2-4 Infrastructure

Marrakech City, situated to the east of the survey area, is an international tourist city having population of 350,000 and over 100 year's history, and designated as a "World Heritage". The electricity, water supply, road system, Medical facility, communication facility, and other infrastructure of the city are satisfactory arranged. The road to the survey area is nicely paved. Handy telephone is well usable in almost whole survey area.

Chapter 3 Existing Geological Data

Following is basically a summary of the concerned part of the last year's report.

3-1 General Geology of Surrounding Area

1) Distribution

The central part of the Jebilet Mountains to the north of the survey area is underlain by the Paleozoic sedimentary rocks showing N-S to NNE-SSW strike, and east dip. The Paleozoic is mainly composed of Devonian to Permian muddy rocks, intercalating limestone, tuff, and sandy layers. Acidic or basic igneous sills are also intercalated in some places.

The Visean upper Carbonate in the central part of the Jebilet Mountains and the Guemassa District is composed of muddy rocks, acidic volcanic rocks, basic volcanic rocks, rhythmic alternation of those and phyllite of the Sarhlef Formation, overlying carbonate rocks of the Tequsim Formation, and uppermost muddy rocks. Figure I-3-1 shows the geological map of the survey area, and Figure I-3-2 shows the integrated geological columner sections, and Figure I-3-3 shows the geological cross section.

The sedimentary rocks consist of shale, slate, and shist, containing abundant sericite and chlorite due to intense regional metamorphism, and mineralization and alteration.

2) Sedimentary Environment

In some places, the hanging-wall alkali alteration is more intense than that of the footwall. It suggests that the hydrothermal activity has been continued after the ore formation, or duplicated with the ore formation activity.

Regarding the principal elements, Al_2O_3 and TiO_2, V, K_2O and P_2O_5 are positively correlated, and SiO_2, CaO and Fe_2O_3 are negatively correlated, showing the same tendency of the seawater. The dispersion of SiO_2 in the Hajar, Draa Sfar, and Kettara Deposits is due to the change of clastic origin material supply caused by the acidic volcanic activity. The high tendency of CaO in the Khwadra Deposit, compared with the other deposits, is due to the abundance of biogenesis origin material supply. In the rare-earth element pattern, LREE is rich showing Eu anomaly, but this is due to the effect from the island arc clastic material supply. It is possible that the tendency of the total rare-earth element, TREE, increase in the hanging-wall of the ore deposit is due to the transfer of the elements from the footwall to hanging-wall by the hydrothermal solution.

The sulfur isotope in the muddy rocks is scattered between –35 and +25 per mill, showing tendency of lighter to the hanging-wall side. It is thought that the sedimentary environment has been shifted from reduction to oxidation (Kajiwara 1989, Kajiwara and Kaiho 1992, Komuro 1999).

3) Characteristics of Volcanic Rock

The chemical component and radioactive age of the volcanic rocks distributed around the ore deposits in the survey area have been investigated in the last year's survey.

The result of the chemical analysis revealed that the rare earth element pattern is rich in the light rare earth elements, the Eu anomaly shows some flat pattern, and the principal components SiO_2 and (K_2O, Rb, Ba, Cs) show the negative correlation, showing same tendency in the acidic volcanic rocks in the Hajar, Khwadra, and Draa Sfar Deposits. These acidic volcanic rocks, therefore, have similar geochemical property, being different from the acidic volcanic rocks, tonalitic mylonite, in the neighboring ore deposit, Safsafa Deposit. Comparing the LIL elements and HFS elements of the basic volcanic rocks, dolerite, in this area and the basaltic rocks in other areas, it is made clear that the basic volcanic rocks in this are show the characteristic of the island arc, rich in LIL elements, being different from N-MORB, poor in LIL and HFS.

Based on the result of the K-Ar radioactive age dating to obtain the mineralization age and igneous activity age, it has been made clear that there exist following main activities, plutonic igneous activity, acidic volcanic activity, and mineralization – alteration activity (the Guemassa Mountains, Jebilet Mountains). The plutonic activity and acidic volcanic activity is 290 to 360 Ma in age, and the mineralization - alteration is 260 to 320 Ma in age. The age of the Jebilet Mountains is corresponded with the last period of the igneous activity, and that of the Guemassa Mountains is corresponded with after the igneous activity.

3-2 Outline of Ore Deposits

In the surrounding area, following known ore deposits are distributed, the Kettara Deposit in the central Jebilet Mountains, the Draa Sfar Deposit and Khwadra Deposit in the southern rim of the Jebilet Mountains near the boundary with the Tertiary formation, the Hajar Deposit in the eastern edge of the Guemassa Mountains, and the Frizen Deposit in the western area.

The ore deposits in the Jebilet and Guemassa districts are the massive sulfide type, mainly composed of copper, lead, zinc, and iron minerals. The deposits are hosted in the alternation of muddy rock and sandstone, alternation of muddy rock and chart, and acidic volcanic rocks of the Sarhlef Formation of Carboniferous Visean.

Figure I-3-7 shows the location of the ore deposits and mineral occurrences.

These ore deposits show the layered, massive, and lenticular form, and are mainly composed of the mineral composition of pyrrhotite, pyrite, sphalerite, galena, and chalcopyrite. The acidic and basic volcanic rocks around the deposits are genetically related with mineralization.

According to Watanabe (2001), the formation in the Hajar Deposit area is classified into three members, the lower, middle, and upper. The lower member consists of an alternation of silt and mudstone, intercalated by dacitic to rhyolitic lava and pyroclastic rocks. The middle member consists of sulfide ore. The upper member consists of 150 to 200 meters thick silt and mudstone, intercalated by thin layers of limestone. In where the sulfide ore body disappears, the upper member overlies the lower member directly. It indicates that the igneous activity intermittently continued after principal mineralization period, because pyroclastic rock is partly seen in the upper member. The main ore deposit of the Hajar Deposit is 50 to 90 meters thick, and traceable to both sides al least 200 to 300 meters.

The near surface of the deposit has undergone oxidation about 20 meters thick. The pyrite replaces pyrrhotite in the oxidized zone. Non-oxidized ore bodies are composed of 75 to 95 percent of pyrrhotite, being accompanied by sphalerite, galena, chalcopyrite, pyrite, and arsenopyrite.

Pyrrhotite veinlet networks exist underneath the massive ore bodies. The veinlet cuts the stratigraphic planes at steep angle. The host rocks of the networks are rhyolite, pyroclastic rocks, and mudstone, and having undergone silicification and chloritization. The alteration by biotite and alkali feldspar is seen in the rhyolite, and chloritization is overlapped on this. Some group of veinlet parallel to the bedding plane appears near the bottom of ore bodies, and grades to the massive part. The rhythmical alternation of sedimentary rocks and sulfide ore layers are seen in parts, and it indicates that those sulfide minerals are of submarine genesis. The principal hydrothermal alteration minerals are chlorite and sericite, and some biotite in the lower part of the ore body. The significant characteristic of the ore deposits is that iron sulfide minerals originally deposited as pyrite has been replaced by pyrrhotite due to the Hercynian metamorphism. It is very difficult to estimate the temperature and property of the original hydrothermal solution at the ore formation stage due to the metamorphism.

The thick clastic material derived from the land terrain has covered the sulfide ore bodies during and after the ore formation stage in the Marrakech area.

(2) Characteristic of Sulfide

The object of this year's survey is to reveal the characteristic of subsurface massive sulfide ore deposits in the target area, and to extract potential targets for the next year's program, judging from the state of the ore deposits in the Jebilet and Guemassa districts. The characteristic of the massive sulfide ore deposits in the area is as follows.

1) Classification of the mineralization and the occurrence of Pyrrhotite

The Khwadra, Draa Sfar, Kettara, and Frizen Deposits are classified into the massive sulfide ore deposit, judging from their deposit form, mineral assemblage, and associating igneous rocks. As a result of the investigation of the occurrence, ore mineral, and host rocks, it has been made clear that a duplicated mineralization process of the early stage and later stage formed these deposits. The sulfide minerals of both stages exist in paragenesis with quartz.

The early and later stage mineralization is represented by pyrrhotite and pyrite respectively, in view of the Fe-S series mineral. In the Khwadra and Hajar Deposits, the early stage mineralization is divided into two, the early I represented by pyrrhotite and early II represented by monoclinic pyrrhotite. The hexagonal pyrrhotite in the early I stage has been extensively replaced by the monoclinic pyrrhotite in the early II stage, and the monoclinic pyrrhotite in the early II stage has been altered to marcasite.

The homogenized temperature of the fluid inclusion in quartz, in paragenesis with the hexagonal pyrrhotite in the early I stage is 270 to 280 ℃. The monoclinic pyrrhotite in the early II stage shows 230 to 250 ℃ as well as quartz and sphalerite, and has been crystallized directly as such mineral. The homogeneous temperature of the quartz, in paragenesis with pyrite and sphalerite, of the later stage is 200 to 250 ℃.

2) Characteristic of sulfur isotope

The sulfur isotope ratio of the sulfide minerals in the Khwadra, Draa Sfar, Kettara, Hajar, and Frizen Deposits show distinct difference for each ore deposit on the early stage mineralization. The sulfur isotope ratio is lowest for the Khwadra Deposit, and higher for the Draa Sfar, Kettara, Hajar, and Frizen Deposits in order. Such big variation of the sulfur isotope within same ore deposit or ore district is contrastive with the uniformity in the Japanese Kuroko ore deposits. The cause of such difference can be explained by the different conditions of physical chemistry of ore formation, contamination of biogenic sulfur, various volume of sulfur supply from seawater to hydrothermal system, etc. This suggests that different ore formation environment for each ore deposit. It is said that the Khwadra Deposit contains relatively much biogenic sulfur contamination, and the Hajar and Frizen Deposits obtain relatively great contribution from the magma origin.

3) Mineralization and magnetism

The intensity of the magnetism around the ore deposits is related with the various types of pyrrhotite for each ore deposit. The Khwadra and Hajar Deposits specifically containing the monoclinic pyrrhotite cause high magnetism, the Draa Sfar Deposit containing the hexagonal (early I stage) and monoclinic pyrrhotite (Early II stage) causes neighboring high and weak magnetic anomalies, and the Kettara and Frizen Deposits containing the hexagonal pyrrhotite and duplicative pyrite cause only weak magnetism. It is possible to expect some potential for weak magnetic massive lead-zinc sulfide ore deposits, composed of hexagonal pyrrhotite and pyrite, such as the

Kettara and Frizen Deposits in the weak to moderate magnetic anomalies. Also it is possible that relatively weak magnetic massive lead-zinc sulfide ore deposits composed of the hexagonal and monoclinic pyrrhotite exist in some highly magnetic and weak magnetic neighboring anomaly zones.

4) Summary

The characteristic of the massive ore deposits around the survey area is summarized as follows.

(1) The massive sulfide ore deposits around the survey area were formed by duplicated mineralization activity. The mineralization can be divided into three stages, the early I stage, early II stage, and later stage.

(2) The early I stage mineralization is represented by the hexagonal pyrrhotite, showing slightly weak magnetism. The early II stage mineralization is represented by the monoclinic pyrrhotite, showing intense magnetism. The later stage mineralization is represented by pyrite, showing weak magnetism.

(3) The homogenized temperature of the quartz, in paragenesis with sulfide minerals, is 270 to 280 ℃ for the early I stage, and 230 to 250 ℃ for the early II stage, and 200 to 250 ℃ for the later stage. It is thought that this indicates temperature gradient of the ore formation.

(4) The great change of the sulfur isotope ratio in the same district can be explained by the different conditions of physical chemistry of the ore formation, contamination of biogenic sulfur, different volume of the sulfur supply from sea-water origin to hydrothermal system, etc. The Khwadra Deposit in the northwest area contains relatively much biogenic sulfur contamination, and the Hajar Deposit in the southeast area and Frizen Deposit in the southwest area have relatively great contribution from magma-origin sulfur.

(5) The type of the ore deposits is classified as follows.

a. Early I stage dominant type, moderate magnetic anomaly (Draa Sfar Deposit)

b. Early I + later duplicate type, moderate magnetic anomaly (Frizen Deposit, Kettara Deposit)

c. Early II + later duplicate type, high magnetic anomaly + low magnetic anomaly (Khwadra Deposit, Hahar Deposit)

3-3 Mining in Surrounding Area

The mining product is the greatest foreign currency income source for Morocco at present, and occupies about 30 percent of the total export value, about six percent of GDP. The most important mineral product of Morocco is phosphorite mainly consisting of apatite, and Morocco is the third largest exporting country in the world, following U.S and China.

Other than phosphorite, Morocco also exports silicon, lead, copper, zinc, silver, and manganese. Ore deposits of gold, cobalt, nickel, iron, uranium, and fluorite are also known in this country.

The massive sulfide ore deposits exist in the surrounding area of the survey area. The Draa Sfar Mine to the north of the survey area and the Hajar Mine to the east are in operation at present. The Kettara Mine to the north of the survey area was in operation in the past.

The Kettara Mine situating to the north of the survey area was discovered in 1937, and been operated until 1982 for pyrrhotite ore. The pyrrhotite was utilized as reducing agent for phosphate ore produced in Morocco. It is said that the mine has about 1,000 tons of reserve at present.

The Draa Sfar Mine situating to the northeast of the survey area started their iron ore production in 1953. The ore is in the oxide zone near surface. BRPM performed a magnetic survey and drilling program in 1962, and succeeded to discover a thin lenticular body of copper-bearing pyrrhotite ore. BRPM mined out about 4,000,000 tons of ore from a zone down to 150 meters during a period from 1968 to 1982. During a period from 1986 to 1996, BRPM performed drilling programs, then sold the mine to a private company, Compagnie Miniere des Guemassa (CMG) in 1997. The Draa Sfar Deposit is hosted in a rhyolite body and overlying rhyolitic tuff in vertical. The ore body extends more than 800 meters to both sides, and is overlain by silty rock.

The Hajar Mine is situated 35 kilometers south of the Marrakech. BRPM discovered the ore by their drilling program for a magnetic anomaly zone in 1984, and continued their exploration activity until 1988. ONA and BRPM founded a new company, Compagnie Miniere des Guemassa (CMG), and CMG bought the mine. CMG started operation in 1992, and is producing about 100,000 tons of zinc, 40,000 tons of lead, and 30,000 tons of copper in every year.