4.4. Metallogenic Provinces

Taking into consideration the results of the supplementary geological survey in 13 deposits, metallogenic provinces are examined putting emphasis on gold and copper deposits. The following five metallogenic provinces have been selected (Table 4.4.1 and Fig. 4.4.1) based on the survey: ① Banded iron formation, ② gold deposit in BIF, ③ gold deposit in greenstone belt, ④ copper and gold deposit in greenstone belt, and ⑤ chromite deposit.

Table 4.4.1 Metallogenic province

Metallogenic province	Geologic province	Deposit type	Deposit	Metal	Mineralization age
① Banded iron formation (BIF)	Reguibat Shield	BIF origin clastics deposit	Tiris El Rhein, El Aouj	Fe	Archean
		Superior-type BIF	Koedia-Idjill T014, M' Haoudat	Fe	Proterozoic
② Gold deposit in BIF (greenstone)	Reguibat Shield	Mesothermal disseminated and network deposit	Tasiast	AU	Proterozoic
③ Gold deposit in greenstone belt	Reguibat Shield	Hypothermal vein	Tijirit Ator	Au	Proterozoic
	Mauritanides	Mesothermal vein	Indice 78	Au	?
④ Copper and gold deposit in greenstone belt	Mauritanides	Carbonate replacement copper and gold deposit (IOCG?)	Guelb Moghrein Tabrinkout (Kadiar, Oudelemguil)	Cu, Au	Late Proterozoic
⑤ Chromite deposit	Mauritanides	Orthomagmatic chromite deposit	Guidimaka	Cr, PGE	Late Paleozoic
	Reguibat Shield	Orthomagmatic chromite deposit	Amsaga	Cr	?

① Banded Iron Formation (BIF) province

This is a metallogenic province of iron formations which were formed in the Reguibat Shield, and consists of the Tiris iron formation group and the Koedia-Idjill iron formation group. The deposits of the Tiris iron formation are considered to probably be a metamorphic deposit of clastic sediments originated from Algoma-type BIF of the Archean. While, the deposits of the Koedia-Idjill iron formation group are Superior-type BIF which formed in the Proterozoic era after the deposition of the Tiris iron formation in the Archean era. Geographically the former formed near the Koedia-Idjill iron formation group. Thus, both of the iron formation groups of the Tiris and Koedia-Idjill can be included in the same metallogenic province. Iron ore reserves are estimated to be over 1 billion tons in this province.

② Gold deposits in BIF

This is a metallogenic province of the gold deposits which were formed in the BIFs in the greenstone belt of the Reguibat Shield, and the Tasiast is representative of the gold deposit. Though the age (the Archean) of formation of magnetite layers as host is different from the age (the Proterozoic) of gold mineralization, the deposit consists of hydrothermal (epithermal to mesothermal) gold deposit with occurrences coming in form of dissemination and/or network along the fractures of the host. An intensive exploration has been done in the Piment sector in the Tasiast area, and the ore reserves including inferred reserves are estimated to be 25 million tons. There are potential areas in the north and south of the Piment where the same type of gold mineralization is probable.

③ **Gold deposits in greenstone belt**

This is a metallogenic province of the vein-type gold deposits which were formed in the greenstone belt in the Reguibat Shield and the Mauritanides composed of the greenstone belt. The gold vein deposit in the Reguibat Shield developed along the fracture zones accompanying the tectonic lines, and the Ator vein is a representative of the gold veins in this province. The Indice 78 is a gold prospect in the Mauritanides, and its formation could be related to the activity of the tectonic lines of the Mauritanides. The gold vein is characterized by a local existence of the high-grade gold ores over 10 g/t Au.

Although this metallogenic province is situated in both areas of the Reguibat Shield and the Mauritanides, it is not clarified whether the gold veins were genetically formed in the same geological age.

④ **Copper and gold deposits in greenstone belt**

This is a metallogenic province of hydrothermal replacement type copper and gold deposits which were formed in the Mauritanides. These are the Guelb Moghrein deposit, the Tabrinkout prospect and the Kadiar prospect in the Mauritanides. The host rock of the deposit is carbonate, and partly greenstone. The occurrence is massive, disseminated and vein. Based on the occurrence of the veins and mineral paragenesis, the Oudelemguil deposit is also part of this province. The province includes a significant copper resource in Mauritania.

Formation age of the deposits is assumed to be Late Paleozoic. Mineralization is summed to take place at the same stage of formation of the greenstone belts. Concreteness of possibility that the deposit is belong to IOCG, is an important subject to clarify the metallogenic province.

⑤ **Chromite deposits**

This is a metallogenic province of podiform-type chromite deposits which were formed accompanying ultramafic rocks in the Mauritanides. This survey has clarified that the Guidimaka chromite deposit is accompanied by platinum group minerals (PGM). There are the same podiform-type chromite deposits in the Amsaga area in the western part of the Reguibat Shield. Although the Amsaga chromite deposit belongs to a different geological province that is the Reguibat Shield, it is also a part of this metallogenic province. To clarify the relationship between difference of geological province and this metallogenic province is a subject in future.

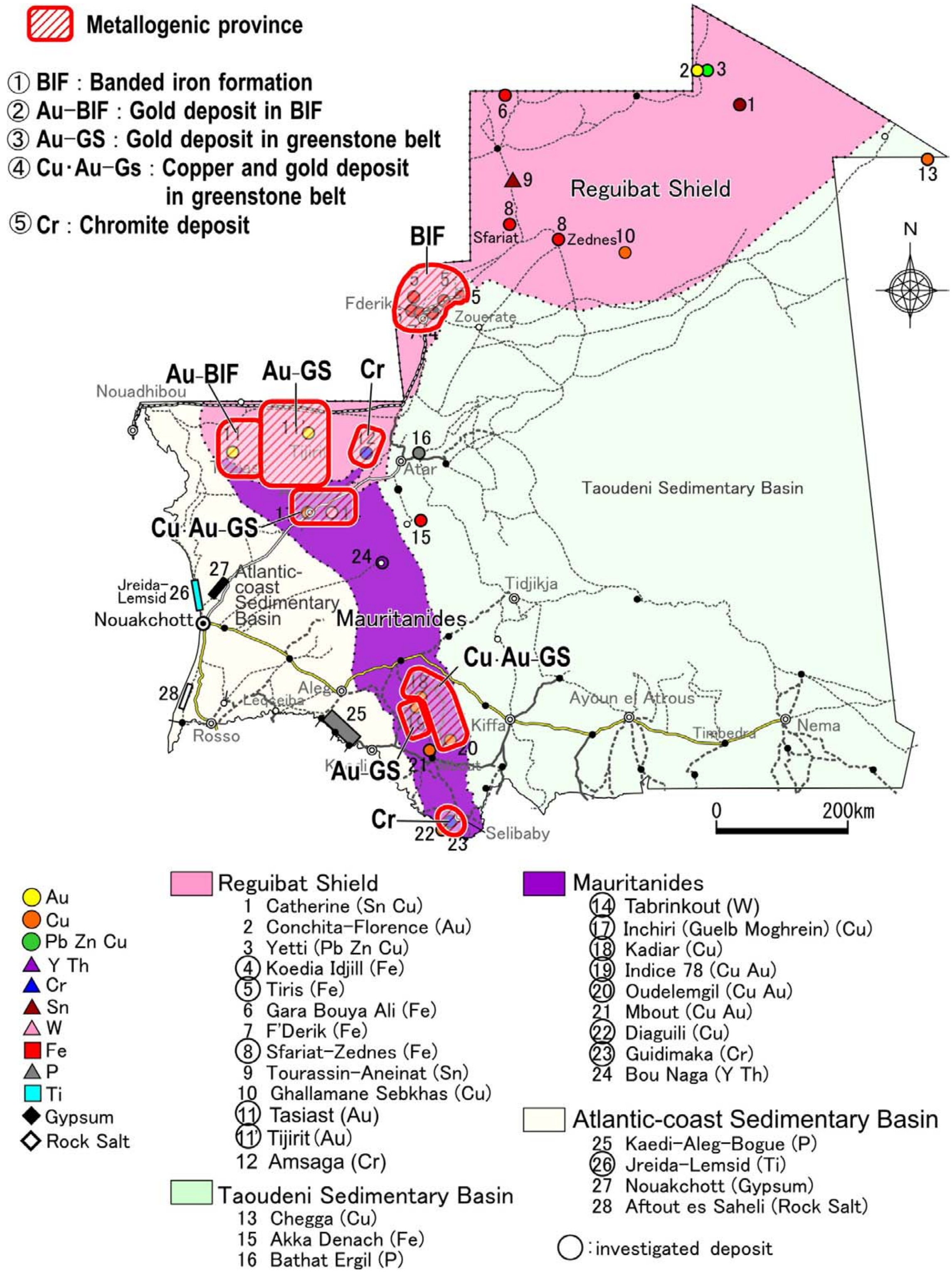

Fig. 4.4.1 Metallogenic provinces in Mauritania

4.5. Mineral Deposit Models

This paragraph describes mineral deposit models of the Tiris iron formation group, the Koedia-Idjill BIFs, the Tasiast gold deposit and copper-gold deposit (Guelb Moghrein, Indice 78) of the Mauritanides based on the supplementary geological survey.

4.5.1. Tiris iron formation group

This iron formation group is composed of the Guelb El Rhein, Guelb El Aouj and Guelb Atomai deposits, etc. Iron ores of coarse-grained magnetite are mined at these deposits. The magnetite ores occur as lenticular and disseminated in quartzite, leptynite and amphibolite of the Tiris group of the Precambrian (before 1.7 Ga at least). The thickness of the ore body is about 100m with the extension of about 1km. Each deposit includes the horizon comprising the iron ores on a large scale (BRGM, 1975; SNIM unpublished report).

Almost all the iron deposits lying in the Precambrian group (especially, before 1.9 Ga) are banded iron formations, but the above-mentioned deposition of Tiris iron formation is a peculiar case. However, there could be possibility that "1) iron contents concentrated as banded iron formation even in this type iron deposit, and 2) after that, iron contents dispersed in other rocks through some other process."

As one of the considerable processes of dispersion, iron contents of the banded iron formation diffused and injected into other rocks due to the high temperature of metamorphism (1.6Ga of the close age of amphibolite, and 1.5 Ga of the close age of potassium feldspar) of amphibolite facies which

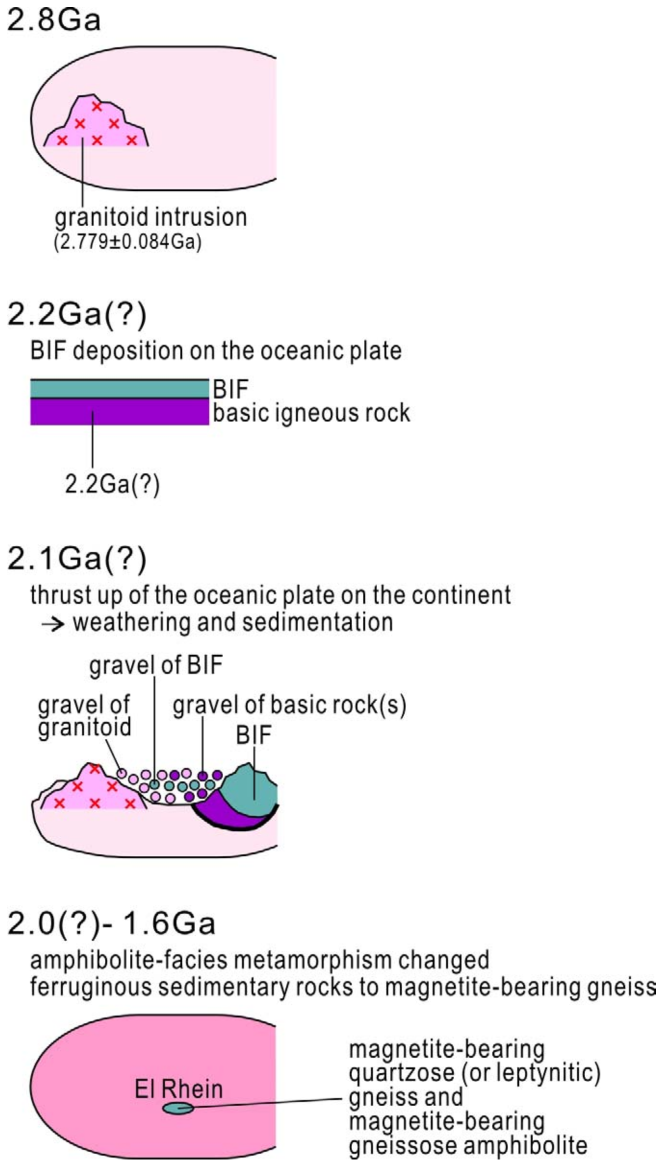

Fig. 4.5.1 Mineral deposit model of the Tiris iron formation

impacted the Tiris iron formation. However, in the geological maps of BRGM (1975) and SNIM (unpublished data), the boundaries among quartzite, leptynite and amphibolite are sharply drawn as lithological boundaries. It is difficult to suppose an intensive diffusion of chemical components caused by high temperature, and chemical mixture and fusion between many kinds of rocks took place in the past geological time.

Mechanical diffusion is considered to be another diffusion process. After weathering and crushing of the banded iron formation, the clastics originating from granitic rocks mechanically mixed with clastics originating from mafic igneous rocks, and iron oxides diffused. There is a possibility that after the regional metamorphism, the quartz-rich clastics turned into magnetite-bearing quartzite, the quartz-feldspar dominant clastics turned into magnetite-bearing leptynite, and the mafic clastics turned into magnetite-bearing amphibolite. The reason why magnetite grain is coarse might be that the iron oxide clastics supplied from the banded iron formation were of conglomerate size. There are multiple possibilities of rocks being the source of supply for mafic clastics. For convenience, in Fig. 4.5.1, the banded iron formation is drawn as the Algoma-type BIF with mafic igneous rocks. Although Rb-Sr model dating shows 2.2 Ga, the amphibolite supplied for measurement undergoes an intensive chloritization. Therefore, it is not clear whether the age recorded is exactly the formation age of the original mafic igneous rock.

4.5.2. Koedia-Idjill iron formation group

This iron formation group is composed of the F'Derik, Seyala, Rouessa, Tazadit, T014, and M'Houdat deposits, and the typical banded iron formation lying in the Idjill group of the Precambrian group. The Idjill group as host rock consists of seven nappes (Fig. 4.2.5, Bronner et al., 1992). Among the seven nappes, three units (of 1), 5) and 6) in Fig 4.2.5) are small in scale and expose out in narrow section, and their geological features is ambiguous. On the other hand, the formations composed of the remaining four units (of 2), 3), 4) and 7) in Fig4.2.5) show different lothofacies. That is, the la broche unit consists of conglomerate, the l'Achouil unit consists of pelitic schist, the Tazadit unit consists of the banded iron formation, and the M'Haoudat unit comprises banded iron formation, basaltic schist, partly hematite dissemination, and meta-basalt. These units show different lothofacies. The following is a description of each unit and the geological interpretation of each case.

(1) La broche unit

The la broche unit consists of conglomerate, and in a certain part of the unit, orthoquartzite is recognized in the shape of pebbles and gravels cemented with iron oxides and silica materials (Fig. 4.5.2). Based on their lithofacies, it is understandable that the deposition of iron and silica diffused into the sea water and deposited to the sea floor as the same phenomenon as the formation of the banded iron formation at the shallow sea near the continent composed of orthoquartzite. Kato et al.

(1998) and Kato (2003) clarify the banded iron formation process by the research on the banded iron formation in West Australia by "1) emission of iron and silica from volcano of the ridge and the lift valley, 2) deposition of oxidized clastics on the seafloor, after oxidation of emission materials." Based on their theory, the above-mentioned mechanism of conglomerate formation is considered as follows:

1) The rift valley was born, and the continent started to divide.
2) After the start of division of the continent, the rift valley was narrow, and pebbles and gravels of orthoquartzite supplied from the divided continent deposited near the shallow sea near the rift valley.
3) Pebbles and gravels are cemented with iron and silica materials which emitted from the rift valley.

Fig. 4.5.2 Pebbles and gravels of orthoquartzite cemented with iron oxides and silica materials

(2) l'Achouil unit

The l'Achouil unit consists of pelitic schist, and its sedimentation is considered to have advanced under the oceanic circumstances; that is, the activity of the rift valley continued, the seafloor spread wider, and the sea area holding oceanic environment took place. Inter alia, this unit lacks concentrations of iron oxide. This means that the emission of iron and silica materials from the rift valley was suspended.

(3) Tazadit unit

The Tazadit unit consists of banded iron formation and lacks clastic rocks. This means that the seafloor continued to spread, and it was under more intense oceanic environment than the l'Achouil unit, that is the sea area having the environment where clastics from the continent seldom reached, was born. In such an environment, iron and silica materials restarted to emit, and the banded iron formation was formed after the deposition of the emitted materials to the seafloor.

In addition, the Seyala deposit includes a small layer of basaltic schist. It means that this basaltic schist can be the extension of basaltic schist distributed in the M'Haoudat unit. Compared with the basaltic schist, the age of the sedimentation of the Tazadit unit was same as the sedimentation of the M'Haoudat unit.

(4) M'Haoudat unit

The M'Haoudat unit is dominant in basaltic schist and meta-basalt, and dissemination of hematite is conformed in the basaltic schist. Thus, it is considered that another basaltic volcanic activity different from the ridge took place at the time of the forming of banded iron, and basalt was spewed out (2.3 Ga at the Rb-Sr model dating of its whole rock), and then basaltic pyroclastics were spouted. The above-mentioned dissemination of hematite might have happened to precipitate iron oxides during the intervals of pyroclastics sedimentation.

(5) Thrust of the Idjill group

Concerning the above-mentioned process, after the seafloor was spread by the rift valley and ridge, varied sedimentation advanced, and the Idjill group was formed. It is conceivable that the Idjill group thrust over the continental crust composed of the Tiris group about 2.0Ga? At this time, the Idjill group was divided onto seven nappes (Bronner et al., 1992). Then, these thrust sheets were subjected to metamorphism of the green schist facies. It is probable that this metamorphism continued until 1.8Ga on K-Ar dating of muscovite from the M'Haoudat unit, or until 1.6Ga based on Rb-Sr model dating of whole rock of basaltic schist from the same unit.

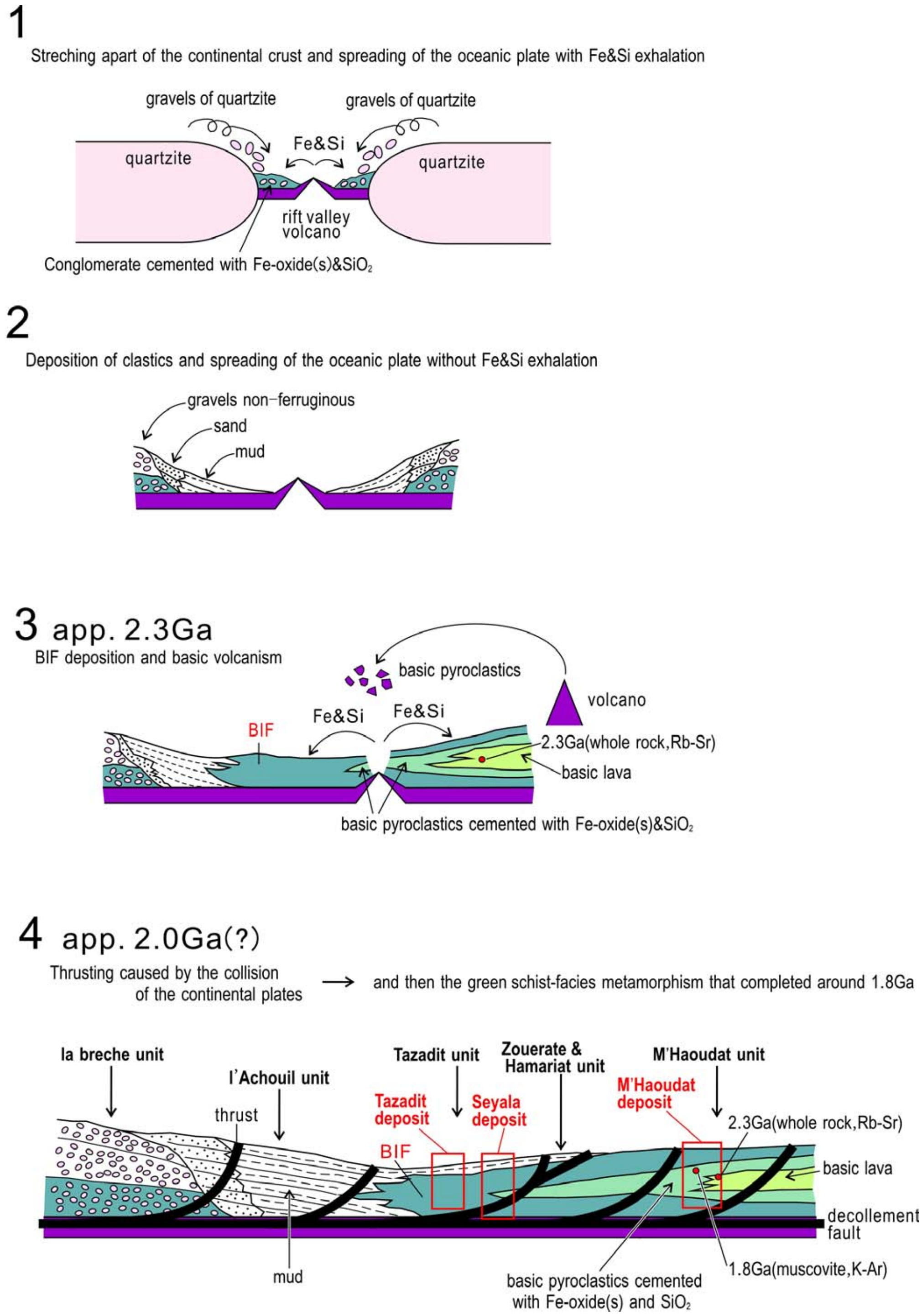

Fig. 4.5.3 Mineral deposit model of the Koedia-Idjill BIFs

4.5.3. Tasiast gold deposit

(1) Hydrothermal stage

This deposit consists of hydrothermal gold-bearing quartz veins cutting Algoma type BIFs, and of gold disseminations in the BIFs. The influence of hydrothermal process in this deposit is confirmed in gold mineralization, small amount of pyrrhotite dissemination, tungsten mineralization, and intensive white argillized zone (see Fig. 4.3.3). Gold mineralization, tungsten mineralization, and intensive white argillized zone are supposed to have formed under various temperatures on the basis of the homogenization temperatures of fluid inclusions and the estimated temperatures based on assemblages of clay minerals. It is needed that formation temperature will be calculated from the homogenization temperature on the basis of pressure compensation. According to depositional circumstance, the pressure is assumed to be 1.5 kb and the formation temperature is presumed the homogenization temperature plus about 100℃.

Tungsten mineralization yielded at the highest temperature of about 380ºC. The salinity of ore-forming fluid is assumed to have been about 37wt% NaCl eq. The ore-forming fluid is assumed to be under the oxidation condition, based on chromium dissolution recognized in the tungsten mineralized region.

White clay argillization occurred at a medium temperature of about 200ºC. Based on the kinds of clay minerals, the ore-forming fluid is assumed to have been neutral to weakly acidic, while intensive dissolution of iron from BIFs suggests it also acted as the reducing factor.

Gold was produced at a temperature of about 250 ºC. The salinity of the ore-forming fluid is assumed to have been about 26wt% NaCl eq. (Fig. 4.5.4).

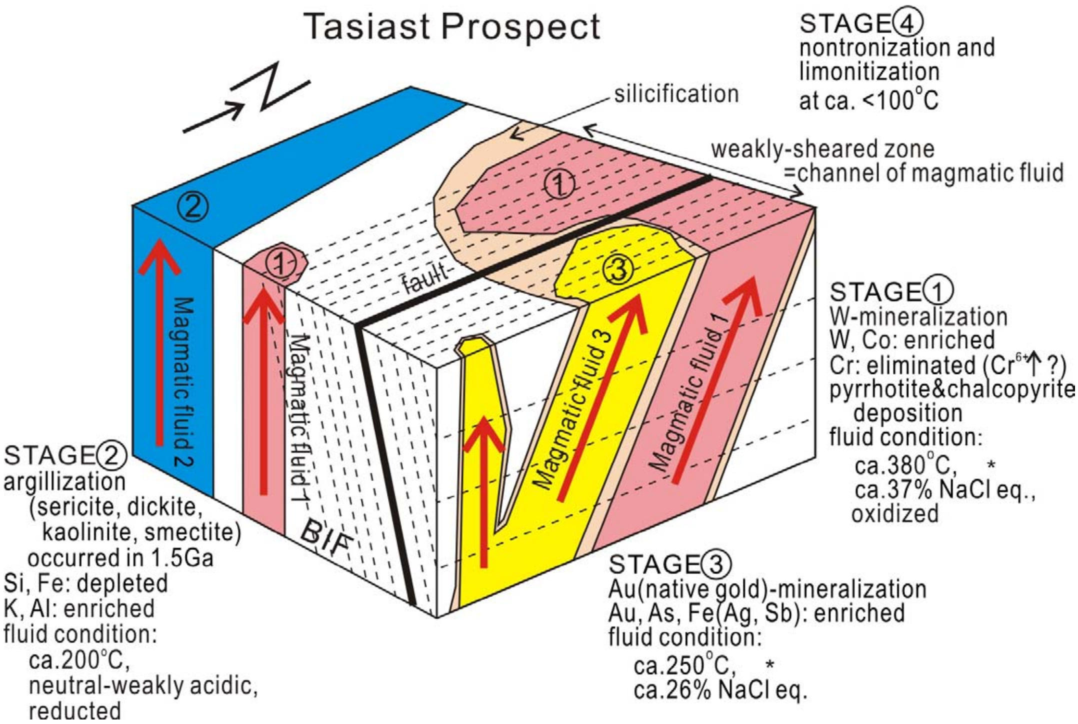

Fig. 4.5.4 Mineral deposit model of the Tasiast gold deposit

(2) Pathway of the ore-forming fluid

In a part of the gold mineralized area over 1 g/t for Au, the detritus from trenches were strongly crushed. The small detritus shows crushing of the strata by the fractures, and it suggests that the ore-forming fluid ascended through the sheared zone and loose parts in the vicinity of the sheared zone. Dominant orientation of the sheared zone is roughly presumed to be N-S direction, taking account of the trend of gold mineralized area showing 0.1-1 g/t for Au - the low gold mineralized area (see Fig. 4.3.3).

Meanwhile, the high gold mineralized area is located not near the central part of the low gold mineralized area, but in the northern-most part. This suggests that the results of geochemical survey are consistent with "gold shoots plunging in a southerly direction (Rio Narcea Gold Mines, 2005)". It seems the ore-forming fluid ascended northerly, not vertically.

(3) Mineralization age

K-Ar closed age shows the age of 1.9Ga in low potassium sericite (sericite approximately having less than 1% for K) from white argillized zone at the surface. Higashihara et al., (2004) pointed out that there was a possibility that K-Ar closed age of low potassium sericite or low potassium muscovite revealed an age which is 29 % older age than the true age. Due to this indication, it can be assumed that the true closed age of the above –mentioned low potassium sericite would be about 1.5Ga. This assumed age is supported by K-Ar dating value of sericite separated from the white argillized zone in a drill core.

If the gold mineralization took place simultaneously with the white argillization (1.5Ga), the age would be 0.2-0.3 billion ages younger than K-Ar closed ages (1.8-1.7Ga) of amphibolite from amphibolite schist as host in the Tasiast deposit, and muscovite from of biotite-muscovite. Since it is presumed that closed ages of minerals in crystalline schists show the terminal age of metamorphism, the gold mineralization took place 0.2 to 0.3 billion years later than the terminal age of the metamorphism. If the anatexis originated under the lower crust at the metamorphic stage, it is possible that magma cooled and set during 0.2 to 0.3 billion years. So, igneous activity as a driving force to hydrothermal process bears no relation to the crustal movement terminated in the range of 1.8-1.7Ga.

Izawa (1993) estimates that one of the peak times of the gold mineralization is 1.5Ga, and total amount of gold produced at that time reaches 600 tons. It is highly probable that certain geological conditions to yield global gold mineralization also in the Tasiast area were in place at that time.

4.5.4 Copper and gold deposits in the Mauritanides

(1) Overview of geohistory of the Mauritanides

According to Lecorche et al., (1989) and Le Page and Lecorche (1991), the Mauritanides consists of greenstone belt composed of numerous thrust sheets lying on the Reguibat Shield. Lecorche et al explained as follows:

Hajar Dekhen continental crust locatd in the west collided with the Reguibat Shield of the east. At this time, the oceanic plate lying between these continental crusts sliced as sheet-like shapes and entered the space between the two continental crusts along the thrust planes.

Higashihara (2005) concluded that the stage when thrust movement formed the Mauritanides could have been about 680Ma taking into account the plate tectonics theory, based on the formation age (691±30Ma) of skarn in the Guelb Moghrein deposit and the intrusion and eruption age (680±10Ma) of the Bou Naga alkali igneous complex including syenite.

After the collision, the Mauritanides underwent metamorphism of the green schist facies. This metamorphism is assumed to have continued until the age of 393±10 to 307±8Ma, based on K-Ar dating of muscovite in the muscovite schist from the Mauritanides (Fig. 4.4.5).

Plutonic activity in the Mauritanides resulted from the collision (about 680Ma) of two continental crusts which formed the Mauritanides (Higashihara, 2005). It is considered that the crust near the thrust logged by the collision of the continental crusts sank into the mantle, and the temperature rose, and anatexis originated, and the plutonic activity took place in the vast area of the Mauritanides. The above-mentioned formation of skarn with copper-gold mineralization in the Guelb Moghrein deposit, and the alkali igneous activity in the Bou Naga were associated to a series of this plutonic activity (Higashihara, 200). It is probable that hydrothermal copper and gold mineralization in other areas in the Mauritanides resulted from this plutonic activity as well.

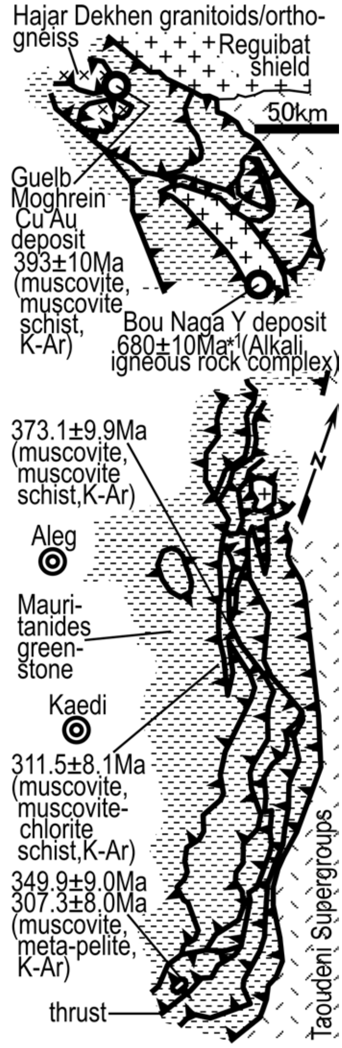

Fig. 4.5.5 Thrust structure in the Mauritanides and geological age (after Le Page and Lecorche, 1991)

(2) Guelb Moghrein copper and gold deposit

The deposit is assumed to be skarn type iron-oxide copper and gold deposit (IOCG) which replaced the carbonate rocks interacted in greenstone. Near the deposit, the greenstone chiefly consists of (biotite-) chlorite schist of the green schist facies, and is associated with meta-gabbro which contains the amphibole showing K-Ar dating of 3.6Ga (Murakami, unpublished data) and the amphibolite showing Ar-Ar plateau of 1.7Ga (Murakami et al., 2005). A small block of black politic-muscovite schist is confirmed in the green schist, and K-Ar dating of muscovite from the block revealed 0.39±0.01Ga showing the terminal age of metamorphism of the green schist facies. The Algoma type BIFs are confirmed to lie as thin layers in the green schist in the vicinity of the deposit (Strickland and Martyn, 2001). It is suggested that the entire greenstone is of the Archean group (Murakami, Homepage).

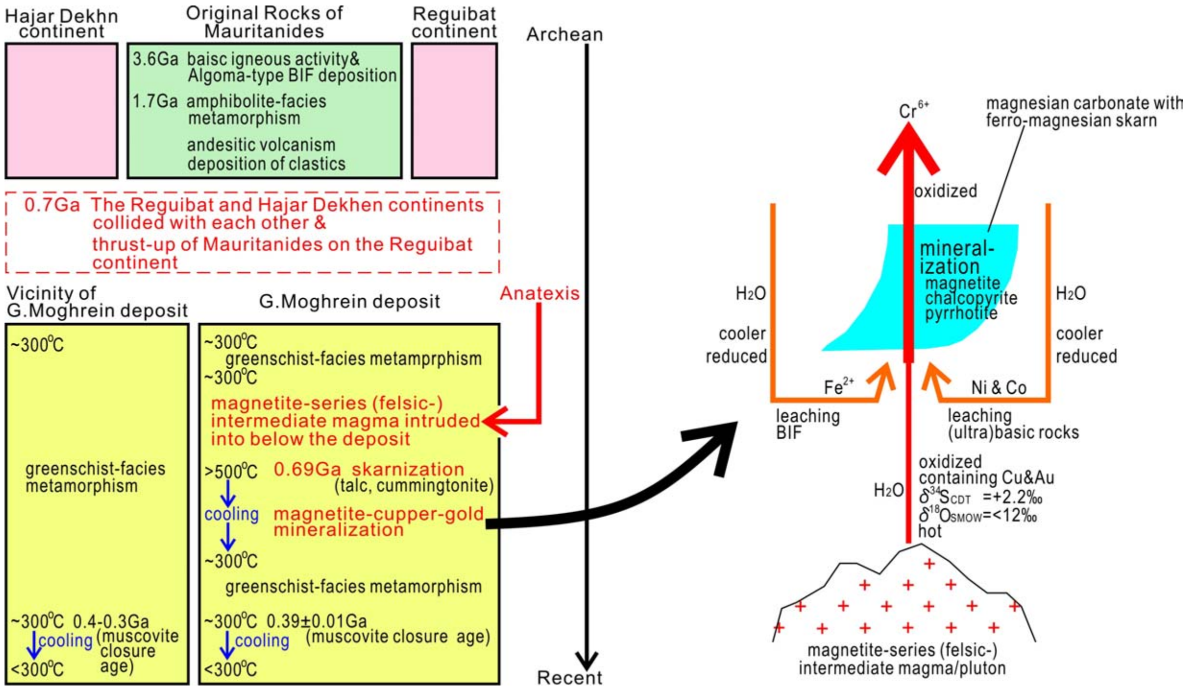

Fig. 4.5.6 Mineral deposit model in the Guelb Moghrein copper and gold deposit

Iron magnesium skarn of talc and cummingtonite was produced in the carbonate rocks and the greenstone at the age of 0.69±0.03Ga before the mineralization in this deposit. It is assumed that the magma originated in the above-mentioned anatexis came up just under the deposit, and heating the carbonate rocks formed skarnization. After that, iron oxide mainly composed of magnetite with a little amount of pyrite and pyrrhotite crystallized, and copper sulfide of chalcopyrite etc., crystallized, and gold mineralization occurred at the same time, carbonate rock and parts of skarn being replaced (Murakami et al., 2005). The $\delta^{34}S_{CDT}$ of chalcopyrite which was produced at this time is +2.2‰ (Murakami, unpublished data). Applying this value to Ishihara and Sasaki (1989), it can be assumed that the granite related to mineralization probably belongs to magnetite series. In the greenstone in the vicinity of the deposit, it is recognized that chromium diffused, and the ore-forming fluid was presumably affected by the oxidation. Iron transfer under the oxidation condition does not seem probable. Apparently apart from magmatic fluid there was also flow of reducing ground water, and this flow transferred iron^{2+} ion into the deposit, where it came across the magmatic fluid of the oxidation condition, and the iron^{2+} ion was oxidized to precipitate as iron oxide. In this case, Algoma type BIFs which were confirmed in the greenstone in the vicinity of the deposit, are regarded as the source of iron supply. Nickel and cobalt which are included in the ores in a high grade must have diffused and transferred in the same way as iron. Copper and gold must be of magmatic origin. In this case, if Meinert (1977) is applied to this deposit, it can be assumed that magma contain less than 63% of SiO_2.

(3) Indice 78 copper and gold prospect

This prospect consists of a hydrothermal deposit composed of chalcocite malachite native gold-bearing quartz veins cutting schistosity, and gold bearing malachite lens injected into schistosity, in the green schist originating from andesitic pyroclastic rocks and meta-andesite. Copper and gold mineralization in this prospect are confined within a 100m wide and over 600m long rectangular zone trending NNW-SSE, and quartz veins out of the zone are barren (see Fig. 4.2.13), though they are spread over a wide area. The fact that mineralization occurs along a straight-extend zone suggests the existence of fractures beneath the straight extension. But at the surface there is no indication of fractures.

Therefore, it is presumed that the expected fractures could possibly be dormant in the Reguibat Shield, just beneath meta-tholeiite unit of the Mauritanides, the host of the prospect. The magma generated in anatexis rose to produce copper and gold along the fracture about 680Ma, and another flow of magma come up to result in barren quartz (Fig. 4.5.7).

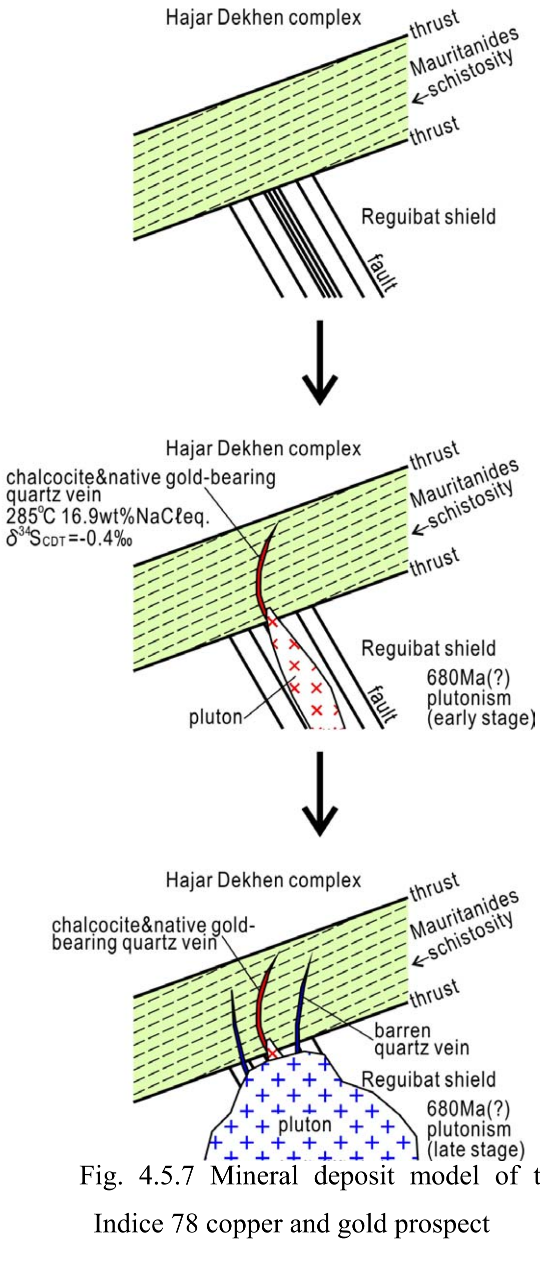

Fig. 4.5.7 Mineral deposit model of the Indice 78 copper and gold prospect

4.6. Selection of promising areas

The 13 deposits chosen for supplementary geological survey have been studied for confirmation of their status as promising deposits, and the promising areas have been selected.

Being the target for exploration and development of metallic deposits in Mauritania, taking into consideration the present situation of infrastructure and the interest of foreign investment, the 1st priority is gold deposit; the next is copper deposit followed by the third, the rare metal deposit. Therefore, selection process of the promising area in the strategic development plan by this study, has focused on the area where promotion of copper and gold exploration is possible.

4.6.1. Promising area

Based on the investigation of deposits and prospects in this survey, the Tasiast area (Au), Tijirit area (Au) and Amsaga area (Cr) were chosen as promising in the Reguibat Shield, and the Akjoujt area (Cu, Au: the Guelb Moghrein deposit and the Tabrinkout prospect) and Guidimaka area (Cr, Pt) in the Mauritanides.

Table 4.6.1 Promising areas

Geologic province	Mineralization	Promising area	Exploration target
Reguibat shield	Mesothermal gold disseminated and network	・Tasiast	・Magnetite bearing BIF ・Hydrothermal alteration with nontronite
	Hypothermal quartz gold vein	・Tijirit	・Quartz vein in basic rock ・Tectonic
	Podiform chromite ore	・Amsaga	・Serpentinite
Mauritanides	Carbonate replacement copper and gold	・Akjoujt	・Carbonates in basic schist
	Podiform chromite ore	・Selibaby	・Serpentinite in greenstone belt

4.6.2. Promising deposit and mineralization

(1) Tasiast area

The Piment deposit in the Tasiast area is a hydrothermal gold deposit in magnetite-bearing BIF of the greenstone belt in the Reguibat Shield. The occurrence includes quartz veinlets, quartz networks and dissemination. Chlorite schist and amphibolite schist are dominant in magnetite, porphyroblast of garnet also occurs. Veinlets and lens layer of pyrrhotite lie in magnetite-bearing chlorite schist. Native gold coexists with pyrrhotite. At the surface, BIF is exposed to hematitization, limonitization, nontrinitization and kaolinitization by supergene process associated with quartz veins.

The Piment sector has been intensively explored, and it was identified that main orebody extends about 1km along a N-S direction which is a strike of BIF with average width of 25m, and that the shoot composed of high grade ores over Au 50g.m, plunges in a southerly direction (Rio Narcea Gold Mines, 2005). The reserves are estimated at about 25 million tons, grade of 2.6 g/t, with a total gold content of 2.084 million oz (65t), The altered BIF subjected silicification, white argillization and nontronitization are distributed about 5km north and about 10km south-southeast of the Piment sector. Therefore, it is probable that gold mineralization similar to the Tasiast Piment deposit exists beneath these sectors, and it is presumably in form of two or three deposits.

(2) Tijirit area

The Ator vein at the Tijirit area consists of gold-bearing quartz veins formed in the Proterozoic greenstone belt of the Reguibat Shield. NNE-SSW tectonic lines develop in this area, and gold-bearing quartz veins were formed along the fractures parallel to these tectonic lines. Characteristics of the gold vein at the Ator vein and vicinity of veins are the co-existence of copper mineralization composed of malachite, and a local existence of the high-grade gold ores over 10 g/t Au.

Exploration under the quartz veins in the Ator sector has not been conducted so far and the downward continuance of mineralization is still unconfirmed. No sufficient survey around the area has been conducted. Since there is a possibility that gold-bearing veins exist there, it is necessary to do the detailed geological survey in the area

Geochemical anomalies over 100 ppb Au are spread in the large region of 6km east to west and 8k north to south about 30km southwest of the Ator sector (OMRG, 1996a). NNE-SSW directed dykes and faults are revealed in this sector. The lithological facies are similar to those in the Ator sector. Based on a similar geological environment, existence of gold-bearing veins is also expected there.

The Tijirit West sector located about 110km southwest of the Ator sector, in the southeastern extension of the Tasiast area consists of the greenstone which spreading in NE-SW direction. Since geochemical gold anomalies are extracted in the area of 30km x 5km in this sector (Fig. 4.3.2), it is possible that hydrothermal quartz vein type and quartz network gold deposits similar to those of the Tasiast deposit also exist there. One of the promising areas is located here.

(3) Akjoujt area

The Guelb Moghrein deposit and the Tabrinkout prospect are hydrothermal copper and gold deposits formed in the Mauritanides. The deposits have replaced magnetite-bearing carbonate layer in the green schist. Coarse grains of magnetite occur in the green schist in the intercalated carbonate layer. Sulfide minerals of chalcopyrite and pyrrhotite occur as dissemination and veins around the grains of magnetite. At the surface, gold-bearing malachite quartz veins cut the green schist, and malachite disseminates in the carbonate rocks. At present, proven reserves are 23.6 million tons, and average ore grade is 1.88% for Cu, 1.41 g/t for Au, and 143 ppm for Co

The top part of this type deposits is altered to silicified gossan, and they resist weathering.

They form hills and hilly landscape penetrating a peneplain. In the 40km area between the Guelb Moghrein deposit and the Tabrinkout prospect, copper and gold prospects as El Khader (principal), El Khader (Breccia), El Joul Est and Anomaly A1 exist (Marenthier, 1997). Apart from the drill and trench works implemented at limited part of these prospects, a sufficient exploration has not been carried out here. In the nearest future, it is probable to discover good copper and gold mineralization replacing carbonate rocks. Therefore this area was also selected as promising.

(4) Selibaby area

The Guidimaka deposit in the Selibaby area is a podiform type chromite deposit in the serpentinite in the Mauritanides. The deposit is 10-40m long and several meters to 15m thick. Eight orebodies are confirmed by this survey. Because major chromium mineral is ferro-magnesiochromite, the grade of chromium is low and ranges between 22-33% Cr_2O_3. It is lower than the grade of commodity ore which is 35-55% Cr_2O_3. But this survey has confirmed platinum group mineralization showing 0.07-0.1 g/t Pt in the chromite ores. Also it has confirmed osmium as a metal grain and irarsite, laurite, erlichmanite and cuproiridsite as sulfide minerals

In this area five chromite deposits were found (BRGM, 1975). No.1, No2 and No3 deposits have been investigated in this survey. Since platinum group minerals were confirmed, there is a possibility that PGM exist in other chromite orebodies in this area.

(5) The Amsaga area

The chromite prospect is located in the Amsaga area in the Reguibat Shield, with a serpentinite in anorthosite complex. The mineralized zone is formed in an area of 4,00m x 300m in chromite prospect in Guelb El Foulet, and an area of about 10km x 500m in El Heinrich. Chromium grade ranges within 30-36 % $C_{r2}O_3$ (BRGM, 1975). From the point of view of the grade it is classified as the refractory grade.

Distribution of chromite ores in the Amsaga is wider than their distribution (4km x 3km) in the Guidimaka deposit in the Selibaby. There is no PGE data in the Amsaga area. Since geological background is similar to the Guidimaka deposit, this is the area where existence of PGE is expected.

4.7. Guideline of the survey and exploration methods

Based on the results of this geological survey, guidelines of the survey and exploration methods for the promising deposit are described as follow:

(1) Tasiast area

1) Guideline

- BIFs related to gold mineralization in chlorite schist and amphibolite schist is dominant in magnetite.

- Observation of altered minerals is very important at the surface. Especially the existence of nontronite due to supergene process, which is the indicator of gold mineralization. Nontronite occurs vein-like and disseminated in the hematitized and limonitized BIFs.
- White argillization zone composed of sericite and kaolinite is spread in the outer section of the nontronite zone of supergene enrichment. Rock and ores are observed and described taking into consideration the alteration zoning.
- Porpyroblast of garnet showing high metamorphic grade occurs near pyrrhotite coexisting with gold in drill cores. The existence of garnet at the surface suggests gold mineralization form around the rocks containing garnet.

2) Exploration methods

- Aeromagnetic survey is an effective means of prospecting to extract magnetite-bearing BIF which is the host rock of the deposits in the greenstone belt.
- Localization of the gold orebody existence area which is, like Tasiast, a mesothermal deposit, discrimination of hydrothermal altered minerals, and alteration zoning are important prospecting methods.

(2) Tijirit area

1) Guidelines

- The gold-bearing quartz veins formed along the NNE-SSW fractures in the greenstone belt. Quartz veins composed of a NNE strike and a NNW strike running diagonally form an echelon arrangement.
- So far, alteration has been weak around gold-bearing quartz veins, and alteration zoning has not been found. Whenever gold mineralization is found in quartz vein, it is accompanied by copper mineralization represented by malachite.

2) Exploration method

- Geological reconnaissance conducted near the junctions of lineaments of ENE-WSW direction and NE-SE direction on the satellite images regionally.
- Because the existence of secondary copper ore as malachite suggests gold mineralization, observation at outcrops of quartz veins is important.

(3) Akjoujt area

1) Guidelines

- Sificified gossan is intensive at the surface, endures weathering, and forms small hills.
- Host rocks are magnetite-bearing magnesite dominant carbonate rocks in green schist. Coarse grains of magnetite occur in chlorite schist.
- Sulfide minerals of chalcopyrite occur in dissemination and vein –like form near magnetite grains in carbonate rocks, also boundaries between chlorite schist and carbonate layer.
- Gold-bearing quartz vein cut magnetite –bearing carbonates, and could be pathway of

hydrothermal activity.

2) Exploration method

- Aeromagnetic survey is an effective prospecting method to extract magnetite-bearing carbonate rocks which is the host rock of the deposit in chlorite schist.
- If copper and gold come up to the surface, there is a certain possibility that the mineralization reaches the depth along the quartz veins and the fracture. It is necessary to carry out drilling in the greenstone of the footwall.

(4) Selibaby area

1) Guideline

- The deposit is podiform type chromite deposit lying in a small scale in serpentinite with a low grade of 22-33% Cr_2O_3.
- Massive chromium ore contains mainly ferro-magnesiochromite with chromite.
- It is confirmed that PGM exists as fine metal grain and sulfide minerals in ferro-magnesiochromite or chlorite. In condition of PGE existence, the market values of chromite ores will be higher. There is a possibility that PGE is concentrated in certain parts of chromite ores.

2) Exploration method

- Aeromagnetic survey is an effective method to extract chromite orebodies from serpentinite.
- Definition of schistosity of the serpentinite is used to trace chromite orebodies. Structure analysis is necessary.
- Drilling survey is needed to explore the depth of chromite orebody, and to grasp existence of PGE.

(5) Amsaga area

1) Guideline

- Chromite deposit must exist in the serpentinite unit similar to the Guidimaka deposit in the Selibaby area. It must be of a podiform type chromite deposit.

2) Exploration method

- Aeromagnetic survey is an effective prospecting method to extract chromite orebody from serpentinite.
- Schistosity of the serpentinite is used to trace chromite orebodies.

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Chapter 5 Mineral Evaluation

5.1 Remote Sensing Data Analysis

5.1.1 Satellite Imagery Overview

Remote sensing is an observing and recording mean of distant features, most commonly from aircraft or satellites. Satellite images, each covering many thousands of km^2, are ideal for mapping vast, remote regions - such as Mauritania with little vegetation (Fig.5.1.1).

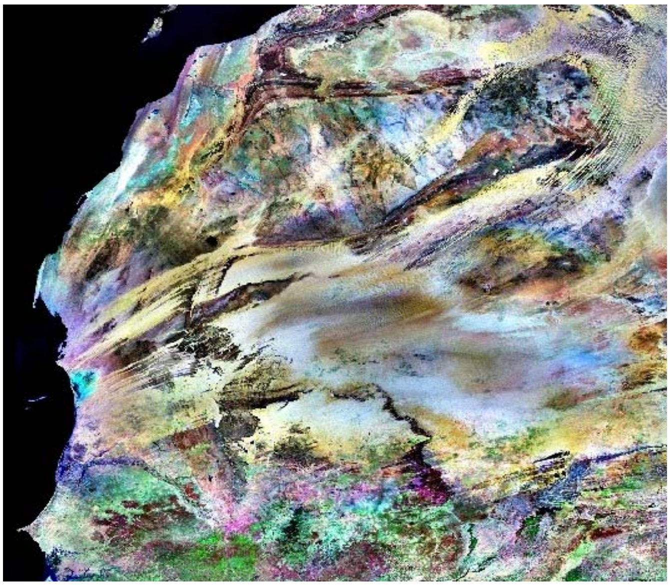

Fig.5.1.1
A mosaic of ca.100 LANDSAT images, covering territory of Mauritania (source: ER Mapper website)

(1) Geological mapping

Geological mapping using remote sensing has two main forms: structural and lithological. Satellite images give a synoptic overview of a region, allowing the mapping of some major features that otherwise would have been missed by aerial photography. There are two aspects of structural mapping: simple lineaments (faults, trends, veins) and complex features (folds, domes, basins) (Fig.5.1.2).

Fig.5.1.2
Draft LANDSAT lineament map of the M'Bout region, Mauritania (Source: British Geological Survey)

Limited lithological mapping can be carried out by an air photo interpreter, relying on differences in image tone and texture, plus pattern and shape recognition. With multi-spectral imagery we can go further and faster, utilizing the distinct spectral responses of different rocks and minerals. Furthermore, as the multi-spectral imagery is digital (unlike conventional photographs), we can use computers to automatically process, enhance and classify the data into lithological maps.

(2) LANDSAT Images

LANDSAT images, each covering ca. 170km x 170km, have been a key element of geological remote sensing since1973. In addition to viewing the Earth in the visible spectrum, multi-spectral satellites such as LANDSAT also detect in the infra-red (Fig.5.1.3): this facilitates the mapping of regional lithologies, structures and land cover types.

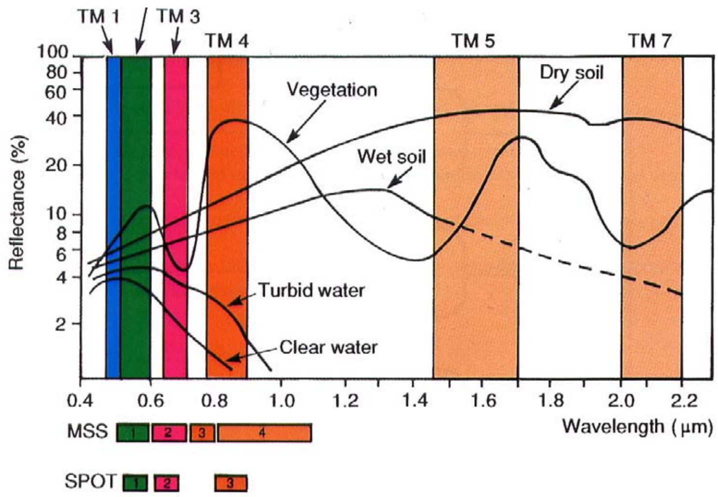

Fig.5.1.3 Spectral signatures for the LANDSAT Thematic Mapper (TM), LANDSAT MSS and SPOT sensors (source: Lawrence *et al*., 1994).

(3) ASTER Satellite Imagery

Aster satellite imagery offers a new improved means of geological mapping and has become the JICA team's main data source for mineral mapping in Mauritania. As well as having twice as many spectral bands as LANDSAT (Fig.5.1.4), ASTER can also view the Earth's surface in more detail and produces a Digital Elevation Model for each 60km x 60km scene – it is also relatively cheap data, at $70 to $100 per scene.

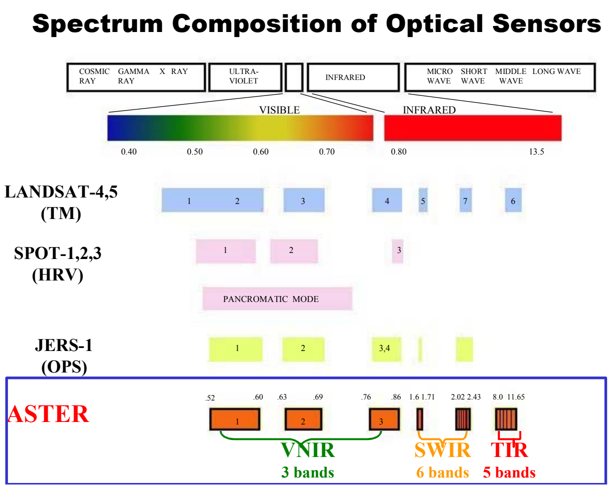

Fig.5.1.4 Spectral resolution of ASTER versus other satellites (source: ERSDAC)

An example of ASTER's better performance for mineral mapping, relative to LANDSAT TM, is given in Fig.5.1.5: with ASTER data we can not only identify zones of hydrothermal alteration, but can also automatically map the main mineral types (Table 5.1.1).

LANDSAT TM **ASTER**

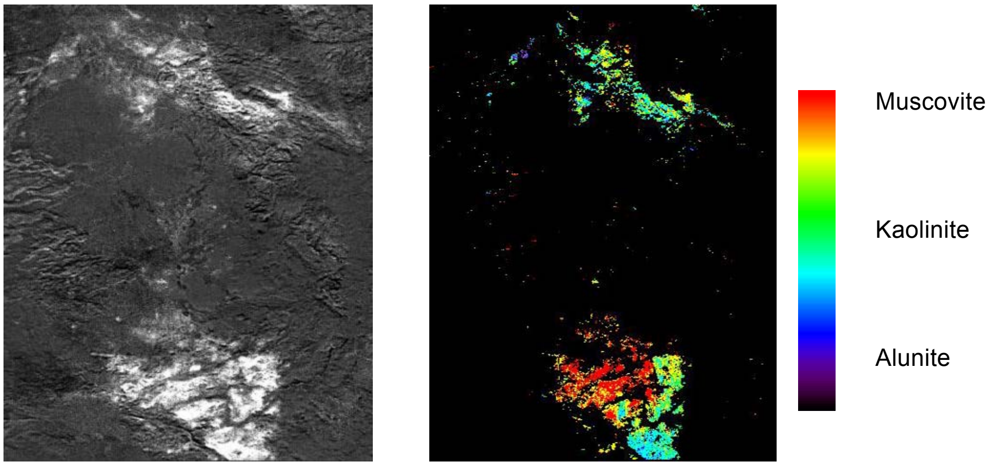

Fig.5.1.5 Comparison between LANDSAT and ASTER to map hydrothermal alteration. Alunite is an indicator mineral for gold deposits (source: Infoterra plc).

Table 5.1.1 Summary of minerals detectable using ASTER (source: USGS)

ASTER SPECTRAL REGION/ SPATIAL RESOLUTION	BAND CENTER, MICROMETERS	COMPOSITIONAL INFORMATION
VNIR / 15 m	B1 - 0.56 B2 - 0.66 B3 - 0.81	FERRIC AND FERROUS IRON AND REE ABSORPTION
SWIR / 30 m	B4 - 1.65 B5 - 2.17 B6 - 2.21 B7 - 2.26 B8 - 2.33 B9 - 2.40	- AL-O-H IN CLAYS, MICAS, SULFATE MINERALS - CO_3 IN CARBONATES - Mg-O-H IN AMPHIBOLES, MICAS - H-O-H IN EVAPORITES, CLAYS
TIR / 90 m	B10 - 8.30 B11 - 8.65 B12 - 9.10 B13 - 10.00 B14 - 11.30	- SILICATE MINERALS, ESPECIALLY SHIFT TO SHORTER WAVELENGTHS - SULFATE MINERALS - CARBONATE MINERALS

(4) ASTER-Based Exploration Strategy

The spectral detection bands of ASTER, in the Short Wave Infrared (SWIR) and Thermal Infrared (TIR) provide a means of improving the effectiveness of mineral prospecting. Key indicator minerals for various types of mineral exploration can be identified directly from the processed ASTER imagery (Table 5.1.1). This saves lots of time, in the initial fieldwork stages of exploration and the geochemical analysis of collected samples, allowing targets for drilling to be selected relatively quickly. What has been called "the ASTER advantage" is summarized in Fig.5.1.6 below.

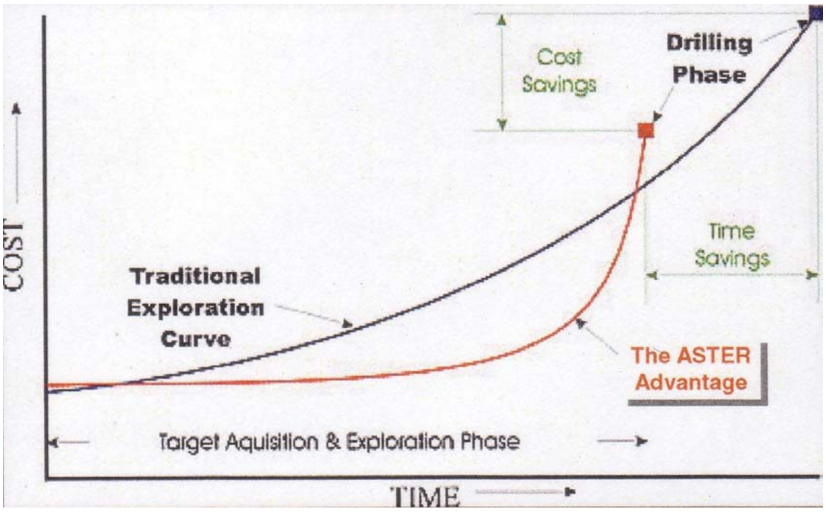

Fig.5.1.6 Savings in exploration time and money: the ASTER advantage
(Source: T. Coudahy, CSIRO, Australia)

One further benefit of using ASTER data is that its DEM can have an ASTER-derived mineral map overlay and be viewed in 3-D, or even as a 'virtual reality' fly-over. This can assist geologists in visualizing the nature of a given deposit, but it is also a useful display tool for attracting prospective investors. An example, from Death Valley, California, is given in Fig.5.1.7.

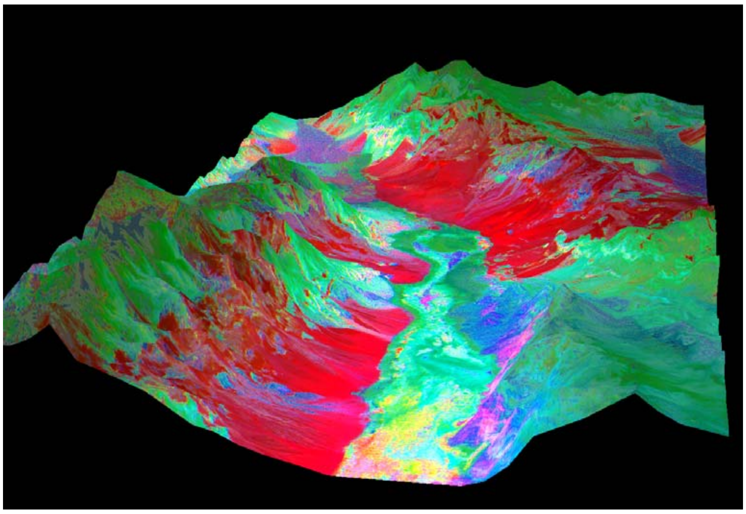

Fig.5.1.7 Death Valley: ASTER DEM overlain with an ASTER-derived mineral map.
Red = Quartzite Green = Carbonate Yellow-Pink = Evaporites (source, USGS)

(5) Effectiveness of Remote Sensing Analysis

- LANDSAT TM and ETM imagery have been useful for regional geological mapping.
- Imagery from the new ASTER satellite provides a means of mapping mineral families associated with various types of ore deposit.
- ASTER-generated mineral maps produce significant savings in time and costs, relative to conventional prospecting.
- The ASTER DEM allows the production of 3-D views and "flyovers", aiding mineral deposit modelers and helping to attract investors.

5.1.2 Mineral Exploration/Development Targeting

LANDSAT ETM images have been used by this study in Mauritania to examine known areas of mineralization. Digitally processed LANDSAT ETM imagery was compared with geological maps held in the PRISM geological information system (SIGM). Fieldwork surveys were made to check "ground-truth" and to collect samples for spectral signature analysis and mineral identification in the OMRG in Nouakchott.

Fig.5.1.8 shows an example from the M'Bout-Kadiar region of the southern Mauritanides mineralization zone. The same image processing routines that were useful for lithological mapping of M'Bout-Kadiar were then applied to other prospective regions, allowing inter-region comparisons (Fig.5.1.9).

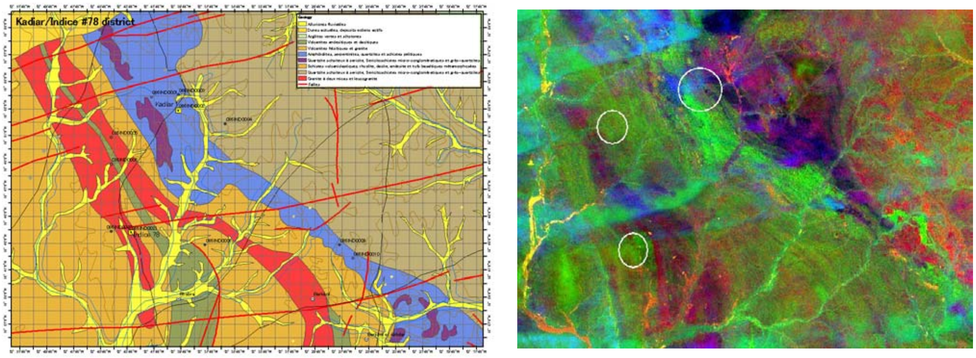

Fig.5.1.8 Geological map (left) and processed LANDSAT image (right), Kadiar region.

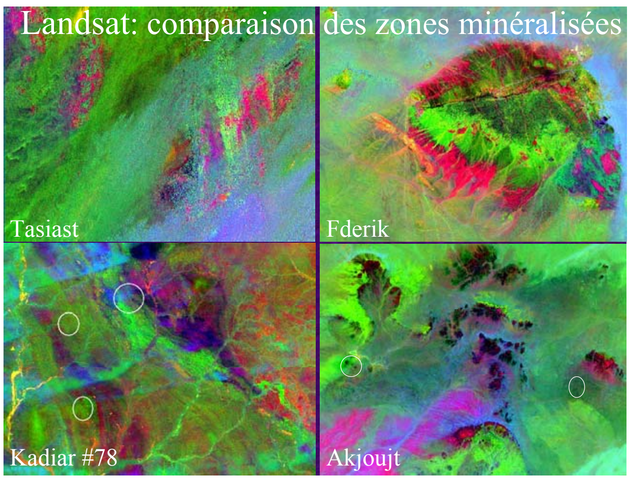

Fig.5.1.9 Comparison of mineralized regions, using the same LANDSAT processing (RGB 5/7 4/5 3/1)

(1) Technical method of Remote sensing analysis

Remote sensing analysis utilized for mineral exploration is described in detail in Appendix I, 3.2 of the Interim Report. Remote sensing analysis encoded along the flow chart of the Fig.5.1.10 by using mineral spectrum characteristic. This analysis is divided to pre-processing, analysis and output.

1) Pre-processing

Pre-processing occupies about 50-60% of the whole processes by the thing which hits the stage of preparation until it goes into the analysis from the acquisition of satellite data.

a. Data search and acquisition

It obtains satellite data to use for the analysis through the Internet. At first, distribution conditions of cloud cover, quantity of cloud, image quality, observation date are checked in the analytic range, every scene from the archives satellite data of the Web site. The data are selected from that result, and it obtains it through Website.

In case of ASTER

http://imsweb.aster.ersdac.or.jp/ims/html/MainMenu/MainMenu.html

In case of LANDSAT

http://edcwww.cr.usgs.gov/

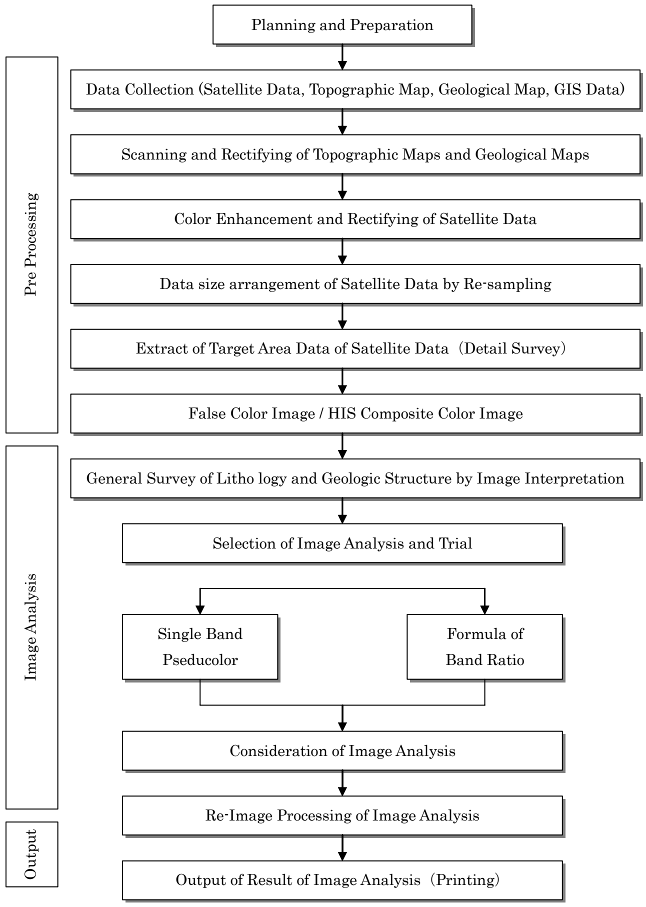

Fig. 5.1.10 Flowchart of Image Analysis

b. Acquisition of the topographical and geological maps and the GIS data

It obtains topographical and geological maps, GIS data and so on that related to the study area. It used as it is when these were digital data. But, when these were paper-printing map, it changed into the digital data by using the scanner.

c. Color enhancement and geometric correction

After satellite data are indicated on the display, a histogram is changed, and color enhancement means the method made a clear image. Geometric correction is the technique that each pixel transfer into the same coordinate so that or it can do overlay processing about satellite data, geological map data and GIS data. After selecting some control points using 1:200,000 scale topographical map, geometric correction was done by the UTM coordinate system 28. As for the geological map and other GIS data as well, geometric correction was done in the same way. Actually, as for geometric correction of the satellite data Geometric correction of the satellite data selects clear points more (in such cases as the intersection of road and bending part of geographical features) with both of the topographical map and the satellite data as the ground control point about twenty points. It was adjusted so that the error of each control point might become within the number pixel.

d. The adjustment and re-sampling the data size of the satellite data

One pixel of the satellite data copes with the resolution of the sensor. In case of ASTER, the resolution is divided into three of VNIR15m, SWIR30m and TIR90m. On the other hand, in case of LANDSAT the resolution is divided into three of visible-infrared 30m, thermal infrared 60m and monochrome visible 15m. The adjustment of the data size is to makes equal image size and makes easily image composition (in such cases as false color image composition) and overlay processing. Actually, in case of ASTER, by taking re-sampling all the bands with in 15m of the minimum resolution, each band composition of VNIR, SWIR and TIR became possible. As for the case of LANDSAT as well, it is the same.

e. Extract of target area and image composition

Extract of the target area which cover the study area followed each data of the satellite data that it has been corrected, topographical map and geologic map. Using three bands in each extracted data it has made false color image or a HIS (hue, intensity and saturation) color emphasis image as basic image of the study. Topographic map and geological map of the same area were output, and it used for the analysis. Fig.5.1.11 shows false color image which the band 3,2,1 of ASTER and HIS color-enhanced image in Akjoujt as the sample. 3 bands are chosen from the multi-band data of ASTER and LANDSAT, and 3 primary colors (Red, Green and Blue) are assigned, and some color composition image is composed. Various color composition images are completed by this method. False color image is called with the human eyes like this from covering infrared wavelength range that can't be seen in 3 bands. Blue is assigned to green, the band 1 in the band 3 in red, the band 2, and composed of the above example. HIS (Hue, Intensity, Saturation) color emphasis image is used for composition hue, intensity and saturation instead of RGB of primary color. It is said that generally this image is suitable for the alteration zone and classification of litho logy.

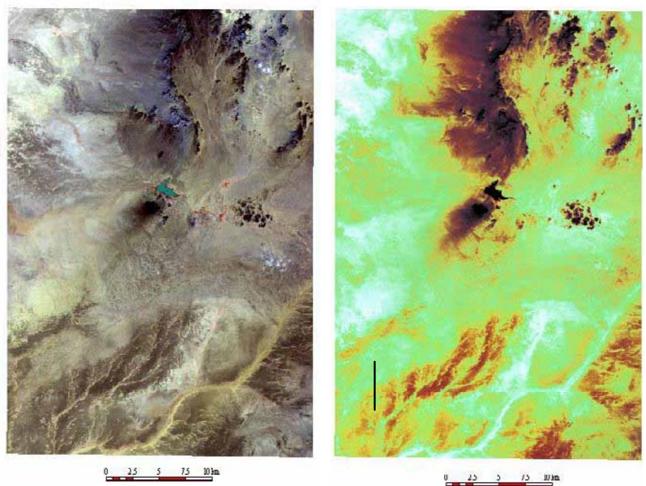

Fig.5.1.11 False Color Image and HIS Color Enhanced Image in Akjout

2) Image analysis

Image analysis classified to image interpretation and image processing.

a. Image interpretation

Image interpretation is technique that interpret geological structure using false color image, HIS saturation enhance image, geological map and so on.

Image interpretation must enforce knowledge such as geomorphology, geology in the study area, and it is placed the point for classification of litho logy and the extraction of lineament. Fig.5.1.12 is the case of lineament extraction in Tijirit.

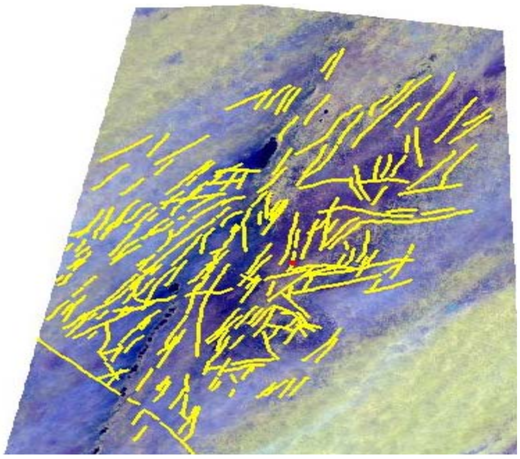

Fig.5.1.12 Lineament extraction in Tijirit

b. Image processing

Image processing is to do various operation and a statistical work by using the various analytic functions of software for remote sensing analysis. There is single band level slice, band ratio processing, and so on in the main image analysis for the mineral. It is judged which technique is the most suitable in the study area from geomorphology, geology, litho logy, spectral characteristic of mineral, and so on, and some trials should be necessary. As for Table 5.1.2 for ASTER and Table 5.1.3 for LANDSAT show mineral image analysis technique from the existent materials. Image analysis was conducted by these techniques in this study.

Table 5.1.2 Image Processing Technique of ASTER

Mineral Commodity	Spectral Absorption (μm)	ASTER	
		Band	Image processing
Ironic oxide	0.4～0.6 0.8～1.0	Band1 Band2	RGB: 321 false color image (green) Ratio:(Band1/Band2 or Band1/Band3)
Calcite		Band8	RGB: 865 false color image (greenish-blue) Ratio:(Band6+Band9)/Band8
Kaorinite Montmorilonite		Band6	RGB: 865 false color image (reddish-violet)
Alunite		Band5	RGB: 865 false color image (yellow) (Band5+Band7)／Band6
Silicate	8～12		(Band11×Band11)／(Band10×Band12)
Carbonate		Band14	Band13／Band14
SiO_2			Band13／Band12
Vegetation		Band2	Band3/Band2

Table 5.1.3 Image Processing Technique of LANDSAT

Mineral Commodity	Spectral Absorption (μm)	LANDSAT	
		Band	Method of image analysis
Ironic oxide	0.4～0.6 0.8～1.0	Band1 Band2	RGB: 321 false color image (green) Ratio:(Band1/Band2 or Band1/Band3)
Vegetation			Band4／Band3

(2) Remote sensing & exploration targeting – summary of progress

a. Visits have been made to a number of key mineralization sites (notably in Akjoujt Fe-Cu-Au region, M'Bout Cu-Au-Fe-Mn-Ba region and Kadiar Cu region) in order to assess the effectiveness of satellite remote sensing for mineral exploration.

b. The American LANDSAT Enhanced Thematic Mapper (ETM) was found to be very useful for regional-scale, general geological mapping, but is of limited use for site-specific mineral mapping.

c. ASTER imagery was found to be much more effective than LANDSAT for identifying many mineral types associated with epithermal and mesothermal alteration zones, as well as zones of silicification and meta-carbonate rock of high economic potential.

d. ASTER also provides a means of using night-time thermal imagery to detect mineralization zones buried under desert sand and alluvium (Fig.5.1.13), especially if used in conjunction with geophysics and borehole data.

e. The JICA-donated portable spectrometer (POSAM) was used to determine the spectral signatures of samples from the field sites: this will be a useful tool to use in conjunction with the ASTER multi-spectral satellite imagery.

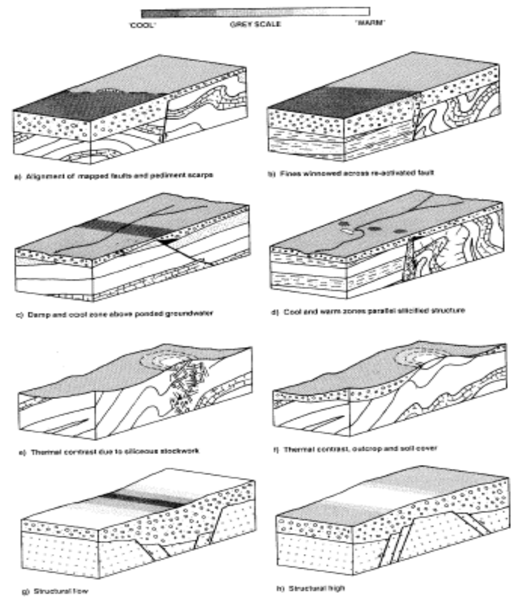

Fig.5.1.13 Buried mineralization zones

(3) Remote sensing & mineral targeting - recommendations

1) Stage 1:

- ASTER imagery should be purchased for all of the mineralization sites that have been recognized as high potential.
- A "ground-truth" survey should be carried out at each site, involving the recognition of key lithological and structural feature, as well as the collection of samples for spectrometer analysis using POSAM.
- Night-time ASTER thermal imagery should be obtained for each site, as the mineralization zones are often buried under recent sediments.

Note 1: ground-truth data, spectral signatures and thermal imaging from the mineralization sites will greatly improve the effectiveness of ASTER-based mineral mapping and will assist mineral deposit modelling.

Note 2: regional airborne geophysics data (gravity / magnetics / radiometrics) are needed as much of the Mauritanides mineralization zone is buried under Cenozoic sands and alluvium.

2) Stage 2:

- Sites considered of secondary importance should be examined using ASTER imagery, as there will be a better chance of detecting mineralization after the known sites have been examined.
- The selection of sites for additional ASTER surveys can be assisted by using GIS to examine multiple exploration datasets (geochemical, geophysical, plus borehole data).

(4) Targeting of mineral resources

Exploration targets are concretized by optimization analysis through images reading, image analysis and information of geography, geology and rock quality etc. In this study, the exploration targets were gold and copper determined by total analysis including the supplementary geological site survey and remote sensing analysis and so on. As mentioned earlier, Akjoujt and Tijirit were examples of targets. To clarify exploration targets more clearly and concretely, it is necessary to accumulate the survey data of geology and ore deposits in Mauritania. Precision of remote sensing analysis is improved by data accumulation indicating geological characteristics of ore deposit-types because there are many types for gold and copper ore deposits. For example, characteristics of alteration gained by ground-truth and POSAM measurement are effective for remote sensing analysis (Fig. 5.1.14).

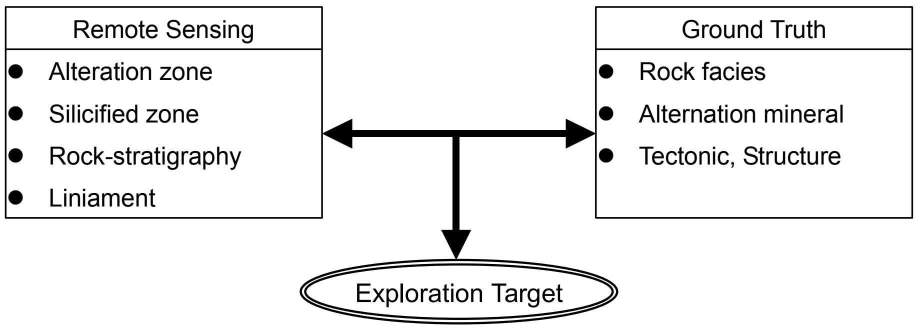

Fig. 5.1.14 Remote Sensing Analysis and Exploration Targets

As Akjoujt and Tijirit-Tasiast areas are currently targets for exploitation, detailed geological data is being steadily accumulated. Therefore, utilization of these data makes new potential targets more effective for remote sensing analysis.

5.2 Geological Provinces and Characteristics of Mineral Deposits

Each geological province is different in ore deposit type due to geological structure and development history of the geological province. The deposit size is often restrained by the ore deposits type which characterizes each geological province. Therefore, it is an important target for exploration, and also a basis of potential evaluation.

5.2.1 Characteristics of Ore Deposits in each Geological Province

(1) Reguibat Shield

The east section hosts gold, copper, tin, lead and zinc occurrences.

- Conchita-Florence gold manifestation ------ Gold bearing quartz vein in migmatites
- Catherine copper-tin manifestation ------ Greisen
- Yetti lead and zinc manifestation ------ Hydrothermal sulfide vein along fractures

In the central part, iron deposits and manifestations are mainly distributed and exploited.

- Koedia-Idjill iron deposits ------ Banded hematite deposit
- Tiris iron deposit ------ Magnetite deposit
- Gara Bouya Ali ------ Goethite ore
- Sfariat-Zednes ------ Magnetite deposit
- Tourassin-Aneinat ------ Tin geochemical anomaly in granite

- Ghallamane Sebkhas ------ Copper geochemical anomaly

In the west, gold deposit and chromium manifestations occur.

- Iron, gold, rare earth and nickel deposits in the Tasiast ------ Gold deposit stretched along fractures in BIF, Li, Be and Ta manifestations in pegmatite, and nickel showing in ultramafic rocks.
- Chromium occurrence in the Amsaga ------ Orthomagmatic chromite deposit (banded, disseminated)

In the Reguibat Shield, a kimberlite was discovered in 1998, and existence of diamond was confirmed. 17 kimberlites were afterwards reported and be found until 2000.

(2) Taoudeni Basin

Copper and phosphate manifestations are discovered in the Taoudeni basin.

- Chegga copper occurrence ------ Copper dissemination in ferruginous sandstone
- Akka Danach ------ Hematite concentrate in sandy schist
- Bathat Ergil ------ Phosphate minerals in ferruginous sandstone

(3) Mauritanides Chain

In Mauritanides composed of green stone, there are lots of manifestations of gold, copper, chromium and rear earth.

- Guelb Moghrein deposit ------ Gold-copper disseminated deposit replaced carbonate rocks in volcano-sedimentary rocks
- Kadir copper occurrence ------ Copper dissemination in magnesium rich ferrous carbonate rocks
- Guidimaka ------ Massive chromite deposit in serpentinite
- Bou Naga ------ Thorium and lithium deposit in alkaline intrusives

(4) Atlantic Coast Sedimentary Basin

Deposits of gypsum, rock salts, phosphate and ilmenite are distributed in the Atlantic Coast Sedimentary Basin.

- Kaedi-Aleg-Boghe phosphate deposit ------ Phosphate sediments associated with dolostone-limestone in Eocene along the Senegal river
- Ilmenite deposits along Atlantic coast ------ Recent and Tertiary coastal sand and dune sediments. Concentration of ilmenite is related to sedimentary cycle (Nouakchott transgression of Quaternary).
- Gypsum to the north of Nouakchott ------ Gypsum formation in dunes
- Afrou-Sahali ------ Rock salt deposits in Quaternary

Table 5.2.1 represents the relationship between the geologic province described above and forms of mineralization.

Table 5.2.1 Geologic Province and Mineralization

Geologic province		Rocks	Mineralization
Reguibat Shield	East	● Granite ● Migmatite	● Greisen (Cu, Sn) ● Gold bearing quartz vein ● Lead and zinc vein
	Central	● Ferruginous quartzite, leptynite ● Itabirite	● Banded iron formation (BIF)
	West	● Basic schist, ferruginous quartzite ● Granite ● Amphibolite, serpentinite	● Gold deposit associated with BIF ● Pegmatite (Li, Be) ● Chromite deposits (banded, disseminated)
Mauritanides		● Basic schist, carbonates ● Serpentinite ● Alkaline granitic rock	● Gold copper disseminated deposit ● Copper disseminated deposit ● Massive chromite deposit ● Thorium and Lithium deposit associated with alkaline intrusives
Taoudeni Basin		● sandstone ● Sandy–muddy schist ● Ferruginous sandstone	● Copper dissemination in sandstone ● Hematite concentrate in schist ● Phosphate minerals
Atlantic Coast Sedimentary Basin		● Dolostone, limestone ● Coastal sand	● Phosphate deposit ● Titanium placer deposit

5.2.2 Target Deposits for Development

The Guelb Moghrein and Tasiast deposits are listed as target deposits of non-ferrous metal for development in Mauritania. These two deposits are concrete examples for resources evaluation Mauritania. After detailed geological survey, the two mines have accumulated data for geology and mineralization which will be effective materials for the next exploration.

(1) Guelb Moghrein Deposit

Guelb Moghrein deposit is located in 250km to the northeast of Nouakchott and about 5km west to the Akjoujt. The deposit is copper-gold, which replaced originally existing carbonates. It had been developed and operated as a copper and gold mine since 1955, call under the name of Akjoujt. However, the mine terminated operations in 1978, due to a sudden rise of energy price and some issues concerning mineral processing.

In 1997, feasibility study was performed by joining an Australian mining company. It is reported that total measured and indicated ore reserves of 23.6 million tons with an average content of 1.88% Cu and 1.41g/t Au have been calculated.

In June 2004, First Quantum Minerals Ltd in Canada signed an agreement with Guelb Moghrein Mines d'Akjoujt SA (Gemak) concerning the acquisition of an 80% share in the Guelb Moghrein copper-gold deposit. In the second half of 2004, MCM (Canada) attained the right and started its action for re-development. First Quantum will begin an operation producing 12,000 t/y copper within 2006. Ore reserve is 23.7 million tons with grade of Cu 1.88% and Au 1.4g/t (Cu 446,000 t and Au 32 t in metal). Around the mine site, there are many mineralized zones in the wide area which has high potential of same type ore deposits. Detailed information about calculated reserve is proprietary information that is not publicly available, making it impossible to make evaluations. At present there is some small-scale production, but it is believed that about 40-50,000 tons of metallic copper could be produced a year from even moderate deposits, if the amount of ore in the surrounding area could be confirmed

(2) Tasiast Deposit

Tasiast deposit, located in 300km north of Nouakchott, is a hydrothermal gold deposit. The Amsaga formation of Archean forms a basement around the deposit. Ferruginous quartzite, chlorite schist, sandy schist and amphibolite are found here. The deposit may be a hydrothermal gold deposit, where gold precipitated along bedding and fractures in sedimentary banded iron formation (BIF).

In April 2004, Tasiast Gold Corporation (Canada) announced the completion of the bankable feasibility study for its 100% owned Tasiast gold project. The study reports that proven and probable ore reserves amount to 9.0 million tons with 886,000 ounces of gold (approximately 28.5 ton) and average grade of 3.06 g/t Au. They already started mine development with a plan to begin producing an annual average of 120,000 ounces of gold per year in late 2006. Mine life is calculated to be less than 10 years. Around the mine site, there are many mineralized zones which have high potential of same type ore deposits, if detailed exploration will be done. Because there is no data available for making resource evaluations, there are questions about the profitability. While estimates of ore grade indicate that it may be sufficiently profitable to extract the deposit by open pit, there are problems with infrastructure and securing the necessary labor, whose associated cost burden is not negligible.

5.3 Evaluation Methods of Mineral Resources

5.3.1 Present Status of Evaluation of Mineral Resources

At present, Mauritania government has no mineral resources evaluation standard and there is no law or regulations related to this topic. Mauritanian government announced its mineral resources (see Table 2.5.1), which is an old data and does not express the actual condition of Mauritania.

Current economical evaluation of mineral resources to be exploited has been performed by parties (exploration or mining) license holders, who carry out explorations and development in the area, and by consultant companies of Western countries. For example, the Guelb Moghrein copper-gold deposit and the Tasiast gold deposit being targets for mining development, had been evaluated on ore reserves, grade and metal contents by Canadian consultant companies on the basis of Canadian Governmental Criteria. The results of evaluation of the mineral resources have been reported to DMG and registered.

OMRG and DMG have no technique on ore reserve calculation method, which is base of mineral resource evaluation, because full-scale exploration in Mauritania is only starting. National iron company SINM, however, uses a technology of ore reserve calculation in its operations. The ore reserves calculation method at iron deposits is not complicated as compared with non-ferrous metal deposits like gold, silver, copper, lead and zinc.

If amount of the mineral resources were not realistic in the guideline and goal of investment promotion, it gives a negative influence to exploration activities. The gold resource amount in Tasiast is about 30t and the copper amount about 45 t and the gold amount 32 t in Akjoujt. If the geological condition of an ore deposit is same as above ore deposits, its expected amount can be calculated. At present there is another ore deposit to be evaluated and calculated except above deposits in this study. Exploration is at level of affirmation of mineralized zones and investigation of mineralization, so it is important to calculate the mineral potential as expected amount. To OMRG, “resource evaluation” means estimating the probable amount of reserves. And then precision of expected amount is improved according to progress of geological surveys. For example, it is possible to find the Guelb Moghrein deposit type 5 – 6 mineralized zones in 50km by 20km (about $100km^2$) from the past survey and this study. They are supposed to contain equivalent metals, copper of 300t and gold of 200t as expected amount. In the Tasiast-Tijirit areas, there is potentiality to find 30 blocks (1 block: 30km by 40km) which contain total gold of 300-900t. Furthermore, the stockwork gold deposit, which is a target of foreign juniors, may have an added potential of 50t in each of the 4 units, for a total added gold potential of 200t. Therefore, in just the Akjoujt and Tasiast-Tijirit areas, there are potential reserves for something on the order of 3-5 million tons of copper metal, and 700-1,500 tons of gold metal. Based on this information, it would be preferable for OMRG, in its capacity as a geological organization, to use survey data to calculate potential reserves and provide this information to foreign investors, which in turn might attract foreign companies to enhance exploration activities.

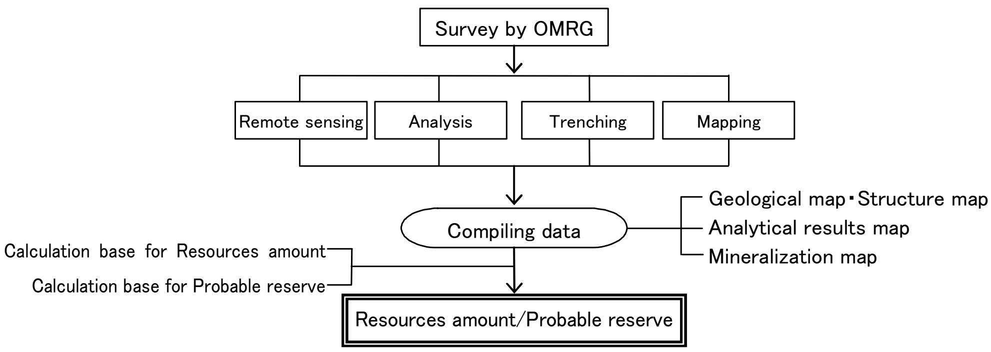

Fig. 5.3.1 Resources Evaluation by OMRG

5.3.2 SNIM Iron Mine

Department of mine and research of National Company SNIM, which have produced iron ore before, have conducted core drilling works to increase minable ore reserves around working sites of TO14 of Tazadit sector, El Rhein and M’Haoudat. SNIM has its own analysis center and engineering geologists. They recalculate ore reserves considering the workable sites changing due to mining (Table 4.2.1).

It is necessary for Mauritanian geologists to share the ore reserve calculation skill. It is needed to improve the skill to calculate each ore deposit for evaluation of mineral resources in Mauritania in the future.