مطالعه رگچه‌ها و ریز رگچه‌ها در کانسار مس پورفیری سونگون آذربایجان خاوری

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Veinlets and micro-veinlets studies in Sungun porphyry copper deposit, East Azarbaidjan, Iran

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چکیده

مجموعه ماگمائی منطقه سونگون بخشی از کمربند ماگمائی دوران نوزیستی ایران است که دارای روند شمال باختری – جنوب خاوری است. پورفیری‌های سونگون به شکل استوک (stock) و دایک (dike) می‌باشند و از نظر ترکیب سنگ‌شناسی از کوارتز– مونزودیوریت، کوارتزمونزونیت و گرانودیوریت تا گرانیت تغییر می‌نمایند.

استوکها به دو گروه I و II تقسیم شده‌اند. استوکهای پورفیری گروه II به عنوان میزبان کانه‌های مس به شدت گسلیده و درزه و شکافدار آبدار شده‌اند. استوکهای کانه‌دار نوع II رویدادهای چندگانه را تحت اثر درزهای آبدار تحمل نموده‌اند که منجر به تشکیل انواع استوک ورک (stock- work) و رگچه‌های کوارتز و همچنین رگچه‌های در پیوند با تشکیل سولفیدها، کربناتها، سیلیکاتها و سولفاتها گردیده است. رگچه‌ها به نظر می‌رسند که در سه مرحله جداگانه ولی بطور پیوسته از درزهای آبدار (Hydro-fracture) تشکیل شده باشند.

رگچه‌ها و ریزرگچه‌های کوارتز نوع E در مرحله اولیه تشکیل شده‌اند. رگچه‌ها و ریزرگچه‌های کوارتز – سولفید، کوارتز– مولی، کالکوپیریت، پیریت، مولیبدنیت، دولومیت، کلسیت – پیریت و سریسیت در مرحله میانه و انیدریت (گچ موجود)، کوارتز نوع L، چرت و مقداری رگچه‌ها و ریزرگچه‌های کلسیت و کلسیت –پیریت مشخصه آخرین عملکرد فرآیند درزه آبدار (Hydro-fracturing) هستند.

واژه‌های کلیدی: ایران، مس پورفیری، سونگون، استوک، دایک، سنوزوئیک

Abstract

The magmatic suites in the Sungun area are a part of NW-SE trending Cenozoic magmatic belt of Iran. The Sungun porphyries occur as stocks and dikes ranging in composition from quartz monzo-diorite through quartz monzonite and granodiorite to granite. The stocks are divided into two groups, I and II. The porphyry stock II, hosting the copper ore experienced intense hydro-fracturing, jointing, and faulting. The mineralized porphyry stock II experienced multiple events of intense hydro-fracturing leading to the formation of stockwork-type and anastomozing veinlets and micro-veinlets of quartz, sulfides, carbonates, silicates, and sulfates. The veinlets are thought to have formed in three distinct, although continuous, hydro-fracturing stages. E-type quartz veinlets and micro-veinlets were formed during the early stage. Quartz-sulfide, quartz-moly, chalcopyrite, pyrite, molybdenite, dolomite, calcite, calcite-pyrite, and sericite veinlets and microveinlets were developed during the middle stage. Anhydrite (present gypsum), L-type quartz, chert, and some calcite and calcite-pyrite veinlets and micro-veinlets characterize the late stage of hydro-fracturing processes.

Key Words: Iran, Porphyry copper, sungun stock, dyke, Cenozoic

Introduction

The Sungun porphyry copper deposit is located approximately 75km NW of Ahar, NW of Iran. The Sungun porphyries are of Oligo-Miocene age, and intruded the Upper Cretaceous rocks, a series of Eocene arenaceous-argillaceous rocks, and a series of Oligocene dacitic breccias and tuffs and trachyandesitic lavas (Emami and Babakhani, 1991; Mehrpartou, 1993). The Sungun porphyries are characterized by a series of igneous rocks featuring typical porphyritic textures. They occur as stocks and dikes, and range in composition from quartz monzo-diorite through quartz monzonite and granodiorite to granite. Some parts of the Sungun porphyries were covered by a series of late Tertiary- Quaternary (Emami and Babakhani, 1991; Mehrpartou, 1993) volcanic rocks ranging compositionally from latite to quartz latite -andesite.

The stocks can be divided into two groups, porphyry stock I and porphyry stock II. Rock types represented in porphyry stock I are principally quartz latite- andesite. The porphyry stock II, hosting the copper ores, compositionally varies from quartz monzonite through granodiorite to granite.

Structural features

Stockwork-type fractures and micro-fractures and certain pre- or syn-mineralization joint sets and faults are the major structural features which prepared the suitable grounds for the formation of many types of veinlets and micro-veinlets in the porphyry stocks. Although some early faults are locally mineralized (Fig. IA), the majority of them in Sungun are barren suggesting that they are post-mineralization structural features.Nine distinct systematic joint sets are recognized in the stocks and dikes. of which seven sets are almost barren and only two conjugate sets (not developed in barren dikes) contain sulfides which might have formed nearly concurrently during mineralization process (Calagari, 1997). The central part of the porphyry stock II has experiensed intense shattering and crackle-type (stockwork) brecciation. This shattered zone is typically characterized by intense cross-cutting, anastomosing, and stockwork- type fracture and micro-fracture patterns. The majority of the individual angular crackled fragments show no rotation, although locally some had been slightly jostled and jiggled around. The fracture density gradationally decreases laterally outward and vertically downward from the center of the zone.

Hydro-fracture-controlled veinlets and micro-veinlets

The development of pervasive alteration and extensive sulfide mineralization in Sungun were facilitated by the intensive cross-cutting stockwor-type fracture system formed during multiple events of shattering caused by retrograde boiling and expansion of the hot confined hydrothermal fluids, probably triggered by the contemporaneous tectonic movements. The fractures and micro-fractures were subsequently filled in by ascending hydrothermal fluids, developing veinlets and micro-veinlets of quartz, sulfides, carbonates, silicates, and sulfates. The hydro-fracturing events took place episodically as characterized by the presence of various types of cross-cutting veinlets and micro-veinlets (Calagari, 1997). The high fracture density manifested by numerous veinlets(generally 100 μ m to 3cm wide) and micro-veinlets (<100 μ m wide) guided the ascending hydrothermal fluids to reach nearly the entire porphyry body. The active ions (e.g., H^+ and K^+) could readily diffuse from micro-fractures and fractures into the host rock, and react with the silicates. Where the fracture density is relatively low, the alteration is appreciably less pronounced. Based upon mineralogy and paragenetic sequence, the veinlets in the Sungun porphyry stock II are classified as follows:

Quartz veinlets and micro-veinlets:

The quartz veinlets are almost ubiquitous. Chronologically there are three distinct types of quartz veinlets and microveinlets developed during different stages of alteration and mineralization within the porphyry stock II at Sungun (Calagari, 1997). They have been categorized as early-stage, middle-stage, and late- stage quartz veinlets and micro-veinlets.

Early -stage (E-type) quartz. veinlets and micro-veinlets:

They are relatively narrow (~ 20-300 μ m wide), and consist predominantly of quartz and are barren or contain minor amounts of sulfides.Quartz crystals are fine-grained (but coarser than those in the matrix) with granular (mosaic) texture, though some show polygonal pattern. The crystals contain some sporadic, very small, fluid inclusions. Sulfides are chiefly chalcopyrite with lesser amounts of pyrite. Sulfides are nearly the same size as quartz crystals, and are, in general, similar to those disseminated in the matrix. Where veinlets cut through primary biotite, a thin film of secondary biotite is developed along the veinlet's walls. Similarly a thin alteration halo (selvage) is formed along veinlet's walls where the veinlet intercepts plagioclase phenocrysts. The halo resisted later hydrolytic alteration. Where the veinlet was inundated by the overgrowth of the secondary orthoclase, its trace is still distinguishable.

The veinlets are curved and locally irregularly crenulated indicating that they underwent plastic deformation probably when the rock had not been completely solidified, and could not rheologically sustain brittle fractures. The formation of a secondary biotite selvage along the veinlet's walls and overgrowths of secondary orthoclase, strongly suggest that they were developed during the early stage of potassic alteration (Fig.3)

Middle-stage quartz veinlets and micro-veinlets:

These can be further sub-divided into two distinct types, (1) quartz-moly and (2) quartz-sulfide veinlets and micro-veinlets.

Quartz-moly veinlets and micro-veinlets: They vary in width from ~ 100 μ m to ~ 1.5cm, and consist predominantly of quartz, and small amounts of sulfides, sericite aggregates, and dolomite. The veinlets have parallel and sharp contact with heavily sericitized host-rock, and do not show visible alteration halos. The quartz crystals are fine to medium-grained (~1mm) with mosaic texture, and are rich in fluid inclusions (including gas-rich and halite-bearing ones). The majority of the quartz crystals show undulose extinction (strained), and contain numerous cross-cutting micro-fractures. The crystals are finer toward the veinlet's walls and coarser toward the middle of the veinlet; the sulfides present are mainly molybdenite, chalcopyrite, and pyrite. The amounts of molybdenite is high (forming ~0.5-5 Vol.% of the veinlet), and mostly concentrated adjacent to the walls where finer crystals are present. The sulfides are similar to those in the matrix. The veinlets are cut by quartz-sulfide veinlets and are spatially and temporally related to the phyllic and potassic- phyllic alteration zones (Fig. 3).

Quartz-sulfides veinlets and micro-veinlets: These are up to 1cm wide, and consist principally of quartz, minor amounts of sulfides and calcite, and small amounts of sericite aggregates (figs. 1A & 1B). The veinlets are continuous, and have parallel sharp contact with the strongly sericitized host-rock. The quartz crystals are medium-grained with a mosaic texture, and comprise numerous sub-parallel and cross-cutting micro-fractures. The crystals are rich in fluid inclusions, and exhibit patchy extinction. The sulfides are mainly concentrated in the middle of the veinlets, and are chiefly pyrite with lesser amounts of chalcopyrite (replacing pyrite) and trace amounts (<0.1Vol.% of the veinlet) of molybdenite flakes. The sulfides are similar to those in the matrix and in the site of altered ferro-magnesians. In the potassic zone, the veinlets cross-cut the secondary overgrown orthoclase. The veinlets cut the quartz-molybdenite veinlets, and are cut by the late-stage quartz veinlets (Fig.3).

Late-stage quartz veinlets and micro-veinlets:

They can be further sub-divided into two discretete types, (1) late-quartz (L-type quartz) and (2) chert veinlets and micro-veinlets.

Late-quartz (L-type quartz) veinlets and microveinlets: They vary in width from ~ 100 μm up to 2mm, and show almost no alteration selvages along their walls which are continuous, parallel, and sharp against a very fine-grained quartzo-sericitic host-rock. The veinlets consist primarily of quartz, and little or no sulfides and calcite. Medium-grained quartz crystals having relatively fewer micro-fractures, show a granular texture, and contain extremely fine fluid inclusions (<2 μm). Sulfides (chalcopyrite and pyrite) and calcite are present mainly in the central parts of the veinlets, and have a similar grain size to enclosing quartz crystals. The veinlets cut through the sulfide and quartz-sulfide veinlets. On the basis of textural evidence and paucity of sulfide content, they are thought to have been developed temporally during the late stage of phyllic alteration (Fig.3).

Chert veinlets and micro-veinlets: They are not ubiquitous, and are only present in the upper (at elevations greater than 2050 m above the sea level) and central parts of the porphyry body. They vary in width from 50 μm to 3mm, and consist predominantly of ultra-fine- grained quartz and small amounts of sulfides and sericite. They display an anastomosing pattern, and have sharp contacts with the fine-grained quartzo-sericitic host-rock. The sulfides are fine-grained pyrite and chalcopyrite, and molybdenite. Textural evidence reveals that fluid deposited the chert, dissolved the early - formed sulfide minerals and re-deposited them as very fine crystals in other sites in the veinlets. As the result of this process, many early-formed coarse crystals of pyrite cut by the veinlets have been marginally granulated dramatic size reduction) along the veinlets walls. These veinlets cross-cut and /or fill the center of the L-type quartz veinlets. They are thought to have been developed during the waning stage of the phyllic alteration (Fig.3).

Sulfide veinlets and micro-veinlets:

They are thought to have been developed mainly during phyllic alteration. They can be sub-divided into three separate types, (1) chalcopyrite, (2) pyrite, and (3) molybdenite veinlets and micro-veinlets.

Chalcopyrite veinlets and micro-veinlets:

These are narrow (up to 100 μm wide), discontinuous, and segmented, and have sharp walls (Fig. 2A), although some show an alteration halo (sericitized selvage). They consist principally of chalcopyrite, with minor amounts of pyrite, quartz, and sericite. The sulfides in the veinlets are similar to those in the host-rock and in the site of ferro-magnesians. The veinlets cut through the secondary orthoclase overgrowths and E-type quartz (in the potassic alteration zone) and quartz-moly and dolomite veinlets (in the potassic-phyllic and phyllic alteration zones).

Pyrite veinlets and micro-veinlets:

They are up to 1cm (locally to 2cm) wide, and consist primarily of relatively coarse crystals of pyrite, and minor amounts of fine chalcopyrite, fine to medium-grained quartz, sericite flakes, and calcite. Quartz crystals contain abundant small (<3 μm) fluid inclusions. The veinlets are irregular and discontinuous, and have sharp wall against heavily sericitized host-rock (Fig. 2B). The pyrite crystals locally suffered intense fracturing and micro-brecciation. The veinlets cut and are cut by quartz-sulfide veinlets indicating they were developed almost contemporaneously. Pyrite crytsals in the host-rock adjacent to the veinlets' margins are similar to those within the veinlets.

Molybdenite micro-veinlets: They are relatively scarce, and are only locally developed. They occur as very thin (~100 μm wide), curved, and discontinuous stringers intimately associated with quartz-moly veinlets. They are present primarily close to border of quartz-moly veinlets within the host-rock where they are stretched nearly parallel to the veinlet's walls. The micro-veinlets consist principally of molybdenite (~40Vol%) and quartz (~40Vol.%) along with lesser amounts of sericite (10-15Vol.%), calcite (3-8Vol.%), and chalcopyrite (~2Vol.%). The molybdenite in the micro-veinlet occurs as very fine to fine anhedral to euhedral flakes (Fig.2C). Molybdenite micro-veinlets are thought to have developed almost synchronously with the quartz- molybdenite veinlets (Fig.3).

Sericite micro-veinlets: They are relatively narrow (<100 μ wide) and discontinuous, and consist mainly of sericite and subordinate pyrite replaced by small amounts of chalcopyrite. They are not ubiquitous, and are more common in samples from potassic zones in which they cut through the secondary orthoclase overgrowths. They formed contemporaneously, during phyllic alteration (Fig. 3).

Carbonate veinlets and micro-veinlets: They are mainly abundant adjacent to skarn patches. The relative scarcity of carbonate veinlets in the porphyry body suggests that the hydrothermal fluids mainly circlated more through the shattered, fractured, and hot porphyry body rather than through the less fractured, less permeable, and much colder limestone body. The carbonate veinlets can be further sub-divided into three distinct types, (1) dolomite, (2) calcite-pyrite, and (3) calcite veinlets and micro-veinlets.

Dolomite veinlets and microveinlets: They are relatively scarce and up to 2mm wid, and have sharp contacts with the host-rock. They consist chiefly of medium-grained (up to 2mm) subhedral to euhedral dolomite crystals showing a granular texture, and minor amounts of calcite, quartz, and sulfides (pyrite, chalcopyrite, and molybdenite). Most of the dolomite veinlets were re-opened and filled in by the quartz-sulfide and pyrite veinlets. The dolomite veinlets are conceived to have formed during the middle stage of alteration and mineralization, and to be temporally coeval with quartz - molybdenite veinlets (Fig.3).

Calcite-Pyrite veinlets and micro-veinlets: They are up to 2mm wide, and mainly present in the vicinity of the skarn patches. They consist chiefly of calcite, considerable amounts of pyrite, and minor amounts of quartz. Calcite in these veinlets occurs as very fine to medium-grained crystals. Quartz occurs as ultra-fine cherty patches as well as fine to medium-grained subhedral to euhedral solitary crystals. Pyrite is present as medium-grained subhedral to euhedral crystals (relatively coarser than the enclosing calcite crystals), and forms about 10-40Vol.% of the veinlet's volume. The veinlets cut the sericite veinlets and are inferred to have developed during the formation of the pyrite veinlets (Fig. 3).

Calcite veinlets and micro-veinlets: They vary in width from ~20 μm to ~2 Cm, and have an anastomosing pattern. The majority are continuous having sharp contacts (Fig. 2C), although some occur as lenticular patches with a vuggy center where euhedral drusy calcite crystals project towards the vug's center (Fig. 1D). The veinlets consist predominantly of calcite, minor amounts of quartz and rare(or no) sulfides(pyrite and chalcopyrite). If present, the sulfides appear to be mainly near the veinlet's walls.

The veinlets cut the E-type quartz, quartz-sulfide, and even L-type quartz veinlets. Calcite micro-veinlets are also locally present in the early dike series indicating that the formation of calcite veinlets was nearly contemporaneous with these intrusions into the porphry stock II. It has been inferred that the calcite veinlets formed mainly during the late stage of phyllic atteration (Fig. 3).

Gypsum(after anhydrite) veinlets and micro-veinlets: They are primarily present close to the skarn patches, and are mainly restricted within the elevation ragne of 1550-1700m above the sea level. They are about 100 μ m to 5mm wide with an anastomosing pattern (Fig. 1E). They have sharp walls, and consist exclusively of gypsum. The veinlets appear to have suffered volume expansion and the walls were pushed apart. It has been inferred that the gypsum veinlets were initially anhydrite veinlets which later became flooded by underground water at low temperatures (<90 °C) and became hydrated and converted into gypsum. This caused about a 60% volume increase in the veinlets, they are thought to be relatively younger, and formed probably at the waning stage of hydrothermal activity (Fig. 3).

Conclusion

One of the most important physical factors which controlled the hypogene hydrothermal alteration and mineralization of the pre-existing silicates in Sungun was the development of stockwork-type fractures and micro -fractures. The development of various types of cross-cutting veinlets and micro-veinlets within the porphyry system in Sungun indicates that the nature of mineralizing fluids changed temporally and spatially. Multiple events of hydro-fracturing were documented by fluid inclusion data (Calagari, 1997). Paragenetically, the veinlets and micro-veinlets are thought to have formed in three distinct, but almost continuous, stages, early, middle, and late.

Early-stage: The separated and evolved fluid phase confined at the pluton's cupola is believed to have been responsible for the initial rupturing and *cracking* of the overlying rocks. The fractures and micro-fractures, thus formed, were subsequently filled in by the E-type quartz veinlets and microveinlets. The crenulated and relatively thin nature of these early veinlets denote that the rocks hosting the veinlets were not fully consolidated and had a plastic behavior, and the fluid pressure was not sufficient to keep the fractures open for relatively a long period of time. The precipitation of quartz and sulfides in these early veinlets caused the initial fractures to be chocked and the fluid to revert to lithostatic pressure regime. The relatively low density of the veinlets and micro-veinlets in this stage indicates the water to rock ratio was relatively low.

Middle-stage: The early veinlets were followed by extensive and intensive hydro-fracturing resulted from retrograde boiling processes analogous to ones mentioned in the early stage. The most intense shattering and crackle-type brecciation occurred in the central part of the cupola of the porphyry stock II. The creation of these widespread and intense fracturings and micro-fracturings furnished suitable conduits for the confined hydrothermal fluids to reach to the almost entire body of the rock materials. Multiple evenets of hydro-fracturings during this stage caused the formation of different types of cross-cutting veinlets and micro-veinlets such as quartz (quartz-moly and quartz-sulfides), sulfides (chalcopyrite, pyrite, molybdenite), silicate (sericite), and carbonates (dolomite, calcite-pyrite, and calcite) ones.

Late-stage: The L-type quartz, chert, some calcite and calcite-pyrite, and anhydrite (present gypsum) veinlets and micro-veinlets are thought to have formed during the waning stage of hydrothermal activity in Sungun.

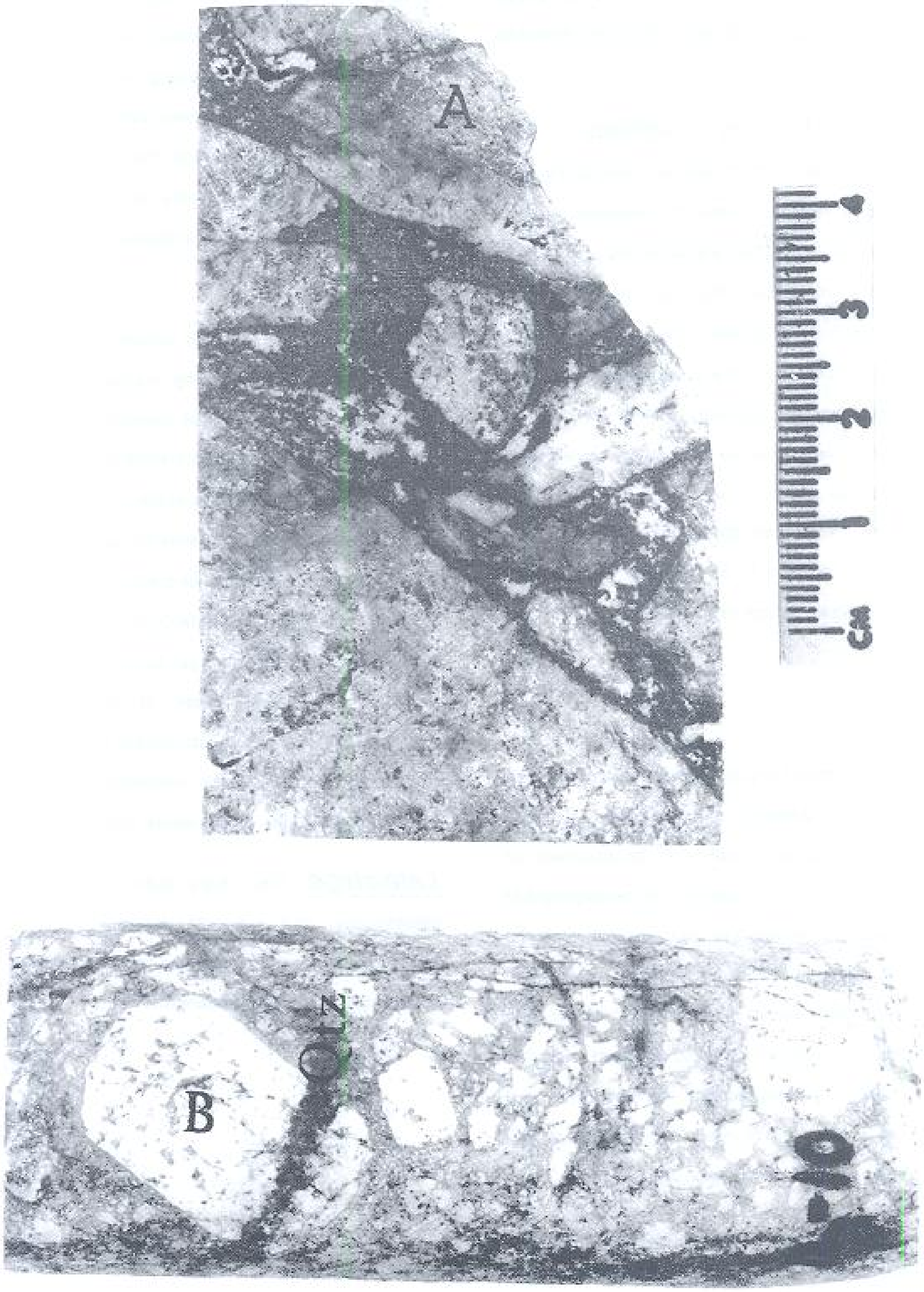
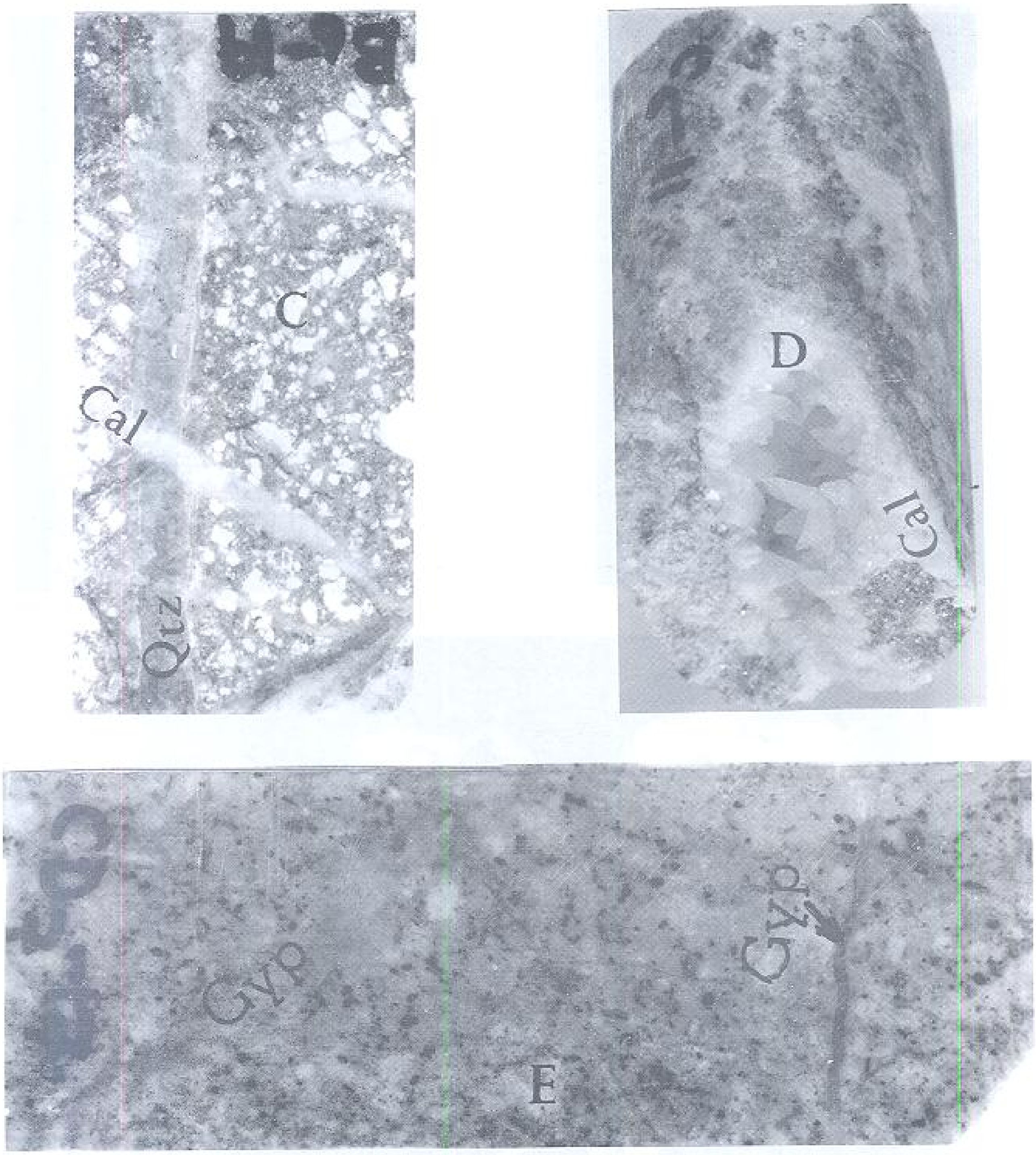


Fig.1: Photographs of cut diamond drilled cores from potassic-phyllic alteration zones in the porphyry stock II at Sungun. Gyp = gypsum, Cal = calcite, Qtz = quartz.

A: Fault breccia cemented by galena and pyrite.

B: quartz-sulfides veinlets and micro-veinlets intersecting feldspar phenocrysts and rock martrix.



C: Calcite veinlets intersecting the quartz-sulfides veinlets.

D: Calcite vugs showing euhedral drusy calcite crystals.

E: Gypsum veinlets.

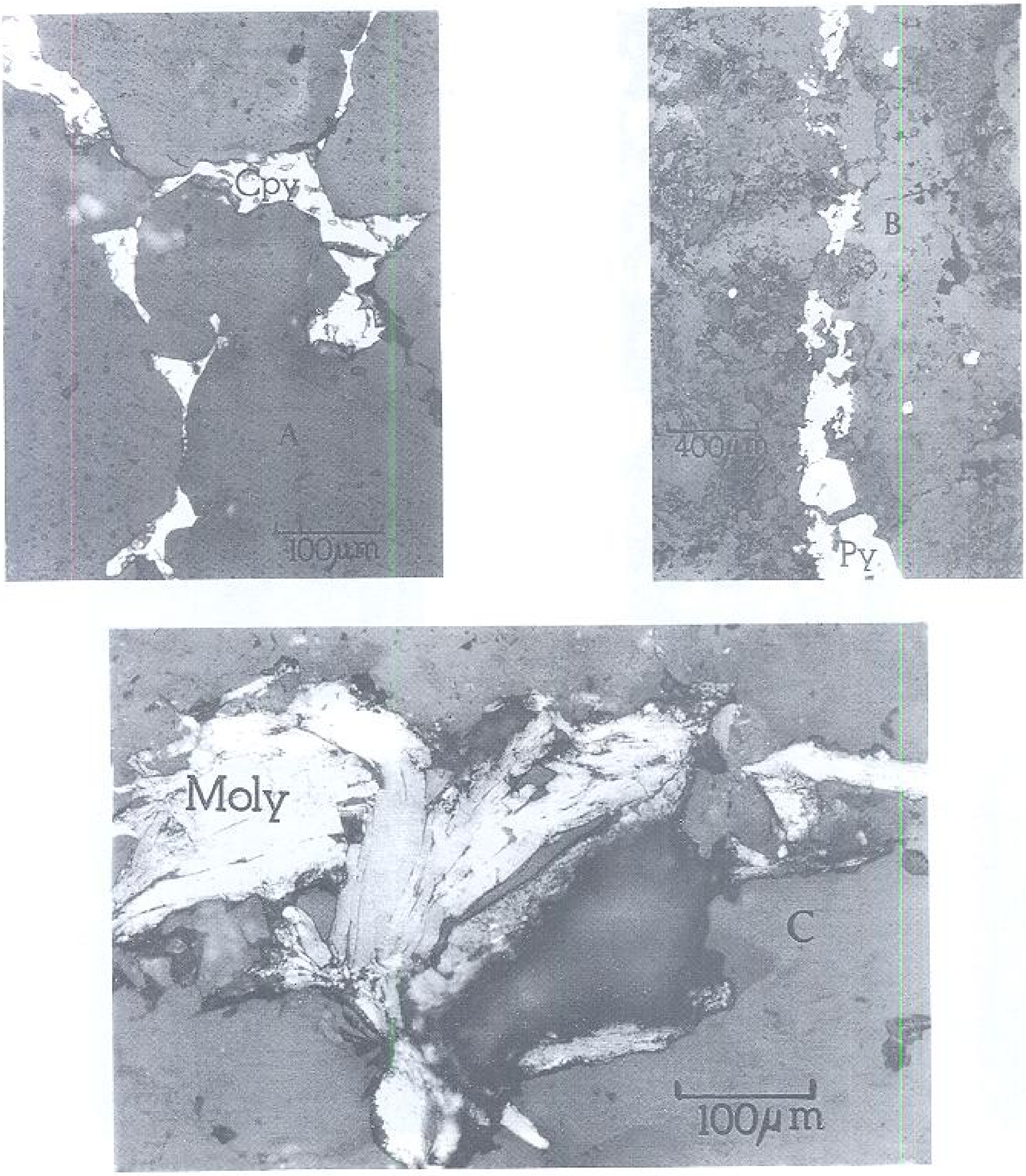


Fig.2: Photomicrographs of sulfide veinlets and micro-veinlets from potassic-phyllic alteration zone in the porphyry stock II at Sungun. Py = pyrite, Cpy = chalcopyrite. Moly = molybdenite. A: Chalcopyrite micro-veinlets. B: Pyrite veinlet. C: Molybdenite micro-veinlet.

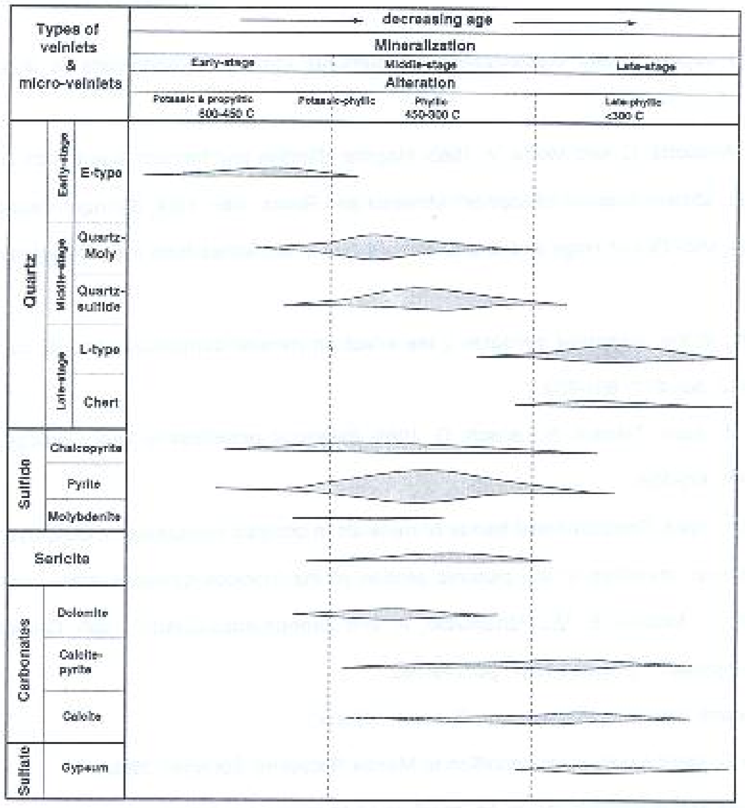


Fig.3: Paragenetic sequence of the development of various types of veinlets and micro-veinlets in the porphyry stock II at Sungun. The thickness of the horizontal bars is related to the relative abundance of the veinlets in the porphyry system.

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