Fool's Gold- Pyrite Tells the Smart Things about Jinguashi Gold Mine

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Abstract

Pyrite, commonly known as "fool's gold", is a common mineral in all kinds of rocks, and is rich in many gold mine areas. Therefore, previously, the pyrite content was used as an important indicator of exploration of gold mines.

In addition to the amount of content, pyrite can reveal many important messages of gold mine, for example: pyrite crystal forms in different environments are different. Crystal size and internal trace elements of pyrite will also vary with the depth of ore body. By careful study of their crystalline forms and other element content, we can know the ores belong to the top or bottom of the gold mine and other important information.

This study conducts the geochemistry study of the pyrite samples taken from different ores at different depths of the occurring environment, and summarizes the gold mine messages displayed by these pyrite samples.

Keywords: pyrite, Jinguashi-Jiufen gold mine, geochemistry

1. Introduction

The main component of pyrite (Figure 1) is FeS_2, and it is one of the main mineral raw materials to extract sulfur and manufacture sulfuric acid. Because of its special shape and color ornamental value, some gemstones of polished pyrite are also very popular.

The pyrite can be generated by magmatism, hydrothermal solution or sublimation heat or in metamorphic rock and sedimentary rock, and it is a common mineral in nature. It is abundant and widespread in Jinguashi-Jiufen and other gold mine areas.

As the color of pyrite is of shiny golden yellow, it is often mistaken for gold, and it is commonly known as fool's gold. In fact, pyrite and gold have big differences. They can be easily distinguished through several simple methods in the field and thus we can avoid being fooled by the "fool's gold".

1. Color: although pyrite is also shiny yellow, but it's usually more whitish, unlike gold of a little yellowish with orange.

2. Streak: namely, regarding the color of the mineral powder, you can use a hard object to scratch the mineral surface, or scratch the sample on the surface of the white unglazed tile, the powder scraped off gold will be of a gold -colored, but the pyrite powder is black.

3. Crystal habit: pyrite often occurs with beautiful crystal shape while gold is generally of irregular shape; therefore, the one with good crystal faces is probably pyrite.

4. Specific gravity: the specific gravity of pure gold is 19.3, although the specific gravity is about 19.3-16 because of silver content, it is still 3-4 times of pyrite (about 4.6~5.2). We can find out the difference by taking it in hand or panning.

5. Brittleness and ductility: by hammer tapping, pyrite can shatter easily while gold will become flat.

It is best to identify by the comprehensive application of the above methods to increase its accuracy to avoid false judgment of the gold as pyrite.

In fact, pyrite is not born to fool. Pyrite in gold mine area often contains gold. For example, the author has found in study that the gold content of pyrite around Xiaojingua can be up to 100 ppm, such gold-bearing pyrite is also an important material for extraction of gold. However, pyrite must undergo calcination before the extraction of gold. In the early times, pyrite from Jingguashi was sent to Taiwan Fertilizer for calcination as raw materials for manufacturing sulphate fertilizer before getting back the alchemical slag to Jinguashi for gold-refining.

【Figure 1】Gold mine is often associated with rich fool's gold-pyrite

2. Geochemistry of Pyrite

Pyrite is the most widely distributed sulfide, hydrothermal ore can generate massive or vein pyrite by precipitation. By the laboratory synthetic and mineral sequential study, it can be learnt that the temperature and pressure and chemical environmental conditions for the generation of pyrite are wide, and the pyrite can be easily seen in hydrothermal deposits (Boyle, 1979).

Auger (1941) studied pyrite trace elements in many of Canada's gold mines, reaching the following conclusions:

1. In the same ore, ore groups or mining area, some trace elements of pyrite will be far more than other elements.

2. The type of deposits and mineralization temperature will affect the nature of trace elements of pyrite.

3. The nature of the rock does not have a significant impact on the distribution of trace elements in pyrite.

Fleischer (1955) summarized the analysis results of a number of scholars of trace elements in pyrite, and the possible meanings of a number of elements. The more clearly related to the environment and mineralization are listed as follows:

1. Cobalt and nickel contained in pyrite will increase with rising mineralization temperature; however, the silver content is just the opposite.

2. Pyrite vanadium content increases with depth, but zinc content is the opposite.

3. Pyrite with higher zinc content is usually in mineralization environment of more manganese; pyrite with higher copper content is usually in mineralization environment of less manganese.

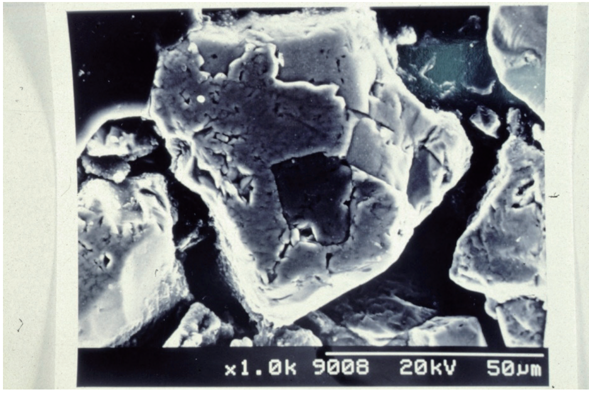
4. If the copper content of pyrite is higher, the nickel content should be lower.

Takahashi (1963) studied the near-surface deposits of different temperature, finding that ore fluid boiling caused by drop of pressure in the ore-forming environment can result in the phenomenon of concentration and differentiation of arsenic, antimony, germanium, gallium, thallium, molybdenum and other volatile elements; he also pointed out, if the pyrite contains higher content of bismuth, cobalt, tin , indium and other elements, it may indicate that the ore is the product of different temperature environments.

Vakrushev & Tsimbalist (1967) argued that pyrite is a mineral that can directly indicate gold-quartz type and gold-skarn gold mines. Santos & Walters (1971) found that pyrite around the gold mine contains more precious metals. Boyle (1979) pointed out that pyrite is the ore the second highest content after quartz in general gold mine. Its content is even higher than quartz in some gold mines.

Herbert (1987) found that pyrite trace element content is not exclusively and related to the content of each element in the solution but related to the activity of each element. Each element's activity depends on the temperature, the partial pressure of sulfur gas, pH ... and so on. The pyrite content of trace elements can directly reflect the environment of generation.

Since pyrite can be easily found in gold mine and can be generated in various periods of mineralization, coupled with the extremely good capability of containing trace elements, it can keep the clues of the chemical environment of mineralization by adsorption, inclusions (Figure 2) and lattice replacement, therefore, pyrite is indeed an excellent geochemistry tool to tell us many smart things about gold mine.



【Figure 2】Pyrite can keep the clues of the chemical environment of various stages of mineralization by adsorption, wrapping and lattice replacement, and thus it is an excellent tool for geochemistry exploration. The SEM image of pyrite indicates that it contains the inclusions of other minerals.

3. Jinguashi Pyrite's Geochemistry

This study analyzes the trace element content of 23 pyrite samples from different deposits at different depths in Jinguashi and Jiufen areas to explore the relationship between the geochemistry characteristics and gold-copper deposits.

(1) Cobalt (Co), Nickel (Ni)

In the periodic table, cobalt , and nickel come closely after iron, belonging to the transition elements (Ⅷ B family), their sulfides: Cotterite (CoS_2) and Vaesite (NiS_2) have the same lattice structure with pyrite (Ribbe, 1982), the three can replace each other in solid solution (Nickel, 1970). Due to the close relationships in between iron, cobalt and nickel, cobalt and nickel has always played an important role in the study of trace elements in pyrite.

Many scholars studied the relationship between cobalt, nickel content and cobalt/nickel ratio and pyrite generation temperature, depth and causes, and the results are as summarized in Tables 1 and 2. It is generally believed that the cobalt, nickel content and cobalt/nickel ratio tend to rise with increasing depth or temperature. If the cobalt content and cobalt/nickel ratio is higher, it means higher probability of pyrogenesis. Huang & Chiu (1979) argued that pyrite cobalt, nickel content in the Jinguashi area can be compared with the three-phase mineralization of Jinguashi proposed by Wang (1973).

In this study, the pyrite nickel content obviously increases with the increasing depth in the case of deposits of Benshan, Changren and Xiaojingua areas in the same trend as found by Huang & Chiu (1979). However, Py11 (Jijiang ground surface) and Py17 (Beiwudangshan area) were not taken from the bottom of the ore, and the depth is relatively not deep. The nickel content is up to 300~400ppm, therefore, depth is not the only factor of pyrite nickel content.

Bezman & Tikhomirova (1975) argued, in the case of pyrite generated in carbonate solution, cobalt/nickel ratio will increase with increasing temperature. If pyrite is generated in the halogen solution, its cobalt/nickel ratio will decrease with increasing temperature; cobalt/nickel

【Table 1】The relationship between cobalt and nickel content of pyrite and temperature and depth as suggested in previous studies

	Changes in the element content of pyrite over generation depth and increase in temperature		
	cobalt	nickel	cobalt/nickel ratio
Gavelin & Gabrielson (1947)	content increases with rising temperature		cobalt/nickel ratio increases with rising temperature
Hawley (1952)	content increases with rising temperature		cobalt/nickel ratio increases with rising temperature
Fleischer (1955)	content increases with rising temperature	content increases with rising temperature	
Johnson (1972)	content increases with rising temperature		
Yeremin, et al. (1977)			cobalt/nickel ratio increases with rising depth
Huang & Chiu (1979)	content increases with rising temperature	content increases with rising depth	

【Table 2】Pyrite cobalt/nickel ratio and causes as suggested in previous studies

Literature	sedimentary generation	hydrothermal generation	Magma generation
Carstens (1942)	Co<100ppm. Co/Ni<1	Co=400~2400ppm. Co/Ni>1	
Hegemann (1943)	Co<100ppm. Co/Ni<1		
Berg & Friedensburg (1944)		Co/Ni=0.1~1	
Talluri (1951)	Co/Ni<1		
Fleischer (1955)		Co/Ni>1	
Loftus-hills & Solomon (1967)			Co/Ni>1
Youh (1971)		Jinguashi Co/Ni<1	Yuli Co/Ni>1
Tan (1972)			Yangmingshan Co/Ni>1
Huang & Chiu (1979)		Jinguashi Co/Ni<1	Central Mountain Range Co/Ni>1

ratio is not only determined by the content of cobalt, and nickel in the original solution but also determined by the content of sulfur, oxygen, carbon dioxide and chloride. In other words, at the same temperature, pyrite cobalt and nickel content will change as the properties of solution may change.

According to Huang & Chiu (1979), pyrite cobalt and nickel content are related to different mineralization periods, that is, ore fluid properties will affect the cobalt and nickel content in pyrite. Therefore, the properties of the ore fluids that generated pyrite in Jijiang surface ground and Beiwudangshan areas will be different.

As the nickel content of pyrite in the central area of mineralization will be higher than the peripheral areas and non-mineralized area, the pyrite with higher nickel content indicates the mineralization, but not in a significant way.

In this study, the cobalt content increases with increasing depth in Niufugui deposit area, and the trend is not obvious in other areas. Ni (1983) pointed out that the relationship between the distribution of the abnormal pyrite with cobalt content in Jinguashi and the known mineralization belt is not clear. Although the average content in the mineralization area is higher than the peripheral areas, the relationship is not clear.

Regarding the cobalt/nickel ratio, Py20 (Lilao) is greater than 3, Py14 (Jijiang group) is greater than 2, the rest are smaller or equal to 1. The findings are the similar with the results of Youh (1971) and Huang & Chiu (1979). The relationship between cobalt/nickel ratio and depth is unknown as the changes of cobalt content are irregular.

The comparison of the cobalt content and nickel content of pyrite suggests that the cobalt and nickel content cannot reflect the three-phase hydrothermal mineralizations, and the results are quite complex. Since a number of Pacific-rim gold mines similar to Jingguashi in the Philippines and Indonesia have the mineralization of more than 4-5 phases (Comsti, et al., 1990; Cooke & Bloom, 1990; Van Leeuwen, et al., 1990), Jinguashi mineralization also may be more complex than the known patterns.

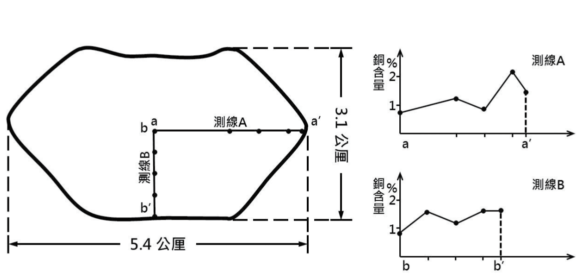
(2) Copper (Cu)

According to Fleischer (1955), pyrite contains copper and the pyrite generated by hydrothermal reaction will have higher copper content than pyrite generated by sedimentary. According to Tan & Yu (1968), in the copper mine area of Jinguashi, the copper content is about 1000~1700 ppm; the copper content is about 40~480 ppm in gold mine area; and it is about 100~120 ppm in the non-mineralization area.

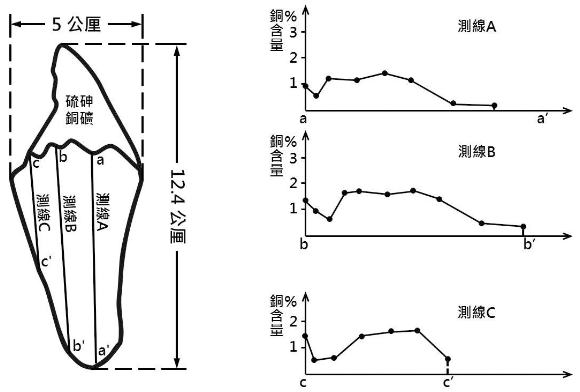
Copper can exist in the form of solid solutions or inclusions in pyrite. Youh (1971) found inclusions in the pyrite with copper content of 10000 ppm in the Haisushan area. Folinsbee, et al. (1972) studied the pyrite of Jinguashi, arguing that the pyrite with high content of copper and arsenic content has optical anisotropy. It is thus inferred that copper and arsenic occupy lattice positions. On the other hand, it is also found that the azurite inclusions. Huang & Chiu (1979) pointed out that the lattice length of Jinguashi pyrite will increase with increasing content of cobalt, nickel, and copper.

In this study, the author uses the electron micro probe and emission spectrograph to analyze the copper content and distribution in pyrite, and the micro probe to test the inclusions of copper ore. The samples Py4, Py5 contain about 1% of copper. If the copper is in the form of chalcopyrite or enargite, the entire pyrite sample should contain nearly 3% chalcopyrite or 2% enargite. However, the X-ray diffraction studies have no diffraction peaks of chalcopyrite or enargite or luzonite. Moreover, the arsenic content of the two samples is far lower than the copper content. This also suggests that the copper cannot exist entirely in the form of enargite. Therefore, copper should exist in the pyrite by replacing iron.

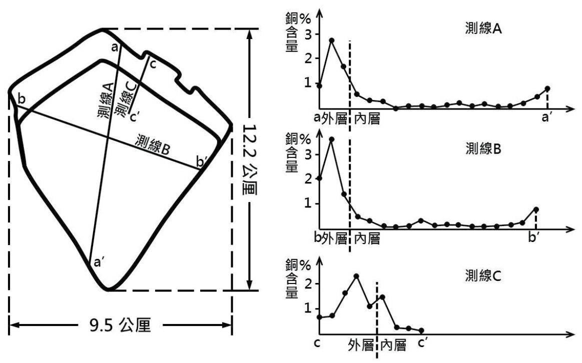
Folinsbee, et al. (1972) and Chen (1986) pointed out the uneven distribution of copper in pyrite. The results of this study show that the distribution of copper in most small pyrite crystals is more uniform. However, in the case of some larger crystals or samples of dual-layer crystals, the copper content changes at the center and the edge. For example, in the case of samples Py4, Py5, Py7 (Figures 3, 4, and 5) the copper content at the edges is greater than that of the center. In particular, in the case of Py5 sample, the copper content in the outer layer is apparently higher than that of the inner layer. In the case of Py16, the copper content at the center is greater than



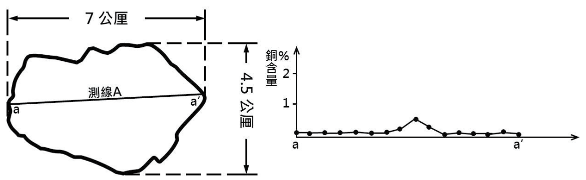
【Figure 3】Py4 (Benshan 7th adit Erzhong Guanyin mine) pyrite sample's electron microprobe analysis measuring lines.



【Figure 5】Py7 (3rd Changreng adit) pyrite sample's electron microprobe analysis measuring lines.



【Figure 4】Py5 (8th adit of Benshan) pyrite sample's electron microprobe analysis measuring lines.



【Figure 6】Py16 (central Xiaojinggua) pyrite sample's electron microprobe analysis measuring lines.

that of the edge (Figure 6). The changes in the copper content of pyrite suggest that the ore fluid contents or temperature changes during the pyrite generation process. Py5 more apparently suggests that the area has undergone more than two periods of ore fluids of different properties. The first ore fluid is lower in copper content as compared with the second ore fluid. The former can represent the pyrite formation period before mineralization and the latter can represent the gold-copper mineralization period.

The Py13 sample's pyrite is coated with enargite. The micro probe analysis suggests that the pyrite generated in earlier period contains less copper and the copper content increases apparently late on. However, the copper content dramatically decreases at locations close to the enargite ore and rises again at the contact edge with enargite ore. This may be caused by the precipitation of copper at the edge of pyrite when the enargite ore was generated.

The pyrite copper content tends to increase with increasing depth in Xiaojinggua, cushishan-Jijiang mine. However, the trend is not apparent in Niufu, Gui mines and Benshan area.

The copper content of pyrite distribution diagram displays two peaks. In the gold-generating mines of Jiufen, Xiaojinggua and Beiwudangshan, the pyrite content is relatively low, ranging in 100~800ppm; in the copper or enargite producing mines of Benshan, Niufu and Gui mines, the copper content in pyrite is relatively higher, ranging in 300~10000 ppm, and it is greater than 1000 ppm in most cases. The copper content of pyrite in the Lilao non-mineralization area is only 200ppm. It thus can be learnt, the copper content in pyrite above 1000 ppm in Jinguashi area may represent the mineralization of copper or enargite; the copper content in area of gold mine is around 200~800ppm; and the copper content of pyrite in non-mineralization area is only around 200 ppm or lower.

(3) Gold (Au), silver (Ag)

Zvyagintsev et al. (1940) argued that the gold in pyrite is mainly related to the gold colloid aggregation process and the properties of the pyrite surface.

Kurauti (1941) synthesized pyrite with gold content of 2000 ppm. The lattice constant of the resulting pyrite became larger, confirming that gold can exist in the form of solid solution in pyrite. McPheat, et al. (1969) used electron microprobe and other methods to test the pyrite of gold content at 0.065 oz/ long ton, finding that 0.02~0.03 oz/ long ton gold exists in the form of solid solution and the rest is distributed in pyrite in the form of gold particles.

Wells and Mullens (1973) found that a thin layer of find gold particles can be found at the external edge of pyrite. Kirillov et al. (1970) confirmed the existence of the thin layer by pyrite prepared in laboratory. It is generally believed that the deposition of pyrite is earlier than gold. In the high-temperature mineralization period, the gold can be replaced by lattice position or hidden gold particles were generated in the early pyrite. The pyrite crystalized during the low temperature period is often associated with gold (Boyle, 1979).

According to Boyle (1979) and Levinson (1980), gold is the best and most direct indicator element of gold mine. The analysis results suggest: in most of the known deposits, the gold content in pyrite is above the testable amount (1ppm), the average gold content of the copper ore belt is 1.5 ppm on average, and the gold average of the auricupride ore belt is around 3ppm. Xiaojinggua is known as a rich gold mine and the gold content can be up to 30 ppm (Py15), the gold content of the pyrite at the edge rich in gold is 3~4ppm, the gold content of the pyrite in the non-mineralization belt (Lilao) is lower than the lower detection limit; hence, in the study region, the gold content of pyrite above 1 ppm can be an indicator of mineralization. The one with gold content above 10 ppm indicates the existence of rich gold mine.

The gold content of most pyrite samples in this study is above 1ppm, in particular, the gold content of Xiaojinggua is up to 30 ppm (Py15). Pyrite is widely distributed in all the mineralization belts in the area of study and it is abundant. From the perspective of resource development, if the gold can be extracted, the amount should be considerable. The gold contained in pyrite cannot be observable under the microscope of 280 times of the micro probe. Further studies should be carried out to find out if the gold exists in solid solution or very small inclusions to facilitate the use and metallurgy method in the future.

Auger (1941) and Hawley (1952) studied the pyrite in the gold mines in Canada. According to the research data, the silver content increases with increasing depth. However, it decreases with increasing depth in some other cases. According to Fleischer (1955), the content of silver in pyrite will decrease with rising temperature. The silver content in pyrite tends to increase in the direction of the mineralization center (Boyle, 1979).

Regarding the relationship between the silver content of pyrite and the deposit depth, from the perspective of elevation, the silver content in the pyrite in the Niufugui mine and Benshan tends to increase with rising elevation, and the trend is the opposite in the case of Xiaojinggua; the trend of the Cushishan-Jijiang mine is not apparent. By comparing the changes in silver content of different types of ores, it can be found that the silver content of the pyrite in the copper ore belt is the lowest (average 1ppm), it is 4~8ppm in auricupride ore belt, 80 ppm in ore belt rich in gold, and it drops to around 5~20 ppm at the edge of ore belt rich in gold. The silver content of pyrite gradually increases from the lowest copper ore belt to the ore belt rich in gold, and falls again above the ore belt rich in gold.

By comparing Shumei outside Benshan and the area of Benshan top, the silver content in pyrite on the surface of Shumei is only 3ppm, and the average silver content of the four samples taken from top of Benshan is 19 ppm, indicating that the silver content tends to increase in the direction of mineralization center.

The silver content of pyrite can indicate the center of mineralization. The area with silver content above 50 ppm is the ore belt rich in gold. In this study, the gold/silver ratio of Jinguashi pyrite is in the range of 0.1~2. In the case of Niufugui ore, the content decreases with increasing depth and the gold/silver ratio rises. The trend of rest cases is not clear, and there is no apparent difference between different ores.

(4) Manganese (Mn)

In the element periodical table, manganese is a VII B family element. Its sulfide mineral Hauerite (MnS_2) has the same lattice structure with pyrite except for the different bonding structure. The amount of iron replaced by manganese is limited (Fleischer, 1955). Gold can be easily solved in oxidizing environment and precipitated in reducing environment (Viewing, 1983). MnO_2 can oxidize gold and greatly contributes to the migration and enrichment of gold (Boyle, 1979). Iron manganese acid salt is one of the features of gold mineralization (Gormasheva, et al., 1973). Petersen (1980) pointed out, if the content of manganese in pyrite is above 4000 ppm, it means the existence of gold mine.

The research results suggest, the manganese content in pyrite from the copper ore belt and the auricupride ore belt is almost below the lower detection limit (60ppm), the pyrite from the ground surface in Jijiang (Py11) contains 200 ppm manganese, and the average gold content in the silicon Andesite rock in the surrounding area is about 3~4ppm, which was of no economic value in past time. However, with the current metallurgy technology, it is worth mining. The manganese content of Xiaojinggua pyrite is 60~100ppm, and the content at the edge of the gold mine is <60~600ppm. The manganese content of the pyrite in the non-mineralization area of Lilao is 80 ppm. In Jinguashi area, the pyrite with manganese content above 100 ppm can indicate the edges of the gold mine.

(5) Arsenic (As)

Newhaus (1942) used the X-ray diffraction to study the pyrite with 5% arsenic, finding that its lattice length is 5.442 angstrom. By comparison, the lattice length of the normal pyrite is 5.417 angstrom. Hence, it is inferred that arsenic exists in the form of solid solution. Youh (1971) argued that arsenic in Jinguashi pyrite exists in the form of enargite or luzonite. Folinsbee, et al. (1972) argued that the arsenic exists in solid solution due to the high light anisotropic nature of pyrite with high content of copper and arsenic. Hawley (1952) studied the four ore veins in Qntarion Porcupine district, finding that the arsenic content of pyrite generated in low temperature is higher. Hence, Hawley argued that arsenic may exist in the form of solid solution or natural arsenic in such circumstances.

If arsenic exists in the form of enargite or luzonite in pyrite, its arsenic /copper ratio should be lower or equal to 0.4. Except for Py2d, Py4, Py6, Py7, Py13 and Py16, the arsenic/copper ratio of the rest samples is far greater than 0.4. In pyrite of arsenic/copper ratio far above 0.4, arsenic should exist in the form of solid solution. In pyrite of arsenic/copper ratio below 0.4, arsenic may exist in the form of enargite or luzonite inclusion. By comparing the relationship between the arsenic /copper ratio and arsenic content of pyrite at different depths, it can be found that the arsenic content peaks lie in the deeper areas of the mines. The arsenic /copper ratio is below 0.4. However, the arsenic/copper ratio of arsenic peaks of pyrite in shallower areas and Beiwudangshan, Jiufen gold mine is above 0.4. Therefore, in deeper areas or the areas of higher generation temperature, most arsenic exists in the form of enargite or luzonite inclusion. At the top of mine or gold mine, the generation temperature is lower, and thus arsenic exists in pyrite in the form of solid solution or natural arsenic.

Since most gold is transferred during the endogenic process in the form of gold-arsenic-sulfur or gold-antimony-sulfur. The pyrite of high content of arsenic and antimony can be an indicator of high concentration of gold (Boyle, 1979). Therefore, arsenic is one of the best indicative elements of gold mine. Pyrite samples taken from the rich gold mine areas such as Beiwudangshan and Jiufen contain high content of arsenic in the form of solid solution or elements, which can indicate the existence of gold mine. If the arsenic in pyrite exists in the form of enargite or luzonite inclusions, it can indicate the copper mine or auricupride mineralization .

(6) Mercury (Hg)

The mercury has great mobility (White, 1967) and can often form obvious diffusion halo in gold mine or other deposits (Williston, 1964), for a long time, the mercury has frequently been used as a tool for the exploration (Hawkes and Willston, 1962). Tan et al. (1984) used the mercury content in soil as a tool for exploration of Saudi Arabia' s gold mine, achieving considerable results. They found, in the non-mineralized area, the soil mercury content is about 0 ~ 200 ppb while it can be up to 30000 ppb in the mineralized zone. Mercury is usually concentrated in the top or edge of the ore (Boyle, 1979).

According to Watling et al. (1973), the temperature for pyrite to release mercury is 450°C, cinnabar at 350°C, and natural mercury at 80°C. In this study, the samples were heated to 350°C, and thus the mercury should be the cinnabar inclusions or natural mercury adsorbed on pyrite.

The mercury content of pyrite in this study changes dramatically. The mercury content increases with increasing depth in Niufugui mine, which is different from the general condition. In other case, it has no apparent relation with the depth of the ore or the location at the center or edge of the ore.

High mercury content may be one of the causes resulting in the formation of breccia in Niufugui. There is an east-west structure in the north of Niufugui. Along the structure, there may be gold mineralization of late stage. The mercury contained in Py07, Py08, Py09 of Niufugui mine may be introduced by the late stage mineralization. As multi-stage mineralization has been found in Jinguashi , the mercury content of Py12 (5th adit, Central Jijiang) and Py5 (8th adit) may be introduced from the edge or bottom by the late stage mineralization.

Overall, the pyrite mercury content in pyrite from Niufugui mine and Benshan area is relatively higher and it is relatively lower in Xiaojinggua and Jiufen.

The mercury content of pyrite from Lilao (Py20) is up to 21000ppb. In early times, when Taiwan Gold Corporation built the Lile Copper Smelting Factory, quartz andesite was found beneath the drill. Mercury in Py20 pyrite may come from the rock.

(7) Barium (Ba)

The barium content of most pyrite samples from Jinguashi is below the lower detection limit (300ppm), showing obvious discontinuity. As the barium ion and iron ion of pyrite are bivalent, the difference in ion radius is 81%, as a result, the replacement is not easy. The barium content above 300 ppm can hardly be explained by the form of solid solution.

By comparing the X-ray diffraction diagram of Py2b and JCPDS table, weak diffraction peak of barite can be found, indicating that barium exists in pyrite in the form of inclusion. Barite can be found in the symbiotic minerals of Py2a, Py6, Py19 pyrite samples. Hence, the author believes that barium comes from the inclusions of barite.

Barite is rare in Precambrian gold mine. The content of barite will be more in younger gold mine (Boyle, 1979). The mineralization of Jinguashi mine was about 1 million years ago when barite was widely distributed in the area. However, it was found by the field study of the author that barite appears only at the top of the ore bodies and the crystal habit of barite varies in different ores. It is mostly of slice shape in the mine of Niufugui. At the top of Benshan, it is slice-shaped and it becomes thicker slice-shape or diamond-shaped in areas below 50 meters. It grows in pointed vibration shape in Shumei and in blocks in Jiufen. The shape of barite and barium content in pyrite all suggest that barium can indicate the top of the ore and the co-existence with the gold mine.

(8) Lead (Pb)

In Jinguashi area, the lead content in pyrite increases with decreasing depth. At the top of the ore, the lead content is 200~1000 ppm; and the content is around 20~60 ppm at the bottom. Beiwudangshan Py17 samples contains lead of 10000 ppm, the symbiotic minerals of the sample include galena. The author guesses that the lead in pyrite is the inclusion of galena. Schwartz (1944) pointed out, in the gold mineralization, galena and gold are minerals generated in the same period, and thus galena is an indicative element of gold mine. In the Jinguashi area, if the lead content in pyrite is greater than 400 ppm, it can indicate the existence of gold mine.

(9) Zinc (Zn)

Huang & Chiu (1979) pointed out that the pyrite zinc content in Benshan area increases with decreasing depth. However, it remains the same in Changreng mine. The research results of this study suggest, in these two mines, regarding the changes in zinc content by vertical height, it increases in Benshan top and remains unchanged in Changreng mine.

By the ore vertical model of zinc content, it can be found that the zinc content in copper mine and auricupride mine is almost lower than the lower detection limit (60 ppm). In the pyrite samples from the gold mine and the mine edges, the zinc content gradually increases (100~300ppm). The zinc content in pyrite from Beiwudangshan can be up to 3000 ppm, which may be the inclusion of blende. Blende is one of the most indicative mineral of gold mine (Boyle, 1979). When the zinc content of pyrite is above 100 ppm, it may indicate the gold mine or edges of gold mine.

(10) Bismuth (Bi)

Bismuth content is highest in the samples from Niufu mine, and it ranges in 30~300ppm with the average value of 105 ppm. It is rare in other mines. Hence, bismuth may represent the existence of ore chimney of breccia.

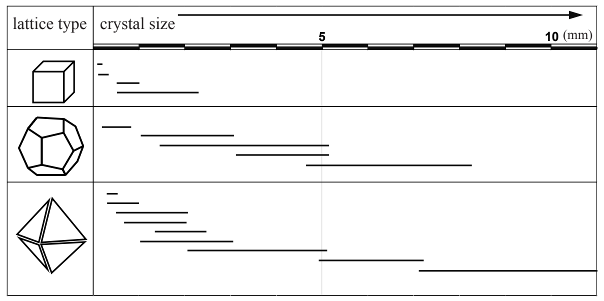
4. Jinguashi Pyrite Crystal Form

Huang & Chiu (1979) pointed out that the copper content of octahedral pyrite from Jinguashi area is higher, and it was generated in high temperature environment. Chen (1986) explained that the octahedral pyrite in Jinguashi was generated because of the higher H_2O pressure in the environment to result in full ion supply rate and rapid crystallization. The crystal planes form the pyramid to result in octahedral pyrite.

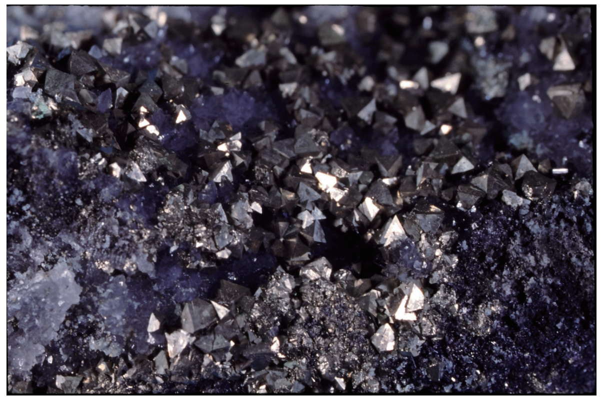
The results of this study suggest that octahedral and dodecahedral pyrite samples contain higher content of copper with the average values at 3700 ppm and 4600 ppm respectively. The copper content of cubic pyrite and pyrite with cubit crystal planes is apparently lower with the average value at 230 ppm and 700 ppm respectively.

As shown in Figure 7, the crystal of the octahedral pyrite is generally larger followed by the crystal of dodecahedral pyrite and the cubit pyrite. The range of octahedral pyrite (Figure 8) is from 9th adit (about 200 m below the sea level) to the ground surface of Dajinggua (530 me above the sea level). The octahedral crystal below the 8th adit can be as big as more than 1 cm. The author observed the octahedral pyrite samples from 8th adit of Jinguashi collected by Mr. Chen Wufu of TaiPower, finding its edge is above 40 cm. By comparison, the size of ground surface octahedral crystal is mostly below 2 cm. Above 7th adit, dodecahedral pyrites can be found and the dodecahedral pyrite crystal in 7th adit can be up to 5 cm, and the size of the near ground surface dodecahedral crystal is only below 0.5 cm. In between 7th adit to the ground surface, composite octahedral and dodecahedral crystals can be found in pyrite. The cubic pyrite can only be found on ground surface or top of the ore, and the crystal size of cubic pyrite is mainly of 0.1~0.3 cm below 2cm. The size of pyrite crystal is correlated to the copper content in a non-regular way (Figure 9). It can be found that larger pyrite usually contains more copper.

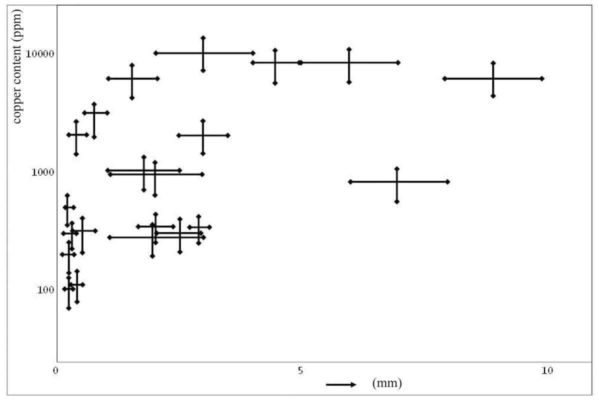
The cubic pyrite can be found on ground surface or top of the mine only, and the copper content is usually very low as its growing environment is of lower temperature and less copper as compared with the growing environment of the octahedral and dodecahedral pyrite. At the in-depth area of the mine, only octahedral pyrite can be found as the growing temperature of the octahedral pyrite is highest. In the overlapping belt of octahedral and dodecahedral pyrite, since the copper content of the two types of pyrite is basically the same, the depth and temperature are roughly the same. By comparing different types of ores, it can be found that pyrite in copper or auricupride is of octahedral or dodecahedral crystals. In the gold mine and its edges, the pyrite is mainly of cubic crystals. The pyrite in the non-mineralized belt of Datunshan is mainly of cubic crystals. However, the copper content is only 50~200ppm (Tan, 1972). In the Jinguashi mineralized belt, the average content of copper in the cubic pyrite is around 225ppm. The copper content of the cubit pyrite in the non-mineralized belt in Lilao is only 200ppm. In terms of lattice, the octahedral or dodecahedral pyrite in Jinguashi area can represent the mineralization of copper or auricupride. Samples of large crystals suggest deeper or high content of copper. If the copper content of cubic pyrite is above 300 ppm, it can suggest the gold mineralization.



【Figure 7】The crystal size of major lattice types of pyrite ores in Jinguashi-Jiufen area (each horizontal line represents the range of crystal size distribution of each sample)



【Figure 8】 Jinguashi octahedral pyrite (with visible triangular crystal plane) is generally produced in environment of higher temperature



【Figure 9】 Relationship of different pyrite crystal size and copper content in Jinguashi-Jiufen area (each cross represents the range of distribution of each sample)

5. Conclusion

Jinguashi-Jiufen area produces many types of pyrite. The shape and crystal size of such types of pyrite are related to the growing environment. pyrite often contain many trace elements that can provide major message for ore exploration or the understanding of the ore. This study uses 23 samples from the different ores at different depths in the Jinguashi-Jiufen gold mine for geochemistry analysis. The results suggest that pyrite can indicate the following important messages about Jinguashi-Jiufen gold mine.

1. Regarding trace element geochemistry:

(1) Gold: the pyrite with gold content above 1ppm can expressly indicate the mineralization; if the gold content is above 10ppm, it means the area is rich in gold.

(2) Silver: the silver content in pyrite, in the horizontal direction, it increases when approaching the center of mineralization, and thus it can indicate the mineralization center; the one with silver content above 50 ppm, it means the area is possibly rich in gold.

(3) Copper: the pyrite in gold mine contains 100~800ppm copper, the copper content in copper or auricupride mines contains 100ppm to 10000ppm, the copper content in non-mineralized area is lower than 200 ppm.

(4) Barium: the barium content of pyrite in gold rich belt or its edges is particularly high. It mainly exists in the form of barite inclusions.

(5) Manganese: the pyrite with manganese content above 300 ppm can indicate the gold mineralization.

(6) Arsenic: the pyrite with high content (above 1000ppm) arsenic in the form of element or solid solution, it means the area is rich in gold. If the arsenic exists in the form of enargite inclusions, it means the existence of copper or auricupride.

(7) Lead: the lead content of pyrite in gold mineralization area is greater than 450ppm.

(8) Zinc: if the zinc content in pyrite is above 100 ppm, it can indicate the gold mineralization.

(9) Nickel: it can indicate the gold mineralization, in an insignificant way.

(10) Regarding depth indication, the silver, lead and zinc content of pyrite tends to increase when the depth becomes lower; the content of nickel tends to increases in Benshan and Niufu mine with increasing depth.

2. Crystal shape and size:

(1) octahedral and dodecahedral pyrite's copper content ranges 300~above 10000ppm, and the average values are 3500ppm and 4200ppm respectively as they were generated in the environment of deeper and higher temperature. The copper content of the cubic pyrite ranges 100~800ppm, the average value is 225ppm, and it can only be found at the top of the mine. The size of the cubic crystals is below 2 cm and is mainly of 0.1~03 as they were generated in the environment of lower depth and temperature.

(2) It can be learnt by inferring from the dual layer crystal overlapping and the co-exsistence of differently shaped crystals in the same sample that ore fluids of more than two phases had flown passing Benshan and Niufu mines.

(3) Octahedral and dodecahedral pyrite, auricupride, and cubic pyrite with copper content above 300 ppm can indicate the existence of gold mine.

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