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**A Mineralogical Investigation Of The Big Mike Prospect
Pershing County , Nevada**

**Prepared for Cerro Corporation , 300 Park Avenue ,
New York .**

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I. Introduction

Purpose of the present study is to investigate mineralogical aspects that may be pertinent to the mineral dressing characteristics of the ores of the Big Mike prospect in Nevada. Mineralogical aspects that are relevant include:

1. the nature of the metal values - the mineral species
2. the size and shape of the economic mineral species,
 - a. their individual crystals
 - b. their aggregates
3. the relation of the economic minerals with adjoining minerals or host rock (intergrowths)
4. fractures, joints and cleavages of the minerals and their aggregates
5. the stability of the mineral paragenesis.

The classification of the ore types will be another result of the mineralogical investigation.

II. Description of the drill core samples

About 20 polished sections were prepared by the Cerro Corporation from representative samples of the #8 and #20 drill cores. I realized how well the samples were prepared only when I wanted to repolish them for mineral-photographic purposes: a few (#20-160', #20-175', #8-185') turned out to be so sensitive to water that their surfaces became disintegrated which spoiled the diamond-impregnated polishing cloths. I had to re-do them in glycerin.

The minerals were identified by their optical properties. In this case they are sufficiently characteristic that with some experience one is able to make a proper identification. Where an exact identification could not be made, such as in the case of delafossite-tenorite, the proper name is only of academic interest since their stability conditions and oxidation state of copper are similar.

Unfortunately there was not sufficient time available for the preparation of thin sections of the transparent minerals and rocks. Especially in the case of altered volcanics of green schist metamorphic facies the texture of the rock is of primordial interest for its identification, because of extremely small grain sizes. In this case my only information came from the investigation of mineral fragments in liquids of a certain refractive index, under the polarizing microscope.

The results are tabulated on the following pages. They are described in terms of:

1. their megascopic appearance
2. their transparent, mainly silicate fraction
3. their opaque, mainly metallic mineral fraction
4. the texture, grain size, and intergrowths of the economic minerals.

Microphotographs have been included of characteristic minerals and textures. They are of two scales:

1. a 200 x one, the horizontal size of the photograph corresponding to 0.60 mm
2. a 310 x one, the horizontal size of the photograph corresponding to 0.38 mm.

Colored indices are used to point to a certain mineral or texture, which is found at the imaginary intersection of the arrows.

Description of Polished Sections and Powder Specimens

#8 - 185', Pale green fine grained rock with iron and copper oxides on joints and in veinlets.

Silicate minerals: Mainly chlorite; remnants of olivines pyroxenes and alkali-feldspars; very little quartz. The rock likely is an altered andesite.

Metallic minerals: Iron and copper occur mainly as oxides in an approximately 1:1 ratio. The iron oxide is goethite, grain size is extremely fine (<1 micron). Goethite builds tabular aggregates and occurs in veinlets. The copper oxides are cuprite and delafossite-tenorite. Because of the fine grain size (<5 microns) delafossite (CuFeO_2) is hard to distinguish from tenorite (CuO). Whether delafossite (favored because of intergrowths with goethite, and moderate birefractance) or tenorite is present, either mineral explains the rarity of native copper, since there are no equilibrium conditions for cuprite + tenorite + native copper. Copper sulfides are also incompatible. Only very small amounts (less than 5% of the total copper minerals) of copper sulfides have been observed. Chalcopyrite is replaced by bornite and digenite ($\text{Cu } 1.77 \text{ S}$). The copper sulfides and likewise small amounts of pyrite are enclosed by silicates and thus presumably escaped oxidation. Jarosite with replacement remnants of pyrite is also common. Cuprite amounts to about 60% of the total copper oxides.

Texture, intergrowths: Since cuprite normally is optically anisotropic, the average grain size can be determined. In this case it must be very small (<1 micron) since individual grains could not be discerned. Moreover, intergrowths in the 0.1 - 1 micron range between cuprite and goethite also point to small grain size. The cuprite aggregates are of irregular shape. Their circumference averages around 50 microns, ranging between 250 and 15 microns. Cuprite is closely associated with goethite. Comminution to ~20 microns will separate cuprite largely from goethite, although more fine grained intergrowths do occur. Separation between goethite and delafossite - tenorite will be very difficult because of the small size of the Cupro-oxide aggregates (5 - 10 microns). The amount of pyrite (less than 2% of metalliferous minerals) is insignificant for leaching purposes.

Total Cu:Cu-oxide: Total Cu=2.66%, Cu-oxides amount to 2.23%, which confirms the mineralogy of about 5% Cu-sulfides.

#8 - 215' Pale green dense rock with iron and copper oxides and gypsum on fractures and joints.

Silicate minerals: A few pyroxenes remnants in a matrix of largely alteration minerals: chlorite, sericite, gypsum. As far as composition is concerned the rock may have been a mafic igneous one.

Metallic minerals: The main metalliferous minerals are copper oxides. In this case tenorite-delafossite is more common than cuprite. Strong anisotropy and lack of intergrowths with goethite seems to favor tenorite. Only insignificant amounts (<2% of total metallics) of Cu-sulfides

(mainly digenite). Jarosite seems to be the main iron mineral.

Texture, intergrowths: Cuprite and tenorite occur in two modes: 1), Cuprite as fracture filling material, of appreciable grain-aggregate size (averaging about 80 microns). 2), Aggregates of tenorite (between 10 and 15 microns), clusters of dendritic aggregates of tenorite average around 200 microns. Cuprite will mill free, tenorite is intergrown with goethite stained chlorite. Since cuprite very typically is situated along joints and fractures, and the tenorite aggregates also line up pretty well, milling down to aggregate size will not be necessary for leaching purposes.

Total Cu:Cu-oxide: Total Cu = 3.80%, Cu-oxides = ^{3.03%} #.30%. Sulfide copper is thus even smaller than in 8 - 215'. Here, too, the observed amounts of tenorite and cuprite are in agreement with assay data.

#8 - 230' Siliceous and Kaolinitic rock.

Silicate minerals: Extremely fine grained (< 0.1 micron) glassy rock, fine grained quartz in stringers and pods and somewhat coarser crystals of quartz (1 - 5 microns). Further chlorite, white mica and kaolinite. The rock likely is an altered-silicified acid igneous rock, presumably a rhyolite.

Metallic minerals: Pyrite is the only metallic mineral, it is idiomorphic.

Texture, intergrowths: Pyrite occurs in two grain sizes; both are scattered over the rhyolite (?): a 200 - 400 micron one and a 5 - 20 micron size. There is no regularity discernable about the distribution of the pyrite. Thus either it is contemporaneous with the igneous rock or its silicification.

Total Cu:Cu-oxide: Total Cu = 0.12%, no Cu-oxides. No Cu-sulfides have been observed.

#8 - 243' Massive fine grained pyrite.

Silicate minerals: A powder sample indicated quartz and an isotropic, glassy material with very small skeleton type crystallites (presumably rhyolite glass) as the only silicates.

Metallic minerals: The rock consists for close to 80% of pyrite and about 20% of chalcopyrite, digenite (Cu 1.77 S) and silicates. Digenite is the most common copper sulfide and accounts for about 75% of the total.

Texture, intergrowths: Pyrite occurs in two ways: a coarse grained one, with idiomorphic crystals, and zonally arranged inclusions (< 0.1 micron) of silicates, chalcopyrite and more rarely digenite. Grain size averages 200 - 100 microns. The other type of pyrite consists of anhedral grains of between 5 and 20 microns with interstitial digenite (grain size < 1 micron). Both larger grains and fine-grained aggregates are broken up and veined by quartz with little or no replacement. This is followed by a second brecciation process, during which chalcopyrite has been introduced, where chalcopyrite forms the bulk of the veinlets, vein walls match, thus little replacement. These veins extend

over the whole section and thus may be quite consistent. In the section they average between 20 and 200 micron width. The sequence is closed by digenite, thoroughly dissecting the former assemblage. Digenite sometimes follows the chalcopryite veins, replacing chalcopryite, and thus being quite well physically separable from pyrite in a -50 micron fraction. Where digenite borders on fine-grained pyrite aggregates a very intricate replacement pattern exists. In the latter case only a -10 micron fraction will produce an acceptable degree of separation. An estimated 60% of the total digenite and chalcopryite can be physically separated from pyrite in the -50 +40 micron fraction. About 40% of the available copper sulfides will stay contaminated and will necessitate further grinding. The pervasive brecciation, however, will enable an upgrading of the ore by discarding the +100 micron fraction, being mainly euhedral pyrite. A chalcopryite-digenite veinlet and a digenite replacement zone is shown in figure 1.

Total Cu:Cu-oxide: Total Cu = 16.99%, Cu-oxides = 0.24%. The apparently carefully controlled ratio between chalcopryite and digenite points to equilibrium conditions prevailing over large part of the massive sulfide body, which implies that because of the present mineralogy very little oxide-copper should be expected.

#8-25B' Massive sulfide ore, coarser grain size than 8-243'

Silicate minerals: Same mineralogy as 8-243'.

Metallic minerals: Same mineralogy as 8-243', except for the rare presence of covellite.

Texture, Intergrowths: The texture is different from 8-243' to the extent that the differences in pyrite grain size are more pronounced. The coarser one averages around 200 microns and is characterized by zonally arranged chalcopryite inclusions where no fractures are present, or digenite inclusions where fractures intersect the inclusions. Inclusions are on the order of 10 microns and smaller. The bigger ones invariably are replaced by digenite, the smaller ones may have survived as chalcopryite. The fine grained pyrite shows how coarsening of grain size took place (figure 2). Figure 3 shows the concentric structure of fine grained pyrite aggregates. The initial material has a very small grain size (in the order of one micron and smaller) and corresponding digenite-pyrite intergrowths. Upon growth of the aggregates, silicate material and Cu-sulfides are removed and/or closed in as zoned inclusions. The frequency of chalcopryite in the isolated inclusions as compared to digenite points to a primordial pyrite-chalcopryite assemblage. A later increase in the partial pressure of sulfur produced the pyrite-digenite assemblage, but not yet the covellite-pyrite assemblage. At the same time any interstitial chalcopryite in the fine grained aggregates became also replaced. Only larger chalcopryite aggregates (in veins) partially survived. Grain growth, brecciation and veining are thus very important for separability of pyrite and copper-sulfides.

Total Cu:Cu-oxide: Total Cu = 24.43%, Cu-oxides = 0.31%. For reasons mentioned with 8-243', Cu-oxide content will be low.

~~#8 - 276~~ Fine grained massive sulfide ore.

Silicate minerals: Mineralogy is similar to 8-243', more silicate material, however (about 20% of total).

Metallic minerals: Mineralogy is similar to 8-243'

Texture, intergrowths: The texture is similar to 8-243', but the amount of quartz breaking up the pyrite and recementing it is larger (figure 4). In some part this process proceeded to the extent of producing scattered pyrite grains embedded in quartz. The coarse grained nature of the pyrite and the fragments of agglomerated spherical pyrite indicate a late origin for the quartz rather than part of the original assemblage. In all three specimens, 8-243', 8-258' and 8-278', the presence of replacement relicts of chalcopyrite, wherever the vein was wider than 50 microns, is striking. It indicates that the alteration was governed by a regional process rather than local (supergeneous) alteration. Compare to #20 drill core. The ratio of digenite: chalcopyrite is about 3:1. Consideration of grain size and intergrowths are the same as for 8-243'.

Total Cu:Cu-oxide: Total Cu = 15.57%, Cu-oxide = 0.20. Ore similar to 8-243'.

#8 - 303' Light colored siliceous rock, with scattered pyrite crystals.

Silicate minerals: Mainly a very fine grained or glassy rock, intersected by fine grained (<1 micron) quartz veinlets. Occasional larger quartz crystals. Similar to 8-230'. Possibly also a rhyolite.

Metallic minerals: Pyrite is the only metallic mineral.

Texture, intergrowths: Pyrite occurs in three ways: 1), concentric aggregates, reaching 50 micron diameter; 2), fine grained idiomorphic ones (5 - 20 microns) with zoned silica inclusions, and 3), large euhedral ones (100 - 200 microns). Pyrite shows a weak spacial relationship to zones of vein quartz intersecting the largely "glassy" rock.

Total Cu:Cu-oxide: Total Cu = 0.39%, Cu-oxides = 0.06%. However, no Cu-sulfides have been observed in the polished section. Some should have been visible, since even 0.1% Cu is recognizable under the microscope.

#8 - 315' Light colored, siliceous fine grained rock with black graphite streaks and many quartz-filled fractures.

Silicate minerals: Mainly dense, "glassy" material, intersected by fine grained quartz veins and intercalated with siliceous graphite streaks. Chlorite alteration products.

Metallic minerals: Pyrite in siliceous material and graphite streaks. Rutile mainly in graphite streaks. Small amounts of digenite.

Texture, intergrowths: Pyrite occurs in two ways: 1), as euhedral grains in the siliceous rocks related to the quartz veinlets similar to 8-303', and

2), as concentric agglomerates (globules average 10 microns) in the graphite-rich streak. Digenite occurs as a coating of the small pyrite spheres, or veining the larger agglomerates (up to 100 micron size). Separation of the two is virtually impossible. Only a few larger aggregates (50 - 100 microns) in the siliceous rock will mill free. The graphite streak with the spherical pyrite aggregates and disseminated copper values is quite instructive as to the original mineral assemblage although we have digenite instead of chalcopyrite). Figure 5.

Total Cu:Cu-oxide: Total Cu = 0.80%, Cu-oxides = 0.02%. This is also borne out by the mineralogy of the polished section.

#8 - 328' Light brown colored siliceous rock with iron oxide stains

Silicate minerals: Chlorite, sericite quartz, gypsum and some carbonate. May have been a more basic rock than the ones up to the massive sulfide zone.

Metallic minerals: Copper-sulfides are the main metalliferous minerals followed by iron oxides (goethite) and pyrite. The copper sulfides are digenite and covellite in a 4:1 ratio. Chalcopyrite is absent (as it should be).

Texture, intergrowths: The copper sulfides replace pyrite which presumably was very much like the pyrite aggregates in the graphite streak of sample 8-315'. Spherical copper sulfide pseudomorphs after pyrite point in this direction. Pyrite remnants are frequent; they are enclosed by digenite on all sides. Covellite replaces digenite. On the contact between digenite and pyrite a thin coating of bornite may exist. The pyrite (remnant)-digenite aggregates range between 1 and 200 microns; most frequent are sizes around 10 and 75 microns. Since copper sulfides outrate pyrite by at least 6:1, and no other intergrowths are found, the prospects of recovery should be good, if it were not for the extremely small grain size of digenite-covellite. Figure 6.

Total Cu:Cu-oxide: Total Cu = 4.64%, Cu-oxide = 2.34%. The discrepancy between the mineralogy of the polished section and the analytical amount of Cu-oxides is striking, since no Cu-oxides have been identified. Moreover, the digenite-covellite-pyrite assemblage in the absence of chalcopyrite is an equilibrium one, and would be incompatible with large amounts of Cu-oxides. Further, the difference between total copper and oxide copper representing sulfide copper = 2.3% would be too low for the actual observed amounts of Cu-sulfides.

#56 - 120' Fine grained, soft, light colored rock with iron oxide stains and malachite on joints and fractures.

Silicate minerals: Quartz and many alteration products like sericite and kaolinite. Very fine grained quartz aggregates may point to devitrified volcanic glass.

Metallic minerals: Copper almost exclusively occurs as malachite in veins and stringers. Only traces of digenite, and some tenorite. Iron oxides as goethite and secondary hematite are frequent, accompanied by

jarosite in earthy brown alteration zones. Anatase is quite frequent, occasional rutile.

Texture, intergrowths: The malachite veins and stringers extend over the whole ore. They average 80 microns width. Very little copper (less than 2% of total copper) occurs beyond the malachite veinlets as digenite. The rock is very permeable and amenable for leaching. However, there is no pyrite left. Anatase also in clusters and stringers, probably a late mineral. The brown streaks are composed of goethite-hematite and jarosite.

#20 - 160' Soft, light brown, highly altered greenstone rock.

Silicate minerals: Chlorite, quartz, goethite and other hardly distinguishable alteration products. Very fine grained material, may have been an intermediate volcanic rock.

Metallic minerals: The water-sensitive nature of the rock is indicated by clay minerals and jarosite as main constituents. Copper largely occurs as oxide (75% of total copper) native metal (15%) and only partly (10%) as sulfide. The sulfide is chalcocite (Cu_2S) or djurleite (Cu 1.96 S); they are indistinguishable. The three copper minerals cuprite-native copper-chalcocite have incompatible equilibrium conditions, which is reason to assume low temperature genesis of the oxides ($20^\circ - 40^\circ \text{C}$) and slow reaction kinetics. This is the only specimen showing chalcocite instead of digenite. The absence of pyrite is significant in this respect.

Texture, intergrowths: Cuprite and chalcocite occur in clusters, stringers and as fissure filling, featuring a reorganization of copper as compared to the primary copper distribution of the massive sulfides. Native copper is wholly contained by cuprite and seems to be confined to the "broader" veinlets (>100 microns). Figure 7. The veinlets extend over the whole polished section and range between 20 and 200 micron width and provide a useful channel way for leaching. Chalcocite occurs in 100 micron aggregates and along the same fissures as cuprite. (Figure 8)

Total Cu:Cu-oxide: Total Cu = 5.7%, Cu-oxides = 4.90%. The analytical result agrees with the mineralogical observation.

#20 - 175' Pale green, porous, very soft rock.

Silicate minerals: The only unambiguously identifiable mineral is quartz; further, we may have extremely fine quartz and kaolinite aggregates.

Metallic minerals: Copper sulfides are the only metallic minerals. They occur as accidental clusters of mainly chalcocite (up to 100 micron aggregate size) and scattered specks of covellite and digenite (1 micron diameter).

Texture, intergrowths: The small amounts of copper sulfides compared to the pervasive green color indicates that most of the copper may be present as a soluble compound.

Total Cu:Cu-oxide: Total Cu = 1.57%, Cu-oxide = 1.19%, which is compatible with the small amount of copper-sulfides observed and the green color of soluble copper.

#20 - 199' Dark siliceous rock with disseminated pyrite crystals.

Silicate minerals: Mainly quartz; in two varieties, a coarse grained vein type and a very fine grained matrix type. The latter is hard to distinguish from devitrified "glassy" material. The refractive index of the latter is lower.

Metallic minerals: Pyrite is the main sulfide, followed by sphalerite (about 2% of sulfides), chalcopryite (1% of sulfides) and digenite (insignificant). Anatase is frequent.

Texture, intergrowths: Euhedral pyrite is the main sulfide. Individual grains occur in silica matrix and in veinlets and range between 10 and 200 microns. They contain inclusions of chalcopryite (5 - 10 microns) and sphalerite (10 - 20 microns). Sphalerite also occurs as individual grains (10 - 20 microns). Tiny specks of chalcopryite within sphalerite serve to distinguish it from rather frequent anatase (with blue internal reflections). One incidental digenite-covellite aggregate has been observed (about 25 micron diameter).

Total Cu:Cu-oxide: Total Cu = 0.49%, Cu-oxide = 0.07%. Agreement with mineralogy.

#20 - 210' Massive sulfide in dark silica-rich matrix.

Silicate minerals: Quartz and very small amounts of chlorite are the only silicates.

Metallic minerals: The metallic minerals include pyrite, two kinds of chalcopryite and the main copper mineral: digenite.

Texture, intergrowths: The texture is very similar as the one described at #8 - 243', 8-258' and 8-278'. Also pyrite broken up and cemented by quartz, the assemblage being veined by chalcopryite and replaced by digenite. The degree of idiomorphy of the pyrite is higher, and crystal size of the euhedral ones is smaller (averaging around 25 microns for the group of small ones and 125 microns for the bigger ones). This implies that the amount of inseparable intergrowths is also smaller, only the 125 micron group contains inclusions of chalcopryite and digenite, which are in the order of 5 - 20 microns. The inclusions, however, do not contribute more than 1% of the total copper sulfides. The brecciation and veining by quartz also enhanced the separability of copper sulfides from pyrite since it 1), improved the idiomorphy of pyrite, and 2), dissected the fine grained pyrite, thus "liberating" interstitial copper sulfides. However, with the reduction of pyrite-copper sulfide intergrowth we also increase the digenite-quartz intergrowths (figure 9). This sample is particularly rich in copper. The introduction of digenite proceeded into a stage that 1), only in the wide (>200 microns) patches of digenite some chalcopryite is left

and 2), pervasive veining of pyrite by digenite into a -20 micron scale. This implies that absolute separation of pyrite and digenite is only possible in a -25 micron fraction. The same holds for the quartz digenite intergrowth. Complete separation can only be realized in the -25 micron fraction. Satisfactory separation (80% recovery) of digenite from quartz and pyrite will already be achieved in a -50 micron fraction, whereby 15% of total digenite-chalcopryrite will be lost in the pyrite fraction and 5% in the quartz fraction.

Total Cu:Cu-oxide: Total Cu = 10.54%, Cu-oxide = 0.09%. Polished sections are not necessarily representative for the core or ore assay. This section by far is the most copper rich and may contain up to 25% Cu, however, its assay apparently is lower. Mineral ratios are more reliable than absolute figures.

#20 - 218' Massive sulfide in dark silica-rich matrix, with copper oxide coatings on joint planes.

Silicate minerals: Quartz is the major silicate.

Metallic minerals Two generations of pyrite, two modes of chalcopryrite, digenite and sphalerite.

Texture, intergrowths: Apparently very little movement of material has taken place in this sample. Only very large pyrite aggregates (>400 microns) show signs of being broken up and cemented by quartz. About half of the pyrite is still in the fine grained spherical agglomerate stage. The latter contains digenite interstitially and in clusters (up to 25 microns). Substantial part of the copper sulfides (about 20%) occurs as inclusion in the coarse pyrite crystals. The inclusions average 10 microns in diameter. (Figure 10). They are largely chalcopryrite. Digenite aggregates larger than 30 microns normally contain chalcopryrite in their center. The coarser aggregates occur interstitially between the idiomorphic pyrite. As inclusions or interstitially digenite and chalcopryrite are closely associated with sphalerite, which is another indication for the mobility of copper-sulfides in this sample. With an idiomorphic pyrite: globular microcrystalline pyrite ratio of 1:2 the outlook for the separation of digenite is considerably inferior to sample #20-210' (figure 11).

Total Cu:Cu-oxide: Total Cu = 11.96%, Cu-oxide 0.20%. Results are compatible with mineralogy.

#20 - 225' Pale green, soft, porous rock with pyrite streaks and iron oxide stains.

Silicate minerals: Fine grained quartz, coarse grained quartz and kaolinite are among the few minerals identifiable in a powder.

Metallic minerals: Pyrite is the main sulfide. It contains small inclusions of sphalerite and chalcopryrite. Individual Cu-sulfides have not been

recognized. Alteration products point to chrysocolla, possibly also other soluble copper-salts.

Texture, intergrowths: Large pyrite crystals (100 - 300 microns) in the streak. Inclusions of sphalerite average 10 microns.

Total Cu:Cu-oxide: Total Cu = 1.17%, Cu-oxide = 0.74%. Results agree with mineralogical observations.

#20 - 230' White, porous, soft rock.

Silicate minerals: Quartz, sericite, kaolinite and alkali-feldspar remnants.

Metallic minerals: Pyrite, covellite, goethite and anatase, and green Cu-stains.

Texture, intergrowths: A few single large (>100 microns) pyrite crystals coated by covellite. Further goethite skeletons, and scattered anatase crystals. Insignificant copper mineralization. Comparable to #8-303' and #20-175'.

Total Cu:Cu-oxide: Total Cu = 0.36%, Cu-oxide 0.27%. Compatible with the mineralogy of the polished section.

#20 - 247' Light colored siliceous rock with black graphite and yellow kaolinite streaks.

Silicate minerals: Mainly quartz: vein quartz and micro-crystalline aggregates. Further almost isotropic glassy material, kaolinite and graphite.

Metallic minerals: Pyrite, fine grained (10 - 20 microns) in the black streaks, coarse grained (20 - 100 microns) in the white siliceous rock. Copper minerals include digenite and small amounts of covellite. Further goethite and unidentifiable iron oxides-hydroxides.

Texture, intergrowths: Rock is very similar to #8-315'. Pyrite in white silica-rich material is euhedral, and is accompanied by larger specks of digenite (20 - 50 microns). In the black streaks pyrite is mostly spherical and replaced by digenite. Digenite aggregates are in the order of 5 - 20 microns. Separation may be very difficult, since all stages of pyrite replacement are present, from fracture filling to pseudomorphs.

Total Cu:Cu-oxide: Total Cu = 0.68%, Cu-oxide = 0.21%. The unidentified Fe-oxides and hydroxides may carry the Cu-oxide values in an adsorbed form.

#20 - 265 Light brown colored porous and soft rock (greenstone)

Silicate minerals: Fine grained quartz, mainly in veinlets. Further iron-oxides, jarosite, gypsum, kaolinite and sericite.

Metallic minerals: Pyrite and insignificant amounts of digenite-covellite-bornite-chalcopyrite.

Texture, intergrowths: Digenite is the major copper mineral. It replaces pyrite and chalcopyrite and occurs as scattered grains of 5 - 25 micron diameter. Only rarely is it larger. On the border between digenite and pyrite a coating of bornite may be seen.

Total Cu:Cu-oxide: Total Cu = 5.44%, Cu-oxides = 3.95%. As in sample #8-328', we are faced again with a significant discrepancy between the observed mineralogical composition and the assay values. The assemblage also hardly leaves space for considerable amounts (that means not occluded in an inert phase) of Cu-oxides under the same equilibrium conditions. Moreover, the difference between 5.44% and 3.95% = 1.43% is definitively too small to account for the observed quantities of Cu-sulfides.

The only relevant aspect may be the feature (also displayed by #8-328) that even after one day of exposition to (even dry) atmospheric conditions the sulfides seem to effloresce into numerous small Cu-oxide blooms. This process is greatly enhanced by the focusing heat of the microscope lamp. I do not know the reason for the phenomenon, but I presume that the analytical Cu-oxide values are related to it, and that oxide coating of sulfide particles will both inhibit flotation and not be completely leachable either.

III. Evaluation of the results, summary

1. The nature of the copper values. Five types of copper mineralization have been distinguished

- a. A carbonate type. Malachite is the major copper mineral in the drill core #56 - 120', which is closest to the surface of any sample investigated.
- b. Oxide copper mineralization prevails in the upper sections of the #8 and #20 drill cores. Copper values are in the 1 - 5% bracket. The mineral assemblages include cuprite - native copper or tenorite-cuprite with or without digenite (Cu 1.77 S) or chalcocite. These are stable assemblages for low S- and CO₂-partial pressures (absence of covellite and malachite)
- c. A disseminated pyrite-chalcopyrite association, altered or not into pyrite - chalcopyrite - digenite. Copper values are in the 1 - 5% bracket. This type is found above and under the massive sulfide zone, characterized by siliceous wall rock.
- d. A massive pyrite - chalcopyrite - digenite type, with insubordinate amounts of silicate material. Copper values are from 10% up.
- e. A digenite covellite association with pyrite only as replacement remnants. Copper values are in the order of 1 - 5% Cu. This type is found near the bottom of the cores (#8-328' and #8-265'). Chemical analysis showed copper to occur mainly as oxides or soluble copper, whereas the mineralogical investigation indicated mainly copper sulfides. This discrepancy may be due to a sampling error, soluble copper from formations above being leached down and absorbed in the highly porous rock. However, if we subtract from the total copper values the amount of supposedly oxidized copper the resulting figure is too small to account for the copper-sulfides actually observed.

It has been suggested in section II that the efflorescence of digenite into copper oxides even after short atmospheric exposure may result in an apparent copper oxide content when leached.

2. The classification of the copper ores.

There exists a certain relationship between the nature of the copper values and the host rock. One can recognize three types:

- a. The massive sulfide type, characterized by an absence of any major silicate host-material, but small, younger, quartz veins. Apparent thickness varies between 20 and 40 feet.
- b. The highly siliceous zones immediately above and under the massive sulfide zone. Depending upon the situation the apparent thickness varies between 20 and 30 feet. The host rock is an acid volcanic extrusive or intrusive rock, because of the frequency of quartz (unless the rock is silicified later) and the presence of isotropic glassy material. Intercalated are graphite and possibly other

streaks of sedimentary origin. The mineralization is of the disseminated pyrite - chalcopyrite - digenite type. Ore grades are low to intermediate.

- c. The third type is characterized by a more basic nature of the volcanic. Rocks are rich in chlorite, sericite and carbonate, and also sulfates (like jarosite, gypsum). They are highly altered, and may represent andesite volcanic intercalation. Under the same metamorphic conditions (green schist facies) the effects of mineral changes are more pronounced with intermediate and basic rocks than with siliceous ones. The rock is very porous compared to type 2a and 26 and one should take into account the possibility of adsorbed metal values that are easily leached. The mineralogy is of the types 1a, 1b or 1c.

3. Grain size intergrowths and the evolution of the ore body

One can distinguish between two types of intergrowths

- a. One, that is the result of progressive grain growth, and an internal reorganization of material, and
 - b. Another that is the result of bodily replacement of an earlier mineral by a later one.
- ad a. The intergrowths that are the result of grain growths are closely related to the evolution of the massive sulfide body. Initially we had an extremely fine grained spherical pyrite, similar to figures 5 and 11, with interstitial copper as chalcopyrite similar to the figures 2 and 3. These intergrowths were maintained even through a later stage of chalcopyrite replacement by digenite. The result is an aggregate where copper and pyrite separation is impossible (one micron scale intergrowth). Part of the pyrite shows grain growth at the expense of the spherulitic pyrite, such as evidenced by the concentric arrangement of micro inclusions in the core of the now euhedral pyrite. These inclusions quite often are copper sulfide, and are inseparable. Further, we notice that when the pyrite grew beyond the 50 micron stage, inclusions grew bigger, but still hardly exceeding the 5 micron size (figure 4, a large one, and the figures 5, a series of small ones) are also hardly separable from pyrite.

It is finally the brecciation and cementing by quartz that improves the separability of copper sulfides from pyrite. Copper sulfides tend to assemble into individual aggregates once the pyrite is fractured (figure 9). The quartz-copper sulfide intergrowths also tend to be fine but still are larger by one order of magnitude (5 - 10 microns) compared to the inclusion in pyrite.

A later reorganization of the copper-sulfides greatly enhanced the situation. The veining by chalcopyrite, later replaced by digenite (the figures 1 and 9), led to a coarse grained assemblage.

In view of the high copper values (exceptional for a massive sulfide), I presume that a large part of the copper has been introduced and is not just a local reorganization. Our studies of metamorphic massive sulfide deposits indicate that the mobility of copper is appreciable. Copper tends to be concentrated in the apical parts of massive sulfide ore bodies.

I may suggest that you look into your files for data about the Macuchi massive sulfide deposit in Ecuador. I studied the deposit some years ago, and found many similarities.

- ad b. The replacement type of intergrowths is a rather simple situation. Where it concerns sulfides, the mineral replaced is chalcopyrite or pyrite. Since the pyrite normally is completely enveloped by copper sulfide the flotation characteristics will be that of the copper sulfides (digenite or covellite).

Because of the disseminated and fine grained nature of the pyrite separation is virtually impossible (figure 6).

The replacement by copper oxides, such as may be the case in the deeper levels #8-328, and #20-265, will cause considerable difficulties, since the floating characteristics will be that of oxides, and the leaching characteristics that of sulfides.

Replacement of Cu-oxides by native copper or others is of less concern, since the aggregates will be treated anyhow as oxides.

4. The influence of fractures and joints.

The influence of fractures and joints is of two kinds

- a. They influence the way the mineral aggregates will break upon milling and separate from host rock.

As mentioned under 3a, the brecciation and cementing by quartz played a major role in the separation process of pyrite and copper sulfides. It will also be important in delineating planes of rock failure during size reduction.

If the physical separation can be made it may be useful to treat the coarse grained pyrite-digenite vein association differently from the spherical pyrite type, since equal treatment may result in a loss of copper sulfide because of over-grinding.

- b. The fractures and joints also are important as aspects of leaching characteristics. The former andesites (upper, and lower most copper mineralization) are most suitable for leaching since the rock is highly porous and intensely fractured. The silica rich disseminated ore types are less amenable to leaching extraction.

New York, January 7, 1969

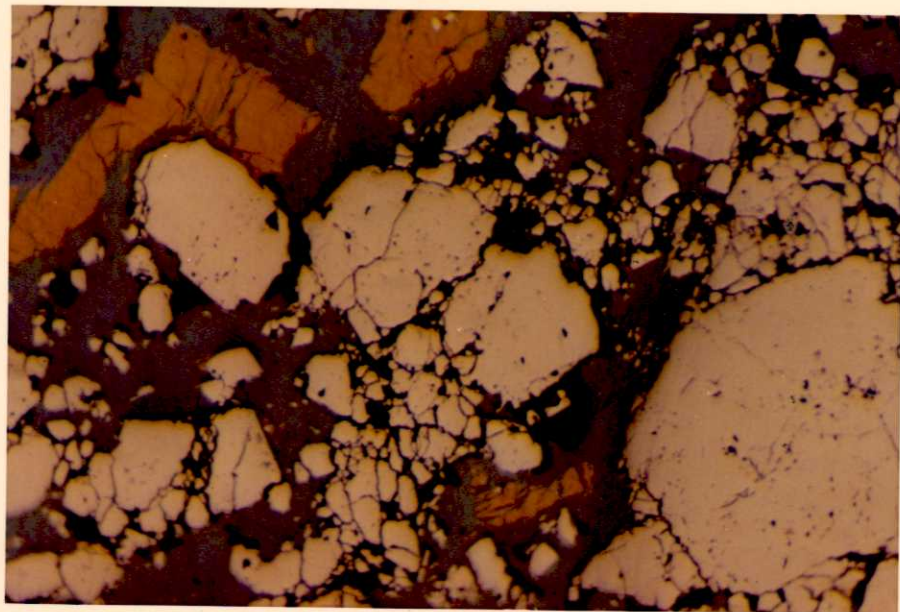


Figure 1, 8-243', 200x
 Pyrite (bright yellow) broken up and cemented by quartz (black) cut
 by chalcopyrite (golden yellow) which in turn is replaced by digenite
 (blue).

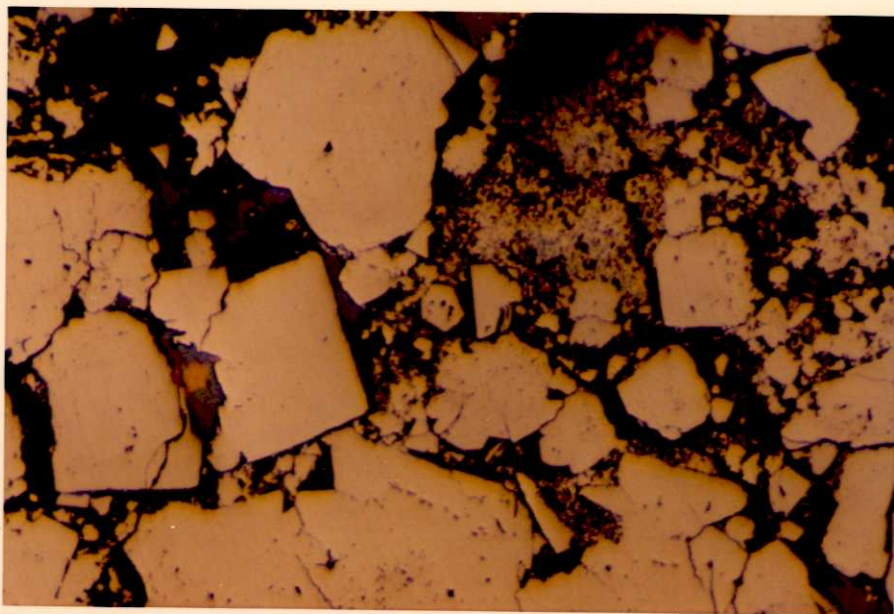


Figure 2, 8-258', 200x
 Pyrite (bright yellow dissected by quartz (black), which assemblage is cut
 by chalcopyrite (golden yellow, red index). The latter is replaced by
 digenite (blue). Note very fine grained pyrite with interstitial digenite
 (blue index). The idiomorphic pyrite shows chalcopyrite inclusions (green
 index) arranged in a zonal fashion.

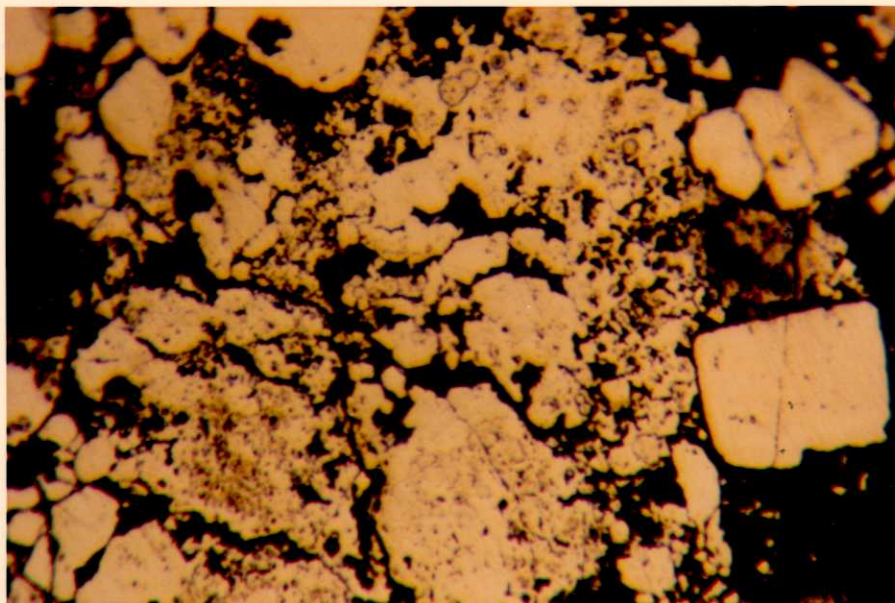


Figure 3, 8-258', oil immersion, 310x

Spherical pyrite (bright yellow) aggregates, with concentric zoning of digenite (blue, blue index). The pyrite crystals and aggregates are dissected and cemented by quartz without significant replacement (vein walls match).

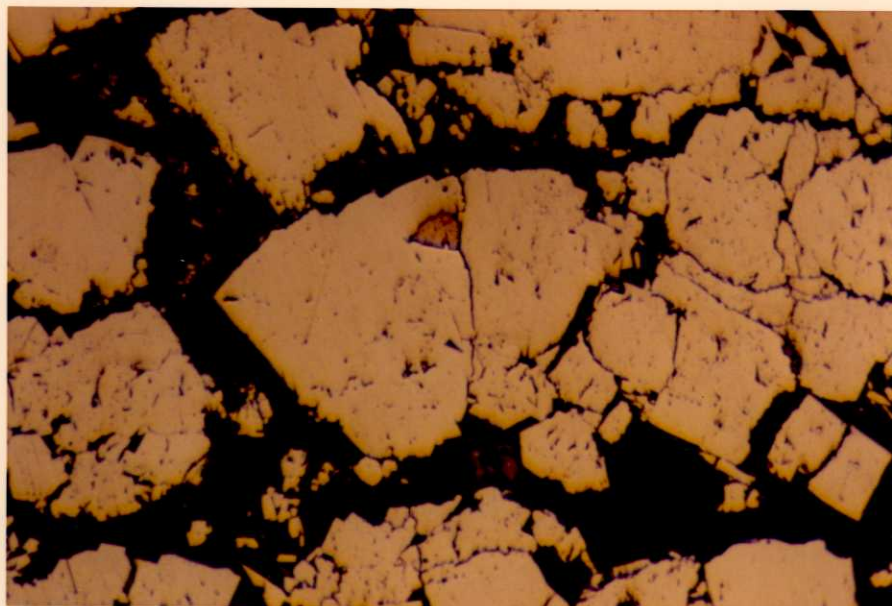


Figure 4, 8-278', 200x

Pyrite (yellow), with inclusions of chalcopyrite broken up and cemented by quartz (black). Notice that vein walls match - little replacement.

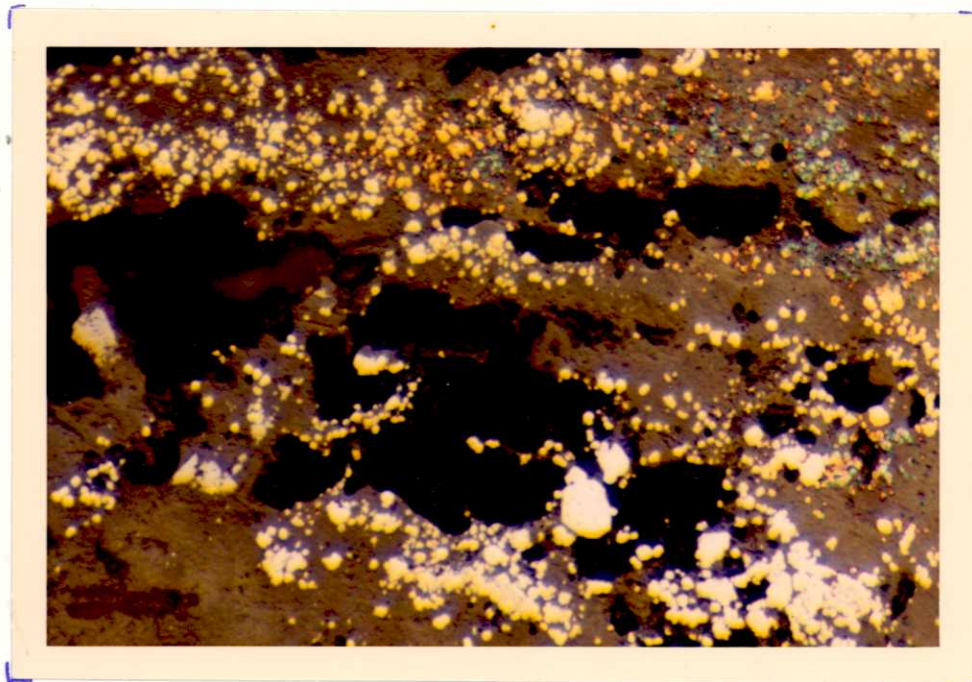


Figure 5, 8-315, 200x
Fine grained spherical pyrite (white-yellow with yellow or blue coating)
in graphite streak. The blue coating is digenite.

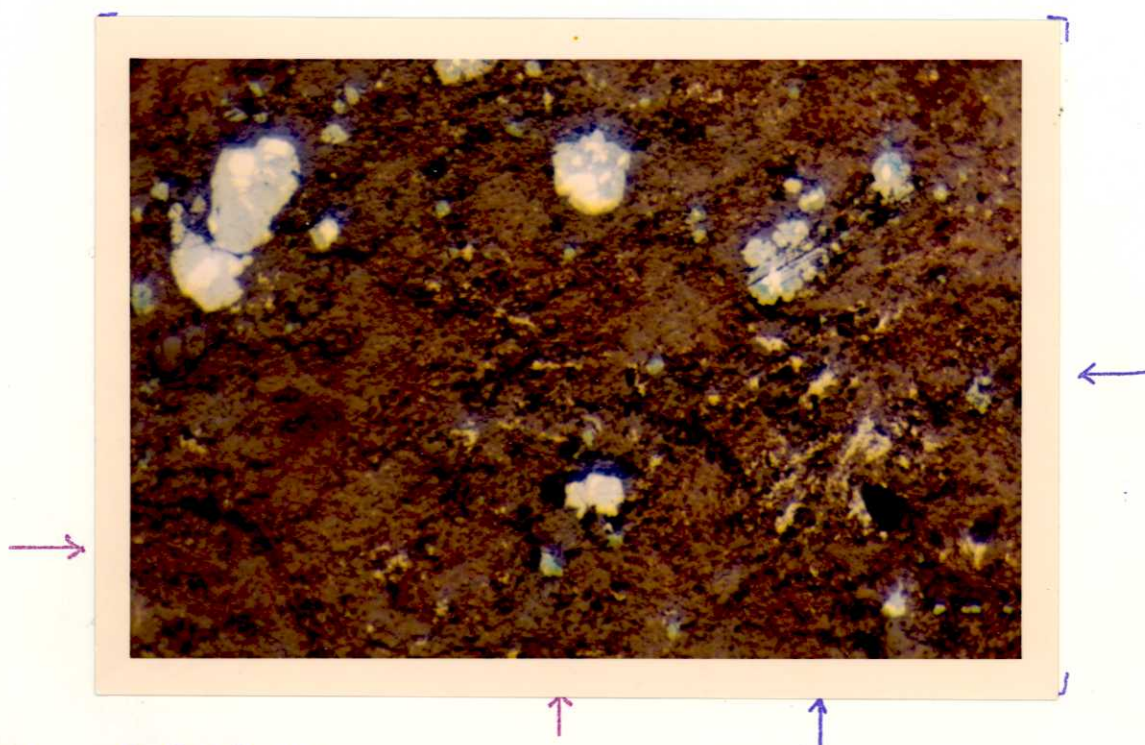


Figure 6, 8-328, 200x
Pyrite (white) only occurs as replacement remnants in digenite (pale blue) and
covellite (deep blue-red index). Note the ragged outlines of goethite (blue
index). On the border between digenite and pyrite or also apparently at random
within the digenite a strong light source or extended atmospheric exposure
causes the digenite to effloresce into a powdery Cu-oxide.



Figure 7, 20-160', 200x
 White cuprite yielding to (?) or replacing native copper (iridescent colors). Usually native copper does not build such large aggregates, but appears as numerous specks in cuprite.



Figure 8, 20-160', 200x
 White cuprite with some native copper specks (red tarnish), close to chalcocite (blue-gray). The poor polish is due to the water sensitivity of the sample, spoiling the polishing cloth.

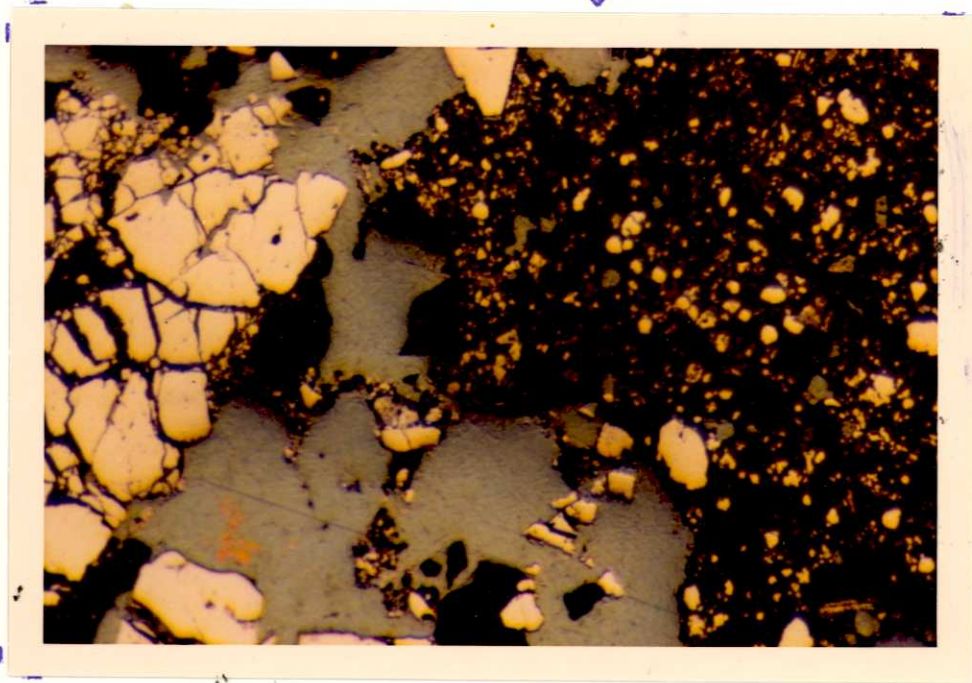


Figure 9, 20-210', 200x

Euhedral pyrite (bright yellow) broken up and cemented by quartz (black). The small globular aggregates and fine pyrite spheres in the upper right corner do not feature this brecciation. Later chalcopyrite (golden yellow) veined this aggregate, resulting also in close quartz-digenite intergrowths (blue index).

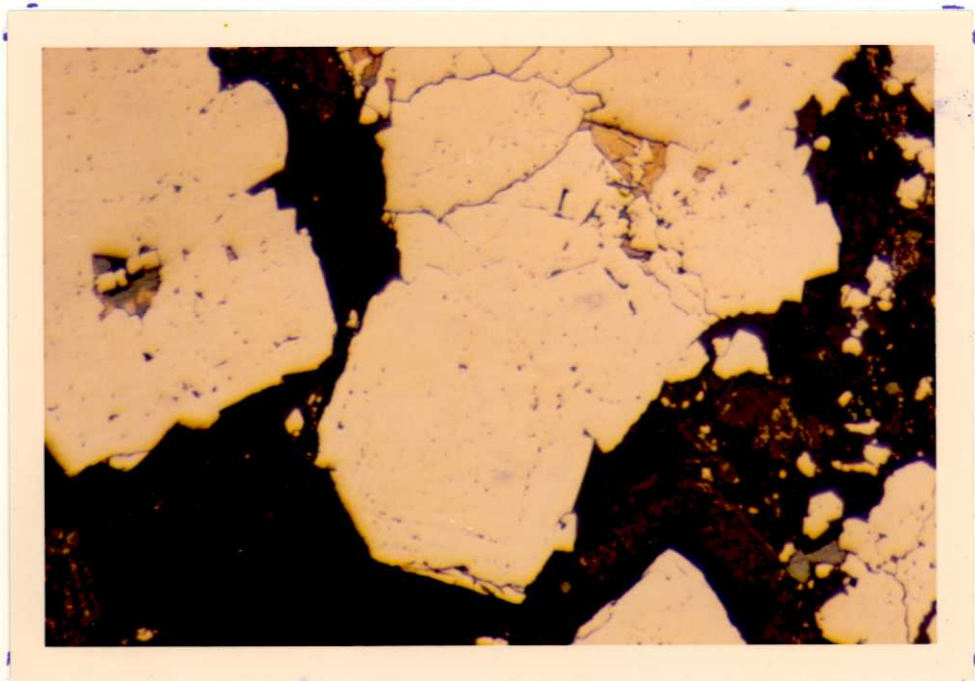


Figure 10, 20-218, 200x

Large inclusions of chalcopyrite (golden yellow) and digenite (blue) in pyrite. Notice also zoned inclusions of chalcopyrite (blue index).

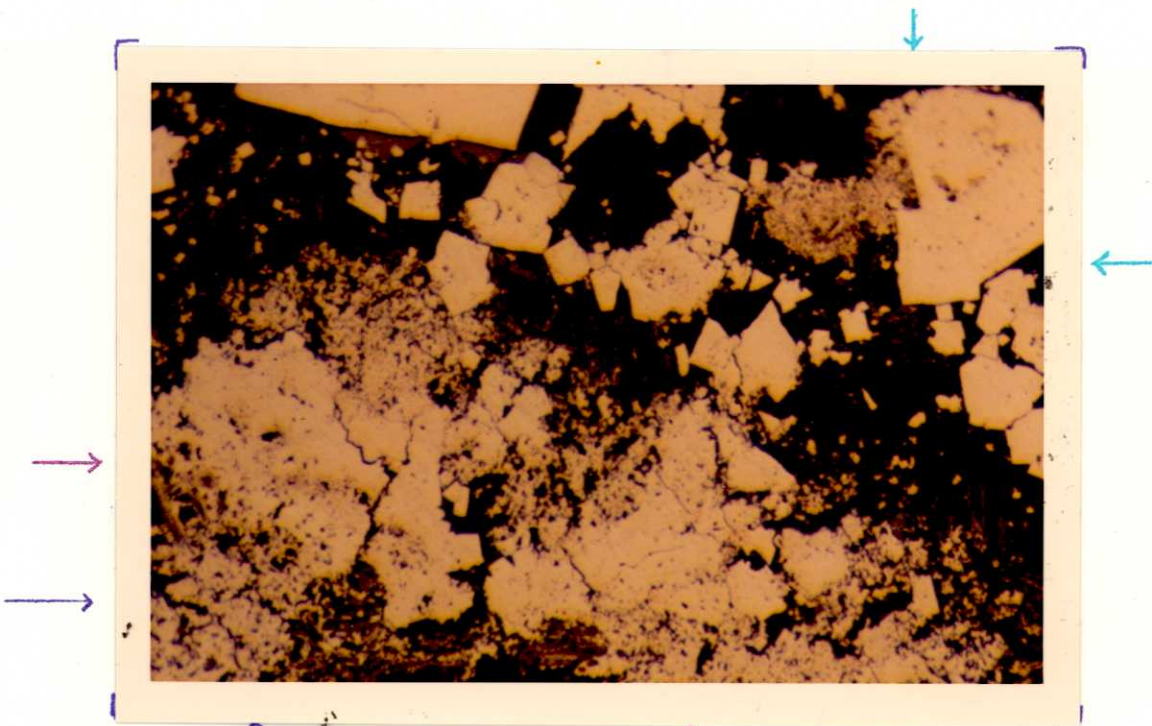


Figure 11, 20-218, 200x

Three types of pyrite: extremely small spherical particles (blue index). Agglomerates of spherical particles still with circularly arranged inclusions (red index) and euhedral pyrite (green index). As far as the separation of copper is concerned the last stage is the most desirable.

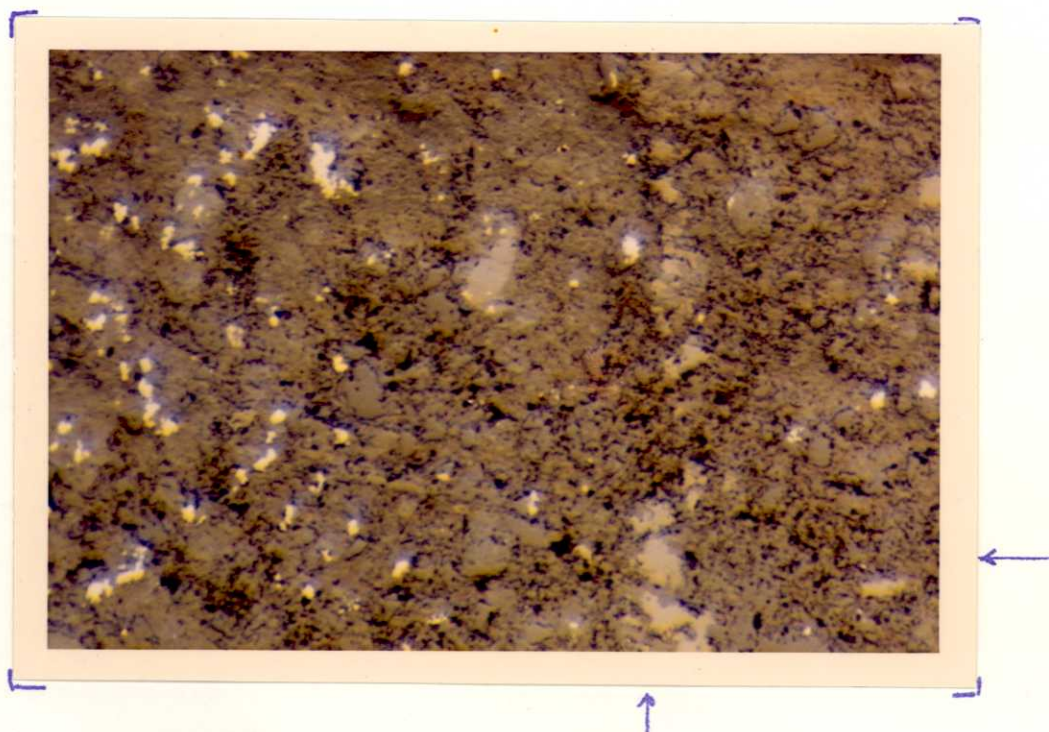


Figure 12, 20-275, 200x

Disseminated chalcopyrite (yellow, red index) and rutile (white) in a matrix of chlorite sericite and quartz (dull grey) and carbonate (dolomite, blue index).