite, and fluorapatite. Formation of a yellow to green scaly mica, tentatively identified as zinnwaldite was next followed by chalcopyrite and then fluorite. Covellite and hematite seem to be encrustations and as such would be last.
>
> "This sequence does not seem to have been followed at all places, because a zoned or banded specimen showing a cross-section of the vein at the Grigsby adit shows the following sequence from the slickensided wall toward the center of the vein; vein quartz; quartz and wolframite; quartz and pyrite; quartz, zinnwaldite and fluorite; quartz, galena, and zinnwaldite with some chalcopyrite; and finally a zone of vein quartz and zinnwaldite."

Francolite and fluorapatite are described by Pomerene as occurring at Silver Mines. These two minerals probably represent the phosphatic material described by Tolman.

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20 Pomerene, Op. cit., p. 31-32.

Hayes[21] offers the following remarks concerning the paragenetic sequence at the Martin and Ozark Mines:

> "Insofar as was determined, the mineral succession at both mines is essentially the same. Quartz was the earliest mineral forming the bulk of the vein material. This was followed by topaz and sericite. The sulfides, pyrite and arsenopyrite were next. Fluorite deposition seemed to precede the deposition of wolframite, which was followed by the chalcopyrite, sphalerite, and galena. A period of quartz deposition at the end of the series is indicated at the Ozark Mine, as it acts as a cement in the breccia."

Richter, Reichen, and Lemmon[22] state that the specimen containing the yellowish-white micaceous aggregates described by Singewald and Milton as ferritungstite was re-examined by Graf and shown to be jarosite. French[23] also obtained some of this material at Silvermine and checked Graf's report of jarosite.

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21 Hayes, Op. cit., p. 45.

22 Richter, D. H., Reichen, L. E., and Lemmon, D. M., Amer. Mineralogist, vol. 42, 1957, p. 85.

23 Grawe, O. R., Personal Communication.

MINERALOGRAPHY

In order to determine the paragenetic sequence of minerals at Silver Mine, thin sections and polished surfaces of selected specimens were examined with the petrographic and mineralographic microscopes. The specimens were selected from those collected by Pomerene and Hayes as well as from those collected by the writer. The significant sections and polished surfaces are described.

Silvermine Granite with Xenolith, Einstein Mine (EMt-1)

Megascopic description:

The rock is a coarse-grained, pink granite which contains a fine-grained angular gray inclusion (50 x 30 x 25 mm.). The boundary of the inclusion and the granite is quite sharp. A higher percentage of dark minerals appear to be present in the inclusion than in the coarser grained granite.

The granite contains orthoclase grains ranging in length from 0.5 mm. to 6 mm. Some of the larger grains have a subhedral to euhedral outline, are zoned, and contain quartz in micrographic intergrowth. The plagioclase grains up to 2 mm. long have a clouded appearance. Altered hornblende laths up to 2 mm. long are distributed throughout the rock. Numerous patches of dark green chlorite 4 to 10 mm. across occur adjacent to the hornblende and also at the margins of orthoclase grains. Anhedral quartz grains up to 1 mm. across are randomly distributed in the rock.

Microscopic description:

A microscopic examination reveals that the significant differences between the granite and the fine-grained inclusion are the variations in grain size and smaller variation in Na-plagioclase and hornblende content. The grain size and visual estimate of the mineralogic composition of the granite and of the inclusion are given below:

	Granite	Inclusion
Grain size:		
Maximum	8.0 mm.	1.5 mm.
Minimum	0.2-0.3 mm.	0.1 mm.
Average	1.5 mm.	0.75 mm.
Mineral Composition:		
Orthoclase	55-60 %	45-50 %
Na-plagioclase	10 %	15-20 %
Quartz	20-25 %	15-20 %
Hornblende	5-10%	10-15 %

Accessories:

Magnetite, epidote, chlorite, biotite, apatite.

The large euhedral grains in the granite are altered, zoned plagioclase. Poikilitic and micrographic intergrowths of quartz in orthoclase are common. Slight sericitization of orthoclase is apparent. The smaller, euhedral plagioclase laths up to 3 mm. long have been intensely sericitized and kaolinized. Extinction angle measurements in the zone perpendicular to 010 indicate that the plagioclase is albite-oligoclase both in the granite and in the inclusion.

Subhedral laths of altered hornblende are widely distributed throughout the section. From the measurement of optic angle and $Z \wedge c$, the hornblende was shown to fall into the "common hornblende" group of Winchell[24]. The hornblende is almost always associated with chlorite (thuringite and negative penninite), irregular epidote masses 0.1-0.2 mm. across and subhedral to euhedral magnetite. Most of the magnetite grains are embedded in the hornblende. Some of the chlorite is an alteration product of hornblende. Epidote invades and surrounds magnetite and is, in turn, invaded by chlorite. The epidote is probably the result of the alteration of hornblende by hydrothermal solutions. A certain amount of albite appears to have been introduced into the rock. This material embays and probably replaces the albite-oligoclase laths and the micrographic quartz-orthoclase intergrowths, and also fills the interstices between these grains.

Greisen Adjacent to Quartz Vein, Einstein Mine Dump (EMt-2)

Megascopic description:

This is a dark greenish-gray rock containing visible quartz and purple fluorite. This probably is the material which some geologists have called serpentine. It looks very much like serpentine, especially on a sawed surface where it has a mottle gray-green appearance. The

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24 Winchell, A. N. and Winchell, H., Elements of Optical Mineralogy, Part II, p. 431.

green mineral is clearly visible on the fractured surface of the rock and exhibits a scaly structure when picked with a needle. Dull reddish patches of hematite further mottle the rock and are probably the result of the oxidation of pyrite.

Microscopic description:

Microscopically, the rock consists of anhedral quartz, up to 2.5 mm. across, and subhedral to euhedral topaz grains, up to 0.4 mm. across, which are surrounded and invaded by fine-grained sericite. Topaz is the principal constituent of the greisen and is distributed throughout the rock as angular, rectangular grains 0.3 mm. long and prismatic crystals up to 0.4 mm. long which show basal cleavage. Sericite invades topaz particularly along the cleavage planes.

Quartz occurs both as large grains up to 2.5 mm. across in the greisen and in association with pyrite and sphalerite in veinlets which traverse the greisen. Most of the grains are strained as evidenced by undulatory extinction and by their slightly biaxial character.

Pyrite up to 1 mm. across occurs in association with sphalerite 0.5 mm. across and fluorite up to 0.3 mm. across in small veinlets in the rock and as smaller disseminated grains in the greisen. Small inclusions of topaz and quartz occur in pyrite. Pyrite invades sericite, and is, in turn, replaced by thin limonite veins which are probably the result of weathering of the pyrite along fractures. Fluorite appears to replace pyrite.

Brownish sphalerite grains up to 0.5 mm. across occur in small veinlets with chlorite and fluorite. The sphalerite invades chlorite along its cleavage plans and also replaces and surrounds fluorite.

A clay mineral, probably resulting from the alteration of sericite, feldspar, or topaz, is present in the greisen. The mineral occurs principally as irregular patches, but a group of slender crystals 0.2 to 0.4 mm. long was found in association with sericite. Of particular interest, is the occurrence of a number of oriented clay mineral crystals with sericite in a grain of a negative, slightly biaxial, low birefringent (.006-.008) mineral. The alignment of the crystals may be due to alteration along cleavage directions in the mineral. If this is true, the grain may be incompletely altered orthoclase (sanidine) or anorthoclase as suggested by the low 2V and birefringence.

Cassiterite, and apatite inclusions in quartz, and red isotropic inclusions (garnet) in quartz also were observed in the section.

No material which might be identified as serpentine was seen in the thin section.

Greisen in Hanging Wall, Gabriel Adit (GAt-1)

Megascopic description:

This rock is medium to fine-grained, hard, smoky gray, and has a highly siliceous appearance. Vitreous white quartz grains occur with smoky gray grains which are probably topaz. The rock appears to be principally a quartz-topaz aggregate. Pyrite cubes and irregular grains are widely distributed as veinlets and disseminations in the rock. A small amount of hematite, probably an alteration product of pyrite, occurs as masses or clots in the pyrite veinlets. A leached crust of limonite and hematite (?) boxwork, often associated with pyrite, coats the rock in some places. Patches of a green chloritic aggregate are rarely seen.

Microscopic description:

Under the microscope, it is seen that the rock is principally composed of topaz, sericite, and quartz, up to 0.3 mm. across. Topaz grains, 0.1 to 0.3 mm. across, and crystals up to 0.5 mm. long showing basal cleavage and quartz inclusions are distributed abundantly in the section. Sericite fills fractures in topaz and quartz, and also occurs in the interstices and at the grain boundaries between these minerals. A number of highly altered grains, having a subhedral outline and having an average diameter of 1.25 mm. occur in the section. One of these grains, upon close examination, was seen to be composed chiefly of sericite, quartz, and a clay mineral in grains aligned parallel to the long dimension of the relict grain. Fine-grained sericite replaces the original euhedral grain along its cleavage direction. Quartz appears to replace sericite. The clay mineral is probably the result of the alteration of sericite. A less fine-grained, colorless to greenish brown, faintly pleochroic, micaceous material, probably chlorite, appears to replace the fine-grained sericite and quartz.

Small sphalerite grains occur in the section and are often associated with chlorite. Veinlets of chlorite and sphalerite occur transversing the greisen. Sphalerite is veined by chlorite.

Pyrite is distributed throughout the section both as cubic grains and as irregular masses associated with and corroded by purple fluorite. Fluorite also occurs in close association with sphalerite and is embayed by sphalerite.

A few cassiterite grains up to 0.2 mm. across and having a subhedral outline, occur in the greisen. These grains are not attacked by sericite and are abutted by sphalerite.

Vein Quartz and Greisen, Einstein Mine (EMt-3)

Megascopic description:

This specimen is a portion of the Einstein vein near its contact with the wall rock. It is composed principally of angular shaped, greenish gray, micaceous, greisenized masses, about 10 x 4 x 4 cm., which are cemented by light grayish white, fractured vein quartz. The greisen masses are composed principally of sericite mica and quartz with lesser amounts of coarse zinnwaldite, fluorite, pyrite, and sphalerite. Pyrite, sphalerite, galena, and chalcopyrite are present as granular aggregates in the vein quartz.

Sericite and quartz occur as fine-grained aggregates in the greisen, and greenish yellow granular aggregates of sericite, 5 mm. across, are visible in the vein quartz.

White and purple fluorite are visible in the vein quartz as fillings in fractures and as embayments in zinnwaldite along cleavage planes.

Zinnwaldite, as brownish spherulitic aggregates up to 10 mm. in diameter occur principally near the greisen margins.

Pyrite is present as minute grains disseminated in the greisen and also occurs as large masses, up to 25 mm. across, in the vein quartz.

Sphalerite is present as small brown granular clusters, up to 2 mm. across, in the greisen, and as larger clusters, up to 25 mm. ac-cross, in the vein quartz.

Galena appears to be contined to the vein quartz.

Microscopic description:

Under the microscope, the greisen is found to consist primarily of topaz, sericite, and quartz with minor amounts of zinnwaldite, chlor-ite, and fluorite filling interstices and fractures in quartz and topaz. Topaz is the most abundant constituent of the greisen and occurs princi-pally as anhedral grains. Veinlets of sericite cut both topaz and quartz, but do not cross the slightly pleochroic zinnwaldite aggregates. Fluorite occurs between the zinnwaldite cleavage planes. Chlorite is to be found principally at the margins of the greisen masses where it invades zinnwaldite along the cleavage planes. On the basis of the nearly uniaxial character, refringence (Ny=1.62±), and colorless to light yellow green pleochroism, the chloritic mineral is believed to be daphnite[25]. A small amount of chlorite occurs in the greisen as interstitial fillings between quartz and topaz. A rim of chlorite around fluorite, quartz, and sericite grains was observed outside the greisen field in the vein quartz. A brownish, highly birefringent grain appears to embay zinnwaldite and is enclosed by chlorite. The tetragonal outline, high birefringence (.07-.09), and uniaxial positive character indicates that the grain is cassiterite.

Close to its contact with the quartz vein the greisen gives way to a narrow band of sericite with minor quartz and topaz. The sericite band is bounded on the veinward side by zinnwaldite "fans" which are partially invaded by chlorite along cleavage planes.

The vein material consists primarily of highly fractured quartz, fluorite, and sericite aggregates. The latter are probably the result of the alteration of feldspar or topaz. The quartz appears to be strained having a slight biaxial character and exhibiting undulatory extinction. The fractures in the quartz are partially filled by chlorite, sericite, fluorite, zinnwaldite, and pyrite.

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[25] Ibid, p. 381.

Vein Quartz, Einstein Mine (EMt-4)

Megascopic description:

The hand specimen consists of a sulphide phase of the Einstein vein. It is composed of rounded to irregular aggregates of sulphide minerals, principally pyrite, 1-10 mm. across, in fractured, white quartz. In addition to pyrite and quartz the minerals present are: galena, sphalerite, chalcopyrite, green fluorite, and limonite. Chalcopyrite and galena vein and embay sphalerite and pyrite. Green fluorite and sphalerite are in close association and appear to attack pyrite. Pyrite is generally associated with fractures in quartz while chalcopyrite appears to replace quartz.

Microscopic description:

In thin section, under the petrographic microscope, the rock is seen to be composed principally of subangular to rounded, pitted and fractured pyrite grains which have an average diameter of 2.5 mm. and a maximum diameter of 3.5 mm. These are surrounded by fine-grained sericite. Sphalerite, fluorite, quartz, cassiterite, and galena occur in the spaces between pyrite grains and in the cavities in the pyrite. Quartz is not abundant, but occurs as anhedral and euhedral, fractured grains up to 4 mm. across. Among the euhedral grains, there is a marked tendency for one rhombohedral face to be better developed than the other faces of the same form. Most of the quartz grains exhibit undulatory extinction and a small optic angle (2V = 15-20°). Sericite surrounds and veins quartz along fractures. Pyrite and quartz appear to have mutual embayment or straight-edged boundaries with one another.

Sphalerite, as irregular masses up to 3 mm. across, surrounds and replaces pyrite and fills fractures in quartz. The sphalerite replaces sericite and chlorite along cleavage directions and also veins chlorite. Veinlets of chalcopyrite replace sphalerite.

Fluorite, up to 1 mm. across, appears to replace pyrite and fills cavities 0.2-0.5 mm. in diameter in pyrite. It replaces sericite along cleavage planes. A small amount of fluorite almost always occurs with cassiterite and appears to cut and embay it.

Chlorite grains up to 0.5 mm. across are sparsely distributed in the section. Chlorite exhibits faint green to colorless pleochroism and a maximum birefringence of 0.010-0.012. The mineral is negative and nearly uniaxial. Chlorite replaces sericite, to a small extent, along its cleavage planes, and is, in turn, replaced along its cleavage directions by sphalerite.

Highly birefringent, light brown cassiterite grains and tetragonal crystals up to 0.4 mm. across are embayed by fluorite and are surrounded by sphalerite. There is also a tendency for sphalerite to embay cassiterite. Cassiterite seldom occurs in the absence of fluorite. Some cassiterite is associated with fractures in quartz. A large subhedral grain of cassiterite, 0.3 mm. across, is surrounded and embayed by pyrite.

Galena veins, surrounds, and embays pyrite and sphalerite, and surrounds chalcopyrite.

Vein Quartz, Einstein Mine (EMt-5)

Megascopic description:

The rock is a sample of vein quartz and sulphides from the Einstein Mine and consists of fractured, white quartz, laths of wolframite up to 1 mm. long, pyrite grains up to 0.8 mm. across, and pyrite cubes up to 0.4 mm. on edge, irregular, fractured grains of arsenopyrite, sphalerite, chalcopyrite, and galena.

Pyrite surrounds and embays portions of the wolframite laths and is in turn attacked by sphalerite.

Fractures in arsenopyrite have been filled by a greenish mineral forming veinlets up to 0.1 mm. in width. The mineral does not vein the other metallic minerals, and is limited in occurrence to arsenopyrite grains and margins. Arsenopyrite shows a slight tendency to embay pyrite and surround wolframite. It is replaced by sphalerite.

Irregular masses of sphalerite, up to 0.4 mm. across, occur in association with the other sulphides. Sphalerite embays or replaces pyrite and arsenopyrite, and is often surrounded by chalcopyrite.

Chalcopyrite masses, up to 0.4 mm. across, are usually associated with sphalerite and appear to replace it.

A few small, cleavable masses of galena, 0.2 mm. across, occur imbedded in quartz.

Microscopic description:

A microscopic examination shows that the quartz varies widely in grain size, from less than 0.1 mm. to 14 mm. Most of the grains are anhedral, but several exhibit a regular outline suggestive of crystal forms. It is apparent from the wide range in grain size and the occurrence of small quartz inclusions in larger quartz grains, that recrystallization has taken place. A number of reddish brown, isotropic inclusions, less than 0.1 mm. across, were noted in quartz. Their index of refraction is greater than quartz. Numerous bubble inclusions, up to 0.1 mm., showing Brownian movement were observed. There is a curvilinear alignment of inclusions within some of the quartz grains. The directions of alignment bear no constant relation to a particular crystallographic direction in the quartz grains. In general, movement is more rapid in the smaller than in the larger inclusions. In addition to the bubbles, a number of minute solid particles occur in some of the inclusions.

There is no preferred orientation of quartz grains within the field. The majority of the grains and crystals exhibit strain fractures and undulatory extinction. The occurrence of irregular twin lamellae, which appear to be parallel to the c axis of the quartz crystals, were noted in several quartz grains and crystals. The irregular shape of the lamellae and their orientation parallel to the c direction suggest that the quartz crystals are twinned according to the Brazilian Law[26].

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[26] Dana, E. S., A System of Mineralogy, 6th Ed., 1920, p. 185.

Sericite and fluorite veinlets cut quartz. A single pyrite cube, 1.5 mm. on edge, and a rectangular grain, 2.5 mm. long, occur in the quartz. Tiny veinlets of sphalerite cutting quartz occur in association with pyrite.

A veinlet consisting of sericite, fluorite, chlorite, sphalerite, and pyrite traverses the section. The sericite fills fractures in the quartz and is, in turn, invaded along its cleavage planes by fluorite. Fluorite fills fractures in quartz. The chlorite shows a colorless to light green pleochroism and an almost uniaxial, negative character. Chlorite appears to embay sericite.

Several brownish wolframite grains, 0.3 mm., occur in fractures in quartz or in the interstices between quartz crystals and grains.

Vein Quartz, Einstein Mine (EMt-6)

Megascopic description:

The rock is composed of fractured, white vein quartz and irregular masses of metallic sulphides and subhedral wolframite laths. It is apparent that the ore minerals have partially replaced the quartz and also one another. Fracture filling of quartz by ore minerals is also apparent. The fractures allowed ready access to the ore bearing solutions. The ore minerals which can be identified are: pyrite, wolframite, arsenopyrite, sphalerite, chalcopyrite, and galena.

Pyrite and arsenopyrite exhibit mutual embayment or straight boundaries with one another. Sphalerite appears to embay both pyrite and arsenopyrite and is, in turn, embayed and veined by chalcopyrite. Galena is not abundant, and appears to replace sphalerite. Wolframite is not associated with the sulphides, and occurs as lathlike grains as much as 10 mm. long embedded and filling fractures in quartz.

Microscopic description:

Under the microscope, the rock is seen to be made up of fractured, angular sulphide masses up to 5 mm. across which replace and fill fractures in quartz. The quartz grains, up to 10 mm. across, exhibit undulatory extinction and show evidence of secondary growth.

Pyrite occurs principally as irregularly shaped, fractured and pitted masses filling and replacing quartz along fractures. Cubes and rectangular grains of pyrite as much as 0.5 mm. on edge are not abundant in the rock. Fluorite often fills pits and cavities in pyrite.

Arsenopyrite is more abundant than pyrite in this particular section. The mineral occurs as fractured, angular masses. A few grains are suggestive of crystal forms. Arsenopyrite exhibits straight-edged and mutual embayment boundaries with pyrite. Light green veinlets of a chloritic mineral cut arsenopyrite and sphalerite. The mineral occurs as scaly aggregates within veinlets. A small fragment of arsenopyrite was crushed with the idea of determining the optical properties of the green mineral by the use of oil immersion. The mineral has an index of

1.65$\neq$-1.66- in basal section, a birefringence varying from 0.004-0.012, and a negative uniaxial or slightly biaxial character. Pleochroism is colorless to light green. The mineral is probably daphnitic chlorite.

Sphalerite occurs as irregular reddish brown masses up to 4 mm. across. It replaces and fills fractures in pyrite and arsenopyrite. The greenish mineral mentioned above veins and cuts sphalerite. A few grains of fluorite are surrounded by sphalerite, and minute grains of fluorite and sphalerite partially fill cavities in pyrite.

Chalcopyrite occurs as small replacement masses, 1 to 2 mm. across, in pyrite, arsenopyrite, and sphalerite.

Several small tetragonal grains of cassiterite occur in association with pyrite and appear to corrode it.

Galena and wolframite were not seen in the section.

Ore, Gabriel Adit (GAp-1)

Brecciated and fractured pyrite is veined by galena and contains galena inclusions. In some areas, where brecciation or fracturing has reduced the grain size, down to 0.1 mm., interstitial galena appears to act as a cementing material. Most of the pyrite occurs as irregular grains, but small cubic and rectangular grains, less than 0.1 mm. on an edge, are present.

Galena occurs in masses, up to 1 mm. across, and as open space fillings between pyrite grains. Small inclusions of galena, less than

0.075 mm. across, occur in pyrite and do not appear to be dependent upon visible fractures in pyrite. Galena surrounds, but does not embay, euhedral quartz. Large masses and tiny veinlets of galena cut sphalerite and chalcopyrite.

Sphalerite, including irregularly shaped bodies and exsolution blebs of chalcopyrite, is quite abundant. The chalcopyrite inclusions may be broadly classified into three groups, (1) the large irregular bodies, up to 0.075 mm., exhibiting no lineation, (2) tubular lineated bodies, and (3) extremely minute blebs, less than 0.006 mm. across, which may or may not show lineation characteristics. Two, and occasionally three, prominent directions of lineation are seen.

A number of measurements of the angles formed by the intersection of lineations of chalcopyrite blebs in sphalerite is close to 60°. Other measurements on lineation directions in the same section show intersection angles up to 90°. It is probable that the lineation directions are parallel to dodecahedral planes.

Ore, Gabriel Adit (GAp-2)

Sphalerite, containing chalcopyrite inclusions which show three directions of alignment which intersect at approximately 60°, is the most abundant mineral in the section. The intersecting lines of inclusions form numerous equilateral triangles in the sphalerite field. Irregular and minute bleb inclusions are present also. Sphalerite appears to be embayed by galena, but also contains galena inclusions which are not related to visible fracture systems. A number of sphalerite inclusions, without chalcopyrite blebs, occur in pyrite. Sphalerite surrounds anhedral grains and crystals of quartz. Veinlets of sphalerite masses embay pyrite.

Fractured pyrite grains of irregular and subcubic outline are veined by galena and embayed by sphalerite. Inclusions of galena, containing inclusions of chalcopyrite, and sphalerite, up to 0.1 mm. across, occur in pyrite.

Galena up to 1.5 mm. across, occurs in association with sphalerite-chalcopyrite aggregates, up to 1.2 mm. across, and with pyrite up to 0.3 mm. across. There is a tendency for chalcopyrite to concentrate at the boundaries between sphalerite and galena. Galena embays some of the chalcopyrite, but there is also an embayment of a portion of the galena by chalcopyrite.

Ore, Einstein Mine (EMp-1)

The section shows pyrite in irregular patches, up to 2 mm. across, and in cubes as much as 0.2 mm. on edge. The pyrite grains are pitted and fractured, and contain numerous inclusions of quartz, sphalerite, galena, and limonite. Limonite also occurs as veinlets as much as 0.1 mm. wide in pyrite and quartz. The metallic sulphides have filled quartz grain interstices, and fractures, and have also replaced quartz.

Galena inclusions, 0-0.2 mm. across, occur in pyrite. These inclusions have irregular shapes and are associated with fractures in pyrite. A certain amount of embayment and possibly replacement of pyrite by galena is evident. Galena grains also occur in fractures in quartz associated with sphalerite. It is apparent that galena embays sphalerite.

Inclusions of sphalerite, 0-0.2 mm. across, occur in pyrite. Only minute bleb type inclusions of chalcopyrite are present in this included sphalerite. Larger irregular grains of sphalerite, 0-0.5 mm. across, occur as fracture fillings in quartz. These grains contain only the minute chalcopyrite blebs even when the sphalerite is not associated with pyrite or galena. Sphalerite embays pyrite.

Ore, Einstein Mine (EMp-2)

Veined and fractured wolframite laths, up to 2 mm. across, are embedded in quartz and also fill fractures in quartz. Small veinlets of quartz cut wolframite. Arsenopyrite and galena inclusions occur in the wolframite laths and are always associated with the quartz veins which traverse the laths.

Large masses of fractured arsenopyrite are veined by quartz and a greenish non-opaque mineral. Sphalerite and galena vein and embay arsenopyrite. A grain of arsenopyrite, 0.25 mm. across, was seen to contain galena inclusions and to be surrounded by galena, chalcopyrite, and sphalerite in order.

Sphalerite, containing irregular and aligned inclusions of chalcopyrite, occurs as irregular granular aggregates and veinlets in quartz.

Minute galena, 0.15 mm., inclusions and veinlets in sphalerite were observed. Numerous chalcopyrite veinlets were seen in sphalerite. These do not appear to be continuous veinlets, but probably represent elongate inclusions aligned parallel to a sphalerite cleavage direction.

Galena grains, up to 0.3 mm. across, occur associated with fractures in quartz.

Several minute, bright red non-opaque grains, 0.12-0.25 mm. across, were seen in the section. These may be spessartite garnet.

Ore, Einstein Mine (EMp-3)

Several fractured wolframite laths, up to 1.2 cm. long, are embedded in quartz. Occasionally the wolframite laths are intergrown with their long axes making large angles with each other (60-75°). Veinlets of quartz traverse the laths perpendicular to their long dimension forming a "healed" texture. Small galena inclusions, less than 0.1 mm. across, occur in wolframite, generally near the margins of the laths, and are probably associated with fractures in the lath. Tiny veinlets containing galena, chalcopyrite, and sphalerite are occasionally seen which cut a wolframite crystal perpendicular to its long dimension. These veins, no doubt, represent fillings of the prominent system of fractures which trend across all the laths in a direction perpendicular to the length of the lath. Sphalerite embays wolframite. Chalcopyrite fills interstices between wolframite grains and also fills fractures in the same mineral.

Large masses of fractured arsenopyrite, up to 10 mm. across, are embayed and surrounded by sphalerite and chalcopyrite, and veined by galena. The fractures are almost always filled by a greenish non-opaque gangue mineral. Arsenopyrite shows a tendency to embay pyrite.

Sphalerite, containing chalcopyrite inclusions, is veined by galena. The chalcopyrite inclusions are again of three types, (1) irregularly shaped masses, up to 0.2 mm. across, (2) aligned tubular bodies, and (3) minute blebs which show a tendency to cluster. Larger chalcopyrite grains, 0.5 mm. across, occur at the margins of sphalerite grains and appear to embay it. A narrow fringe of galena often occurs at the contacts between sphalerite and arsenopyrite.

Irregularly shaped masses of chalcopyrite, up to 0.3 mm. across, are often surrounded by galena.

All the metallic minerals, except wolframite, appear to be associated with fractures in quartz, or to have filled interstices between quartz grains or crystals. Wolframite is embedded in quartz. It is quite interesting to note that fractures in quartz do not end at quartz-wolframite contacts but rather continue across the wolframite lath. Where quartz fractures meet pyrite or the other sulphides, the fractures are terminated. It is quite apparent, therefore, that fracturing took place subsequent to the deposition of wolframite, but prior to sulphide deposition.

Ore, Einstein Mine (EMp-4)

The section shows arsenopyrite, sphalerite, pyrite, chalcopyrite, and galena in order of decreasing abundance.

Cubes, up to 1.5 mm. on an edge, and irregular masses of pyrite, are embayed and corroded by arsenopyrite and sphalerite. Mutual embayment relations between pyrite and arsenopyrite are also to be seen. A few small inclusions of sphalerite and galena, up to 0.2 mm. across, occur in pyrite, and arsenopyrite. Most of the galena occurs at the grain margins of pyrite, arsenopyrite, and sphalerite.

Sphalerite containing numerous, widely distributed chalcopyrite inclusions clearly embays pyrite and arsenopyrite. The chalcopyrite inclusions are either irregular, non-lineated bodies, up to 0.07 mm. across, or aligned minute blebs. Wherever sphalerite contacts pyrite or arsenopyrite the number and size of the chalcopyrite inclusions decreases markedly. Sphalerite inclusions in pyrite and arsenopyrite do not contain chalcopyrite bodies.

Ore, Einstein Mine (EMp-5, same material as EMt-6)

Granular aggregates of cubes of pyrite up to 0.4 mm. on edge, and irregular, fractured pyrite grains contain numerous minute inclusions of sphalerite, chalcopyrite, and galena, 0.012-0.1 mm. across. In one area of the section, the pyrite appears to be brecciated and cemented by sphalerite, chalcopyrite, and galena. Sphalerite embays pyrite.

Sphalerite contains numerous irregular and aligned tubular chalcopyrite blebs, as much as 0.1 mm. long. The small sphalerite inclusions in pyrite contain no chalcopyrite. Irregular discontinuous veinlets of chalcopyrite occur in sphalerite.

Chalcopyrite masses, up to 10 mm. across, surround pyrite cubes up to 0.1 mm. on edge. Chalcopyrite embays sphalerite. The sphalerite which contacts the chalcopyrite contains no chalcopyrite inclusions. A few small grains of covellite, less than 0.1 mm., occur in cavities in chalcopyrite.

A few grains of arsenopyrite, up to 0.3 mm. in diameter, are present in the section. There is a slight tendency for arsenopyrite to embay pyrite. Chalcopyrite inclusions, less than 0.1 mm. across, occur in arsenopyrite. Sphalerite embays arsenopyrite.

Ore, Einstein Mine (EMp-6)

The sulphide minerals in this section occur as open space fracture fillings in quartz. There is no positive evidence for replacement of quartz by sulphides.

Irregular fractured pyrite masses, up to 0.5 mm. across, and fractured pyrite cubes, up to 0.5 mm. on edge, containing sphalerite and galena inclusions are embayed and veined by sphalerite, galena and chalcopyrite. The inclusions, 0.012-0.074 mm., are often associated with fractures in pyrite, but numerous inclusions in which such a relation is not visible are distributed in pyrite. The orientation of these inclusions, when not associated with fractures, appears to be entirely random.

Arsenopyrite occurs in the section as angular to irregular masses up to 1 mm. across. Arsenopyrite shows a tendency to embay pyrite, but straight-edged boundaries are more common. Tiny veinlets of chalcopyrite are occasionally seen traversing arsenopyrite. Embayment of arsenopyrite by galena, sphalerite, and chalcopyrite is common in the section.

Sphalerite is present as irregularly shaped masses up to 0.7 mm. across. The irregular, tubular and bleb inclusions characteristic of chalcopyrite are numerous. Two directions of alignment are visible for the tubular inclusions in some sphalerite grains, making an angle of $86^{\circ} \pm$ with each other. Sphalerite embays arsenopyrite and pyrite, and also forms veinlets in the latter mineral. Veinlike extensions of larger masses of chalcopyrite, up to 0.4 mm. across, appear to embay sphalerite. Sphalerite also occurs as fracture fillings in quartz and surrounds quartz grains and crystals.

Galena is the least abundant of the sulphides in this particular section. It occurs as irregularly shaped masses, up to 0.1 mm. across, filling fractures in quartz in association with sphalerite and chalcopyrite. Meager evidence indicates an embayment of sphalerite by galena. Galena often forms an incomplete rim around chalcopyrite and appears to embay the chalcopyrite.

Ore, Einstein Mine (EMp-7)

Fractured wolframite laths, up to 0.8 mm. long, embedded in quartz, are veined by chalcopyrite and quartz. The quartz veins traverse the wolframite laths perpendicular to their long dimension and probably represent "healed fractures" in the laths. The laths are remarkably free of inclusions other than quartz. There is a slight tendency for sphalerite to embay the wolframite. A V-shaped open space between two intergrown laths is filled by sphalerite. Wolframite and pyrite boundaries are generally mutual, but there appears to be some embayment of the former by pyrite.

Pyrite, less than 0.1 mm. to 1.5 mm., invades wolframite and is, in turn, embayed by sphalerite. A few, extremely minute brecciated pyrite grains, 0.012-0.74 mm. across, are cemented by sphalerite.

Sphalerite is the most abundant sulphide in the section. It occurs as large granular aggregates associated with quartz and is also veined by quartz. It contains inclusions of chalcopyrite which occur as: (1) irregular masses and as much as 0.75 mm. in diameter, (2) tubular aligned bodies, or (3) extremely minute blebs. Discontinuous veinlets of chalcopyrite in sphalerite are formed by the irregularly shaped inclusions. The paths of the chalcopyrite veins may mark the position of sphalerite grain boundaries. Alignment of the minute particles and tubular bodies in one or occasionally two directions is often apparent. When two directions of alignment exist, these make approximately 60^{o} angles with each other. Sphalerite often rounds cube edges of pyrite and also embays pyrite. Inclusions of sphalerite in pyrite are small and not abundant. Sphalerite veins and embays arsenopyrite. It is significant to note that wherever sphalerite is in contact with pyrite or arsenopyrite, the chalcopyrite inclusions in the former mineral are extremely small or completely absent.

Chalcopyrite in masses, up to 0.3 mm. across, and in veinlets occur in quartz in association with sphalerite and galena. Again, wherever large independent chalcopyrite grains contact sphalerite, the chalcopyrite inclusions in the sphalerite tend to be few and small or absent. Veinlets of quartz and chalcopyrite are rarely seen to traverse the wolframite laths.

Galena grains, up to 0.5 mm. across, occur in fractures in quartz. Minute inclusions of galena are rare in sphalerite. Occasionally galena can be seen surrounding and embaying chalcopyrite.

<u>Ore, Einstein Mine</u> (EMp-8)

Lath-shaped crystals of wolframite, up to 0.7 mm. across, occur embedded in quartz and are associated with sphalerite. The characteristic "healed fractures" are evidenced by minute quartz veinlets in wolframite. The wolframite laths are slightly embayed by pyrite and sphalerite and are abutted by chalcopyrite and galena. A tiny veinlet of galena crosses a wolframite lath.

Pyrite occurs as fractured masses, up to 0.6 mm. across, and as cubes, up to 0.1 mm. on edge. The pyrite is veined, surrounded, and embayed by galena, and also contains minute inclusions of galena. Some recementing of brecciated pyrite by quartz has occurred.

Chalcopyrite is present as masses, up to 0.075 mm. across, which embay pyrite. A narrow fringe of galena often occurs at the boundaries between chalcopyrite and other minerals. Chalcopyrite occurs as fracture fillings and veinlets in quartz.

Sphalerite, as irregular masses, up to 0.4 mm. across, is not abundant in the section. Generally it is associated with wolframite and it usually is not possible to determine which mineral invades the other, but at a few contacts the sphalerite seems to invade the wolframite. Chalcopyrite blebs, up to 0.05 mm. across, occur in sphalerite. Sphalerite grains in contact with larger chalcopyrite grains show straight-edged or mutual embayment boundaries.

Irregular grains, 0.5 mm. across, and veinlets of galena occur in association with wolframite and as fracture fillings in quartz.

Ore, Einstein Mine (EMp-9)

Wolframite laths up to 5 mm. long are cut and offset by pyrite and arsenopyrite. One of these laths has been offset at least 0.15 mm. in the plane of the section. The two offset portions of the lath have the same optical orientation. It is also quite evident that the pyrite embays the wolframite. Many of the wolframite laths show the characteristic quartz-filled healed fractures. Occasionally tiny veinlets and grains of galena and chalcopytiet occur in wolframite. Sphalerite shows a slight tendency to embay the laths, but straight-edged boundaries between sphalerite and wolframite are more common.

Pyrite masses, up to 3 mm. across, occur in the section. Numerous tiny inclusions of galena and sphhalerite, less than 0.1 mm. in diameter, are common in pyrite. Sphalerite and galena vein and embay pyrite.

Fractured arsenopyrite grains, up to 5 mm. across, are veined by sphalerite. Arsenopyrite and pyrite show mutual boundaries when they are in contact.

Large masses of sphalerite, as much as 10 mm. across, contain abundant inclusions and discontinuous veinlets of chalcopyrite. Wherever sphalerite contacts one of the other sulphide minerals, the chalcopyrite blebs are smaller in size and fewer in number. Minute inclusions and veinlets of galena are present in sphalerite.

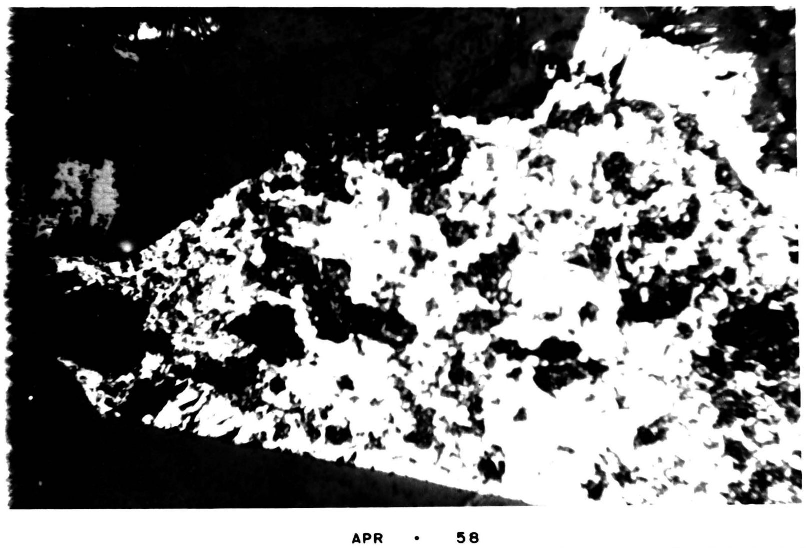

Figure 1. Chalcopyrite, rimmed by galena, filling interstices between quartz crystals. 100X

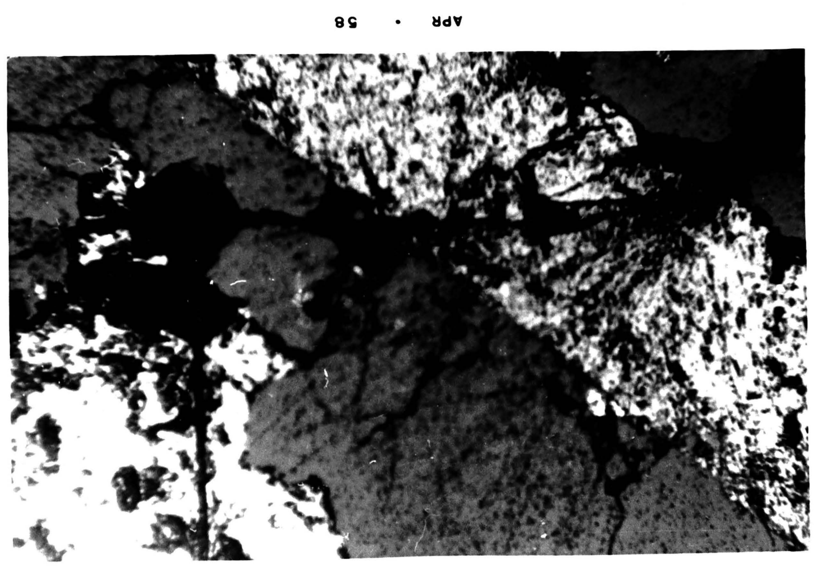

Figure 2. Wolframite lath traversed by a fracture. Sphalerite fills the same fracture (lower left). 100X

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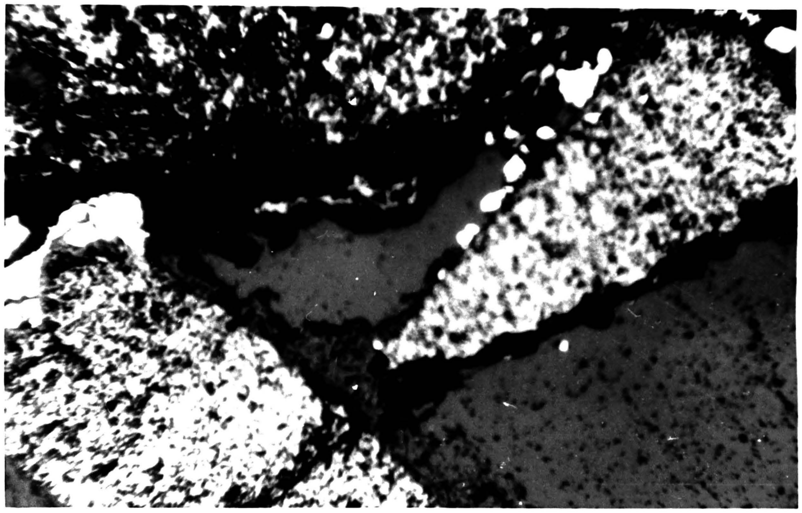

Figure 3. Pyrite invading wolframite lath (left middle) and pyrite grains aligned along the margin of wolframite. 100X

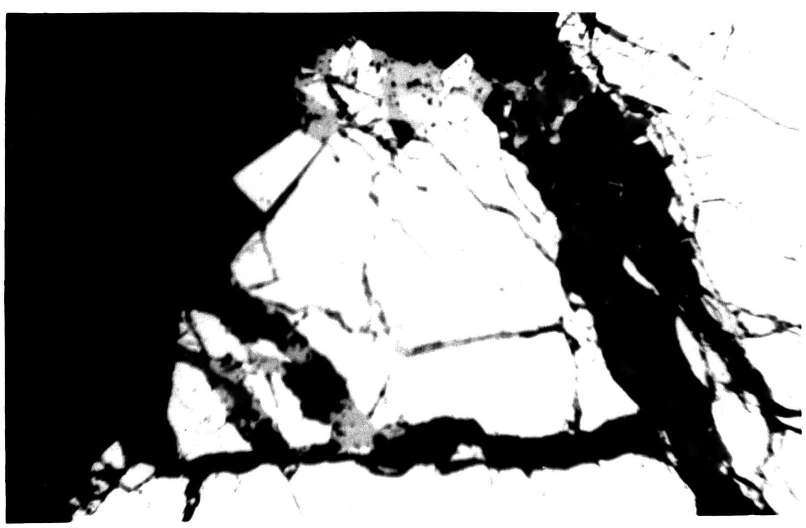

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Figure 4. Galena and sphalerite veinlets cutting pyrite. 100X

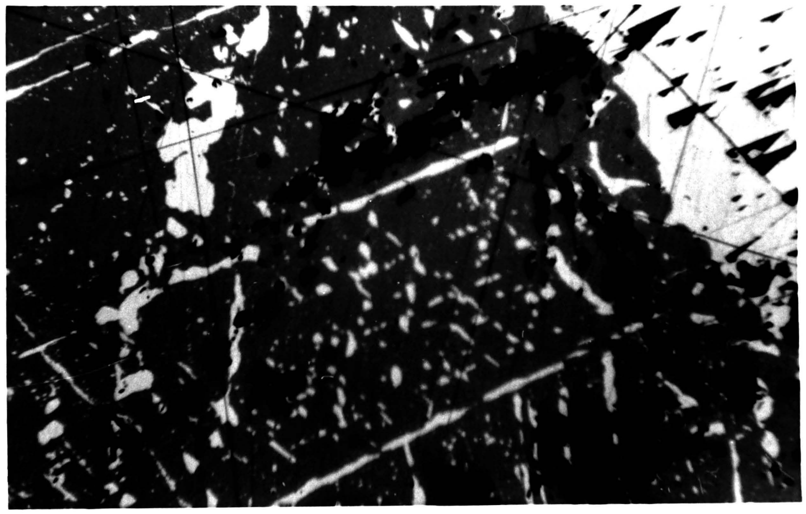

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Figure 5. Lineated and irregular bodies of chalcopyrite in sphalerite. Note equilateral triangles formed by three prominent lineation directions. Galena at upper right. 100X

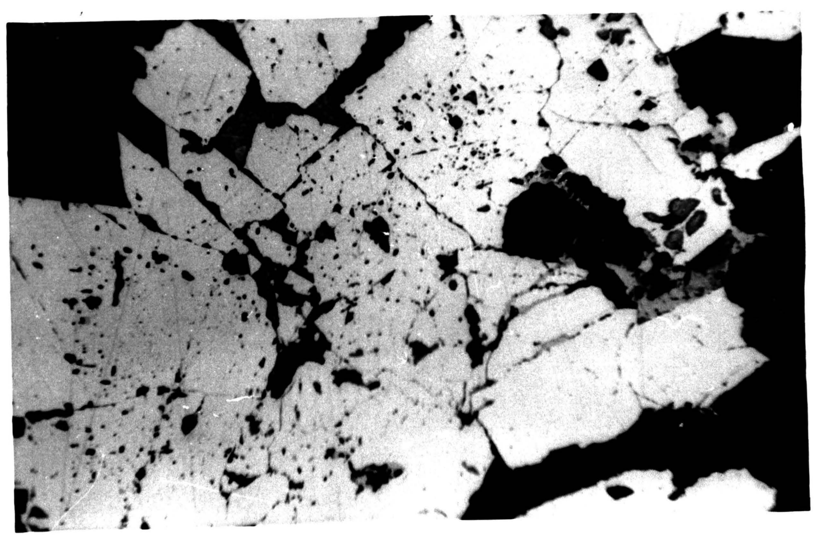

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Figure 6. Arsenopyrite veined by chalcopyrite and invaded by sphalerite (right). Pyrite (left) with galena and sphalerite inclusions and galena veinlets filling fractures. 100X

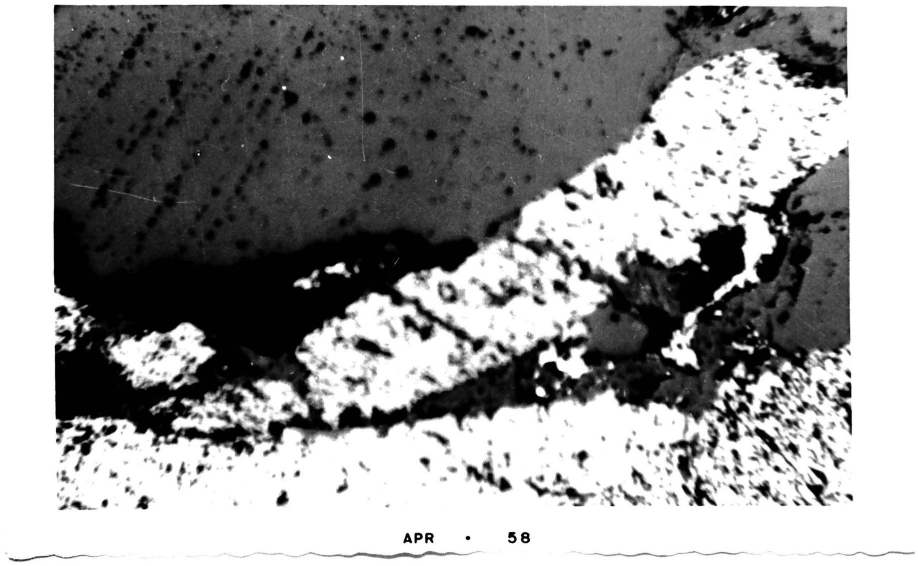

Figure 7. Wolframite lath with quartz-healed fractures imbedded in quartz. 100X.

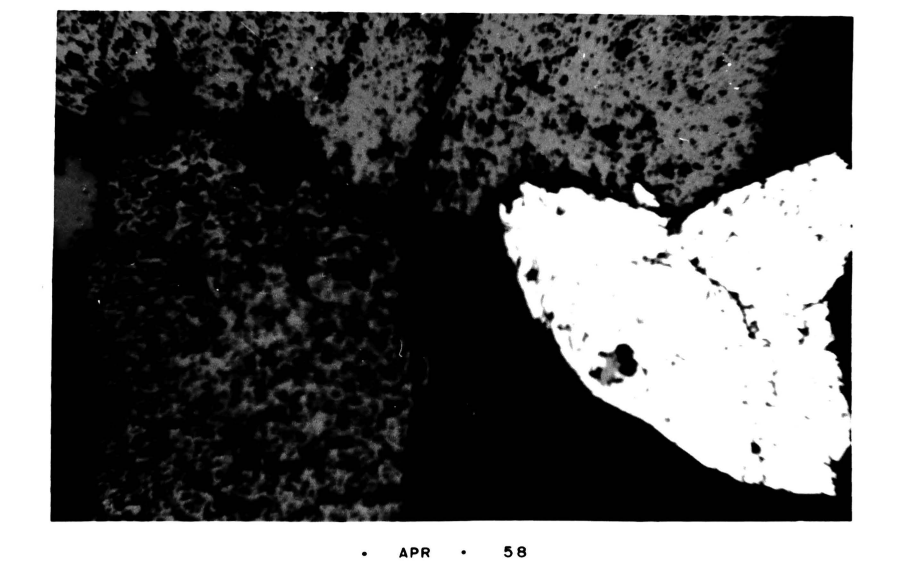

Figure 8. Arsenopyrite embays wolframite. Note quartz-healed fracture traversing wolframite lath (upper left). 100X.

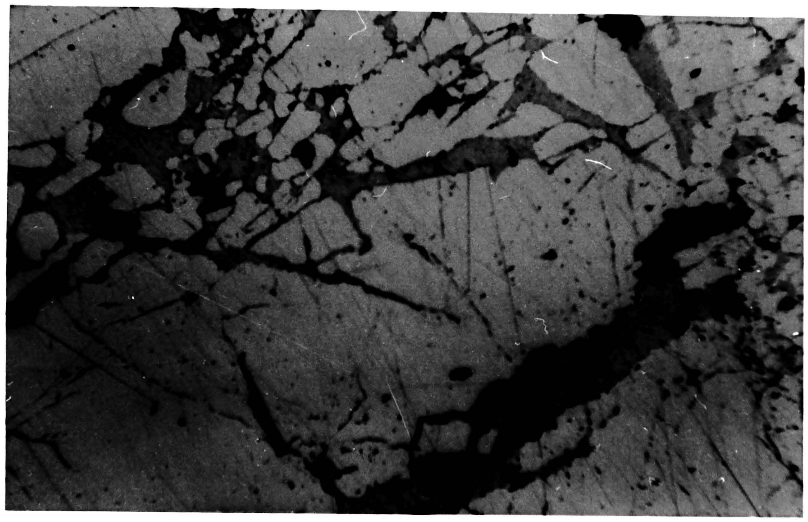

Figure 9. Arsenopyrite veined by galena and sphalerite. 100X.

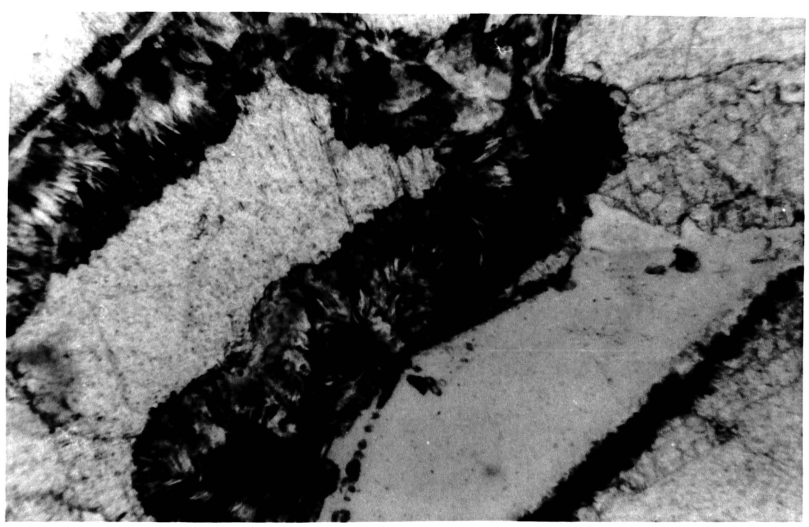

Figure 10. Daphnitic chlorite rosettes replacing topaz (to the right of center). Fluorite (areas showing high relief) replaces topaz and invades chlorite. Ordinary light. 35X.

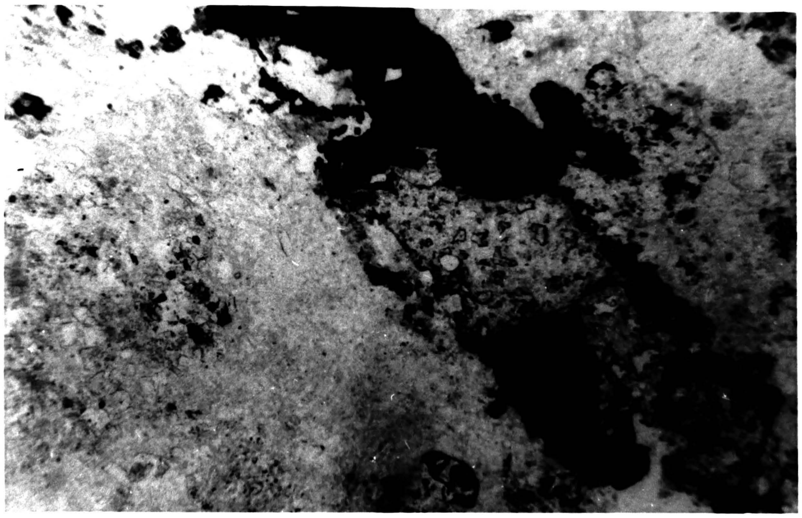

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Figure 11. Fluorite (center, pitted) attacking pyrite (opaque) which, in turn, invades quartz-topaz-sericite greisen. Ordinary light. 35X.

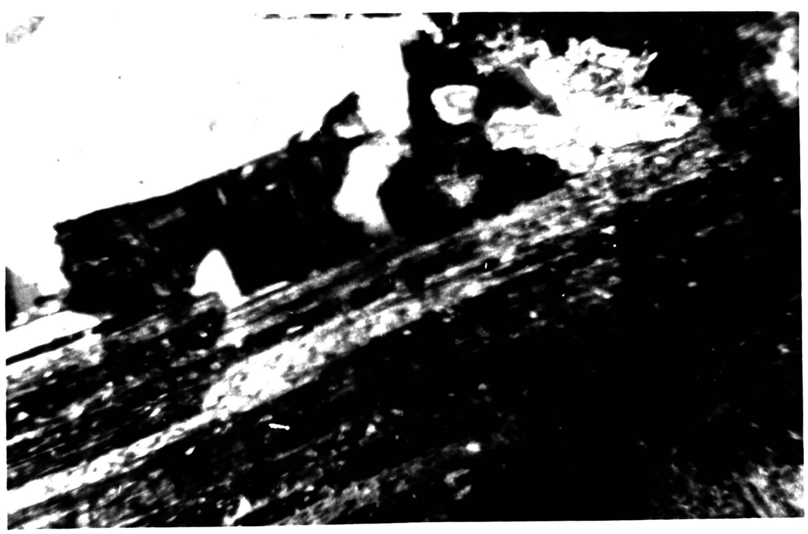

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Figure 12. Sericitized plagioclase (albite-oligoclase) attacked by epidote (upper right), magnetite (opaque), and chlorite (middle left). Crossed nicols. 150X.

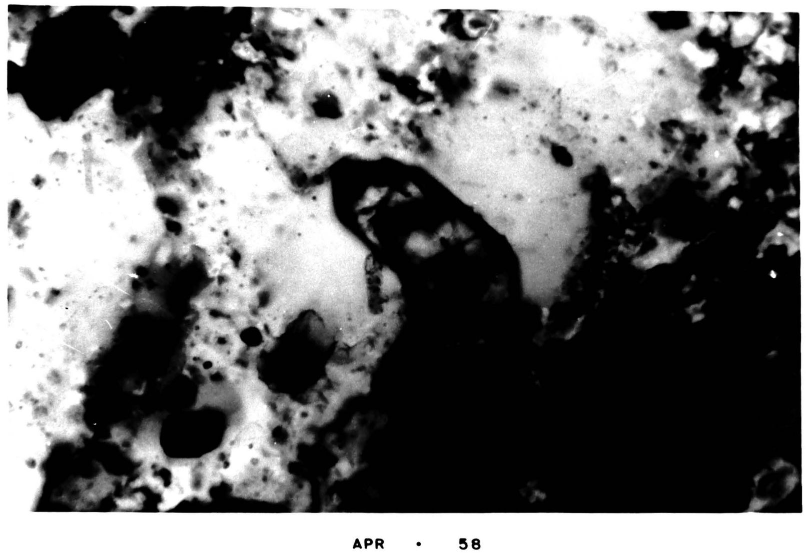


Figure 13. Cassiterite crystal in quartz. Pyrite (opaque) in sericite field. Crossed nichols. 200X.

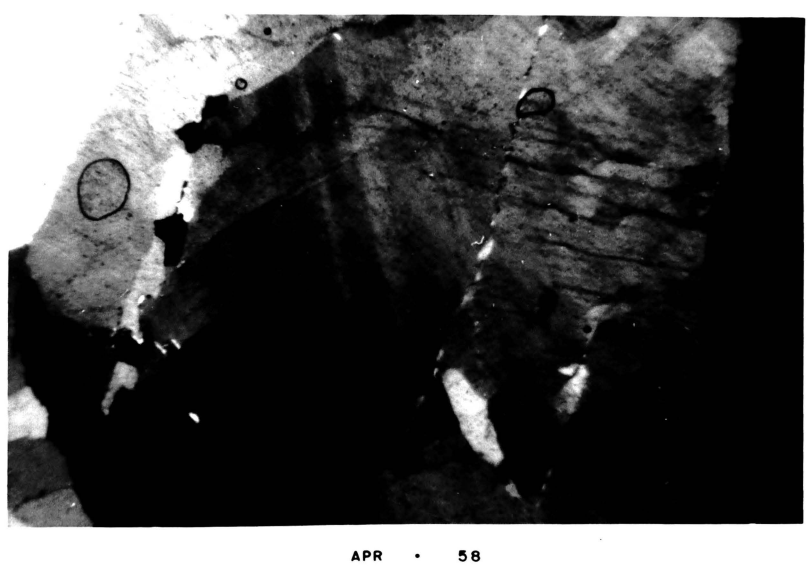


Figure 14. Brazilian twin lamellae and undulatory extinction in vein quartz. Crossed nicols. 35X.

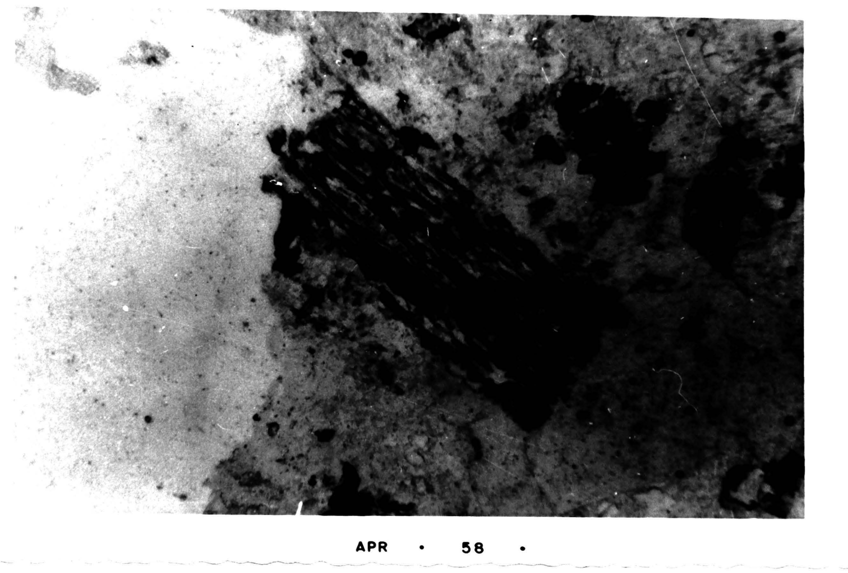


Figure 15. Outline of feldspar (orthoclase?) lath completely altered to sericite and kaolinite (opaque), and invaded by quartz. The relict lies in a greisen field (gray). Vein quartz stringer (light gray) appears to the left of the relict. Ordinary light. 35X.

PRECISION UNIT CELL (a_o) DETERMINATION OF THE ISOMETRIC SULPHIDES IN THE EINSTEIN VEIN

As part of a broader program concerning the possible relationships between the crystal constants and the origin of the minerals in the various types of ore deposits in Missouri, Dr. Grawe asked the writer to determine the unit cell dimensions or a_o values for the isometric sulphides present in the Einstein vein: galena, pyrite and sphalerite; and to compare these values with those for the same minerals from other deposits (Table III). Originally it was intended to present spectroscopic analyses of these minerals and ascertain the influence of minor constituents on the unit cell, but these analyses will not be available in time for inclusion in this thesis.

Selection of Material for Analysis

As clean a mineral specimen as possible was picked from hand specimens of the Einstein vein material and, at the same time, clean minerals were selected from other deposits: galena from the Federal Mine, Flat River, Missouri; pyrite from Moselle No. 10 Mine, a sink structure deposit, Phelps County, Missouri; and a yellowish sphalerite from Mascot, Tennessee.

Sample Preparation

Approximately 0.2-0.5 gram samples of each mineral, containing less than 0.1% impurities were ground to minus 300 mesh in an agate mortar. Samples 1, 2, 3, 4, and 6 were annealed in a small electric furnace at various temperatures ranging between 250-425° C. to improve the sharpness of the diffraction lines, as suggested by Wasserstein[27]. The conditions and effects of the annealing process are given in Table II.

Apparatus and Method

A Picker X-Ray unit was used with unfiltered cobalt radiation ($K\alpha_1$ = 1.78891 Å). The X-ray tube was operated at 40 KV and 7 MA and 1 1/2 hour exposures were made. Temperature variations from 25° C. were slight. The Straumanis technique was employed. Film measurements, with a precision of 0.001 mm., were made with the dividing engine. At least three measurements on each of three pairs of front reflection lines, and four measurements on a single pair of $K\alpha_1$ lines in the back reflection region were made on each film. The back reflection angle ϕ was calculated for the $K\alpha_1$ line measured, and the unit cell dimension was calculated according to the equation:

$$a_o\,(\text{Å}) = \frac{\lambda(\text{in Å})\ \sqrt{h^2 + k^2 + l^2}}{2\cos\phi}$$

a_o = Unit cell dimension

λ = 1.78891 Å ($K\alpha_1$ for Co radiation)

hkl = Miller Indices of back reflection line

ϕ = back reflection angle

[27] Wasserstein, B., "Precision Lattice Determination of Galena", Amer. Mineralogist, vol. 36, p. 105, 1951.

Each film was measured twice and the two values of a_o were averaged. The largest deviation (0.0009 A) occurred in the measurement of film for the Einstein Mine galena where the back reflection line measured was somewhat fuzzy.

Conclusions Drawn from Unit Cell Dimensions

The following conclusions may be inferred from the unit cell dimensions for the Einstein Mine material, (1) minor element constituents, particularly bismuth, would be expected in the galena, (2) the high unit cell dimension of the sphalerite is due to the substitution of iron for zinc in the structure to a marked degree, and (3) the minor element constituents in pyrite cause no great change in cell dimension.

EFFECTS OF SAMPLE ANNEALING ON X-RAY DIFFRACTION POWDER PHOTOGRAPHS

Sample No.	Mineral	Annealing Temperature	Effects
1	Galena Einstein Mine Madison Co., Mo.	5 min. @ 250° C	Several lines in back reflection region fuzzy. Other lines sharp.
2	Galena Federal Mine, Flat River St. Francois Co., Mo.	10 min. @ 350° C	Sharpness improved in back reflection region. Other lines sharp.
3	Sphalerite Einstein Mine Madison Co., Mo.	10 min. @ 350° C	All lines sharp.
4	Sphalerite Mascot, Tenn.	5 min. @ 425° C	No change from 3.
5	Pyrite Einstein Mine Madison Co., Mo.	not annealed	Almost all lines sharp.
6	Pyrite Moselle Mine Phelps Co., Mo.	5 min. @ 250° C	Only slight improvement from 5.

TABLE II

COMPARISON OF
UNIT CELL DIMENSION VALUES OF EINSTEIN SPHALERITE, GALENA AND PYRITE WITH REPORTED VALUES

Mineral	Source	Origin of Sample	a_o (Å)
Sphalerite	Swanson & Fuyat[28]	Prepared in RCA Lab.	5.4060 @ 25° C
Sphalerite	This paper	Mascot, Tennessee	5.4105 @ 25° C
Sphalerite	Wyckoff[29]	----	5.412
Sphalerite	This paper	Einstein Mine	5.4170 @ 25° C
Galena	Wasserstein[30]	Benoni, S. Africa	5.9310 @ 25° C
Galena	This paper	Einstein Mine	5.9336 @ 25° C
Galena	Wasserstein[31]	West Rand, S. Africa	5.9343 @ 25° C
Galena	Wasserstein[32]	Joplin, Missouri	5.9360 @ 25° C
Galena	Swanson & Fuyat[33]	Nat'l. Lead Co., N.Y.	5.9362 @ 26° C
Galena	This paper	Flat River, Missouri	5.9362 @ 25° C
Pyrite	This paper	Moselle No. 10 Mine	5.4166 @ 25° C
Pyrite	This paper	Einstein Mine	5.4168 @ 25° C
Pyrite	Swanson, et.al.[34]	Prepared in Nat'l. Bur. Stds. Lab.	5.4168 @ 26° C
Pyrite	Donnay & Nowacki[35]	----	5.4172
Pyrite	Donnay & Nowacki[36]	----	5.4179 @ 25° C

TABLE III

28 Swanson and Fuyat, Nat'l. Bur. Stds. Circ. 539, vol. II, p. 16, 1953.
29 Wyckoff, R. W. G., Crystal Structures, vol. 1., chap. IV, table p. 35, 1951.
30 Wasserstein, B. *Op. cit.*, p. 109.
31 *Ibid.*, p. 109.
32 *Ibid.*, p. 109.
33 Swanson & Fuyat, *Op. cit.*, p. 19.
34 Swanson et. al., Nat'l. Bur. Stds. Circ. 539, vol. V, p. 29, 1955.
35 Donnay, J.D.H., and Nowacki, W., Crystal Data, G. S. A. Memoir 60, pp. 500-501, 1954.
36 *Ibid.*, pp. 500-501.

DATA USED FOR CALCULATION OF UNIT CELL (A_o) DIMENSIONS

	Θ	hkl	d/n (Å)
Galena Einstein Mine Madison Co., Mo.	81.302	533	.9048
Galena Federal Mine Flat River, Mo.	81.139	533	.9053
Sphalerite Einstein Mine Madison Co., Mo.	77.653	531	.9156
Sphalerite Mascot, Tennessee	77.966	531	.9146
Pyrite Einstein Mine Madison Co., Mo.	82.198	600	.9028
Pyrite Moselle No. 10 Mine	82.213	600	.9028

TABLE III-A

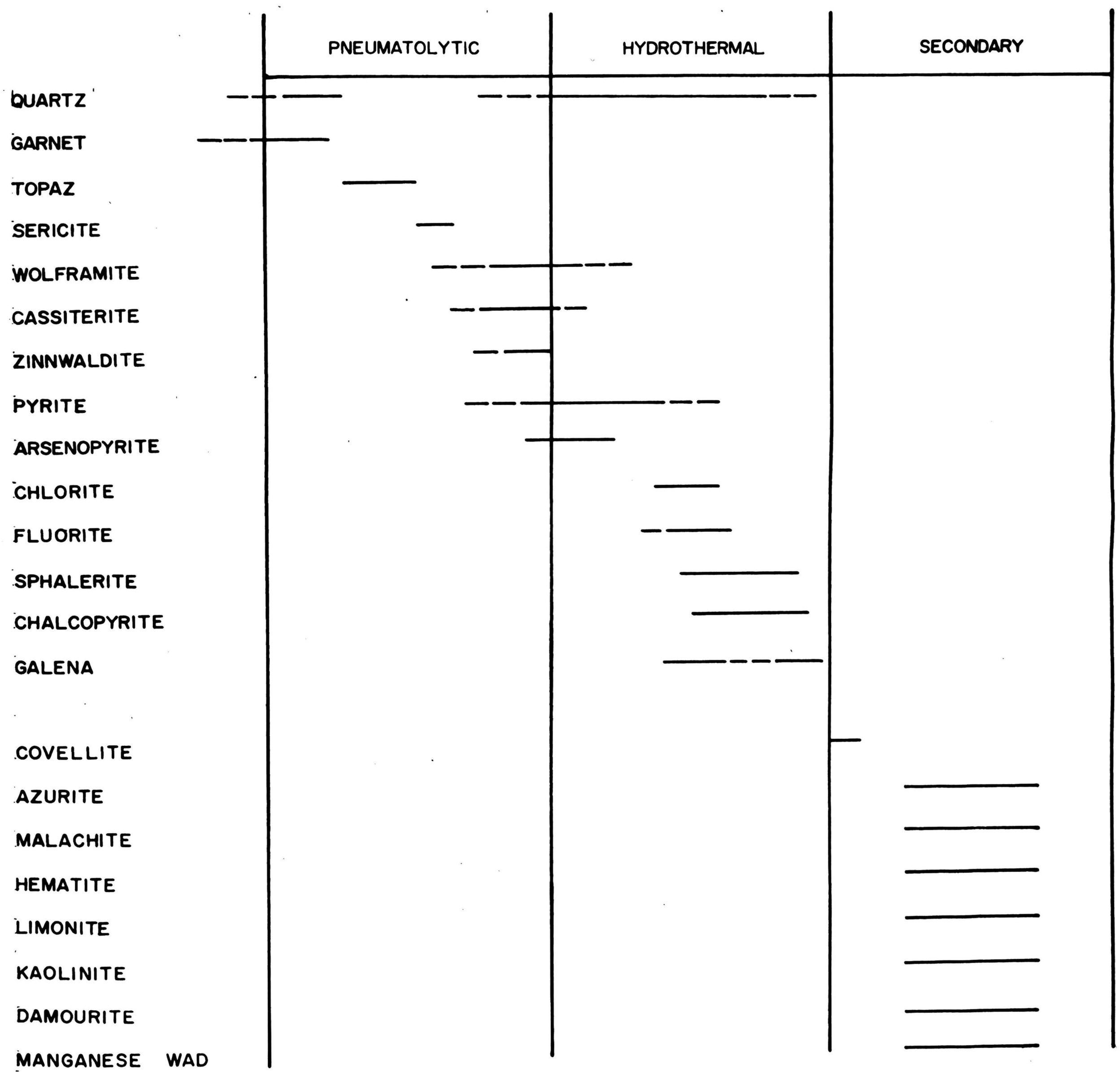
PARAGENESIS

The paragenesis of the Einstein Mine minerals as determined from the preceding observations is illustrated in Table IV. The sequence differs from those of Singewald and Milton, Tolman, and Pomerene with respect to the positions of wolframite, arsenopyrite, pyrite, and fluorite.

Quartz is the earliest mineral and was deposited almost continually throughout the mineralization period. The presence of quartz-healed fractures in wolframite and the occurrence of wolframite laths embedded in quartz suggest that quartz deposition is in part later and in part contemporaneous with that of wolframite. Quartz is also observed to fill fractures in pyrite. Early quartz may be readily distinguished from later quartz in thin section by the presence of abundant sericite filled fractures in the former. Recrystallization of the quartz of the original granite has been mentioned by Tolman and is a source of a portion of the vein quartz.

A pod-shaped mass of quartz crystals was noted to occur in zonal arrangement with massive quartz and green mica crystals (zinnwaldite ?) in the east wall of the New Discovery incline. The quartz crystals form the core of the vein and are surrounded by massive quartz which is, in turn, rimmed by the green mica. The wall rock is altered greisen. Only massive quartz was observed to occur at the Einstein Mine which is located 900 feet to the east on the same vein.

PARAGENESIS AT THE EINSTEIN MINE



Tolman[37] and Hayes[38] mention the occurrence of brecciated wolframite cemented by later generation quartz at the Ozark Mine.

The red isotropic grains, tentatively identified as garnet, are probably both earlier and simultaneous with the early generation quartz. The bright red color, index 1.70 ±, and the pneumatolytic mode of occurrence suggest, that if the mineral is garnet, it is the manganese variety, spessartite.

Topaz is later than the early quartz. As in quartz, recrystallization has often resulted in a local reduction of grain size. Optical data on the Einstein Mine topaz show it to be composed of 85% AlF_2AlSiO_4 molecule and 15% $Al(OH)_2AlSiO_4$ molecule[39].

Sericite is definitely later than much of the quartz. It is later than topaz in every instance where the two minerals were seen to be in contact. Much of the sericite is undoubtedly the result of the attack of the magmatic vapors upon topaz and the feldspars of the original granite.

The relations between wolframite and sericite are uncertain since wolframite occurs almost exclusively in the veins, while sericite is present almost entirely in the greisenized wall rock.

Cassiterite and zinnwaldite are clearly later than the sericite. Cassiterite, zinnwaldite, and a portion of the wolframite are believed to

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37 Tolman, Op. cit., p. 28.
38 Hayes, Op. cit., p. 45.
39 Winchell, Op. cit., p. 510.

have been deposited essentially contemporaneously. It is known that the deposition of zinnwaldite occurs only under pneumatolytic conditions. The deposition of zinnwaldite, therefore, may represent the end of the pneumatolytic stage.

The analyses given below show the Einstein Mine zinnwaldite to have a lower lithium content than three other analyses of zinnwaldite as observed by Singewald and Milton[40].

	1-Zinnwald	2-Zinnwald	3-Altenberg, Saxony	4-Einstein Mine
SiO_2	45.87	46.44	41.78	----
Al_2O_3	22.50	21.84	22.76	----
Fe_2O_3	0.66	1.41	0.98	----
FeO	11.61	10.06	14.24	8.88
MnO	1.75	1.89	----	----
K_2O	10.46	10.58	10.51	----
Li_2O	3.28	3.36	2.42	1.26
Na_2O	0.42	0.55	0.67	----
MgO	----	----	0.55	----
H_2O	0.91	----	1.41	----
F	7.94	7.62	6.48	----

As a result of the low lithium content, it was suggested by Singewald and Milton that the mineral may not be a pure member of the lepidolite

40 Singewald and Milton, Op. cit., p. 585-586.

system, but probably tends toward phlogopite. This suggestion might be corroborated by the fact that in analyses 1-3 above, and in 5 other analyses of mica belonging to the lepidolite group, given by Dana[41], there is a sympathetic variation between the FeO and Li_2O content. That is, an increase in FeO content is accompanied by a proportional decrease in Li_2O suggesting a diadochic relation between Li^+ and Fe^{++} in the lepidolite micas. The lower lithium content of the Einstein Mine zinnwaldite is also accompanied by a decrease of FeO content when compared with other analyses of zinnwaldite and lepidolite. The MgO content of the Einstein Mine mica would be of considerable interest in determining affinity with the phlogopite molecule. In phlogopite, of course, the variation between FeO and Li_2O would not be expected to show the sympathetic relation shown by lepidolite since Li probably substitutes for both Fe and Mg.

Arsenopyrite-zinnwaldite relations are not clear, but arsenopyrite is contemporaneous and partly later than pyrite. The deposition of pyrite appears to have continued throughout most of the mineralization period. Pyrite is partly contemporaneous with wolframite, but the evidence in polished sections EMp-7, EMp-8, and EMp-9 show that pyrite is also later than wolframite. Arsenopyrite and pyrite appear to be "transition"

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41 Dana, Op. cit., p. 626-627.

minerals in the sequence which represent deposition in both the pneumatolytic and hydrothermal phases.

Chlorite follows pyrite in the paragenetic sequence. The chlorite was identified by Tolman[42] as the thuringite variety. The present writer cannot agree with this identification on the bases of pleochroism, birefringence, and the index of refraction in basal section of the chloritic mineral. According to Winchell[43], thuringite is an olive green to dark green chlorite having an index of refraction in basal section of 1.66, birefringence of 0.004-0.010, and pleochroism, nearly colorless to dark green to dark green in the X, Y, and Z directions respectively. A mineral having these properties does occur in the granite in thin section EMt-3, but was not observed in the vein material. The chlorite in association with the sulphides, particularly sphalerite, is dark green, and has an index of 1.64±, birefringence = 0.003-0.10, and a colorless to yellow green pleochroism. These properties are those of daphnite and brunsvigite chlorites as given by Winchell[44]. Thuringite is stated by Dana[45] to occur principally as a constituent of metamorphic rocks whereas daphnite has been reported to occur in association with tin at Penzance, Cornwall.

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42 Tolman, Op. cit. p. 25.
43 Winchell, A. N. & Winchell, H., Op. cit. pp. 384-385.
44 Ibid. pp. 384-385.
45 Dana, Op. cit. p. 657.

Chlorite invades zinnwaldite along its cleavage planes, and is, in turn, replaced by fluorite along its cleavage directions.

Colorless, purple, and green fluorite is later than pyrite, but appears to be partially earlier and contemporaneous with sphalerite. The relations between fluorite, and chalcopyrite and galena could not be directly determined.

A small portion of the sphalerite, chalcopyrite, and galena is contemporaneous with pyrite, but the bulk of these minerals is clearly later than pyrite.

Chalcopyrite appears to be largely contemporaneous with sphalerite. Kullerud[46] reports that sphalerite may contain up to 40% $CuFeS_2$. It is possible that much of the chalcopyrite present in sphalerite has originated as an exsolution phase. The irregular discontinuous veinlets might then represent exsolved chalcopyrite which has migrated along crystallographic directions in the earlier formed sphalerite to sphalerite grain boundaries. The possibility of later replacement of sphalerite by chalcopyrite along cleavage directions cannot be denied, but at least a few continuous or anastomosing veinlets would be expected. No veinlets of chalcopyrite in sphalerite of this type were observed.

Galena is partially contemporaneous with sphalerite and earlier than chalcopyrite, but a later generation of galena which surrounds and invades chalcopyrite represents the bulk of the galena mineralization.

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[46] Kullerud, G., Sulphide Systems, Annual Rept. of the Dir. of the Geophysical Lab., Carnegie Inst. of Wash., 1955-56, p. 180.

Early galena occurs as minute veinlets and pinpoint inclusions in sphalerite (EMp-14). These inclusions and veinlets bear a striking resemblance to the chalcopyrite exsolution bodies which are always present in sphalerite. Apparently similar galena inclusions in sphalerite were noted by Buerger[47] who commented on the possibility of a galena-sphalerite solid solution. The large difference in the ionic radii of Zn and Pb^{++} make this possibility extremely improbable.

Buehler[48] has mentioned the production of 3000 ounces of silver from the argentiferous galena of Silver Mines. No exsolved or included silver minerals were observed to occur in galena or any other mineral in the area. An etching test for silver, given by Short[49], using nitric acid and potassium dichromate, was negative.

The secondary minerals occurring at the Einstein Mine are covellite, hematite, limonite, malachite, azurite, kaolinite, and damourite.

Covellite is present in small quantities filling cavities in chalcopyrite. It is believed to have a supergene origin. Hematite and limonite are oxidation products of pyrite and wolframite. Black incrustations of a powdery mineral, believed to be manganese wad, were seen coating the

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47 Buerger, N. W., "The Unmixing of Chalcopyrite from Sphalerite", American Mineralogist, vol. 19, no. 11, pp. 528-529, 1934.

48 Buehler, Op. cit. p. 97.

49 Short, M. N., Microscopic Determination of the Ore Minerals, p. 200.

wall in the New Discovery Mine. It is undoubtedly an alteration product of wolframite. Azurite and malachite are the usual oxidation products of chalcopyrite. Kaolinite has developed by the alteration of sericite and the feldspars of the country rock.

The green serpentine-like mineral, damourite, described by Singewald and Milton[50] appears to be an oxidation product of the earlier sericite. The mineral forms a greenish crust on greisen specimens, but is not distinguishable from the earlier sericite in thin section. Optically, it is identical to the sericite having an index of 1.57 $\pm$, 2V nearly 0°, and no detectable pleochroism. In Table V a comparison is given of X-ray diffraction data for the green mineral (damourite), sericite from the Longfellow Mine, California, and the serpentine from Montville, New Jersey. From this comparison the similarity of the Einstein mineral to sericite and its difference from serpentine is obvious. According to Dana[51], damourite, or hydrous mica, is often derived by the alteration of topaz. This fact would account for the absence of damourite outside the limits of the greisen.

Although the determined paragenetic sequence differs markedly from that of Singewald and Milton, and Tolman, it is essentially in close agreement with mineral successions determined by various writers for widely scattered tungsten-quartz vein deposits. Broadly corresponding

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50 Singewald and Milton, Op. cit. p.585.
51 Dana, Op. cit. p. 614.

INTERPLANAR SPACINGS FOR GREEN MINERAL FROM EINSTEIN MINE, SERICITE FROM LONGFELLOW MINE, CALIFORNIA, AND SERPENTINE FROM MONTVILLE, NEW JERSEY

Longfellow Mine Sericite		Einstein Mine Green Mineral (Damourite)		Montville, New Jersey Serpentine	
dA	I/I_1	dA	Est. I	dA	Est. I
9.96	100	9.94	90	7.12	90
4.97	80	4.99	70	4.61	10
4.47	100	4.49	90	3.95	30
4.33	20	-		3.81	5
4.11	40	4.10	20	3.59	100
3.95	20	-		3.49	5
3.87	60	3.89	40	2.78	10
3.75	80	3.66	50b	2.68	5
3.44	80	3.50	50	2.51	60
3.32	100	3.31	90	2.45	5
3.22	80	3.18	60	2.41	30
2.99	80	2.99	60	2.37	5
2.85	60	2.84	50	2.21	5
2.77	60	-		2.15	30
2.58	40	2.58	30	2.10	5
2.56	100	2.56	100	1.96	5
2.50	20	-		1.88	5
2.45	40	-		1.83	10
2.38	60	2.38	60	1.81	10
2.34	40	-		1.78	10
2.19	40	-		1.72	10
2.13	60	2.14	40	1.69	5
2.05	20	-		1.58	5
1.99	60	2.00	50	1.56	40
1.95	40	-		1.54	30
1.66	40	-		1.52	10
1.64	60	1.65	40b	1.50	10
1.60	20	-		1.49	10
1.55	-	-		1.47	5
1.52	-	-		1.46	5
1.50	80	1.50	80		
1.34	40	1.35	30b		

TABLE V

paragenetic sequences of particular interest are presented in papers by Victor[52], Jones[53], Campbell[54], Hsu[55], Hobson[56], and Brown and Heron[57].

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52 Victor, I., "Burnt Hill Wolframite Deposit", Econ. Geol. vol. 52, no. 2, 1957.

53 Jones, W. R., "Tin and Tungsten Deposits: The Economic Significance of their Relative Temperatures of Formation", Trans. of the Inst. of Mining & Met., 29th Session, pp. 320-346, 1920.

54 Campbell, J. M., "Tungsten Deposits of Burma and Their Origin", Econ. Geol., vol. XV, no. 6, pp. 511-534, 1920.

55 Hsu, Ke-Chin, "Tungsten Deposits of Southern Kiangsi, China", Econ. Geol., vol. XXXVIII, no. 6, pp. 431-474, 1943.

56 Hobson, G. V., "The development of the Mineral Deposit at Mawchi as Determined by Its Geology and Genesis", Trans. of Min. Geol. & Met. Inst. of India, vol. 36, pp. 35-78, 1940.

57 Brown, J. C., and Heron, A. M., "The Geology and Ore Deposits of the Tavoy District", Memoirs of Geol. Survey of India, vol. XLIV, Part 2, pp. 167-354, 1923.

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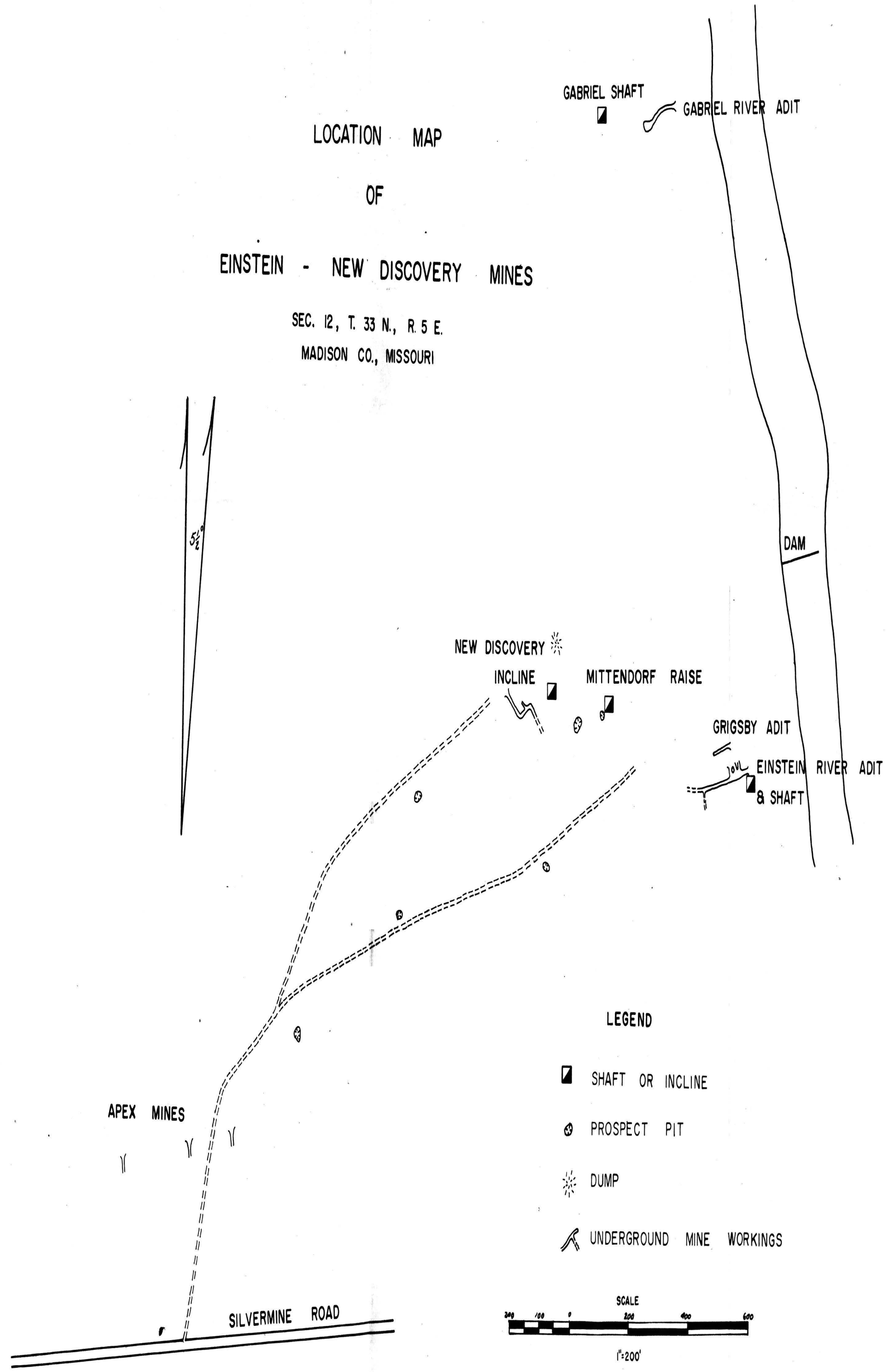
VITA

Robert Paul Stevens was born in Chicago, Illinois on January 26, 1934. After graduation from Tilden Technical High School, Chicago, in June 1952, he was accepted for admission at the South Dakota School of Mines in the Fall of 1952, in the geological engineering curriculum. In the Fall of 1954, he transferred to the University of Illinois and received a Bachelor of Science degree (Geology) in June, 1956. Mr. Stevens accepted a position as a graduate assistant at the Missouri School of Mines and Metallurgy, and began graduate study leading to the Master of Science degree in September, 1956. He was married to D'Jeanne Welden of St. Louis, Missouri on March 14, 1957.


LOCATION MAP
OF
EINSTEIN - NEW DISCOVERY MINES
SEC. 12, T. 33 N., R. 5 E.
MADISON CO., MISSOURI
GABRIEL SHAFT
GABRIEL RIVER ADIT
DAM
NEW DISCOVERY
INCLINE
MITTENDORF RAISE
GRIGSBY ADIT
EINSTEIN RIVER ADIT
& SHAFT
APEX MINES
SILVERMINE ROAD
LEGEND
SHAFT OR INCLINE
PROSPECT PIT
DUMP
UNDERGROUND MINE WORKINGS
SCALE
1"=200'