Mineral Exploration in Mawat Region, Kurdistan-Iraq, based on Satellite Data and Terrain Prospection

The main goal of the presented exploration was to estimate potential for mineralization in the Mawat Ophiolitic Massif in Kurdistan, Iraq. The aim of the study was to explore existing copper mineralization and assessor elements gold, platinoids and chromium. Geological exploration detected two types of Cu occurrence a) secondary Cu carbonates (malachite) and b) Cu sulfides (chalcopyrite-pyrite). The Mawat region is mostly built of ultrabasic and basic rocks: peridotites, gabbros, serpentinites and basalts which are heavily deformed, with faults mostly oriented NNW-SSE, and NE-SW. The first phase of exploration comprised digital processing of ASTER and QuickBird satellite images, with appropriate geometrical and radiometric corrections and transformation into coordinate system. Color composite images were produced in different scales. They served to define lithological composition, tectonic settings, location of the points of interest etc. The field work was designed to check satellite data in situ, with focus on perspective rock formations, which might host copper mineralization, and other elements. The host rocks of the ore occurrences are primarily gabbros and metagabbros intersected by diabase dykes, epidote and quartz veins. Secondary mineralization is the product of surficial weathering and its represented by malachite and limonite. The geophysical survey was very useful in the detection of area with elevated induced polarization and low resistivity. Three perspective areas have been selected for detailed explorations: Waraz, Mirava-Chenara and Konjirin-Kuradawi. The concentration of copper varies highly in very wide ranges; the maximum measured concentration of Cu was determined in Waraz area 6.7%. Some rock samples also show concentration of gold from 0.36 to 2.59 ppm Au.

Keywords: Mawat Ophiolitic Massif, Geologic-geophysical Explorations, Copper Mineralization, Kurdistan-Iraq

Introduction

The goal of this exploration was to estimate potential for mineralization of Mawat Ophiolitic Massif in Kurdistan, Iraq. The aim of the study was to explore existing mineralization of copper as well as of other metals like gold, platinoids, chromium etc. The explored area has about 250 km², about 40 km² of which was selected for detailed exploration of mineral resources. In addition to geologic-geophysical survey, satellite ASTER and QuickBird imagery have also been used. Color composite images were produced in different scales, which served for rock discrimination, registration of tectonic elements, location of control and sampling points, etc. The field work was designed to check satellite data in situ, with focus on perspective rock formations, which might host mineralized rocks. The ore host rocks are primarily gabbros and metagabbro intersected by diabase dykes and epidote and quartz vein.
Secondary mineralization is the product of surficial weathering and is represented by malachite and limonite.

The geophysical explorations were applied in detection of anomaly area (induced polarization-IP, magnetic resistivity and SP methods) and proved very useful.

Three areas: Waraz, Konjirin-Kuradawi and Mirava-Chenara area were selected as potential by perspective for increased mineralization and were subjected to detailed exploration and sampling for chemical and petrological analyses. Measurement Cu in rock samples in ppm are as follows: Waraz area 1.53 - 60705, Konjirin-Kuradavi 68-36287 ppm and Mirava-Chenaran 135-16803 ppm. Maximum value of 6.7% Cu was determined in Waraz area. In some rock samples the gold concentration of 0.36 and 2.59 ppm were registered.

Study Area

The study area is situated in northeastern part of Iraq (Kurdistan), about 30 km north of Sulaimany City (Figure 1), with topography altitudes which ranges from ca 940 m (south part) to more than 1400 m a.s.l. (north part). The main ultramafic body represents low area, surrounded by high peaks made of mafic intrusions which are grey and dark green in color showing pseudo stratification.

Figure 1. Positional of the Explored Area in Mawat Region, Kurdistan-Iraq

Geological Setting

According to previous geological studies, the studied area belongs to the Zagros Mt. chain which extends SE-NW. It is a young Alpine orogeny formed by collision of African elements with Euroasian continental plate, and closing the Tethyan Ocean. The Zagros orogenic system consists of several large distinctive geotectonic units which correspond to Cretaceous - Palaeogene subduction of the Arabian plate beneath the Central/East Iran microplate,
which is still active in the prolongation within the Gulf area. A wider area is
built of Arabian platform formations, covered by Tertiary foreland units. Early
foreland formations are Kolosh Tanjero, Shiranish, and Late foreland
formations are Sinjar, Gercus, Pila Spi, Lower Fars and Upper Fars. This
molasse formations are overthrust by ophiolitic mélange incorporated within
the Qulqula Uper Cretaceus hinterland group. They indicate a regional Zagros
nappe system and have a tongue-shaped form, named Mawat Nappe. Its central
part consists of ophiolite and metamorphic rocks, surrounded by outcrops of
Red bed series, as well as Naopurdan Series. More detailed chronological
overview of earlier studies is given in the following section.

PREVIOUS STUDIES

Mawat Ophiolitic massif was studied by numerous geologists. G. M. C.
Bolton (1955) made the first geological map of this region and discussed
tectonical zones as well as economic prospects of the area, and named, and
distinguished both Bulfat and Quandil thrust blocks.

Geology of the central sector of the Mawat igneous rocks has been
published by S. Z. Jassin (1975). The dispersion of Cu, Ni, and Cr
mineralization in Mawat Ophiolite Complex was reported by A. R. Al-Hashimi
& H. M. Al-Mehvidi (1975). The northern part of studied area was explored by
F. R. Hamasalh (1982) who wrote that Ultramafic rocks comprise peridotites,
dunites, pyroxenites and hornblendites which contain more than 90% mafic
minerals. The geological prospecting for copper mineralization in Waraz
locality, Mawat Igneous complex was performed by group of domestic experts
Mussaab A. H. Al-Hilali (1991), etc. According to earlier conclusions, Mawat
Massif was generally considerit without economical importance (Bolton, 1953).
Power (1954) considered copper occurrences unimportant and without
economical potential. Smirnov & Nelidov (1961) in Waraz area determined
3.71% of Cu and concluded that mineralization is insignificant with no
commercial concentrations of copper. However, some newer exploration (Al-
Hasimi & Al-Mehaidi, 1975) reported that copper content which in the
mineralized zone reaches up to 5440 ppm Cu (5.4% Cu). Detailed geological
investigations in the Waraz locality with the one borehole (240 m deep) alows
for recognition of two types of Cu occurrence a) secondary Cu carbonates
(malachite) and b) Cu sulfides (chalcopyrite-pyrite) which is probably primary
mineralization. Geochemical analysis of borehole samples provided
concentrations of copper in span from 11 ppm to 4910 ppm (average 638 ppm).
Recent exploration of Mawat Ophiolite complex (Yassin et al, 2015.)
documented copper sulfides (Chalcopyrite, Bornite, Chalcocite and Covellite)
in copper–rich deposits.
Geologic-Tectonically Exploration

SATELLITE IMAGERY - ANALYSIS AND INTERPRETATION

In this study was used Satellite imagery obtained by Tera-ASTER and QuickBird satellites. ASTER image cover wide spectral region with 14 bands and spatial resolution which varies from 15 m, 30 m and 90 m, coverse the area of 60 x 60 km. These resolutions were suitable for regional interpretation of the Mawat complex. The images were used to evaluate large areas of terrain for a variety of properties like tectonics, rock discrimination, and geomorphology. QuickBird imagery has higher resolution (1 - 4 m) and was useful for more detailed analysis of physical landforms such as outcrops or structural features and for location of control and sampling points etc.

Figure 2. ASTER Colour Composite (VNIR & SWIR) of Mawat Ophiolitic Complex: B-Basalt, Diabase, Metadiabase; G-Gabbro, N-Wallash-Naopurdan Nappe, Metagabbro; P- Peridotite, Serpentite, RB-Mollase - Redbed Series, F- Fold Zone; Q- Qulgula (Image was Recorded in 2003)

ASTER satellite color composite was produced from different spectral channels: 6, 3, 1; 3, 2, 1; 9, 7, 5 and 3N/3B, in scale 1:25 000, while QuickBird Color composite produced in the scales 1:10 000 and 1:1000. Color composites in the cartographic projection, were used for orientation, basis for drawing of collected data (GPS), and for tectonic interpretation and rock discrimination (Figure 2).
In the NE part of the explored area predominant rocks are basalt and diabases (B), meta gabbro and gabbro (G), peridotites and serpentites (P), and the zone of Mollase - Redbeds unit (RB). In the SW part Mollase – Redbed series dominates, which extends in zonal form around the central part of the terrain. Wallash and Naopurdan Nappe have been thrusted over Redbed series, which are very intensely disturbed (folded), with many plicative structures (anticlines and synclines). The rocks are intensely ruptured, with numerous faults predominantly NW-SE orientation (Figures 3-5).

**Figure 3. Digital Terrain Model of Mawat–Waraz Area (Satellite ASTER Image Shaded Relief Azimut = 315°)**

**Figure 4. Lineaments in Mawat-Waraz Area Registered on ASTER Imagery**
Dominant strikes of faults are NNW - SSE and NE – SW. Streams and deep valleys are predisposed by faults and are located along them (direction NE-SW). The localities on intersections of different fault systems frequently show enrichment in copper mineralization.

Field Work

The field work comprised two phases; first, gathering general information on geology of the explored area, and the second focused on detailed observation on the ore occurrences, their host rocks, mineralization, etc. The field work comprised cruises crosscutting geological units of the Mawat Ophiolitic complex to acquire general idea on their mutual relationship with special accent on the position of mineralization. The rock composition is very heterogeneous, and the area is heavily tectonized (Figures 6 and 7). On crosscuts we have observed characteristics of Upper Cretaceous Shiranish, Tanjiro, and Agra formations, Redbed series (molasses unit), and Naopurdan-Wallash Formation (melange nappe).

Figure 6. Redbed Sediments - Intensely Folded, in front of Zagros Overthrust
Special attention was given to the Mawat nappe ophiolite rocks including peridotites, serpentinites, gabbros, basaltic rocks and metamorphics rocks of the Gimo sequence. More detailed work was carried out on the three separate areas which were recognized as most promising for copper mineralization.

**Detailed Exploration of the Separated Locality**

Three localities were identified as potential perspective zones of increased sulfide mineralization, and selected for detailed geological and geophysical explorations. These are Waraz (A), Konjirin-Kuradawi (B) and Mirava-Chenara (C) localities (Figure 8).

**Figure 8. ASTER Color Composite of Waraz-Mawat Area and Perspective Localities (A, B, C)**
Waraz Area (A)

Waraz area is located in southern part of Mawat Ophiolitic Masif and has the surface of about 12 km² (Figure 8). Based on interpretation of satellite data, geological field reconnaissance and geophysical survey, as well as microscopic and geochemical study, the Geological sketch-map was produced displaying the host rocks, tectonic elements and mineralisation zone (Figure 9).

The map illustrates distribution of major rock types (upper pillow lavas, sheeted dykes etc.), and perspective zones of copper mineralization. More dominant rocks are basalts (β) and diabase (ββ), followed by gabbros (U) which are frequently followed by epidotes veins, isolated in different blocks. The terrain is intensely tectonized and cut by numerous faults in various orientations (Figure 10).

Figure 9. Geological Sketch-Map of the Waraz Area with Mineralization Zone
Figure 10. Rose Diagram of Ruptures in Waraz Area

The mineralization zone extends coherently in SE-NW direction in the length of about 1500 m and about 800 m wide in the central part of explored terrain. Mineralization is mostly located in pillow lavas, basaltic dykes and gabbro-diabase formation (Figure 11).

Figure 11. Pillow Lava Highly Tectonized Contains Copper Mineralization

Copper ore crops out as thin horizons, ranging from 10 cm to 50 cm in thickness and between 1 to 5 m in length, distributed within an area of about 0.4 km². Mineralization is situated within sheared and fractured zones in the basalts and greenschists, closely associated with acidic rocks and quartz veins. The sheared and fractured zone strikes NW and dips 50-70° to NE. Mineral association consists of malachite, pyrite, limonite and chalcopyrite. The copper content in mineralized zone varies in very wide ranges from 1.53 to 60505 ppm.

Primary minerals in the mineralization zone are represented by: chalcopyrite, bornite and pyrite. In the oxidation process from chalcopyrite, malachite and limonite were developed, and from pyrite formed limonite. The rocks were intensely fractured and dissected by numerous epidotic veins.
Mineralization is evidenced by limonatization which primarily follows epidote veins. At places, one may find traces of the secondary copper mineral malachite, originated by weathering of chalcopyrite. The gabbro-diabase formation is crosscut by numerous epidote and, in lesser extent, quartz veins.

The intensity of mineralization correlates well with the intensity of epidotisation.

**Geophysical Survey**

Geophysical survey (geoelectric and geomagnetic techniques) were utilized with the aim to identify a) the distribution of lithological units with sulfide mineralization, b) faults and fault zones, and c) the intensity of total magnetic field \( \Delta T \). Geoelectric mapping and sounding was applied for the geophysical/geoelectric surveys, which included induced polarization (IP) techniques electrical resistivity method. The used method in combination with field reconnaissance, resulted in data showing sulfide mineralization and its field distribution (Figure 12).

**Figure 12. Induced Polarization (IP) Anomaly and \( \rho a \) Value of Lower and Higher Resistivity (B-1 Borehole)**

The zones with increased induced polarization-IP value are, as a rule, the zones of increased sulfide mineralization, which were registered almost in all measured profiles, in the area of about 1.5 km². The IP values showed that the primary sulfides are situated in the compact gabbro-diabase rocks. Larger zones of lower electrical resistance, characteristic for diabase rocks with enrichment of secondary minerals (limonite, malachite with epidots), are located westwards and eastward of the exploration borehole B-1.

The higher IP values were registered in the areas with increased mineralization of secondary minerals (limonite and malachite with epidots). The values of gradients self- potential (SP) changed from -25 mV to more than
+ 45 mV. This data suggest that the increased self-potential $IP$ are related to the areas with increased values of $IP$ polarization. Decreasing values of $IP$ indicate secondary mineralization like in the locality west of borehole B-1. There are registered lower values of electric resistivity because of increased mineralization.

The anomalies of total magnetic field $\Delta T$ changed within bounds from 46700 to 48600 that indicate strong magnetic field, because of the presence of basalt and metabasalt with magnetic minerals (e.g. piroxene). The expressive anomalies of total magnetic field ($\Delta T$) compared with anomalies of $IP$ are shown in Figure 13. It is obvious that the orientation of anomaly have NW-SE strike, that coincides with tectonic dislocations.

**Figure 13. Waraz Locality: IP Anomaly and Intensity of Total Magnetic Field $\Delta T$**

Larger magnetic anomaly in central part of the explored area corresponds with the zone of diabase rocks and secondary minerals – malachite, limonite etc.

**Mineralization**

The main host rock of mineralization in Waraz area are pillow lava formation connected with basalt and basalt dykes and epidote veins, that showed $IP$ measurement. Pillow lava lithofacies is highly tectonized, along the regional sheared zone. The potential area of ore mineralization has the area of about 3 km$^2$. The mineralization host rocks are located at the very contact of the gabbro-diabase formation. Gabbro-diabase formation contains primary and
secondary mineralization (Figure 14). Locally, pillow lava formation is
thrust over the gabbro-diabase formation or onto the Naopurdan mélange.

**Figure 14. Secondary Copper Mineralization within Gabbro-Diabase Formation**

The zone can be recognized by limonitization of sulfides, and limonite staining on the rocks and numerous outcrops of secondary copper mineralization with malachites. The source of copper which occurs in the pillow lava formation has a significant importance. It is recognized by widespread occurrence of secondary minerals (*limonite, malachite, azurite*) and primary sulfide minerals (*chalcopyrite, pyrite, bornite*). The gabbro-diabase formation is crosscut by numerous epidote and, in lesser extent, quartz veins. The intensity of mineralization correlates well with the intensity of epidotization. Massive limonite were formed stainings on the basalt after oxidation of massive vein sulfide-malachite (Figure 15).

**Figure 15. Samples of Secondary Copper Minerals (Malachite)**
Geochemical analysis of representative rock samples taken in situ showed that the samples have increased Cu and some increased values of Au, Ti, and Fe (Table 1). The other elements Cr, Ni, As, Mo, Ag, Rb, Bi, and Zn contain lesser concentrations.

Table 1. Contents of Au, Ti, Fe and Cu in the Analysed Samples (10 000 ppm = 1% Cu)

<table>
<thead>
<tr>
<th>Nr</th>
<th>Sample No</th>
<th>Au (ppm)</th>
<th>Ti (ppm)</th>
<th>Fe (%)</th>
<th>Cu (ppm)</th>
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<tbody>
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</tr>
<tr>
<td>4</td>
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<td>949</td>
<td>3.51</td>
<td>174</td>
</tr>
<tr>
<td>5</td>
<td>W-22</td>
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<td>1.34</td>
<td>35</td>
</tr>
<tr>
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<td>1587</td>
<td>4.46</td>
<td>621</td>
</tr>
<tr>
<td>7</td>
<td>W-30</td>
<td>&lt;0.05</td>
<td>613</td>
<td>4.41</td>
<td>8073</td>
</tr>
</tbody>
</table>

The Rare Earth Elements (REE) were also analysed (16 elements), and (TR) 51 elements, but the concentration of the elements have not increased values.

Konjirin-Kuradawi Area (B)

This area is situated in central part of the Mawat Ophiolitic Complex, and covers the area of about 6 km² (Figure 8). The area is primarily composed of the gabbro-diabase formation. Gabbro–diabase formation are cut by epidote and quartz veins, which contain limonite and malachite (Figure 16). The Konjirin area contains basaltoids of the pillow lava formation and a sheet dyke complex. At the contact with the mélange it obtained a wide range of textures from the pegmatitic gabbro, micro- and medium crystalline leucocratic and melanocratic gabbro, and at places achieved doleritic and diabase texture. The dominating types of the rocks in the study area are: diabase, gabbro, plagiogranite and epidotic veins.

Figure 16. Mineralization zone of Gabbro-Diabase Rocks with Epidote and Quartz Veines
Tectonics in this area was very active and the rocks are very dissered and disarrangement. Specially stressed is the fault zone, NW-SE strike which is cut by numerous transverse faults (Figure 17).

Figure 17. Rose Diagram of Ruptures in Konjirin Kuradawi Area

At the same time the localities with increased mineralization and limonisation have been registered. In the diabase-gabbroid rocks were registered Fe-Cu ore effusive cataclastite enriched with iron and copper minerals, which at the surface create limonite and malachite coatings. Flasered metadiabase (altered into greenshist metamorphic facies) have been determined by microscopic analyse (Figure 18).

Figure 18. Thin-Section of Flasered Metadiabase in Konjirin Area (P32x. N+)

Geophysical Survey

The map of induced polarization has values of $IP$ between 2 msec and 34 msec. Zones with higher values of $IP$, with higher sulfide mineralization, are determined only on geoelectric profile measured in a creek, probably in a fault zone. On the map of apparent resistivity ($\rho_a$), values of $\rho_a$ are in span between less then 600 Ohmm up to more than 2800 Ohmm. The zones of higher
mineralization $IP$ are probably located on the contact of lower- and higher
electrical resistivities and they are also caused by faults.

The map of self potential $SP$ shows values of $SP$ in range from -32 mV to
over +28 mV. The values of $SP$ also changed polarity on the contact zones.

The map of total magnetic intensity field ($\Delta T$) shows values of $\Delta T$ in the
span of 46200$\mu$T up to 49800$\mu$T. Higher values of total magnetic field $\Delta T$ are
detected on the north and northwest parts of the exploration area, partly on the
same place where induced polarization $IP$ is also high. Based on measurement
data, it could be concluded that anomaly zone $IP$ of smaller dimension is
situated on the intersection of larger dislocations with NE-SW and NW-SE
strike. The zones of lower and higher resistivity generally correspond to
existing NW-SE dislocations.

**Mineralization**

The mineralized zone generally stretches from SE to NW, and is the best
developed in central part of the terrain. The main bearer of the mineralization
are pillow lavas, connected with basaltic rocks and basaltic dykes, as well as
with well developed epidote-quartz, closely associated with leucocratic rocks,
supposingly plagiogranite. A wide zone of alteration has been recorded on the
southern border of the Konjirin exploration area (Figure 19).

**Figure 19. Alteration Zone with a Few Meters Thick Mineralization**

A fairly large number of geochemical analysis have been done, but here
are presented only some of them (Table 2).
<table>
<thead>
<tr>
<th>Nr</th>
<th>Sample No</th>
<th>Au (ppm)</th>
<th>Ti (ppm)</th>
<th>Fe (%)</th>
<th>Cu (ppm)</th>
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<td>896</td>
<td>4.50</td>
<td>217</td>
</tr>
<tr>
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<tr>
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<td>0.05</td>
<td>1683</td>
<td>2.44</td>
<td>3652</td>
</tr>
</tbody>
</table>

Mirava – Chenaran Area (C)

Mirava-Chenaran area is situated in northern part of the Waraz-Mawat ophiolitic complex, and covers about 9 km² (Figure 8). Dominant rocks are gabbro with metagabbro, then basalts with metabasalts, metatuff/effusive and quartz-metaeffusives (Figure 20).

Figure 20. Thin Section of Actinolite Shist with Iron Minerals (Actinolite, Acidie Plagioclase, Quartz- Epidote, Chlorite), the Rock is Rich with Magnetite and Pyrite (P32x, N+)

Diabase was found in central part of the area, and in places metabasalt is located more often along tectonic dislocations. Locally, plagiogranite was determined which can be gold bearer rocks. Epidote rocks are located in eastern and northwestern part of the area, more often connected to gabbro and diabase. These rocks often comprise increased mineralization especially of secondary minerals. Epidotic mineralized veins are connected to tectonic ruptures, and they are good indication of the mineralization. Tectonic activity in this area was very intensive, in particular radial tectonic, one can observe two general directions of faults: NW-SE, known as Zagros trend and NE-SW (Figure 21).
**Figure 21. Rose Diagram of Ruptures in Mirava–Chenaran Area**

![Rose Diagram of Ruptures](image)

**Geophysical Survey**

The same geophysical techniques have been used like in the studied areas A and B. Two IP smaller anomalies (15-70 msec) were registered in the zones of increased electric resistivity (a) which have been caused by gabbro and basalte rocks, that indicate increased sulfide mineralization (Figure 22).

**Figure 22. Induced Polarization (IP) Anomalies and (a) Value of Lower and Higher Resistivity**

![Induced Polarization](image)

The zones of lower electric resistivity can be related to the occurrence of epidote, and that coincide with tectonic dislocations of NW-SE strike.

**Mineralization**

The main bearer of mineralization in this area is pillow lava formation connected to basalts and basalt dykes. Mineralization is connected with well developed epidote-quartz, closely associated with leucocratic rocks, supposingly plagiogranite.

The outcrops with rich mineralization occur along the roadcut near the village of Mirava and Chenaran. It consists of highly limonitized gabbro and
diabase dykes with occurrences of secondary and primary copper mineralization (Figure 23).

**Figure 23. Gabbro-Diabase Formation with Epidote-Quartz Veins and Copper Mineralization (Close to the Road to Mirava)**

The rocks are intensely fractured and dissected by several generations of veins. The first system consists of epidote veins, ranging in size from several cm to 0.5 m. The epidote veins are cut by quartz veins. Mineralization consists of secondary copper minerals, malachite and iron oxides. The whole rock unit was intruded by diabase dykes and sills, up to 1 m thick. Mineralization is closely related to the epidote-quartz veining (Figure 24).

**Figure 24. Diabase Dykes Intruded and Tectonically Displaced in the Gabbro Rocks**

The Chenaran locality is characterised by a wide limonitization zone, which follows general strikes of the rock formations, mostly built of gabbro-diabase. Its intensity increases toward the Chenaran Village, where epidote-
quartz ore veins are exposed, with malachite, limonite and primary sulfide minerals. The locality is mostly composed of gabbro-diabase rocks, which incorporate significant masses of plagiogranites (Figure 25).

**Figure 25. Copper Mineralization: Primary Mineralization: Bornite, Chalcopyrite and Pyrite, and Secondari: Malachite and Limonite, (Near Chenaran Village)**

Primary mineralization zone it is evident in the Mirava village locality too, in gabbro-diabase formation, which incorporates significant masses of plagiogranites (Figure 26).

**Figure 26. Mineralization Zone in Gabbro-Diabase with Plagiogranites in the Mirava Village Locality**

The Mirava locality is built of basalt-diabase formation with variable contribution of diabase, epidote-quartz veinis, gabbro pegmatites, and several zones of plagiogranites which are closely associated with mineralization. The mineralization is recognized in many outcrops in the area which extends from Mirava village to the contact with the Naopurdan formation. The plagiogranites contain 2.5 g/t gold. The area of mineralization is very large, approximates 10 km².
The clear signs of the primary mineralization are weathering products of sulfide: limonite, malachite, and chalcocite. Primary mineralization, consisting of bornite, chalcopyrite and pyrite (Figure 27) underwent replacement within the cementation zone, by chalcocite. The secondary mineralization is dominated by massive limonite and brown stainings of limonite (e.g. goetite) over the surface surrounding host rocks. With decreased weathering, oxidizing zone turned sulfides into malachite and limonite, with rare relics of the chalcocite (Figure 28).

**Figure 27.** Copper Minerals: Chalcopyrite, Bornite, Pyrite and Malachite and Limonite in the Epidote-Quartz Veins

The mineralization zone can be followed generally from SE to NW and is the best developed in the central part of the study area. The southeastern boundary of the mineralization is not constrained; a possible extension of the mineralization zone extends toward Waraz. Mineralization terminates on the north above the Kuradawi village too.

*Geochemical* analysis has been done on 17 elements and gold. The contents of gold in analysed samples is low (< 0.05 - 0.22 ppm) and the contents in other elements is insignificant. Here are presented only Au, Ti, Fe, and Cu (Table 3).
Table 3. The content of Au, Ti, Fe and Cu in the analysed samples

<table>
<thead>
<tr>
<th>Nr</th>
<th>Sample No</th>
<th>Au (ppm)</th>
<th>Ti (ppm)</th>
<th>Fe (%)</th>
<th>Cu (ppm)</th>
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<tbody>
<tr>
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Conclusions

Geological exploration of copper mineralization was in the area of Mawat Ophiolitic Masif. Satellite ASTER and QuickBird images were used together with field prospection and geophysical survey, as well as petrographic and chemical analyses. The explored terrain is mostly composed of ultrabasic and basic rocks (peridotite, gabbros, serpentites, basalts etc.). The rocks are intensely tectonised and intruded by numerous basic magmatic bodies. The host rocks of the mineralization are primarily gabbros and metagabbros intersected by diabase dykes, epidotic and quartz veins, covered by pillow lava formations. Copper mineralization is usually stained with limonite crust which is a good indicator of mineralization. Primary mineralization is represented by chalcopyrite, bornite and pyrite, while secondary mineralization malachite and limonite is a product of weathering.

In the study area, three smaller perspective areas were selected: Waraz, Konjirin-Kuradawi and Mirava-Chenaran, which have copper mineralization. The registered concentration of copper varies highly, in wide range. The concentrations of Cu in samples are: Waraz area 1.53 - 60705, Konjirin-Kuradawi 68-36287 and Mirava-Chenaran 135-16803 ppm. Maximum value of Cu was determined in the Waraz area 6.7% Cu. In some rock samples gold concentration of 0.36 and 2.59 ppm were also determined. Based on the collected information, the possible perspective of the mineralization bearing rocks has been roughly estimated.

References


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