The Relationship Between Gold and Sulfide Mineralization in Quartz Veins of the Felsic Porphyry, Virginia Horn Area, Northeastern Minnesota

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advised by Dr. James Welsh

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Abstract

Hydrothermal quartz-carbonate veins and alteration are associated with gold-bearing Archean porphyry bodies of the Virginia Horn. Evidence suggests that hydrothermal alteration is contemporaneous with shear structures in the porphyry. Examination of polished thin sections of these rocks using reflected light microscopy has revealed the presence of minute blebs of a bright yellow metal in association with sulfide crystals. Electron microscopic study of these blebs reveals them to be gold. Previous examinations have suggested that gold only occurs free within the quartz-carbonate veins of the porphyry. This evidence suggests that gold may also occur within the rock body in association with sulfide minerals.

ACKNOWLEDGMENTS

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INTRODUCTION

Gold occurrences have been described within quartz-carbonate veins of the felsic porphyry of the Virginia Horn area, northeastern Minnesota. Gold mineralization is linked to hydrothermal alteration which produced abundant pyrite and arsenopyrite, along with other minor sulfide minerals in the adjacent rock (Welsh et al. 1988). The purpose of this study is to distinguish the relationship between the gold and pyrite mineralization. Gold mineralization in association with other sulfides, such as pyrite, may relate the origin of the gold and sulfide mineralization. If both minerals formed simultaneously, exploration for gold may be aided using the related sufides as indicator minerals. Whereas, if gold and pyrite stem from separate alteration events, gold may be confined to preferred veins.

Regional Geology

The "Virginia Horn" refers to the Z-shaped outcrop pattern of the Animikie Group rocks in the Virginia-Eveleth area of northeastern Minnesota (Figure 1). This outcrop pattern is the result of a gentle northeasterly trending, steeply plunging, synclinal-anticlinal fold of the Animikie Group. Erosion has exposed the Archean basement rocks in the core of the anticline (Figure 2).

Archean rocks exposed in the Virginia Horn area include a supracrustal greenstone-graywacke complex intruded by a series of small gold-bearing felsic porphyry bodies and bordered to the north by the Giants Range batholith. The Proterozoic Animikie group rocks unconformably overlie the Archean rocks and consist of the Pokegama Quartzite, Biwabic Iron formation, and the Virginia Slate and occupy the eastward-trending Animikie basin (Sims, 1976).

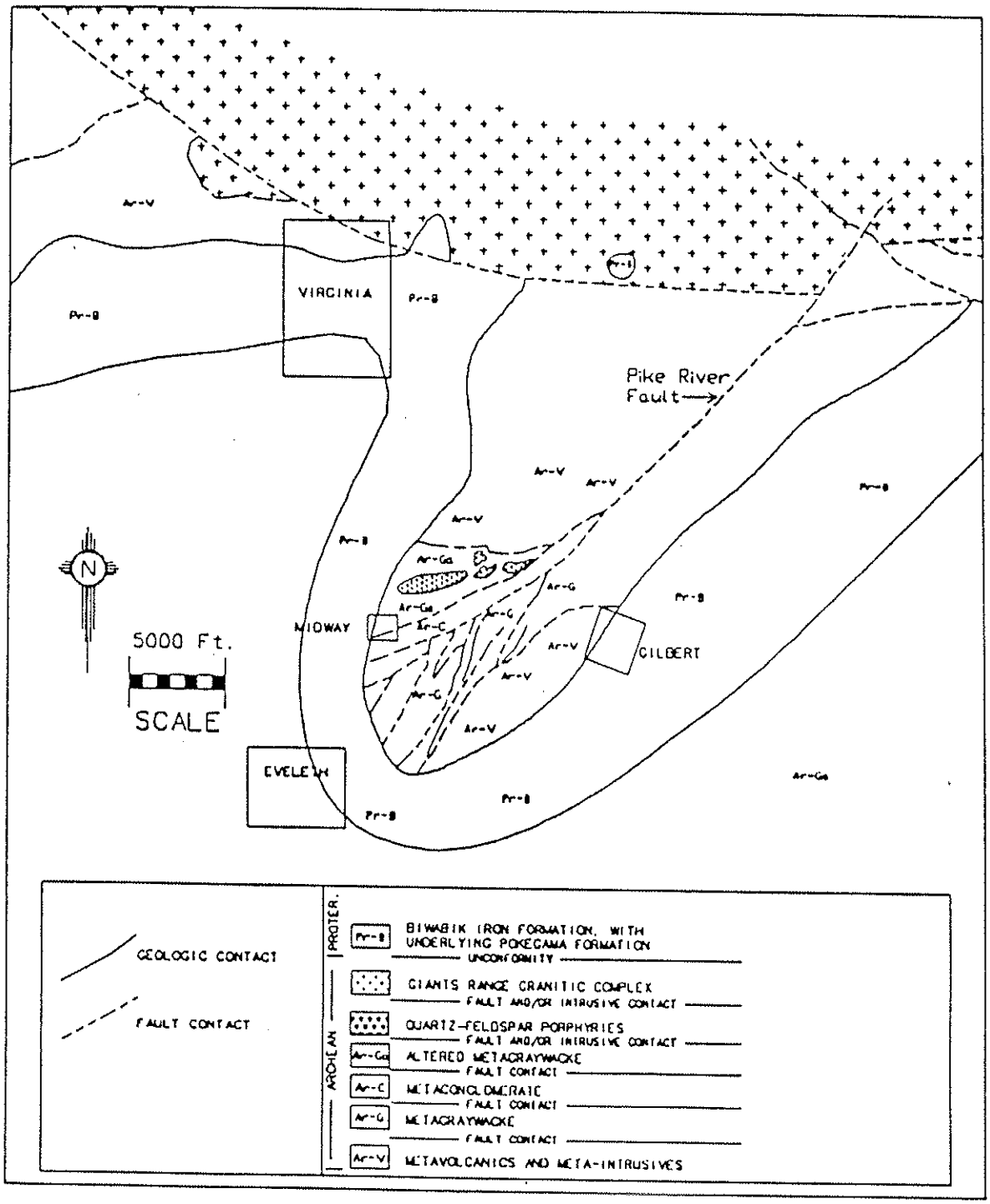


Figure 1 Generalized geologic map of the Virginia Horn area showing the felsic porphyry bodies. From Welsh et. al. 1991.

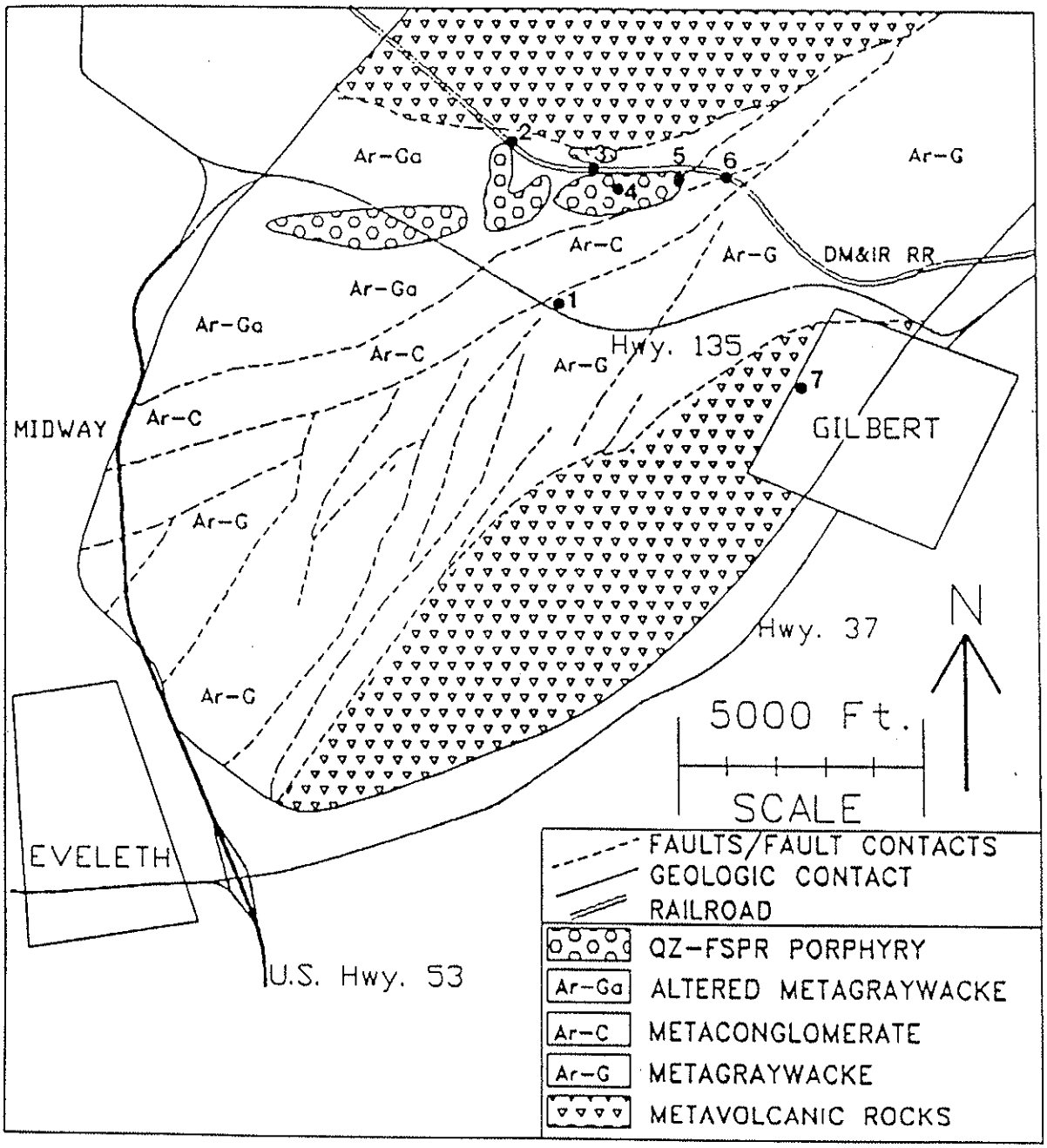


Figure 2 Map showing the Archean geology of the Virginia Horn area. Adapted from James Welsh and Eric Levy (1991).

Previous Work

The first descriptions of the Archean rocks of the Virginia Horn area were provided by C. K. Leith (1903) as part of his investigations of the geology of the Mesabi District. J.W. Gruner also studied the Mesabi District and reported an occurrence of visible gold in the felsic porphyry body (Grout, 1937). Using Gruner's findings, T. C. Sutton developed a more detailed geological map of the area. Sutton also provided petrographic descriptions for some of the metasedimentary rocks and the felsic porphyry bodies. He reported that plagioclase comprises 20-30% of the porphyry, is nearly pure albite, and can occur as phenocrysts ranging in size from 2 mm to 1.5 cm (Sutton, 1963).

In addition to Sutton, much descriptive work has been conducted recently by J. L. Welsh. Welsh mapped the Virginia Horn rocks in detail focusing on structure (Welsh, 1988, Welsh et al., 1991). He particularly identified two major periods of folding and a significant fault/shear complex (Welsh, 1988, Welsh et al., 1991). Welsh also provided petrologic and geochemical descriptions of the Virginia Horn rocks including the porphyry bodies. He reported that the felsic porphyry bodies are of light color and contain conspicuous ovoidal quartz phenocrysts. These phenocrysts comprise 2-5% of the rock and range in size from 0.5 cm to 2 cm. The matrix is white to greenish-gray quartz and feldspar, and is aphanitic in texture. Quartz-carbonate veins run throughout the intrusive bodies. Secondary sericite and carbonate (siderite or ankerite) and disseminated sulfides (principally pyrite and arsenopyrite) are associated with the veins, however, vary greatly in distribution from one vein to another (Welsh, 1991).

The majority of work regarding gold mineralization was carried out by Newmont Exploration Limited during mineral exploration of the porphyry bodies. Newmont's descriptions of the porphyry body include drill core data as well as chemical assays of the rock body made once every five feet. Reports by Newmont show that gold and sulfide mineralization varies from core to core. Sulfide percentages range from less than 1% up to 6% in the rock body. General alteration minerals within the cores include sericite, chlorite,

and dolomite. Gold assays of the rock body indicate gold values ranging from 3 to 10,100 ppb. Areas with the highest gold ppb values often contain visible gold.

Geochemistry

Welsh et al. 1991, provided chemical analyses of samples from the porphyry body. An AFM diagram representing the felsic porphyry samples exhibits a clear calc-alkaline plot and the porphyries consistently plot as rhyolites on most igneous classification plots. However, these plots do not take into consideration the effects of silicification due to hydrothermal alteration. Therefore, plots based on relatively immobile elements were made in attempt to indicate the original rock composition. Using this procedure, the felsic porphyry bodies plotted within the rhyodacite to dacite field.

CIPW norms calculated for several porphyry samples were split into two groups based on gold values. Both "fresh" porphyry samples and the gold-bearing samples have very similar whole-rock geochemistry, with exception to high sulfur values in the gold-bearing samples. However, a comparison of trace elements reveals the gold-bearing samples to be higher in As, Cr, Cu, and Au and lower in W. High As and S can be explained by the abundance of pyrite and arsenopyrite in these samples. Gold bearing samples are not concentrated in any one area of the porphyry bodies, but rather are scattered randomly indicating that the chemical differences are due to secondary alteration (Welsh et al., 1991).

METHODS

Outcrops of the felsic porphyry bodies in the Virginia Horn area were examined for sulfide content of the quartz-carbonate veins and samples were collected. Drill cores obtained previously by Newmont Exploration Limited, housed at the Minnesota Department of Natural Resources, were also examined. Samples were collected from the drill cores that assayed with high ppb gold values or that were highly veined or sheared. Six drill core

samples were selected to make polished thin sections. Thin Sections were examined using a transmitted light petrographic microscope, and textural and mineralogical relationships were noted. Maps of the thin sections were then constructed by hand using a grid system (Fig. 3, 4, & 5). Following the initial petrographic examination, the thin sections were studied using a reflecting light petrographic microscope. This process allowed the identification of sulfide minerals and possible gold mineralization. Smaller minerals were still unidentifiable, therefore a Scanning Electron Microscope (SEM) examination was necessary for high magnification. SEM studies also gave spectrographic analyses of the minerals revealing their exact mineralogy. Electron microprobe scans were also carried out.

THIN SECTION # 1

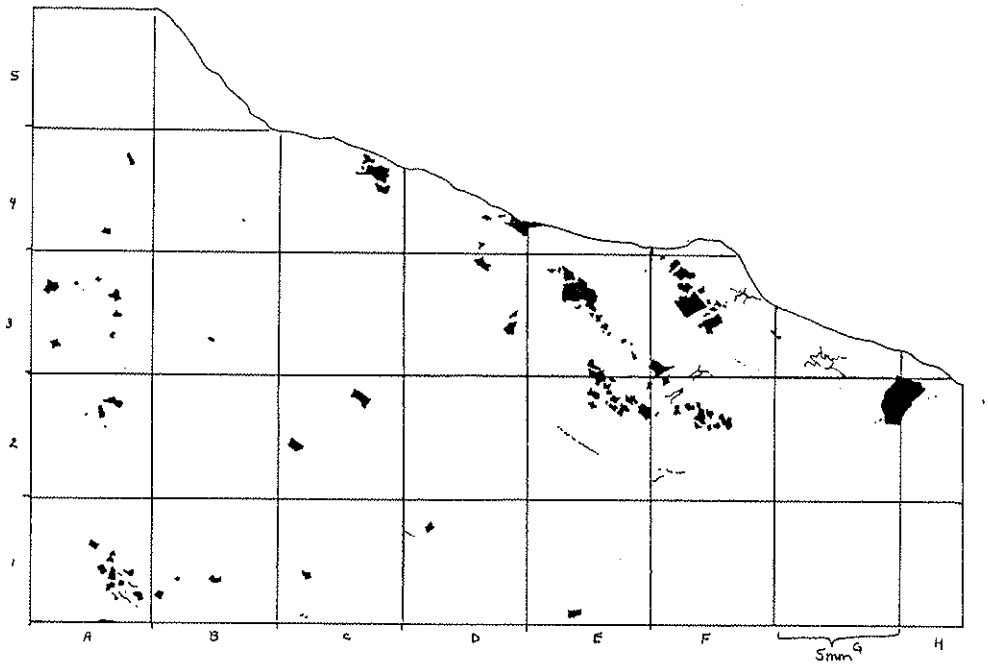


Figure 3 Map of opaque minerals under transmitted light on a thin section taken from a depth of 257 ft.

THIN SECTION # 2

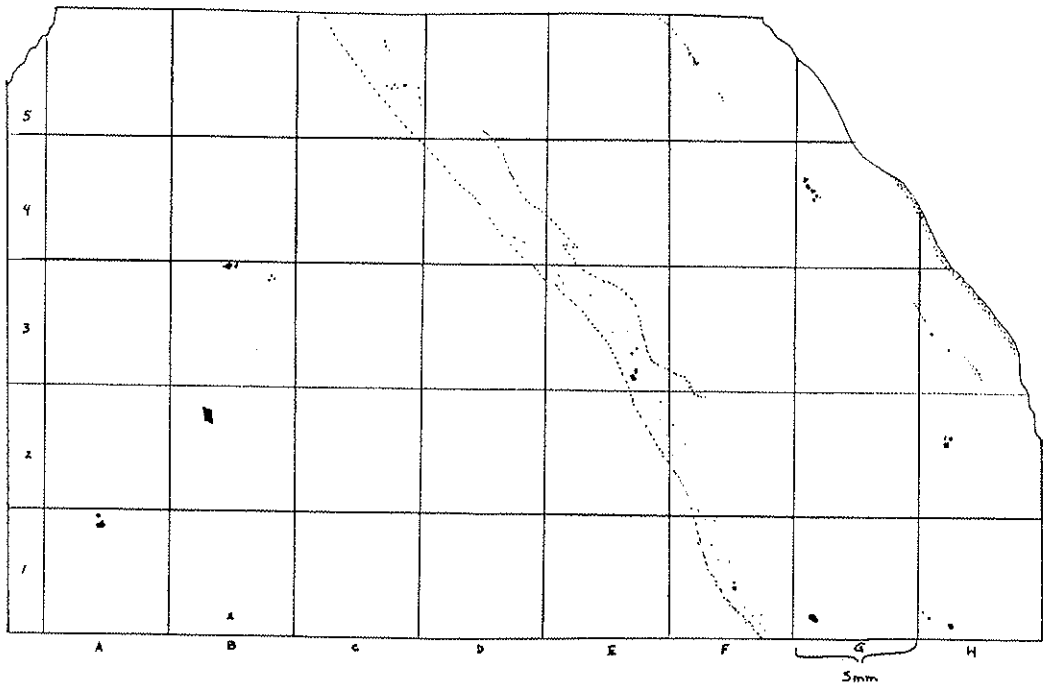


Figure 4 Map of opaque minerals under transmitted light on a thin section taken from a depth of 233 ft.

THIN SECTION # 3

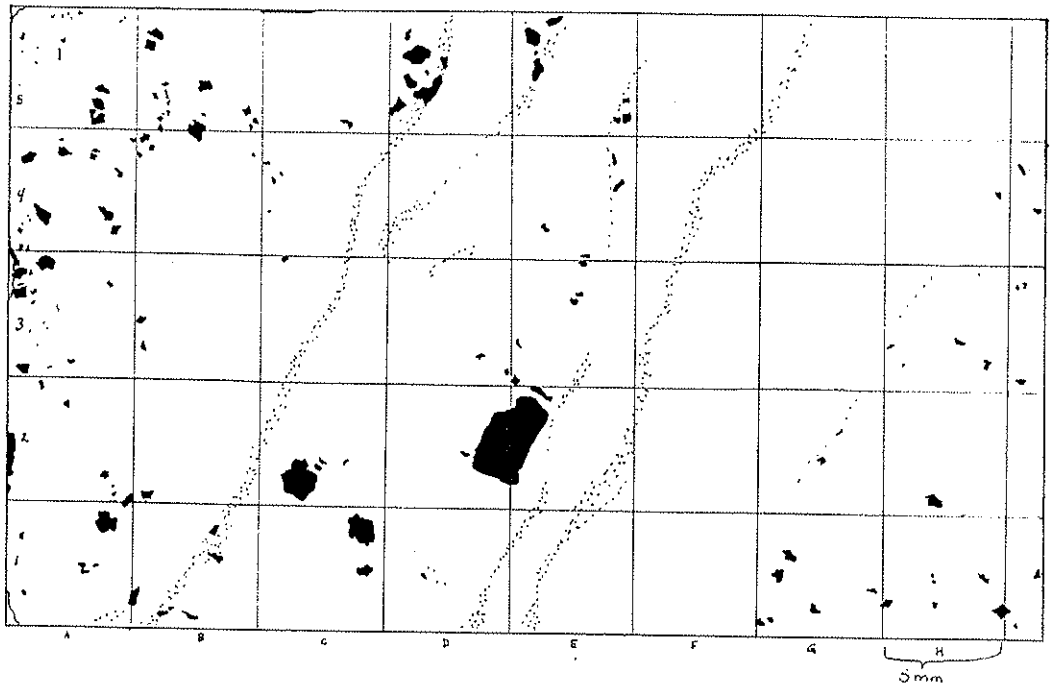


Figure 5 Map of opaque minerals under transmitted light on a thin section taken from a depth of 130 ft.

RESULTS

Outcrops between Virginia and Eveleth, although highly weathered, revealed an abundance of sulfide minerals, especially pyrite, within quartz-carbonate veins and within the rock body. Those sulfides that occur within the quartz veins are concentrated along the vein/host rock contact. Red-brown siderite is evident along vein edges. No gold mineralization was observed on this scale, although previous reports had sighted free gold in the vicinity.

Drill cores display less weathered, yet highly altered host rock periodically interrupted by quartz veins and shear zones. Most quartz veins are relatively barren of sulfide mineralization although the host rock exhibits sulfides throughout the core. Identifiable sulfides are pyrite and arsenopyrite. Shear zones are characterized by dolomite mineralization and range from less than a centimeter to 10 cm thick.

Transmitted light microscopy reveals the spatial relationships shown in Figures 3, 4, & 5. Figure 3 illustrates a highly silicified area in which opaque minerals (probably sulfides) are suspended within one of the two quartz-carbonate veins. Sulfide crystals range from <1mm to 3mm across. Some appear to have been fractured while others are in the form of stringers. The thin section represented in Figure 3 was taken from a drill core depth of approximately 257 ft that was previously assayed as having a gold content of 1660 ppb.

Figure 4 represents an area of veining and shearing at a depth of ~233 ft with a gold content of 725 ppb. The shear zone appears to parallel the quartz-carbonate vein. Fine grained sulfide minerals are concentrated along the outside edges and the interface of the shear zone and quartz vein. This particular area of the host rock appears to have a lower sulfide content in the host rock.

Figure 5 illustrates a very highly altered area of the porphyry at a depth of 130 ft. Assays at this depth show a gold content of 321-136 ppb. Like the previous thin section, shear zones and quartz-carbonate veins are parallel in this sample. Sulfide minerals on this

thin sections range from <1 to ~4 mm across and are concentrated in the rock body or along the vein and shear zone boundaries. Some sulfide minerals occur with quartz pressure shadows that have been rotated in the direction of the shearing (Figures 6 & 7).

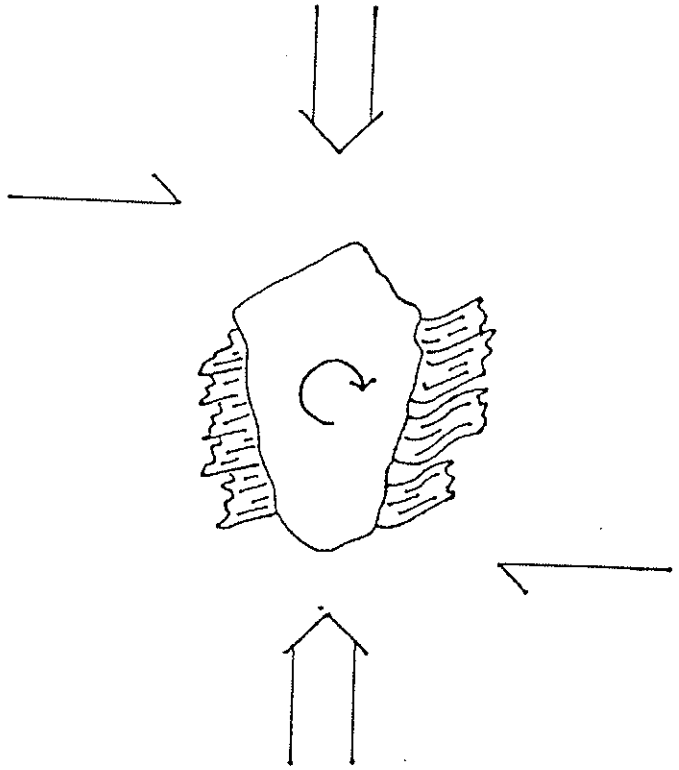
Examination of the same thin sections under a reflecting light petrographic microscope reveal pyrite and arsenopyrite to be the principal sulfide minerals. Re-examining thin section #1(Figure 8) reveals the larger sulfide crystals to be pyrite and the smaller minerals to be arsenopyrite. The majority of the sulfide mineralization within the rock body tends to be pyrite, whereas sulfides within the quartz-carbonate vein are approximately 50% arsenopyrite. The sulfide stringers are still unidentifiable at this scale. Reflecting light microscopy applied to thin section #2 (Figure 9) shows that the fine-grained sulfides are generally arsenopyrite and the larger grained crystals are pyrite.

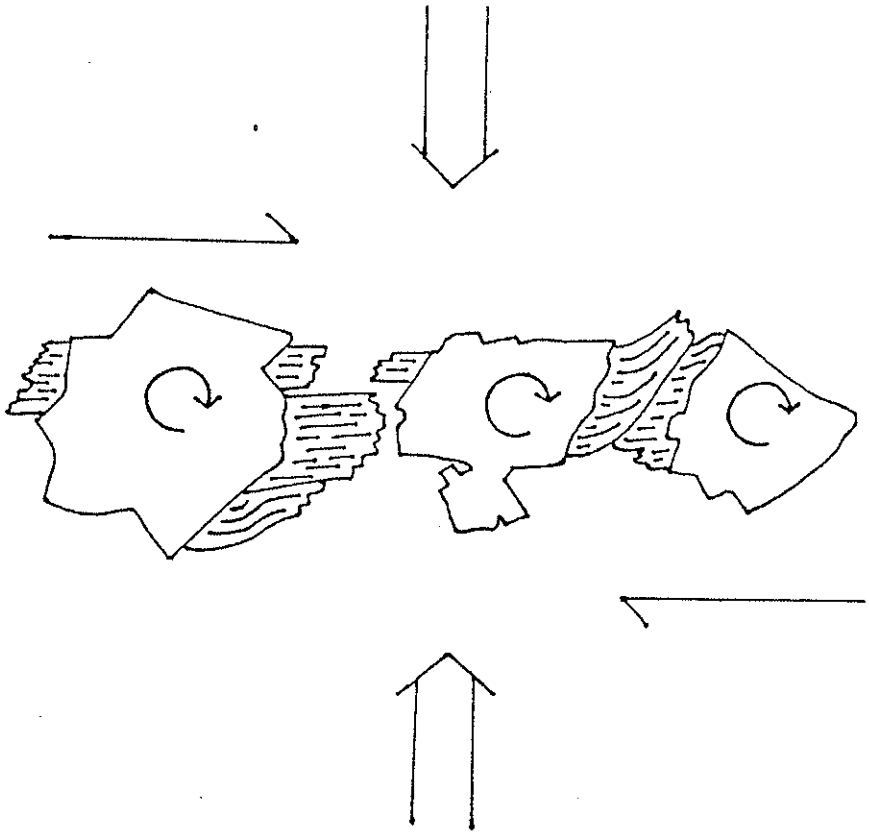
Thin section #3 (Figure 10) exhibits equal parts pyrite and arsenopyrite with arsenopyrite concentrated along the shear zone and quartz vein boundaries. Like the other thin sections, pyrite tends to form larger crystals than arsenopyrite and more commonly occupies the host rock as opposed to quartz veins. This section reveals multiple specks of bright yellow mineralization in association with the pyrite and arsenopyrite. However, identification of these minerals is not possible at this magnification due to the size of the crystals.

SEM examinations of thin section #1 reveal the sulfide stringers to be exsolved galena and otherwise confirm the mineralogy determined using reflected light. Close examinations of individual pyrite grains on this thin section shows the presence of small inclusions of galena, chalcopyrite, and arsenopyrite (Figures 11 & 12). SEM scans also revealed native antimony associated with the sulfide minerals (Figure 13). The small bright yellow specks in thin section #3 were analyzed and, in most cases, were identified as chalcopyrite inclusions within pyrite or arsenopyrite (Figure 14). However, the bright yellow mineralization located along the interface between pyrite and an arsenopyrite overgrowth was revealed to be gold (Figures 15, 16, & 17). This gold tends to occur in

small rounded bleds, not as stringers, and is generally located within the arsenopyrite along the contact with pyrite. This particular area of sulfide and gold mineralization is within the rock body adjacent to a quartz-carbonate vein. Spectrographic analysis of these gold specks reveal them to be pure gold with the exception of one grain that contains silver and gold. Galena inclusions are also common in the arsenopyrite but occur as more angular crystals and seldomly come in contact with the pyrite.

Quantitative analyses of a pyrite crystal in thin section #1 and the gold-hosting pyrite and arsenopyrite minerals in thin section #3 using the electron microprobe give percentages of lead, copper, and arsenic (Figure 18), and percentages of gold, arsenic and lead (Figure 19).





Figures 6 & 7 Sketches of representative pyrite crystals showing rotated pressure shadows. Vertical arrows show compression while horizontal arrows represent shear direction.

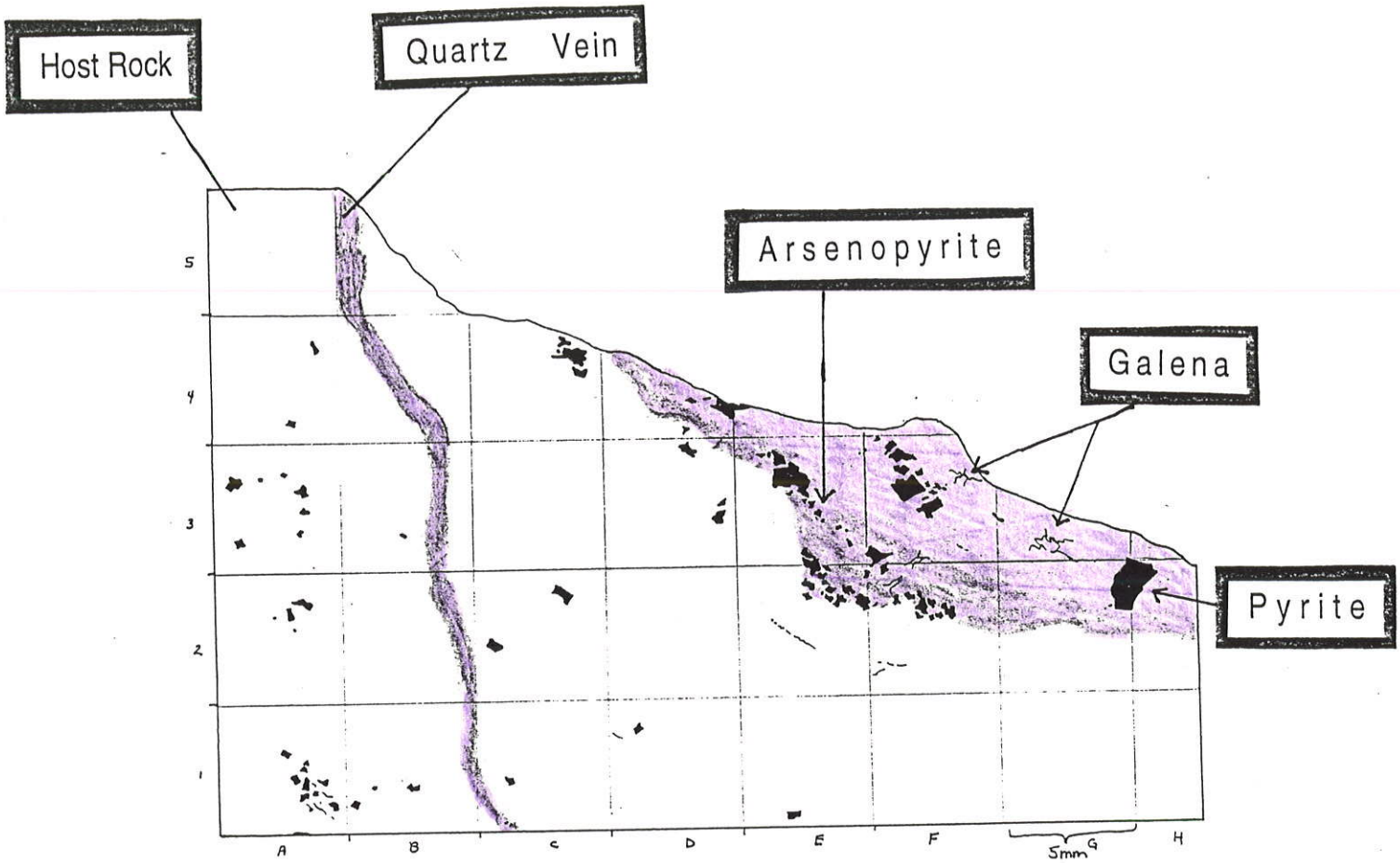


Figure 8 Map of thin section #1 identifying sulfide minerals. Pyrite forms larger crystals. Galena is shown in the form of stringers.

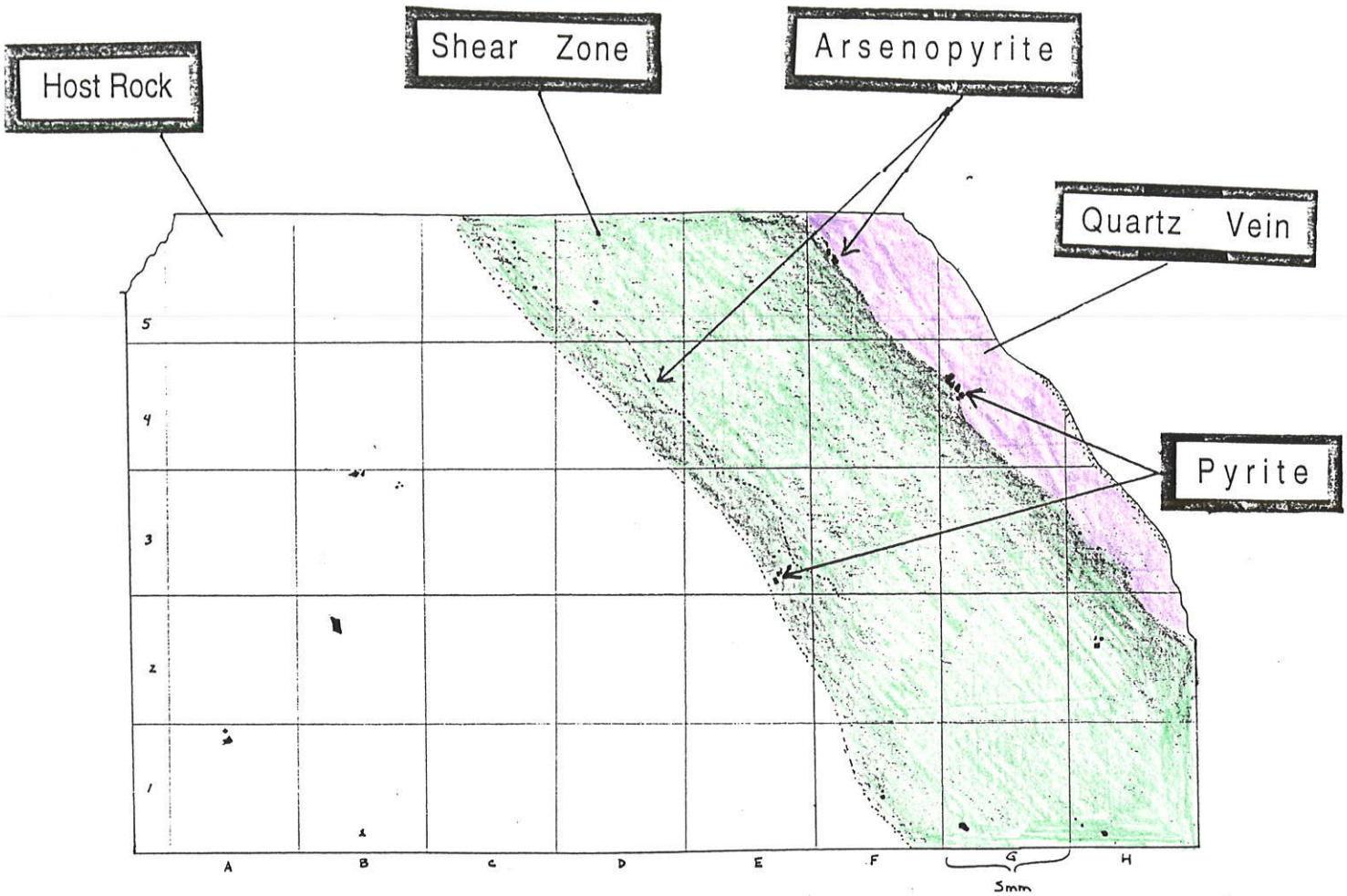


Figure 9 Illustration of thin section # 2 identifying sulfide minerals. Pyrite tends to form larger crystals as smaller arsenopyrite crystals coat the edges of both types of zones.

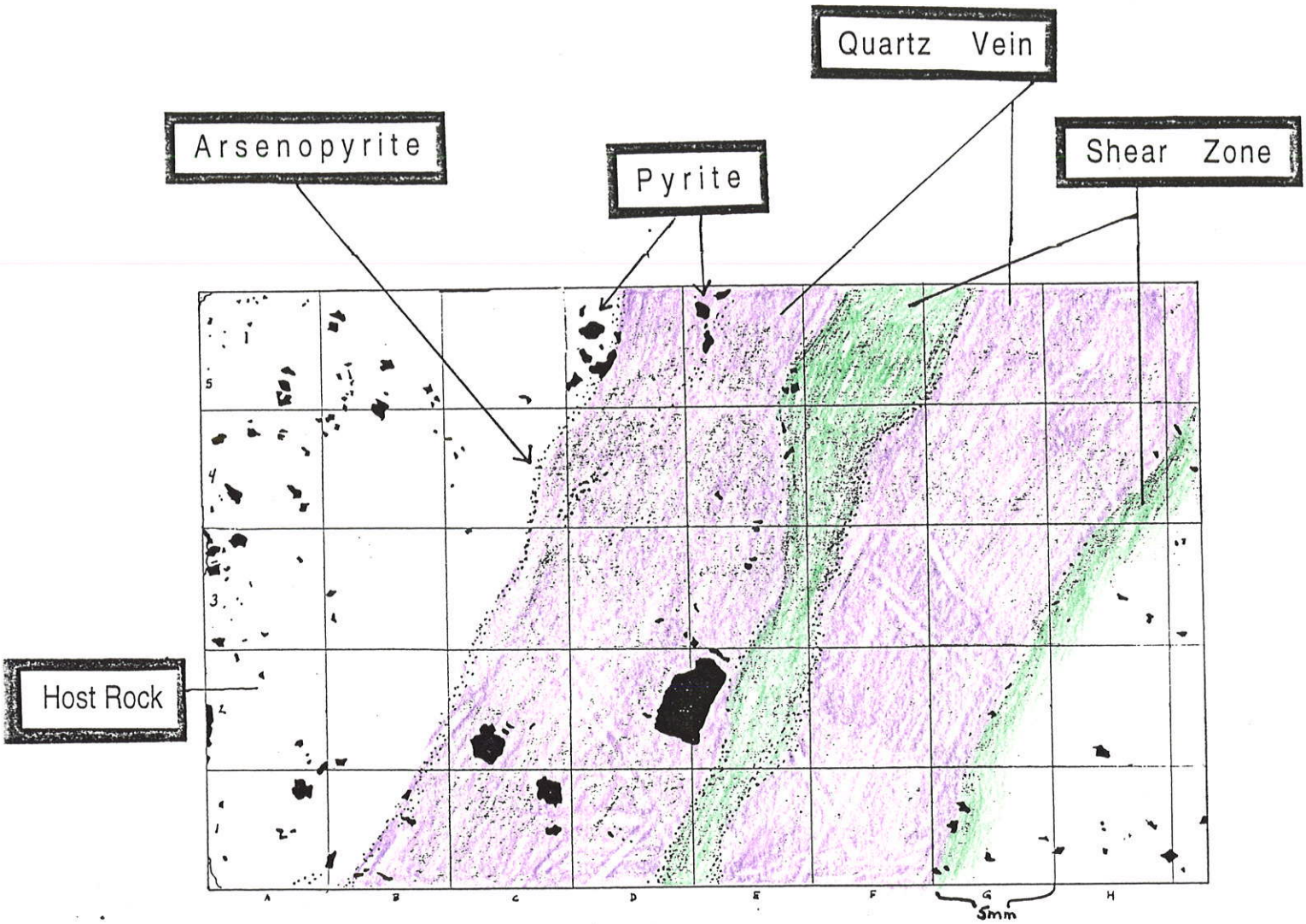
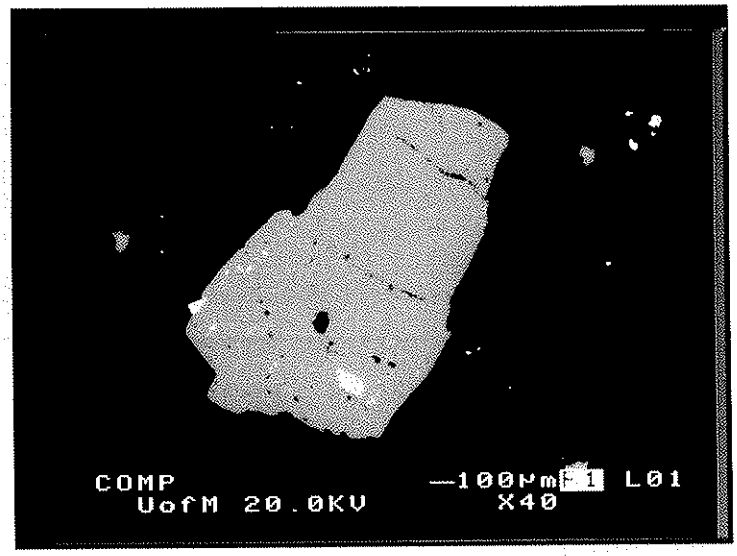
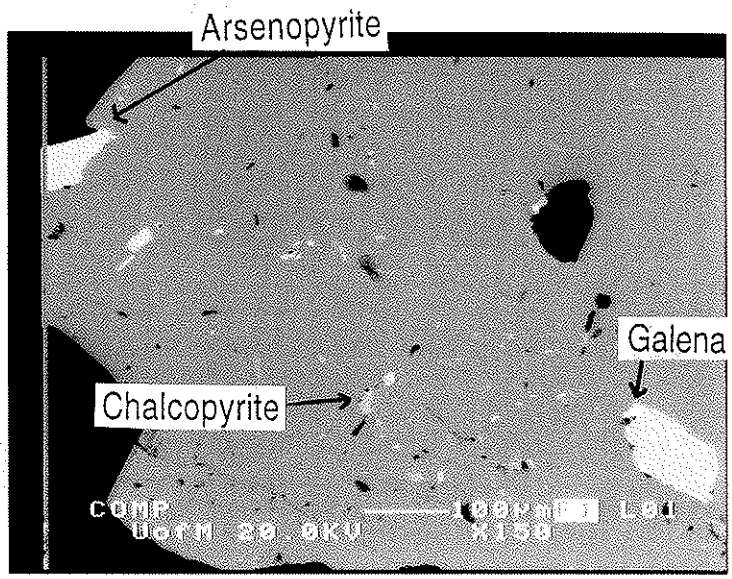


Figure 10 Map of thin section # 3 identifying sulfide minerals and the area of gold mineralization. Mineralization of sulfides occurs within the rock body and within quartz veins. The nature of the sulfide mineraliztion ranges from small inclusions within other sulfides to a rare relationship with arsenopyrite enclosing pyrite. This boundary between pyrite and arsenopyrite serves as a host for the gold mineralization.





Figures 11 & 12 Scanning Electron Micrograph of a pyrite crystal with arsenopyrite, chalcopyrite and galena inclusions.

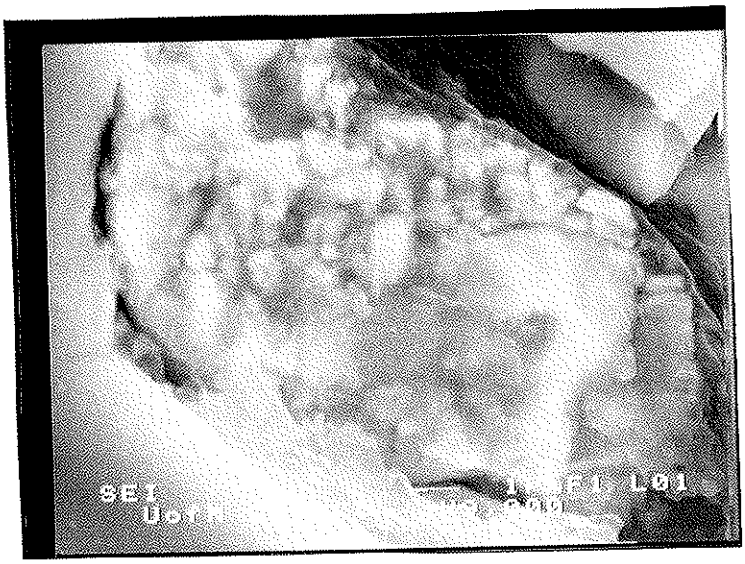


Figure 13 Scanning Electron Micrograph of native antimony (magnification X9000)

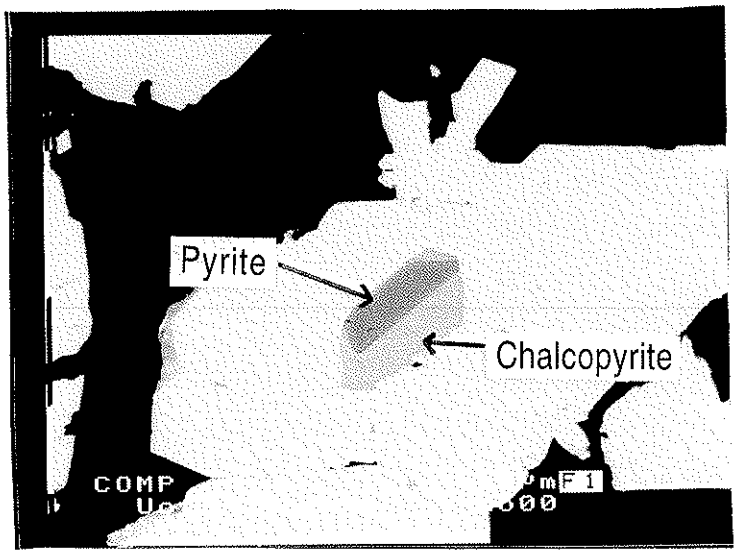


Figure 14 Scanning Electron Micrograph of an arsenopyrite crystal hosting chalcopyrite and pyrite inclusions.

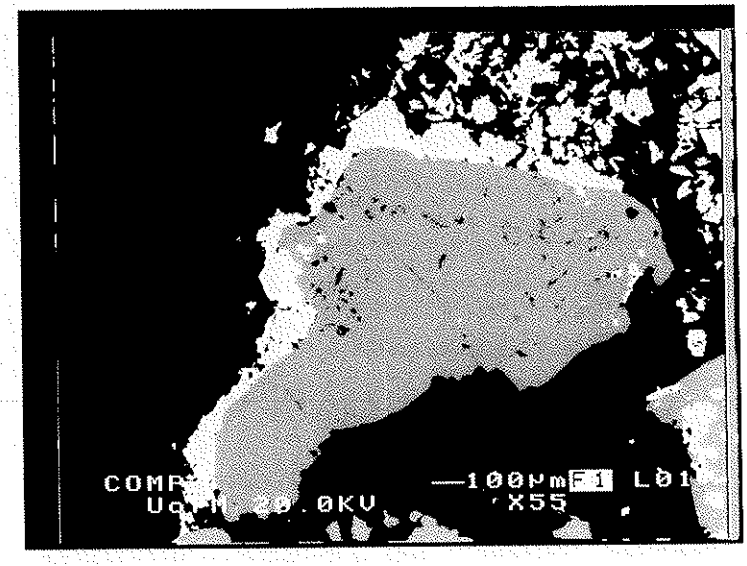


Figure 15 Smaller scale Scanning Electron Micrograph illustrating the relationship between the pyrite and arsenopyrite.

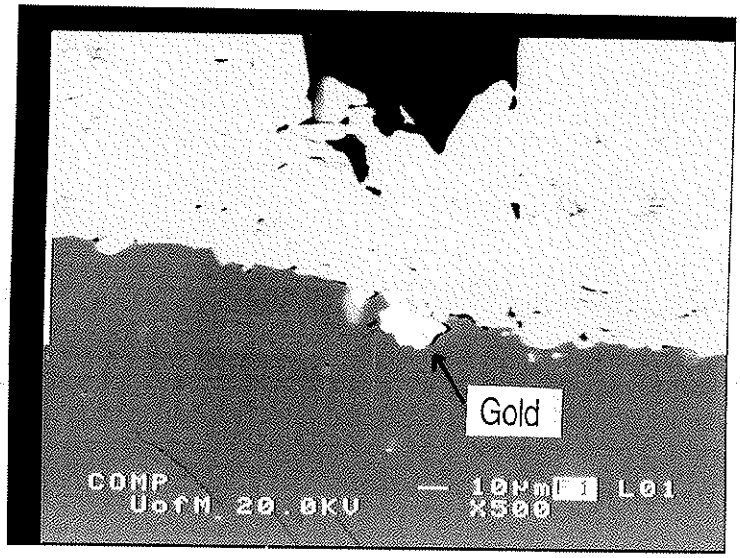


Figure 16 Scanning Electron Micrograph of a pyrite crystal (dark gray) coated with arsenopyrite (light gray). Gold occurs along the contact between the two sulfides.

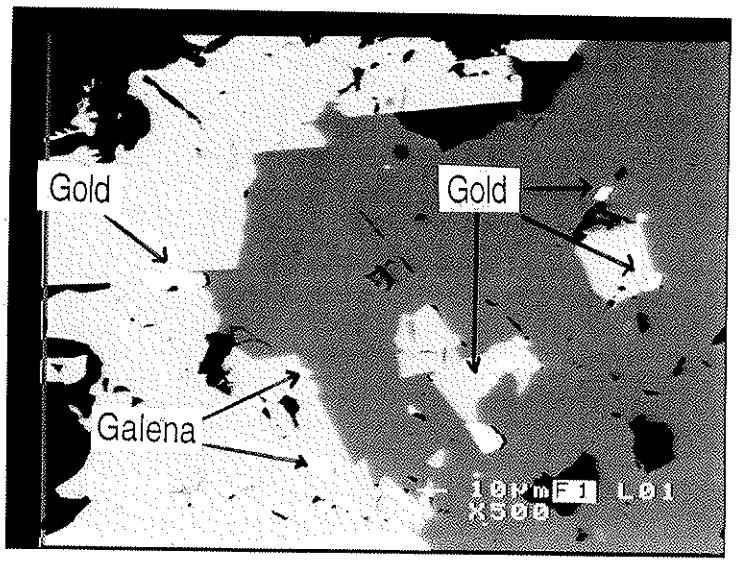


Figure 17 Scanning Electron Micrograph of the same pyrite/arsenopyrite crystal. Again, gold is along the boundary between the two sulfides and generally is located within the arsenopyrite. Galena mineralization is also present and occurs along the boundary as well as in the form of inclusions within the sulfides.

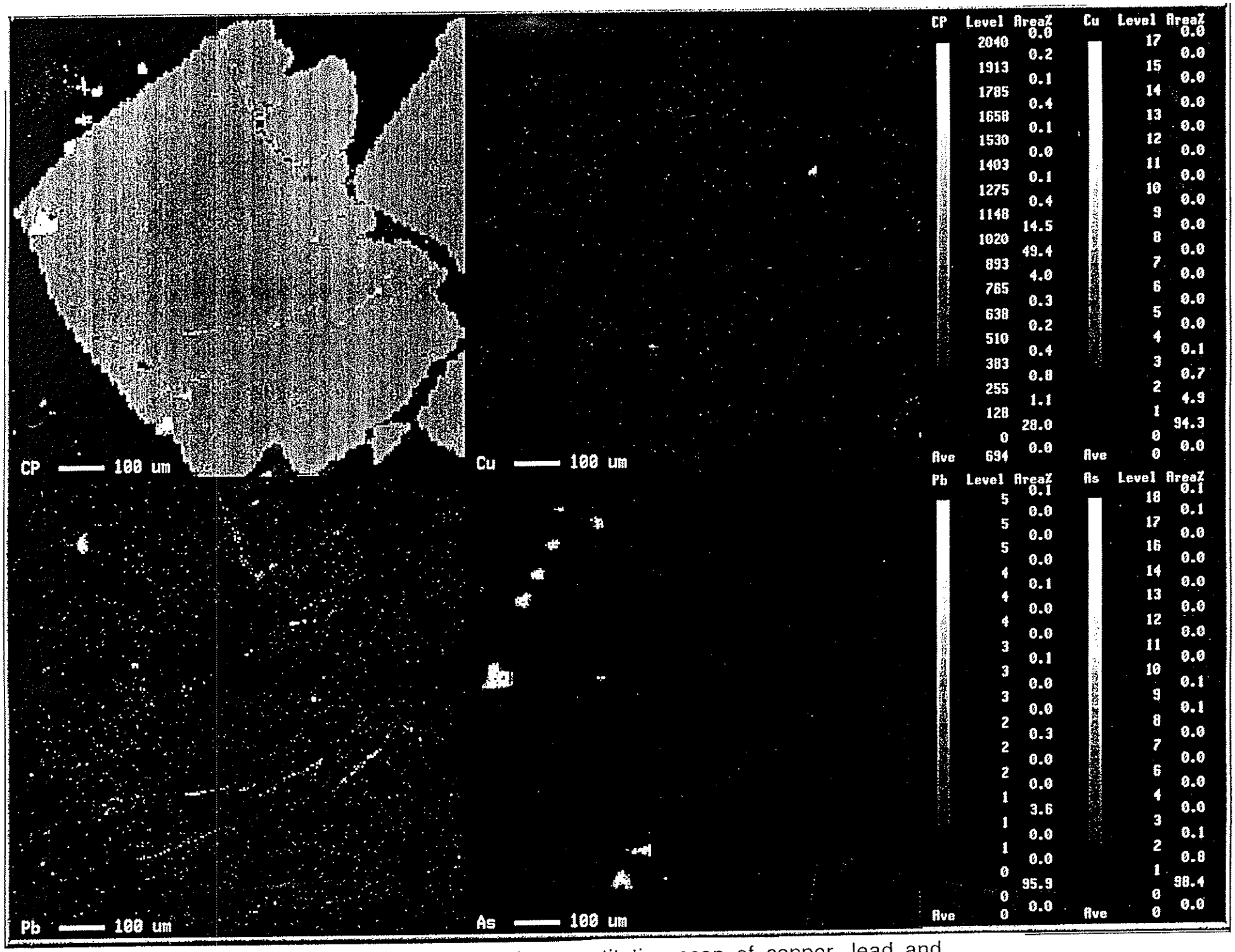


Figure 18 Electron Microprobe quantitative scan of copper, lead and arsenic in a typical pyrite crystal.

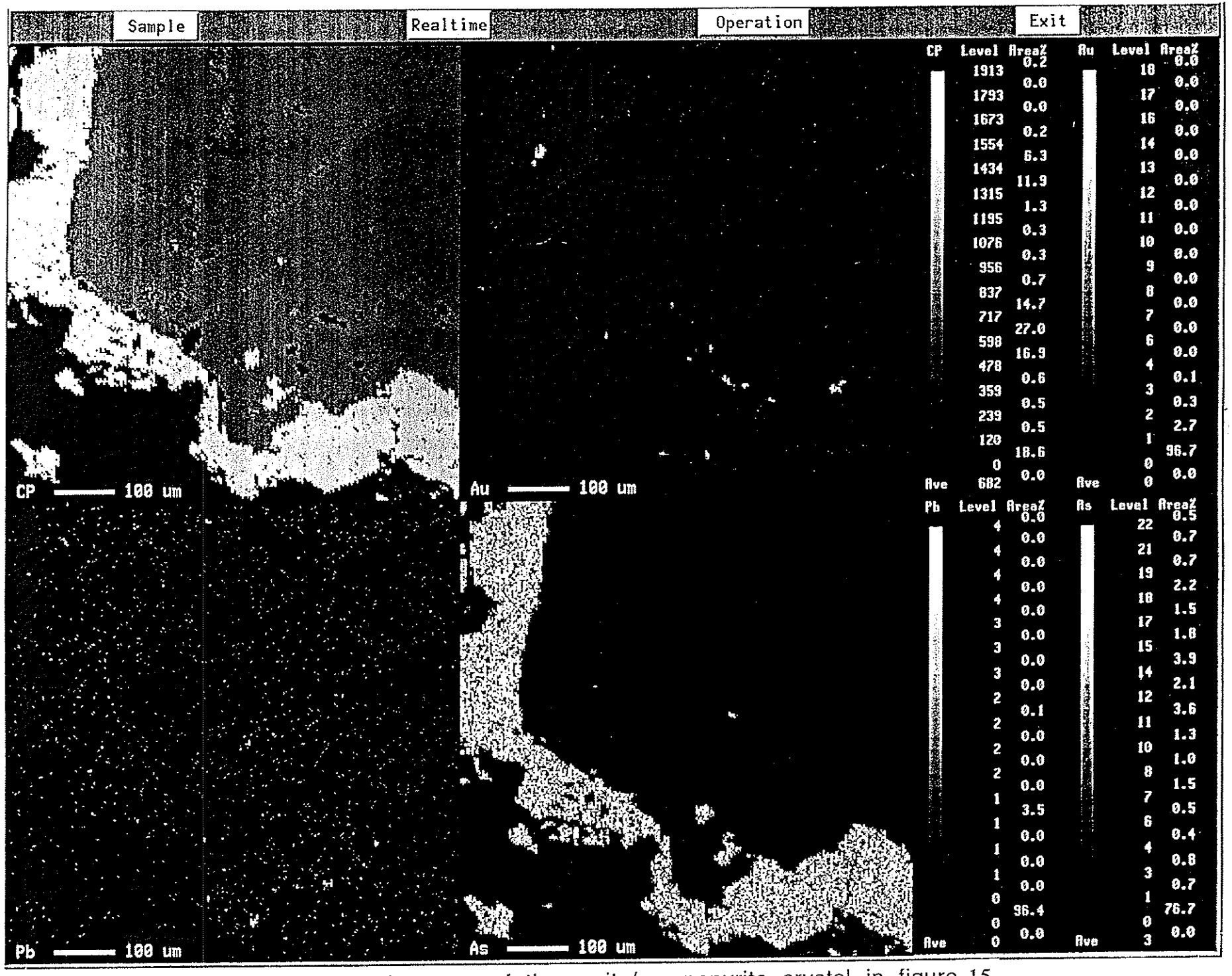


Figure 19 Microprobe scan of the pyrite/arsenopyrite crystal in figure 15 showing the quantitative values of gold, lead and arsenic.

INTERPRETATION

As stated previously, the observed nature of the gold is in small specks and blebs along an arsenopyrite/pyrite interface. Therefore, the gold is probably not an exsolution product but is instead an isolated crystal inclusion. The timing of precipitation of the gold and sulfides was probably contemporaneous as evidenced by their spatial relationships. However, the fact that the arsenopyrite is coating the pyrite and the gold is within the arsenopyrite along the contact may suggest that the pyrite crystallized first. It may also be noted that since gold, pyrite and arsenopyrite occur in association with one another, they were probably derived from the same hydrothermal fluid. Therefore, the cause of mineralization may have been a single controlling factor.

The relationship between sulfide minerals already discussed may indicate that all types of sulfides mineralized from the same hydrothermal fluid. Specifically, this is shown by the inclusions of chalcopyrite and sphalerite within pyrite and arsenopyrite. Galena stringers are also occasionally enclosed by pyrite and can be interpreted as exsolution products.

The parallel nature of the shear zones and hydrothermal veins may indicate that these two structures were formed at approximately the same time. It is therefore conceivable that the shear zones acted as passages for the hydrothermal alteration fluids. The duration of the shearing is evidenced by the pressure shadows. The presence of the rotated pressure shadows indicates that compressional stress and shearing must have still been in effect after the crystallization of pyrite. Therefore, either the shearing occurred over a long period of time or there was more than one episode of shearing.

DISCUSSION

Previous literature explains that gold in association with sulfide minerals tends to occur either in the lattice of sulfide minerals or as an exsolution product. Where the metal is physically within sulfides, it occurs as blebs, specks and small crystals (Boyle, 1979). As

indicated before, gold of the felsic porphyry occurs as specks and blebs within sulfide minerals and does not show any evidence of exsolution.

Literature also shows that gold tends to occur either in pyrite or arsenopyrite (Sakhorova and Lobacheva, 1969). In pure pyrite the Au/Ag ratio is consistently less than 1. The ratio within arsenopyrite is generally greater than 1. This suggests a tendency for arsenopyrite to concentrate gold whereas pyrite tends to take up silver (Boyle, 1979). This data holds true for the concentration of gold within the felsic porphyry. The gold mineralization identified in this study generally occurs within arsenopyrite along a contact with pyrite.. Gold-silver ratios were not explored, however, SEM chemical scans revealed all but one crystal to be pure gold.

CONCLUSIONS

This study was intended to establish the relationship between gold and sulfide mineralization. It had previously been accepted that gold occurred only as free gold within the quartz-carbonate veins of the porphyry. However, this study provides evidence for alternate forms of gold mineralization as well as a more detailed understanding of the sulfide mineralization. This study particularly concludes the following:

1. Quartz-carbonate veins are the result of hydrothermal alteration that introduced sulfide minerals and gold.
2. Sulfide mineralization occurs within the rock body and within the quartz-carbonate veins of the felsic porphyry bodies.
3. Mineralization of sulfide minerals occurred either within a long period of shearing motion within the rock or between two separated shearing events as evidenced by rotated pressure shadows enclosing pyrite crystals.
4. Precipitation of the major and minor sulfide minerals seems to have been contemporaneous as evidenced by inclusions of chalcopyrite and galena within arsenopyrite and pyrite.

5. Galena mineralization is commonly the result of exsolution as evidence by its occurrence in the form of stringers.

6. Precipitation of gold and sulfide minerals seems to have been generally contemporaneous as evidenced by the association of gold, arsenopyrite, and pyrite in one particular thin section of the felsic porphyry.

7. Gold also occurs as isolated blebs and specks within arsenopyrite along the boundary of adjacent pyrite located within the rock body adjacent to a quartz-carbonate vein as well as in the form of free gold within the quartz-carbonate veins.

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