Aynak Information Package

Part III Preliminary report on results of geological exploration on the Aynak copper deposit from 1974 to 1976

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Aynak Exploration Group

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Preliminary report on results of geological exploration on Aynak copper deposit from 1974 to 1976

Volume I: Explanation note to evaluation of reserves (as at 1 March 1977)

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1 Introduction

The Aynak deposit was discovered on July 1973 during the first days of the republican regime. The discovery was made by the Akreskan Group while carrying out a prospecting survey in the central part of the Kabul block (head of group Ismatullakhan Nazarzey, technical chief Yu.I. Shcherbina). Over 30 additional copper occurrences were identified during the survey.

Aynak copper deposit, as well as the other occurrences, belong to a distinct stratigraphic level (terrigenous carbonate rocks of the Vendian-Cambrian Period), have a high metal content and a suitable geographic location and economic conditions. These factors resulted in a decision to carry out exploration work on the Aynak deposit, detailed prospecting work on the Darband deposit and distinguish the new copper-ore region in the central part of the Kabul block (managed by Chmyrev and G. I. Teleshev).

Comprehensive geological and geophysical research on the Aynak orefield commenced in 1974, with technical assistance provided by the USSR (according to contract 50728 and 55-184/17500). Positive results, conclusions and recommendations from this research, provided by I.Z. Samonov, an expert-consultant of the Ministry of Geology, USSR, resulted in a detailed exploration project of the Central area and preliminary exploration of the Western area of Aynak deposit to be undertaken between 1975–1977

Between 1974 and 1976 geological maps of the Aynak orefield were compiled on a 1:10 000 scale instrumental topographic base. Maps of the Central and the Western area were compiled at 1:2 000 scale and these partly defined the Main orebody and numerous other stratiform bodies. Following this, a number of detailed surveys were undertaken including geophysical surveys, geotechnical investigations to assess ground conditions, technological sampling of ores from the Central area (of the 8 samples taken, 2 were studied), a 1:10 000 scale topographical survey of the area (covering more than 200 km^2) and hydrogeological surveys to identify water resources for human consumption and to supply further mine exploration and future mining and metallurgical plant. This report summarises the key characteristics of the Aynak ore field, incorporating both the Central and Western area. Ore and copper reserve and resource estimations were performed for both areas as at 1 March 1977 (Table 1). This report also provides important information pertaining to the processing of future ore from the Central area.

Table 1 Ore and copper reserves of the Central area of the Aynak deposit as at 1st March 1977 (copper cut-off content 0.4%)

Orebody	Unit	Total	Category	
Other orebodies			C_1	C_2
Ore reserves	kt	254116	148394	105722
Copper reserves	kt	4790	2 735	2056
Copper content	%	1.88	1.84	1.94
Main orebody				
Ore reserves	kt	170187	89044	81143
Copper reserves	kt	4023	2199	1824
Copper content	%			

In addition, C_2 category ore and copper resources and probable resources were calculated as follows:

Category C_2	ore resources	37833 kt
	copper resources	428 kt
	copper content	1.13 %
Probable	ore resources	33900 kt
	copper resources	380 kt
	copper content	1.13 %

The Ministry of Geology, USSR completed the detailed exploration of the Central area of the Aynak deposit three months ahead of schedule. Ore reserve targets set by the Ministry of Geology, USSR were exceeded by 160%. On the basis of existing data, future increase in reserves can be expected in the Central and the Western Area of the deposit, as well as in the whole ore field.

Extensive technologic properties of the ore were collected. Geotechnical and hydrogeological conditions render the Central area suitable for open pit mining. Adequate water supplies occur in the region of the deposit, however, local construction materials will be required.

The exploration campaign was first supervised by V.V. Chmyrev, followed by G.I. Teleshev (to June 1976) and later by V.N. Zaycev. A.S. Salah was President of the Department up until June 1974. Following a general reorganisation of the group, N.A. Azimi was appointed General Manager.

The Aynak Exploration Group consisted of the following personnel: Group Manager first Ismatullkhan Nazarey (to May 1975) and later Sh.A. Deleri; Technical Manager E. Yerov (1974) followed by V.S. Kirichek (to June 1975) and later by V.D. Shcherbonos (from June 1975) and Field and Office Manager of both the Soviet and Afghan teams, E.A. Krishkov (from November 1974).

Consultant and expert, Dr I.Z. Samonov PhD accompanied by A.M. Fillipin from Ministry of Geology, USSR, provided extensive advice during their three visits to the Aynak exploration programme.

A large number of Soviet geologists were involved in the exploration of the Aynak deposit: L.A. Akocdzhanyan (from January 1974), O. A. Vasilyev (from December 1975 to March 1976), G.P. Gabelaya (from May to December 1976), A.V. Zhdan (from May 1975 to May 1976), G.G. Zagorodniy (from July 1975), A.A. Kashin (from October 1974), A.N. Korol (from May 1974 to August 1975), N.Ye. Kozorez (from August 1974 to June 1976), V.P. Koloskov (from December 1976), I.S. Kutkin (from November 1974 to October 1975), Kh.L. Latypov (from June 1975), T.M. Makimov (from November 1975), V.M. Novoselcev (from February 1976), E.B. Nevretdinov (from March 1976), A. Polvanov (from August to November 1974), K.I. Sulikayev (from August 1975), I.T. Cheban (from January 1974 to November 1975), V.G. Cheremycin (from September 1976), Yu. L. Cherencov (from November 1976), L.P. Cvetkov (from May 1975 to December 1976).

During that period a group of Soviet mining and drilling specialists also worked on the deposit.

2 General information about the deposit

The Aynak deposit is located 30 km SSE from Kabul near the settlements of Gulkhamid, Chenaray and Anorkhel in the Logar Province. The town of Barakibarak, in the centre of the Province, is situated 35 km SW from the deposit (sheet 510-Ye-P).

The extent of the Aynak orefield (110 km^2) is delimited by coordinates: 34º12'–34º18' and 69º13'30"–69º19'30". The Aynak deposit, which is divided into the Central area and the Western area has a surface area of 6 km^2.

The deposit is accessed by an asphalt road from Kabul to Gardez, leading to Kishlak Zaydabad (34 km) and then by an earth road (16 km) which is navigable throughout the year. Equipment and materials from the USSR were transported 400 km on asphalt road to Kabul from the river port of Shirkhan.

The orefield extends to the central part of the watershed of the Logar and Butkkhak Rivers at the foothills of the western offshoot of the Safedkokh Range.

The Aynak deposit is situated on the northwestern margin of the mountain depression within Neogene molasse deposits. The relief of the region is characterised by hills and valleys with altitudes from 2275 to 2675 m. Some peaks are up to 2750 m high (Mt Sarvanday NE of the deposit). Relative altitude of the area varies between 50 and 200 m. A ring of mountain ranges with altitudes up to 3452 m rims the depression. The mountains are formed of metamorphosed Upper Proterozoic to the Vendian-Cambrian rocks, cut by small intrusive bodies. On the southern margin of the depression, Upper Permian sediments occur. On the west, towards the Logar River, an area of lower relief, between 1875 and 1900 m occurs.

The Logar River, the main water artery of the region and a tributary of the Kabul River, is situated 15 km west of the deposit. The river is fed by snow and rain running off the surrounding mountain ranges and has low water levels from July to September and high water levels from October to May (maximum level occurs in April). The river is only partly frozen during the winter period.

According to long-term observations (from 1962) from the Sangenavesht stream-gauging station (34º26' and 69º21', 1805 m in altitude) which has a 9772 km^2 catchment area, the average annual flow of the river is 318,000,000m^3 with an average monthly flow volume of 9.99 m^3/sec. During the period of low water level in 1976, near the Aynak deposit (Sangarkhel settlement), the minimum flow volume recorded was 1.5 m^3/sec.

The water in the river is muddy (suspension count of 20.5 to 70.6 kg m^3 measured during the high water level period and during the April, May and August rains), fresh, with a low alkalinity. The total mineralisation content and solid remnant content of the water is 0.80 g/l and 0.53 g/l respectively. The water is of hydrocarbonate–sulphate-magnesium-sodium type with a carbonate hardness of 7.4–7.5 mg/equiv. It is widely used by locals for irrigation.

In the vicinity of the deposit, water flow is seasonal occurring during the spring as a result of the melting snow and spring rains. During autumn and spring, water flows resulting from precipitation affect the local settlement.

The Aynak region is located within a continental climatic zone and is characterised by warm summers and relatively mild winters. Precipitation during the autumn and spring periods is in the form of rain and during the winter in the form of snow. Snow cover of up to 0.5 m has been recorded.

Long-term observations have been obtained since 1967 from the Logar meteorological station (34º06' and 69º05', 1935 m altitude) and since 1973 from the Logar Airport meteorological station (34º11' and 69º08' in altitude 1950 m). Both stations are situated in the River Logar valley, 30 and 16 km southwest from the deposit. During the cold period (November to April), average annual precipitations of between 197 and 229 mm have been recorded at the Logar meteorological station and between 181 and 203 mm at the Logar Airport meteorological station. Maximum precipitation per day is between 46.8 and 18.3 mm.

The average annual air temperature in the vicinity of the deposit is between +10.5 and +12.8º C. Average monthly temperatures from December to February are between -5 and -7º C with minimum temperatures ranging from -29 to -20º C in January and from -42 to -37º C in February. Frost was observed in October (min -3º C), November (min -6º C) and in March (min -13º C).

Average monthly temperatures for the warmest period of the year (from June to August) ranges between +23 and +24º C with an average maximum temperature of +36.6 to +36.0º C observed in August.

The maximum and minimum temperatures recorded on the ground surface are +64º C and -35.5º C respectively. During the winter months, the soil freezes to a depth of 0.5 m. Relatively stable soil temperatures occur below 1.6 to 1.7 m.

During the cold period of the year, the relative air moisture content varies between 64 and 52 % (maximum 78 to 67 %). During the warm period the moisture content ranges between 41 and 30 % (minimum 30 to 21 %). In Kabul region 1610 mm of surface evaporation occurs annually.

At the Logar meteorological station, the prevailing wind direction during the cold period is west to southwest and during the warm period, north. At Logar Airport, south, southeast and southwest wind directions prevail during the cold period whilst during the warm period, a northerly wind direction prevails. From this, it can be concluded that in the Logar River Valley, the air flows from the lower part during the winter and from the upper part during the summer. Maximum wind speeds of between 25 and 30 m/sec have been recorded. Meteorological observations were obtained by the Department of Meteorology within the Ministry of Civil Aviation and Tourism. Generalized results from all meteorological stations in the country are published monthly.

Water supply for both inhabitants and to support workings of the Aynak Exploration Group has recently been provided from a dedicated borehole (flow 0.3 l/sec) and from springs occurring within rock fissures (flow ranging from 0.3 to 0.9 l/sec).

Hydrogeological investigations to identify a water supply for the construction of the copper ore processing plant has recently focused on the waters flowing underneath the channel of Logar River. According to preliminary results from 1976, more than 1 000 l/sec of water could be extracted from the valley of the Logar River. Supplementary water supply could be obtained from the "Surhab" water reservoir which has a volume of 890 000 m^3 and is situated 15 km south of the Aynak deposit (34º08' and 69º13'). However, before exploitation of this reservoir can occur, maintenance is required to eliminate the loss of water from the reservoir by filtration. In addition, a study of the source of the reservoir water is required to be undertaken.

Electric power supply for mining and drilling works and inhabitants of the Aynak Exploration Group is provided by mobile generators (ZhES 60, DSM 50 and DSM 30). However, it is important that a source of electric power supply required for the construction and operation of the Aynak copper mining and processing plant is resolved. The Aynak deposit is situated near the so called ‘Kabul energetic zone’ which incorporates the provinces of Kabul, Parvan, Kapisa, Lagman and Vardak. Electric power supply is generated from hydroelectric power stations at Naglu, Makhipar, Sarobi, Dzhabul Seradzh and Chak Vardak with a power supply capacity of 182800 kW and from a thermal power station (“Nassadzhi Afghan” company) in Gulbakhar with a capacity of 2 800 kW. The electric power stations, with the exception of HES Chak Vardak which has a stated power supply capacity of 33 600 kW, are interconnected and are also connected with sub-stations in the towns of Kabul and Gulbakhar (DEP – 110 kW).

Construction materials have yet to be explored in the region of the Aynak deposit. “Cvetmetpromexport”, a USSR company, defined the following list of essential industrial minerals required for the construction of the mining, processing and metallurgy plant: 200 kt of quarry stone, 3300 kt of gravel, 3000 kt of sand, 100 kt of lime and 2000 kt of brick clay. Prospecting works carried out during 1976 identified many prospective occurrences of the above mentioned construction materials (see volume II, annexe 4) within 15 km of the Aynak deposit. Further exploration work on these occurrences is planned for 1977.

The Aynak deposit is situated near the densely inhabited Kabul region, which has concentrated agriculture, industry and trade. Unskilled labour from neighbouring settlements could be hired for future exploration and mining work.

3 Geological research of the region and the deposit with a short description of work undertaken

The Afghan Republic dates back to the ancient civilizations of the Middle East. Numerous old mine workings, dumps and smelting furnaces are witness to the ancient exploitation of iron, copper, lead, gold, lapis-lazuli and others commercial minerals.

Geological research in the Kabul region, as well as in the entire country, can be divided into two periods: the first period occurred up until 1963 when research was carried out by many geologists and geological missions from different countries. In the second period, from 1963 onwards, geological research was carried out by the Afghan Department of Geological Exploration within the Ministry of Mining and Industry, with technical support from the USSR.

During the first period of geological research, French and German geological missions carried out geological mapping and prospecting for chromite ore. Prospecting and preliminary exploration was carried out in the Logar ultramafic massif by M. Volin (1949). Elongated orebodies ranging from 10 to 50-60 m in length and from 1 to 10 m in thickness were discovered. Chromite reserves were estimated at 182 kt. A further two zones of chromite ore, 10 to 15 km in length, were discovered during a detailed study of the central part of the Logar ultramafic massif (H. Sielbrat 1965).

In 1961, G. Mennessier prepared a 1:50 000 scale geological map and stratigraphic scheme of the Kabul region based on aerial photographs and limited fieldwork. Between 1964 and 1966, geological mapping of the Kabul region was carried out at 1:50 000 and 1:100 000 scale by the German geologist G. Andritzky. Whilst his geological maps sufficiently capture the structural and petrologic features of the metamorphic, intrusive and sedimentary complexes of the region, no information on commercial minerals was provided.

In 1964, D. Wirtz published a paper in which he incorporated the Kabul zone and southeast Afghanistan into the Baludzhistan-Indus geosyncline.

During the period of research by foreign geologists, no research focused on identifying commercial minerals within the Kabul region or indeed within other regions of Afghanistan. However, numerous copper occurrences were mentioned in the Kabul region but no perspective was provided. In a report by D.R. Hunger published by the Geological Survey of Afghanistan (1964), “poor copper occurrences of large extension” are mentioned in the Logar River Valley. Copper deposits in the Salanga, Goprbanda and Panjshera regions, studied by the French geological mission were described as “without obtaining promising results”. Japanese geologist Nakadzava (1960) also mentioned copper occurrences “northeast and southeast from Kabul represented by veins and fissure fillings”.

In the 1933/1934 “Kabul” annual, a number of operating mines were referred to; including copper exploited using ancient artisanal methods. The Maydan deposit, in the Mt. Cheregan area, is mentioned as the largest copper deposit. This deposit was originally assessed by Soviet geologists whom concluded it to be unprospective.

The second phase of geological research entailed systematic and detailed geological research of the country with technical cooperation provided by the USSR. From 1970 to 1973, geological mapping and prospecting at a scale of 1:500 000 was carried (Sh.Sh. Denikayev et al 1970, 1971). Maps of Afghanistan at 1:1 000 000 scale were compiled by Soviet geologists with V. M. Chmyrev and S.H. Mirzad as editors (including information on geology, commercial minerals, tectonics and magmatic complexes). Map explanations were published in Kabul in 1973.

Geological mapping and prospecting at 1:500 000 scale finished in 1974 and in 1976 geological maps and maps showing the commercial minerals of the country were prepared for publication at 1:500 000 scale

Geological teams, led by V.M. Chmyrev, G.I. Teleshev and S.Kh. Mirzod, carried out an assessment of all previous geological research and summarised information on geology and commercial minerals. This resulted in V.M. Chmyrev and G.I. Teleshev selecting the Kabul block as the most perspective area for copper mineralisation. As a result, in 1973, a prospecting and mapping project was scheduled for this area at 1:1 000 000 scale. In 1973 the area’s copper potential was confirmed by the discovery of the Kabul ore-bearing region which included the Aynak and Darband deposits (Yu.I. Shcherbina et al 1975). This important discovery was made by the Andreskan Group. From 1974 onwards, exploration for copper was carried out by the Aynak, Darband and Dzhavkhar (Jawkhar) exploration and mapping teams.

As a result of detailed prospecting and exploration work by the Aynak mapping and exploration team, which included geophysical surveys (magnetometry, “Vp, YeP, VEZ-VP and VEZ” electric methods), the Aynak deposit was realised to be a potentially significant industrial operation. The Kabul copper-bearing region, together with oil and gas deposits in the northern regions of Afghanistan, took a lead role in planning for the future development of the national economy.

In 1974, on the basis of exploration work, the geological setting and structure of the Aynak deposit was broadly outlined and a detailed exploration programme was developed (G.I. Teleshev, Ye. A. Kryukov, L.A. Akocdzhanyan and others). The “Project of exploration of Aynak copper deposit from 1975 to 1977” was expanded (Ye.A. Kryukov, L.A. Akocdzhanyan and others) with additional exploration and laboratory studies undertaken. These were required for detailed geological and industrial evaluations of the deposit and surrounding prospective areas. Copper reserves in the Central area were estimated at 4 millions tons.

The numbers of mapping, prospecting and exploration studies carried out on the Aynak deposit between 1974 and 1976 are shown in Table 2.

Geological mapping at 1: 10 000 scale, incorporating elements of detailed prospecting, is documented on instrumental topographic bases of the same scale. The geological map comprises outcrops of Upper Proterozoic and Vendian-Cambrian rocks with a 40 km^2 aerial extent surrounded by Neogene sediments. Neogene and Quaternary sediments were not studied in detail and are thus are not distinguished on the map face.

Within the Aynak ore field, apart from the previously studied Central and Western areas (1973), many occurrences of copper occur, the largest of which are the Pache and Tobagi occurrences. Both the Pache and Tobagi occurrences have been preliminary studied by trenching.

1:2 000 scale geological mapping of the Central and Western area was carried out on 1:1 000 topographic bases with all observation points recorded on the map face. Outcrops of copper-bearing carbonate-schists of the Vendian-Cambrian Period were studied in detail by a trenching programme. Parallel trenches were dug over 50 m and geological plans were drawn at 1:500 scale.

Detailed exploration of the Aynak deposit involved mining horizontal exploration adits and drilling vertical core boreholes. This allowed exploration sections for the upper horizons to be compiled, both vertically and horizontally. Horizontal exploration adits No. 1, 2, 4, 5, 6 and 8 were mined in the Central area and adits No. 3 and 7 in the Western area, in outcropping parts of the deposit.

Exploration of the deep parts of the deposit was carried out at specifically constructed core drilling stations ZiF-300 M, SBA-500, ZIF-650M and UKB-500S. Percussion drilling was used through the Neogene sediments and diamond core drilling for the copper-bearing carbonate-schists. Every 20 m of drilling, zenith and azimuth angles were measured by inclinometers (Mi-30 and IG-50) and geophysical measurements obtained (by AEKS-900).

Table 2 Basic types and volumes of works carried out by Aynak exploration group in deposit and in the ore field from 1974 to 1976

Work	Unit	Total	Area											
			Central area				Western area				Ore field			
			Total	Year			Total	Years			total	Years		
				1974	1975	1976		1974	1975	1976		1974	1975	1976
Geological mapping 1:10 000	km^2	40	-	-	-	-	-	-	-	-	40	-	10	30
Geological mapping 1:2 000	km^2	1.6	0.9	-	0.9	-	0.7	-	0.7	-	-	-	-	-
Survey map 1:10000	km^2	196	-	-	-	-	-	-	-	-	196	30	45	121
Survey map 1:1000	km^2	5.0	2.4	2.4	-	-	2.6	2.6	-	-	-	-	-	-
Survey map 1:2000	km^2	5.3	4.7	-	2.7	2.0	0.6	-	0.6	-	-	-	-	-
Topography 1: 5000	km^2	10.3	-	-	-	6.4	-	-	-	3.9	-	-	-	-
Topography 1: 2000	km^2	10.3	-	-	-	6.4	-	-	-	3.9	-	-	-	-
Total core drilling	m	33460	30067	4476.9	8586.1	17004	3393.7	842	2553	-	-	-	-	-
- inclined drilling	m	29369	26467	4279.4	5785.7	16402	2902.7	564	2339	-	-	-	-	-
- horizontal drilling	m	4091	3600.1	197.5	2800.5	602	491.0	278	213	-	-	-	-	-
Tunnelling	m	3566	2785.3	1107.8	1561.5	116	781.0	578	203	-	-	-	-	-
Trenches	m^3	14483	7880	-	-	7880	920	-	920	-	5683	3710	1083	890
Technologic sampling	sample	8	8	-	2	6	-	-	-	-	-	-	-	-
Core sampling	sample	8616	7752	1405	2165	4183	864	225	639	-	-	-	-	-
Total channel sampling	sample	5891	3189	675	654	1860	1240	431	809	-	1462	1028	257	177
" in mining works	sample	2018	1329	675	654	-	689	431	258	-	-	-	-	-
" in trenches	sample	3873	1860	-	-	1860	551	-	551	-	1462	1028	257	177

4 Geological characteristics of the Aynak ore field

4.1 STRATIGRAPHY

The Aynak ore field comprises metamorphosed Upper Proterozoic and Vendian—Cambrian rocks, Upper Permian and Neogene sedimentary rocks and Quaternary sediments, infilling a wide erosion-tectonic depression.

4.1.1 Upper Proterozoic Group

Previous mapping at 1:100 000 by Shcherbina et al. (1975), distinguished the metamorphic rocks of the Upper Proterozoic as Welayati Formation. The **Upper Proterozoic Group** is divided into six formations based on lithology and metamorphic grade. The age of the rocks is considered to be Upper Proterozoic as they are unconformably overlain by lower grade metamorphosed carbonate-schists containing Vendian and probably Cambrian fossils.

4.1.1.1 Lower Gneiss and Crystalline Schist Formation (PR_3^1A)

Rocks of this formation have a surface outcrop of about 4 km^2 in the southern part of the area, between the Pache and Abdurrakhman Valleys. The formation is subdivided into lower and upper members based on lithological features.

a) Lower Microgneiss and Muscovite-Garnet Gneiss Member of ($PR_3^1A_1$)

This member is represented by grey and yellowish-brown garnet gneiss and microgneiss with large, 2 to 5 mm brownish-red garnets (almandine). The matrix texture is lepidogranoblastic to microblastic and is typically finely crystalline. The rocks are lenticular with a parallel schistosity and comprise garnet (to 30 %), muscovite (sometimes biotite and hornblende up to 20 %), oligoclase (30-50 %) and quartz (10-30 %).

Beds (1–10 m) of sillimanite-andalusite schist are characteristic throughout the member, with less common beds of anthophyllite-andalusite schist. These are yellowish-green in colour with nematoblastic and fibroblastic textures, soft and greasy to touch.

Isolated beds (3 to 5 m) of hornblende orthogneiss with weakly defined contacts occur. The rock is greyish-white, massive, and very hard with gneiss like structure resulting from the sub-parallel distribution of porphyric hornblende crystals (1.5 to 5 mm). The orthogneiss comprises hornblende (5–20 %) with fine-crystalline clusters of isometric oligoclase-andesine grains (60–70%) and quartz. Isolated porphyric plagioclase can rarely be found. This member is greater than 180 m in thickness.

b) Upper Muscovite Orthogneiss and Crystalline Schist Member ($PR_3^1A_2$)

Rocks of this member occur in the watershed between the Abdurrakhman and Pache Valleys, south of the Sisa Valley and northwest of the Tobagi occurrence in the Isortangay settlement area.

The typical lithologies within this member are muscovite schist and muscovite orthogneiss, with intercalations of hornblende and carbonate-hornblende-plagioclase (1 to 10 m) schist, and lenticular bodies of hornblende-muscovite and hornblende orthogneiss.

The muscovite schists are greyish-white, schistose and finely crystalline and comprise oligoclase-andesine (30 %), quartz (40 %) and muscovite (30 %). Accessory magnetite, titanite and apatite are also present (up to 2 to 3 %). The texture of the rock is lepidoblastic and granoblastic.

The muscovite orthogneiss is greyish-white in colour and has a predominantly massive texture with some relic porphyry and rare gneiss textures. Clusters of quartz occur and more often clusters of feldspars, including potassium feldspar and quartz. The muscovite orthogneiss comprises: feldspar (40 to 65 %), quartz (20 to 40 %), muscovite (to 20 %), biotite and hornblende (5 to 10 %). The matrix texture is finely crystalline and lepidogranoblastic. The fragments have a flattened schistose fabric and their margins are more or less distinct. The composition of the fragments is similar to the matrix and can be distinguished only by their higher content of darker minerals. Fragments represent 30 to 40 % of the whole rock and their size is 1x5x15 cm.

The muscovite orthogneiss and schist member has an average thickness of 280 m.

The gneiss and schist member are metamorphosed to the medium temperature subfacies of amphibolite facies. The characteristic mineral assemblages within the formation are: almandine-muscovite-plagioclase (oligoclase-andesine)-quartz (±biotite, hornblende) and sillimanite-andalusite (±anthophyllite).

4.1.1.2 Upper Amphibolite and Gneiss Formation (PR_3^1B)

Rocks of this formation outcrop between the Sisa Valley and the Abdurrakhman settlement. They also form large outcrops near the Chenaray and Aynak settlements. They conformably overlay the Upper Muscovite Orthogneiss and Crystalline Schist Member of the Lower Formation, although in many outcrops denudation of the underlying rocks can be observed.

The formation is distinctly divided into lower, middle and upper members.

a) Lower Orthoamphibolite and Hornblende Microgneiss Member ($PR_3^1B_1$)

The lower part of the section comprises orthoamphibolite and the upper part, hornblende microgneiss. Intercalations of hornblende orthogneiss and muscovite schist, several meters in thickness, characterise the middle part of the section.

The orthoamphibolite is gneiss-like and massive and varies in colour from dark-grey to almost black, with a greenish to greyish-green tint. Less distinct relic amygdaloidal textures are often observed. Amygdules, flattened parallel to schistosity are 1 to 5 cm in length and are mostly filled with quartz and to a lesser extent with calcite.

The amphibolite comprises hornblende (75–80 %) and oligoclase-andesine (20–25 %). Accessory apatite and magnetite are also present.

The hornblende microgneiss is a banded, schistose, dark grey rock with a greenish tint. It consists of hornblende (20–30 %), oligoclase-andesine (50–70 %), biotite (5–15 %), quartz (up to 10 %) and rare crystals of staurolite. Common accessory minerals include apatite, magnetite, rutile and zircon. The rock has a micronematoblastic texture.

The average thickness of the member is 300 m.

b) Middle Muscovite-Garnet and Garnet-Hornblende Gneiss Member ($PR_3^1B_2$)

Rocks of this member outcrop at surface northwest from the Abdurrakhman settlement, over 2 km^2. Small outcrops occur near the Aynak settlement. They lie conformable on the Lower

Orthoamphibolite and Hornblende Microgneiss Member. They are predominantly light- to silver-grey muscovite-garnet gneisses with a characteristic form of discoid carbonates. Less common beds include two-mica-garnet gneiss (1 to 8 m) and hornblende-garnet gneiss and hornblende gneiss. The rarely massive muscovite-garnet gneiss has a parallel schistose fabric and a porphyritic texture. The porphyries predominantly comprise garnet (3 to 5 mm) with rare hornblende porphyries. The gneiss consists of quartz (10 to 40 %), oligoclase-andesine (30 to 60 %), almandine (15 to 30 %), hornblende (10 to15%), muscovite (up to 20 %) and biotite (up to 5 %). Accessory minerals, although not very common, include magnetite, apatite, tourmaline, rutile, zircon and titanite. The member has a thickness of about 500 m.

c) Upper Para-amphibolite Member ($PR_3{}^1B_3$)

This member is formed of para-amphibolite with common garnet and biotite. Intercalations of hornblende schist (0.5 to 1 m thick) rarely occur. This member outcrops exclusively near the Aynak settlement, where it underlies the ore-bearing Carbonate-Schist Formation.

The rarely massive para-amphibolite is a dark greenish-grey rock with medium crystallinity, a parallel-schistose fabric and nematogranoblastic texture. It is composed of hornblende (30 to 50 %), plagioclase (30 to 60 %), garnet (up to 10 %), biotite (5 to 10 %), magnetite (up to 5 %) and sporadic apatite and tourmaline. The member has a thickness of about 200 m.

The metamorphic grade of the amphibolite and gneiss formation corresponds to the low-temperature subfacies of the amphibolite facies. The following mineral assemblages are characteristic: hornblende-oligoclase-andesine and almandine-muscovite-oligoclase-andesine-(± biotite, hornblende and quartz).

4.1.1.3 Metabasite Formation ($PR_3{}^2A$)

The Metabasite Formation outcrops southwest of the Pache settlement and northwest of Western Aynak. Small outcrops also occur near the Tobagi, Pache and Abdurrakhman Valley (on the right side of Sisa Valley) mineral occurrences.

The metabasite lies unconformably on the Upper Amphibolite and Gneiss Formation. A thin (3 to 10 m) horizon of breccia tuff occurs at the base of the Metabasite Formation within which weakly rounded fragments of the underlying rocks occur (amphibolite, gneiss and schist).

The shape and composition of the metavolcanics is relatively uniform. Basaltic lavas or andesitic-basalts are intercalated with pyroclastic rocks. Basic massive and amygdaloidal volcanics are distinctly dominant over more acidic hornblende and plagioclase varieties. The Metabasite Formation is divided into 4 members according to lithological composition.

a) Member 1 ($PR_3{}^2A_1$)

Amygdaloidal metabasalt and meta-andesitic basalt prevail with minor intercalations of metatuff and metatuffite. Beds of plagioclase rich metaporphyry also occur. In sections of the lower part of this member, metatuff is dominant. The average thickness of the member is 120 m.

b) Member 2 ($PR_3{}^2A_2$)

The lower contact of this member is represented by 8 to 13 m thick lava flows of andesitic composition (plagioclase metaporphyry). The member is distinct as it contains flows of plagioclase metaporphyry (25 to 30 % of total thickness) within massive aphyric lavas of basic composition. In the middle part of the member rare beds of metatuff occur (1 to 3 m thick), often containing carbonates. The average thickness of the member is 250 m.

c) Member 3 ($PR_3^2A_3$)

The base of this member is represented by layers of hornblende metaporphyry. The upper half of the member comprises hornblende metaporphyry (about 45 %), aphyric basalt and andesitic-basalt (35 %), metatuff and metatuffite (10 %), carbonate breccia and lenses of marble (8 to 12 %). The lava flows are typically 10 to 15 m in thickness and the tuff intercalations several meters thick. Carbonate breccias form either extensive stable horizons with intercalations of metatuff or lenses of unstable thickness. The carbonate breccia contains abundant magnetite. The average thickness of the member is 150 m.

d) Member 4 ($PR_3^2A_4$)

Member 4 is represented by predominantly banded metatuff with intercalations of aphyric lavas of Meta-andesite-basalt. In the lower part of the member, thin (2 to 4 m) lava flows of hornblende metaporphyry or intercalations of fine carbonate-tuff breccia occur. The thickness of the member is about 100 m. The metabasalt and meta-andesitic-basalt consists of oligoclase-andesine (50 to 55 %), bluish-green sodium hornblende (30 to 35 %), magnetite, titanite (2 to 7 %) and apatite (0.5 to 1 %). Minor secondary minerals present include (to 5%) albite, epidote, actinolite and chlorite. The typical rock textures include blasto-ophitic, spotted and rarely massive.

Amygdules form 30 % of the rock and they vary in size from 1 to 15 mm. They are elongated, flattened and rarely isometric. They are filled with epidote and rarely with hornblende and calcite.

The mineral assemblages and well preserved relic textures indicate a relatively low grade of metamorphism of the epidote-amphibolite subfacies of amphibolite facies.

4.1.1.4 Meta-andesite and Metadacite Formation (PR_3^2B)

The Meta-andesite and Metadacite Formation conformably overlie the Metabasite Formation. Rocks of this formation have the same extent as the Metabasite Formation. Outcrops of this formation were mapped north of the Isortangay settlement and west of the Abdurrakhman settlement.

Lavas, welded tuffs and Meta-andesite-dacite tuffs dominate the lower part of the formation whilst the upper part is dominated by alternating layers of lava, tuff, meta-sandstone and carbonate-plagioclase schist.

a) The Meta-andesite and Metadacite Lower Member of ($PR_3^2B_1$)

This member is represented by alternations of Meta-andesite and metadacite lava, lava-breccia, tuff and tuff-breccia. The thickness of flows and layers ranges between 2 and 10 m. Aphyric varieties prevail but porphyry and amygdaloidal rocks are also present. Fine disseminated chalcopyrite can be seen in some flows.

Meta-andesite and metadacite represent chloritised biotite-plagioclase rocks with a low actinolite content (0 to 15 %) and various amounts of quartz. Accessory minerals are present including magnetite (up to 10%), apatite and titanite.

The Meta-andesite matrix is composed of quartz (15 to 25 %), oligoclase (35 to 45 %), biotite (20 to 30 %) and actinolite (5 to 15 %). Porphyry plagioclase and quartz form up to 20–25 % of the rock.

The Meta-andesite differs from the metadacite by increased basicity of the plagioclase (An_{30}) and a lower quartz content (0 to 10 %). The thickness of the member varies from 50 to 200 m.

b) The Meta-andesite and Metadacite Upper Member ($PR_3^2B_2$)

This member is composed of volcano-sedimentary rocks including lavas, lava-breccia and meta-andesite-dacite tuffs with intercalations of terrigenous-carbonate rocks present in different ratios.

The volcanic rocks in the upper and lower members have similar petrographic compositions. The thickness of individual flows and layers varies from 10 to 15 m.

The sedimentary rocks comprise metasandstones with rare beds of biotite-actinolite-carbonate-plagioclase schist and quartz-epidote-carbonate-plagioclase schist usually containing some chlorite and sericite. The rocks are grey with a greenish tint and are distinctly schistose.

The lava-breccia, tuff-breccia and sandstone contain increased concentrations of magnetite. In the Isortangay settlement area, lenticular intercalations of magnetite-bearing sandstones, 1 to 3 m in thickness were mapped. The upper member is about 150 m in thickness.

The mineral assemblages in the metamorphosed volcanic and sedimentary rocks suggest a low metamorphic grade corresponding to the albite-epidote-biotite subfacies of the greenschist facies.

4.1.1.5 Volcanic Breccia Formation (PR_3^2C)

The Volcanic Breccia Formation has a limited extent in the Aynak ore field area. Small outcrops have been mapped in a 1 to 1.5 km wide belt which extends from the Abdurrakhman settlement to the Isortangay settlement. The most significant outcrop of this formation occurs north of the Sisa Valley (0.5 km^2). The breccia lies on eroded older rocks.

The appearance and composition of the rocks in this formation is monotonous. Overall, the formation comprises metamorphosed psammitic to psephitic sediments, represented by metasandstones, actinolite-carbonate-plagioclase schists and sedimentary breccias. Coarse fragments of varying sizes are common in the sedimentary breccias. The coarse fragment content varies from 5–10 % to 30–40 % and their size from 1–5 cm to 2–30 m. The rocks are light grey in colour. Within the massive rocks, lenticular layers of brecciated biotite marble and thin-bedded carbonate sandstone with actinolite and actinolite-plagioclase occur. Typically these layers vary from several metres to rarely 10 m in thickness. The breccia fragments are composed of underlying rocks including metabasalt, Meta-andesite, schist, gneiss, amphibolite, gabbro-amphibolite and keratophyre. Fragments of magnetite crystals (up to 5–7 %) are present in the cement and large blocks of massive magnetite (up to 3 m) were also observed.

The following mineral assemblage occurs within the rocks of the formation: plagioclase (10–30) + dolomite + actinolite + quartz ± biotite, epidote and chlorite. This assemblage suggests a low metamorphic grade corresponding to the albite-epidote-biotite subfacies of the greenschist facies. The thickness of the v

Volcanic Breccia Formation is variable with a maximum thickness of 200 m.

4.1.1.6 Schist Formation (PR_3^2D)

The Schist Formation is found in two areas of the orefield: on the northern margin of the Dashtak stream valley, between the Isortangay and Chenaray settlements and in the south between the

Makhmudkhel and Pache settlements. It conformably overlies the Volcanic Breccia Formation, although in some outcrops local erosion has been observed.

The formation is divided into two members based on lithology: the lower Quartzite Schist Member and the upper Carbonate-Plagioclase Schist Member.

a) Quartzite Schist Member ($PR_3^2D_1$)

Outcrops of this member are known only in the southern part of the orefield, east from the Makhmudkhel and Khundara settlements. The basal horizon in distinct as it unconformable overlies the Lower Microgneiss and Muscovite-Garnet Gneiss Member ($PR_3^1A_1$). The lower part of the member is represented mainly by grey quartzite schist. The schist contains fine-crystalline quartz with microgranoblastic texture, and has distinct crystallization schistosity. Fine banding is common (mm scale) resulting from layers of intermixed muscovite, carbonaceous material, and sometimes plagioclase. Intercalations of quartzite, quartzitic sandstone, epidote-carbonate-plagioclase and carbonaceous schist also occur ranging from 0.5 to 3 m in thickness.

In the upper part of the member, in addition to quartzite schist, a significant part of the section consists of finely crystalline, green chlorite-albite schist.

The observed mineral assemblages include: quartz-muscovite; quartz-oligoclase-andesine-muscovite; epidote-oligoclase-andesine-dolomite; chlorite-albite-quartz; and biotite-muscovite-dolomite. This assemblage suggests a low metamorphic grade corresponding to the albite-epidote-biotite subfacies of the greenschist facies. The average thickness of the member is 280 m.

b) Carbonate-Plagioclase Schist Member ($PR_3^2D_2$)

Outcrops of this member occur in the northern part of the region with some small outcrops occurring in the southern part (south from the Pache settlement).

The lower part of the member is represented by epidote-carbonate-plagioclase schist and in places, a sedimentary breccia occurs at the base. Lenticular horizons of piemontite–carbonate-plagioclase schist occur up to 70 m in thickness. The upper part of the section is represented by chlorite (sericite)-carbonate-plagioclase-schist.

Rocks of this member are grey with a greenish tint, fine-grained, finely-schistose or lenticular-spotted with lepidogranoblastic texture. Relics of (“blasto”)-aleurolitic and (“blasto”)-psammitic textures with angular fragments of plagioclase have also been observed.

In addition to the main rock-forming minerals present, biotite, quartz (up to 10 %), and magnetite occur with lesser amounts of apatite, tourmaline, rutile and zircon.

The mineral assemblages present include: (oligoclase-andesine + albite)-dolomite-epidote (±biotite, quartz); and plagioclase-dolomite-chlorite (±muscovite, sericite). Relic structures and relic minerals, in particular plagioclase, indicate a relatively low metamorphic grade corresponding to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. The maximum thickness of the Carbonate-Plagioclase Schist Member is 500 m.

4.1.2 Vendian-Cambrian rocks undivided

Carbonate-Schist Formation (V-C)

Carbonate schists occur at the base of the metamorphic section, unconformably overlying Late Proterozoic rocks. Previous research distinguished them as the Loy Khwar Formation (Slavin

1973; Shcherbina 1975). A Vendian-Cambrian age has been assigned to the formation based on fossils from the Kabul Block region.

In the Bavarkkhel settlement area, the basal layer overlies different layers of the Gneiss and Schist Formation (PR_3^1A). In the Abdurrakhman settlement area, the Sisa Valley and the Central area, it overlies the Amphibolite and Gneiss Formation (PR_3^1B). South of the Pache settlement, west of the Abdurrakhman settlement and north of the Gulkhamid settlement, it overlies different members of the Metabasite and Meta-andesite-Dacite Formations (PR_3^2A and B). East of the Makhmudkhel settlement and in the Dashtak valley area, different layers of Schist Formation (PR_3^2D) and Volcanic Breccia Formation (PR_3^2C) are overlain.

The basal member of Carbonate-Schist Formation can be observed overlying different older formations on the east side of Sisa Valley, in the Dashtak Valley area, on the east side of the Pache Valley and in other areas. A distinct angular unconformity at different angles (up to 90 degrees) has been observed between the older layers and the overlying basal member of the -formation. Traces of old metamorphosed weathered surfaces and hornblende gabbro containing copper sulphides have been observed on the erosion surface of the underlying rocks.

The best known section of the Carbonate-Schist Formation is about 400 m thick and occurs in the Central area of the deposit. The formation is divided into 8 members based on lithology. This detailed division was based on the substantial and comprehensive data resulting from the exploratory mining works (adits) and boreholes. The remaining part of the orefield is less detailed.

A detailed description of the Carbonate-Schist Formation of the Central area is provided later in the report in the section describing the Aynak deposit. However, a description of the members and their extent in other areas of the orefield is provided below.

Member 1 $(V\text{-}C)_1$

Member 1 is represented by biotite-plagioclase, actinolite-plagioclase, carbonate-biotite-actinolite-plagioclase, actinolite-carbonate schist and sedimentary breccia, the proportion of which varies in different areas.

Fragments of underlying gneiss, schist and amphibolite are often present in the basal layers of the member, especially on the eastern side of Sisa Valley. In other areas, layers of thinly bedded (up to 1 cm) green actinolite schist with intercalations of carbonate (1–3 mm) are observed (on the southern slope at 2467 m in altitude). Above the base actinolite schist alternates with biotite schist.

North of the Gulkhamid settlement, rhythmically alternating biotite-plagioclase and actinolite-plagioclase schist, with layers (0.5 to 0.6 m) containing carbonates prevails. Intercalations of sedimentary breccia occur in places. The rock is grey with a brownish-greenish tint, finely schistose and finely crystalline. The upper part of the member is distinguished by a layer (1 to 3 m thick) of actinolite-carbonate schist containing large, radial, long and needle-shaped actinolite.

In the western area, a sedimentary breccia containing actinolite-plagioclase schist with minor quantities of mica and carbonate prevails. At the base of the member, a breccia, containing small fragments of light coloured metabasite with actinolite-plagioclase cement occurs. The rock is typically finely schistose with an even distribution of biotite and actinolite. The member has an average thickness of 10–15 m.

Member 2 $(V\text{-}C)_2$

Rocks in Member 2 are represented by white to yellowish-white dolomite marble of medium-crystallinity. The marble, which contains biotite, is bedded (thickness of beds ranging between 10 and 12 cm) and contains thin intercalations (less than 5-7 cm) of biotite-carbonate schist. Intercalations of light-grey microquartzite (1 to 3 cm thick) can be found in places, in particular in the middle and upper part of the member.

Some of the marble contains clasts of quartz (5 to 15 %) together with biotite and rare plagioclase.

Layers, formed by thin lenses containing tourmaline (to 0.5-5 %), apatite and titanite occur. Layers of chalcopyrite and rarer chalcopyrite-bornite mineralisation predominantly occur in the lower half of the member, although in some places it is found throughout. The copper mineralisation is not continuous along strike. Low-grade mineralisation has been identified in areas close to the Central and the Western area, on the sides of Sisa Valley and south of the Dashtak Valley. However, this member has not been identified in some parts of the Aynak orefield. The thickness of the member varies from 2 to 20 m.

Member 3 $(V\text{-}C)_3$

Member 3 is composed of biotite, two-mica-plagioclase, zoisite-biotite-plagioclase and rare biotite-carbonate schist, with minor intercalations of marble and actinolite-carbonate schist, containing biotite.

The rocks are irregularly bedded, schistose, platy, with fine to medium-crystallinity and granoblastic and (“blasto”)-aleurolitic textures. The thickness of the member varies from 10 to 25 m.

Member 4 $(V\text{-}C)_4$

Member 4 is composed of dolomite marble containing quartz, with intercalations (5 to 20 cm) of microquartzite and carbonaceous schist, and to a lesser extent biotite-quartz-plagioclase schist. The member can be divided into three beds in many places.

Lower beds: light grey to grey, parallel bedded, finely crystalline dolomite marble containing quartz with intercalations of microquartzite and carbonaceous microquartzite. Thickness of the lower beds varies from 20 to 40 m.

Middle beds: carbonaceous schist and carbonaceous microquartzite, with frequent layers of carbonaceous-carbonate schist (1-5 cm). Thickness of the middle beds varies from 7 to 15 m.

Upper beds: light-grey, finely crystalline dolomite marble containing quartz with rare intercalations of mica microquartzite. In places, light green, finely crystalline muscovite-quartz-plagioclase-chlorite phyllitic schist represents these beds almost entirely. Thickness of the upper beds is approximately 50 m.

The marble often contains quartz (up to 5-20 %) with lesser amounts of biotite. Accessory pyrite (to 1 %), tourmaline, apatite and titanite are also present.

The division of the Carbonate-Schist Formation into 4 members is supported mainly by outcrops in the northern part of the orefield and north of the Sisa Valley. Outcrops in the southern and western part of the orefield have yet to be studied in detail.

Sections of the Carbonate-Schist Formation along the western border of the orefield are represented as follows. At the base, finely crystalline brownish-grey biotite-carbonate schists occur up to 4 m in thickness. Above these, monotonous grey, fine to medium crystalline marble occurs with thin (1 to 3 cm) layers of microquartzite and carbonaceous microquartzite in places. The thickness of the member is approximately 200 m.

The upper part of the formation is represented predominantly by dark-grey almost black, carbonaceous schist with scarce lenticular (0.5 to 1 m) intercalations of brownish-grey schist. The thickness of the upper member is approximately 50 m.

The maximum thickness of the Carbonate Schist Formation in the orefield, with the exception of the Central area, does not exceed 350 m.

The formation is weakly metamorphosed. Recrystallisation of primary minerals can be seen in the dolomite marble, however newly-formed tremolite and biotite (phlogopite) can be seen only in places. In terrigenous rocks, a quartz-albite-muscovite-chlorite (±clinozoisite, phlogopite, epidote) assemblage is typical; in basal layers actinolite occurs. These mineral assemblages, preserved fragments of plagioclase and carbonaceous matter together with ("blasto")-aleurolitic and ("blasto")-psammitic textures indicate a relatively low metamorphic grade corresponding to albite-muscovite-chlorite subfacies of the greenschist facies.

4.1.3 Permian rocks

Upper Permian (P_2)

The Upper Permian rocks of the region are represented by the lower part of Khingil sequence. Three small outcrops occur in the western and the southern part of the Aynak ore field, unconformably overlying older rocks in the region. Conglomerate, gritstone and coarse-grained quartz sandstone occur at the base. The basal conglomerate contains well rounded pebbles of mostly quartz and quartzite and has a thickness of between 0.5 and 3 m.

The Permian rocks are predominantly finely crystalline thin-bedded limestones of varying colour: greyish-white, yellowish and bluish. Significant beds of massive, medium crystalline dolomite (about 30 %) with intercalations of phyllite, carbonaceous and chlorite schist occur in the upper part. The thickness of the Permian rocks attains 550–600 m.

4.1.4 Neogene rocks

Neogene rocks in the Aynak orefield area are widespread. They infill intermontane depressions – Aynak in the east and Logar in the west and unconformably overly older rocks in the region. They are represented by terrigenous alluvium-proluvium sediments. A basal breccia, 1 to 40 m in thickness, frequently occurs infilling the lower parts of the older relief. The breccia is dominated by rock debris and poorly rounded blocks of underlying rocks cemented by clay-carbonate material.

Sand prevails in the upper part of the section. In the lower part of the section, red sandstone occur which are frequently clayey and aleurolitic with intercalations and lenses of blocks, boulders, pebbles (to 10–15 m) and marl (to 3 m).

The sand is equigranular, fine to medium-grained and sub-angular. It is cemented in places by carbonates, is partly altered and rarely solid. The Neogene and Quaternary deposits are described in further detail in the hydrogeological and engineering geology conditions report of the Aynak deposit (Malyarov, 1976).

The Neogene deposits attain a thickness of 600 m with maximum thicknesses intersected in the Central area (borehole 87).

4.1.5 Quaternary rocks

The extent of the Quaternary sediments in the orefield area is insignificant. They are bound to foothills and to the valleys of occasional streams. They are represented by different genetic types: prolluvial, delluvial, colluvial and technogenetic. The most common are delluvial–prolluvial Upper Quaternary (d.pl Q_{III}) and recent (d.pl Q_{IV}) sediments. Exposed thicknesses of Quaternary sediments does not exceed 13 m.

4.2 INTRUSIVE ROCKS

Intrusive rocks of the ore field can be divided into three intrusive complexes according to their age and composition:

A. Late Proterozoic complex of small intrusions and sub-alkaline bodies;

B. Vendian-Cambrian dyke complex; and

C. Lower Cretaceous complex of ultramafic rocks.

4.2.1 Late Proterozoic complex of small intrusions and sub-alkaline bodies

The Late Proterozoic intrusive complex is relatively widespread throughout the ore field area. It is only missing in the areas where Vendian-Cambrian and younger formations occur. On the basis of wallrock relationships, metamorphic grade and petrography, two phases can be distinguished:

1) Gabbro-amphibolite and keratophyre,

2) Hornblende gabbro and gabbro-diabase.

III.2.A.1 Intrusions of gabbro-amphibolite (γ, PR_3^2) and keratophyre (φ, PR_3^2),

Numerous intrusive bodies belonging to the first phase can be found in the eastern part of the ore field in a 2 to 3 km wide belt, from the Tobagi occurrence in the south to Dashtak Valley in the north. Petrographically, two groups of intrusive bodies can be distinguished: gabbro-amphibolite and keratophyre.

a) Gabbro-amphibolite (γ, PR_3^2)

Intrusive bodies of gabbro-amphibolite are concentrated in two areas: in the Sisa Valley area where 15 bodies occur in a 2 km^2 area and south of the Pache settlement where 5 intrusive bodies were mapped covering 1.5 km^2. An addition, three intrusive bodies occur west of the Chenaray settlement, two on the northwestern margin of the Central area, three northwest of the Western area and a number of other bodies have been identified southwest of the Sisa Valley and in the areas of the Pache and Tobagi occurrences.

The orebodies are stratiform or stock-like and the floor and roof of the bodies is usually parallel to the wallrocks. In some places however they cut the wallrocks. The thickness of the stratiform bodies is typically several tens of meters and on rare occasions in excess of 100 m. The stocks are isometric and less than 100 m in diameter. The surface contact of the stock bodies is steeply dipping, often vertical and distinctly cuts the wallrock bedding. Distinct wallrock alterations were unable to be distinguished as they have been overprinted by later metamorphic processes.

The gabbro-amphibolite is greenish to dark-grey and massive with extensive, banded stratiform bodies occurring at the contacts. This is caused by the alteration of thin bands (several mm) of hornblende and plagioclase.

In the internal parts, the gabbro-amphibolite is coarse- to medium-grained, inequigranular and porphyritic due to the presence of large (1–2 cm) hornblende crystals. The endocontact, is fine- to medium-grained and equigranular with a xenomorphic to blasto-gabbro texture. The rock consists of approximately the same ratio of polysynthetic twins of plagioclase (An_{35}) and bluish-green hornblende. There are deviations towards leucocratic or melanocratic varieties. A deviation to leucocratic varieties is characteristic for the marginal parts of the massif. Accessory minerals within the gabbro-amphibolite include apatite (from rare crystals to 2 %), magnetite (up to 2 %), leucoxene and garnet. Grains of titanite and rutile can be seen in the marginal facies. Secondary minerals present include chlorite (usually formed together with epidote and quartz after hornblende) and saussurite. The rock is intensively chloritised and epidotised in places and has a blasto-gabbro or ("blasto")-poikilitic texture.

The largest outcrop of stratiform gabbro-amphibolite occurs in the northwestern part of the Central area. It occurs in contact with the para-amphibolite ($PR_3^1B_3$) and garnet gneiss ($PR_3^1B_2$).

The gabbro-amphibolite is dark-green, coarse grained and inequigranular with bands of a finer grained leucocratic variety occurring in the upper part of the body. The lower part is banded with fine-grained varieties occurring at the margins, up to 10 m thick.

Chemically, the composition of the gabbro-amphibolite (see table No 3 and diagrams) is close to spilite. The chemical analyses of the rock indicates that it is weakly saturated by silica (Q=-12.8), poor in alkalies (a:c=1.96) and melanocratic (v=28.3).

The gabbro-amphibolite cuts older rocks of the region, up to the Meta-andesite-Dacite Formation (PR_3^2B) and itself is cut by intrusive keratophyres. They are covered by the Volcanic Breccia Formation (PR_3^2C) within which fragments of gabbro-amphibolite occur. On the basis of above mentioned, the age of intrusion is thought to be Upper Proterozoic.

b) Keratophyre

This group comprises subvolcanic bodies of porphyritic rocks and are concentrated in two areas. The first area is located north of the Western area, where ten bodies have been observed along a 2 km long and 0.5 to 1 km wide belt, concordant to folding. The second area is situated east of the Makhmudkhel settlement where 17 small bodies occur within a 1 km^2 area. They are composed of metabasite and Meta-andesite-dacite formations and their extent corresponds to a synclinal structure with the keratophyre bodies following the folding of surrounding beds. Two small "clusters" occur south of the Pache settlement and in the area of the Pache occurrence. Isolated small intrusive bodies have also been identified in other parts of the orefield.

The bodies have various forms, from isometric to elongated dependant on the structures of the surrounding rocks. The size of the outcrops is mostly small, up to 0.1 km^2.

Petrographically, the following varieties were distinguished:

1) keratophyre (φ, PR_3^2),

2) quartz-keratophyre ($q\varphi$, PR_3^2),

3) porphyric granite ($\gamma\pi$, PR_3^2),

4) porphyric plagiogranite ($p\gamma\pi$, PR_3^2)

These varieties form isolated bodies with a gradual transition occurring between them.

1) The best studied keratophyre body occurs on the northwestern margin of the Western area. It is isometric in plan and slightly elongated (100 m x120 m). It is transgressively overlapped from the south by the Carbonate-Schist Formation (V-C) and from the north by the Volcanic Breccia Formation (PR_3^2C). The basal parts of both formations contain fragments of intrusive rocks. The contact with overlying formations is less distinct in places where remnants of the old weathering crust were preserved.

The keratophyre endocontact (internal contact) is a massive, fluidal, light-grey rock with a porphyritic texture. The matrix displays aphanitic texture. 15 % of the rock is formed by homogeneously disseminated albite, rare potassium feldspar, greenish-brown biotite and bluish-green hornblende. Disseminated grains (2 to 4 mm) as a rule are corroded by the matrix. Relic trachytic texture occurs in the endocontact while orthophyric texture occurs in the internal part of the body. Dark minerals are completely replaced by chlorite and calcite. The matrix consists of fine albite, quartz and chlorite. Accessory minerals include magnetite and apatite (to 3–5 %).

The chemical composition of the keratophyre is shown in Table 3.

It is a leucocratic (b=7.4), alkaline-rich (a:c=10.21) intermediate rock. Based on its chemical composition it is classed as belonging to R. Daly's average composition of keratophyre

2) Quartz-keratophyre is widespread in the orefield but less so than keratophyre. It forms one of the largest igneous bodies north of the Western area. It cuts the Metabasite Formation and the Meta-andesite-Dacite Formation but the Volcanic Breccia Formation (PR_3^2C) transgressively overlaps it.

The quartz keratophyre displays porphyric texture with albite, quartz and to a lesser extent potassium feldspar (replaced by fine-grained clusters of albite) in a dense grey matrix. Bluish-green hornblende (5 to 10%) is also replaced by clusters of quartz-chlorite. The phenocrysts are often corroded by the matrix which is fine-grained and orthophyric, consisting of albite and quartz (up to 25 %). Accessory minerals present include magnetite (up to 5 %) and apatite (up to 1 %).

3) Porphyritic granite forms several small stocks and dykes in the orefield area. The largest body (330x130 m) was found northwest of the Western area. The granite is a light-grey crystalline porphyritic rock, containing quartz, oligoclase, potassium feldspar and biotite. The matrix texture is micro-subhedral and microgranitic. It consists of quartz, oligoclase, potassium feldspar, sericite and biotite. Accessory minerals present include apatite, magnetite and titanite.

4) Porphyritic plagiogranite is found only as rare separate small (to 50x100 m) bodies, cutting the Metabasite Formation and Meta-andesite-Dacite Formation. It has a predominantly fine-grained matrix of granitic texture and is composed of: oligoclase (50 %), quartz (30 %) and hornblende (20 %). Accessories minerals include apatite and magnetite.

The average chemical composition of the keratophyre group of rocks, based on 4 samples (Table 3), allow the following key characteristics of the group to be determined. Based on silica saturation index (Q=-1.87) the rocks are saturated by silica. Based on alumosilicates composition (a:c=6.67) the rocks are moderate in alkalis and by femic components (b=15.3), they are leucocratic.

Subvolcanic bodies of the keratophyre group can be found mainly in the Meta-andesite-Dacite Formation (PR_3^2B) overlain by the Volcanic Breccia Formation (PR_3^2C). The age of the group is accepted as Upper Proterozoic.

Table 3. Chemical composition and numeric characteristic of magmatic rocks in the Aynak orefield

No	1	2	3	4	5	6	7	8	9
Rock	Gabbro -amphi-bolite	Gabbro -amphi-bolite	Kera-tophyre	Kera-tophyre group	Kera-tophyre group	Kera-tophyre group	Horn-blende gabbro	Dunite	Harz-burgite
No of sample	3048	3074	3049	3144	3075	3085	3070	3166	3166/1
SiO_2	45.66	47.58	61.9	60.58	51.24	49.28	45.9	38.54	40.48
TiO_2	1.95	1.69	1.95	2.47	3.19	1.95	2.08	0.05	0.07
Al_2O_3	14.28	15.3	18.36	16.67	11.92	14.62	16.17	1.44	3.96
Fe_2O_3	6.54	6.38	4.79	2.46	8.18	20.16	5.61	1.17	2.28
FeO	7.02	7.16	0.54	0.239	4.86	0.54	8.57	7.41	7.8
MnO	0.5	0.17	0.02	0.04	0.04	0.05	0.25	0.14	0.18
MgO	<0.10	6.85	1	0.3	4.83	<0.10	4.73	39.41	33.66
CaO	14	8.96	1.54	5.11	6.44	5.2	10.22	5.62	3.22
Na_2O	4	4	8.8	7.64	6.8	4.8	2.48	0.1	1.1
K_2O	0.9	0.48	0.06	0.16	0.1	0.06	0.34	0.1	0.1
P_2O_5	0.56	0.12	0.37	0.06	1.30	0.28	0.23	0.09	0.13
SO_3	<0.05	<0.05	0.05	<0.05	0.07	0.49	>0.05	0.17	0.31
LOI?	4.5	2.22	0.75	3.9	1.21	3.07	2.63	5.08	6.3
a	10.9	9.5	19.4	17.6	15.3	11.5	6.3	0.3	2.1
c	4.8	5.5	1.9	2.7	-0.6	4.8	5.3	0.4	1.2
b	27.1	29.5	7.4	6.7	25.8	21.2	30.6	64.5	58
s	57.2	55.5	71.3	73	58.3	62.5	57.8	34.8	38.7
a'	-	-	16.4	-	-	-	-	-	-
f'	50.1	42.1	60.9	37.9	40.5	90.2	45.8	10.2	13.8
m'	-	39.4	22.7	7.4	30.4	-	28.2	82.1	82.6
c'	49.9	18.5	-	54.7	29.1	9.8	26	7.7	3.6
n	86.70	92.80	99.30	98.40	89.70	98.70	93.00	66.70	100.00
φ	22.1	18.5	54.5	33.7	23.3	87.8	16.7	1.3	2.8
t	3.1	2.6	2.4	3	4.5	3	3.3	-	0.2
Q	-12.2	-13.5	1.9	8.1	-14.6	-2.8	-2.3	-31.4	-28
a:c	2.27	1.73	10.21	6.52	25.5	2.4	1.19	0.75	1.75

4.2.1.1 INTRUSIONS OF HORNBLENDE GABBRO (ΓPR_3^2) AND GABBRO-DIABASE ($\Gamma B_2PR_3^2$)

Several intrusive bodies belonging to the second phase outcrop in the region: in the northern part of the orefield in the Dashtak Valley area, in southern part west of the Pache settlement and 1 km south of the Isortangay settlement. Several small bodies outcrop at the entrance to the Pache Valley cutting the rocks of the Schist Formation (PR_3^2D). Small massifs and dykes of gabbro and gabbro-diabase cut the Carbonate-Plagioclase Schist Member ($PR_3^2D_2$).

Individual stocks and dykes attain a maximum size of 350 m x 100 m. Contacts with wallrocks are distinct with weak contact hornfelses.

The gabbro is medium grained, equigranular (rarely porphyritic) and structurally massive with a gabbroic texture. The gabbro-diabase is fine-grained, gneiss-like and rarely massive with a diabase-ophitic texture.

The main minerals present are oligoclase-andesine (55 to 65 %) and bluish-green hornblende (35 to 45 %). In leucocratic varieties of gabbro-diabase the hornblende content decreases to 20 %. Accessory magnetite, chalcopyrite, titanite and apatite can also be present. Secondary minerals are represented by epidote (up to 20 %) and chlorite.

In the northern part of orefield, the gabbro and gabbro-diabase bodies often contain disseminated chalcopyrite and bornite or quartz-sulphide veinlets with chalcopyrite and bornite.

The chemical composition of the second phase rocks is shown in Table 3.

The rocks are silica saturated, alkali poor and by composition they are ("leucocratic")-melanocratic. They are compositionally close to spilite and can be distinguished from the first phase gabbro-amphibolites by their lower silica saturation, lower "a" value and related lower a:c ratio (see petrochemical diagram).

The rocks are accepted to be Upper Proterozoic in age. They are younger than the rocks of the first phase as they do not cut the youngest Upper Proterozoic Schist Formation (PR_3^2D) and are cut by the Vendian-Cambrian Carbonate-Schist Formation.

4.2.2 Vendian-Cambrian dykes

Vendian-Cambrian dykes are only found in the northwestern part of the Central area. Petrographically, these have been distinguished as andesite and syenite.

The andesite (α V-C) forms five northeast striking dykes that are 10–12 to 70–100 m long and about 0.4 m thick. Their contacts are distinct and the surrounding wall rocks are unaltered. In places, quartz veinlets can be observed near the contact. The andesite is a dark-grey or yellowish-grey, massive, porphyritic rock with less than 10 % plagioclase and hornblende phenocrysts, 1 to 2 mm in size. The plagioclase is partly replaced by a fine-grained cluster of chlorite, sericite and carbonate. The hornblende is replaced by chlorite, calcite, quartz and rutile. The matrix displays a hyalopilitic and rarely pilotaxitic texture.

The syenite (ξ V-C) forms two dykes on the northwest of the Central area, 60 m long and 0.4 to 1 m wide. The syenite is a massive, pinkish-grey, medium grained, equigranular rock with rare phenocrysts of pinkish feldspar. It is composed of subhedral crystals of potassium feldspar (60 %), plagioclase (30 %) and biotite (10 %). Feldspar crystals are intensively sericitized and weakly albitized and the biotite crystals intensively sericitized and chloritized. Hornblende is completely replaced by a fine-grained aggregate of epidote and carbonate. The only accessory crystals found are small quantities of magnetite.

The andesite and syenite dykes cut Vendian-Cambrian rocks but they are not associated with younger rocks.

4.2.3 Lower Cretaceous ultramafic rocks (σK_1)

In the southwest part of the orefield, a small outcrop of the large ultramafic Logar massive has been mapped, in faulted contact with Upper Permian limestone. Neogene and Quaternary deposit cover the majority of the massif. Harzburgite is the dominant rock within which lenticular bands of dunite have been mapped on the east side of the Abparan stream. As a rule the rocks are serpentinized with the most intensive serpentinization (and mylonitization) occurring at the contact with the Khingil limestone.

The harzburgite is a massive, medium-grained, subhedral rock, consisting of olivine (60 to 70 %), rhombic enstatite pyroxene (30 to 40 %) and chromite (up to 3 %). Serpentine is a common secondary mineral.

The dunite is a massive, fine-grained, equigranular, dark-green to almost black rock with euhedral texture, consisting of olivine (35 to 95 %), chromite (3 to 5 %) and rhombic pyroxene (5 to 15 %).

The serpentinite is a massive, greenish-black compact rock with micro-fibroblastic texture. The dominant mineral is chrysotile, which displays a typical loop-shaped texture, reflecting olivine fissures in the primary rock. Small grains (0.1 mm) of magnetite are abundant (< 5 %).

The chemical composition of harzburgite and dunite is shown in Table 3. The ultramafic rocks are holomelanocratic, under saturated in silica and alkali poor. The harzburgite and dunite have analogous petrochemical compositions characterised by minute values of “a” and “c”.

4.3 STRUCTURE

The Aynak ore field occurs within an elevated area in the Kabul block, a fragment of Baykal basement in an area of late Alpine folding. Five independent structural-formational complexes have been distinguished on the basis of deformation style, mutual relationships and faulting.

4.3.1 Structural-formational complexes

Three structural-formational complexes have been distinguished in the basement rocks: lower – gneiss and schist (PR_3^1); middle – metavolcanics and metamorphosed schist (PR_3^2); and upper – carbonate-schist (“productive” or ore bearing), corresponding to the sub-platform stage of the Baykal geosyncline (Vendian-Cambrian). Younger rocks are divided into two structural-formational complexes: the Upper Permian (P_2) and the Neogene-Quaternary.

4.3.1.1 Lower structural-formational complex (PR_3^1)

This complex comprises schist, different gneisses and amphibolite. In the central part of the ore field (Abdurakhman-Pache-Bandzhakhor settlements) rocks of this complex form plunged a horseshoed anticline 7 km long and about 2 km wide. A large part is overlapped by Neogene cover. The structure was distinguished using geophysical techniques, in particular by a distinct negative anomaly of 10 to 20 me intensity. The fold axis bends sharply. In the south it spreads for 1.5 km (northeast of Khundara settlement) at 60 degrees after which it sharply bends towards the northwest. In the Bandzhakor settlement area, the core and northern limb of the fold are overlapped by Neogene deposits.

The southeast and northwest limbs of the plunged anticline are composed of higher order folds, cut by a series of faults. The inclination of the beds is steep, nearly vertical and often reversed. In the southwest, the limbs of the plunged anticline dip between 50 and 70 degrees transferring to a plunged syncline.

A particular type of deformation folding characterises this complex. High order isoclinal folds prevail that are inclined and reversed, reflecting the extraordinary complexity and tension of the structure.

In the southern limb of the plunged anticline a series of isoclinal reversed folds with keeled curves are distinguished. They trend at 60 to 70 degrees to the northeast with limbs inclined at 40 to 55 degrees to the northwest, with an amplitude of between 10-12 to 20-40 m. In the central part of the plunged anticline, north of the Abdurrakhman valley, the amplitude of folds increases to 40-60 m and the fold axis meanders and undulates. The common inclination of the limbs is between 60 and 80 degrees towards the west and rarely to east. In the northwestern limb of the plunged anticline, isoclinal folds are elongated almost east—west and as a rule are reversed. The amplitude of the limbs is between 40 and 70 m inclining between 60 and 70 degrees to the south.

The highest order folds show pleating and placation, the most distinct occurring in amphibolite schist (Abdurrakhman Valley) and in mica-garnet gneiss (northeast of Abdurrakhman Valley).

Rocks of the lower structural-formational complex are exposed in the cores of many small folds in the southern and northern part of the ore field.

4.3.1.2 MIDDLE STRUCTURAL-FORMATIONAL COMPLEX (PR_3^2)

This complex is represented by metavolcanics and metamorphic schists (quartzite, epidote-carbonate-feldspar) including intrusive gabbro-amphibolite and keratophyre. On the magnetic map of the area, these outcrops are characterised by distinct, localised and narrow positive and negative magnetic anomalies with an amplitude of 30 m.

The rocks of this complex unconformably overlie older rocks at a distinct angle and are known to occur in three areas. In the first area (northwest from the Aynak deposit) they form a synclinal core. The visible length of the fold is 2.3 km with an amplitude of between 200 to 300 m. The northern limb dips at 60 to 70 degrees to the northwest. The southern limb is cut by a series of northwest faults, overlapped by Neogene cover.

In the second area (southern margin of the Pache valley), two coupled folds have been mapped over 3 km^2: in the north a near faulted syncline and in the south a domed anticline with undulated limbs. The axis of the northern fold extends in a northeasterly direction for 1.5 km. To the southwest it turns to the north. The limbs have an amplitude of 400 to 5000 m. The northern limb is attached to a fault zone, reversed and dipping to the northwest at 65 to 70 degrees. The southern limb dips to north at an angle between 40 to 45 degrees. Rocks of the lower complex are exposed in the core of the southern anticline. The inclination in the central part of the fold is steep, 70 to 75 degrees; away from the dome it shallows to between 50 to55 degrees.

A fragment of concentrically plunged syncline, which displays a negative magnetic anomaly, was mapped in the third area, northwest from the Abdurrakhman settlement.

The upper (terrigenous schist) part of the structural-formational complex is exposed in the northern part of the orefield in the Dashtak Valley area, in the form of a monocline, complicated by flexural bends. The monocline is sub-latitudinal with beds dipping to the north at 50 degrees.

In the southern part of the orefield, the monotonous quartzite schist formation is compressed into a series of complicated folds with amplitudes of less than 80–100 m.

4.3.1.3 UPPER STRUCTURAL-FORMATIONAL COMPLEX (V-C)

The productive Vendian-Cambrian Carbonate Schist Formation, unconformably overlying older formations at a distinct angle, represents this complex. Unlike the lower structural formational complexes, the deposits of the Carbonate-Schist Formation are compressed into simple, gently dipping synclines with an oval outline, becoming more complicated in the limbs. They are between 0.5 to 2.5 km long and 1.2 to 1.5 km wide. About ten such folds have been identified in the orefield area. All of them are overlapped by Neogene molasse deposits.

The largest fold in this complex is the Central area syncline of the Aynak deposit, which bears the main copper-ore reserves. The Western area also occurs in a synclinal fold but it is less extensive. Both folds are described in detail in the section describing the ore deposit.

The other folds of the complex are less well known and are situated in different parts of the orefield. The outlines of these folds are not defined as they are overlapped by Neogene-Quaternary cover. It is presumed that analogous syncline structures occur hidden within the carbonate-schist rocks at the basement of the Neogene depression.

Oval plunged synclines occur in the area of the Pache and Bavarkkhel settlements with fold curves exposed in recently eroded sections. Fold bends plunge to the east below the Neogene-Quaternary deposits. The dominance of terrigenous rocks, the presence of copper-ore occurrences and the structural similarity with ore-bearing synclines of the Aynak ore deposit confirmed by magnetic data, make these structures prospective for further Aynak type ore-mineralisation.

4.3.1.4 UPPER PERMIAN STRUCTURAL-FORMATIONAL COMPLEX (P_2)

This complex occurs in the sedimentary cover of the epi-Baykal platform. It consists of rocks belonging to the Khingil series of the Upper Permian carbonate formation, occurring on the periphery of the orefield as three isolated outcrops. The carbonate rocks are gently folded, with beds inclined at 30 to 40 degrees. This complex does not play an important role in the formation of the orefield structure.

4.3.1.5 NEOGENE-QUATERNARY STRUCTURAL-FORMATIONAL COMPLEX (N-Q)

This complex extends into the recent depressions, covering more than 60 % of the orefield area. Morphologically, these depressions represent intermontane and foothill basins with differing extension and orientation. They are filled with horizontal beds of grey-coloured coarse-grained rocks: conglomerate, cobble and sand alternating with sandy clay and loam which in many places contain intercalations of gypsum and limestone. The thickness of these deposits varies between 10 to 500 m. In some places the basin margins are fault bounded with local sediments and rocks affected by recent tectonic movements.

4.3.2 Faults

Faulting is widespread in the orefield varying in nature, age, morphology and size. The most significant faults are a gently dipping thrust in the area of the Abparan settlement and a sub-meridian fault east of the Central area of the Aynak deposit.

The Logar massif ultramafic rocks are thrust into contact with the metamorphic rocks of the Aynak area extending over 30 km in a northwest direction. The thrust plane dips to the southwest at about 30 degrees and in frontal areas, near the surface, between 50 and 55 degrees. Shearing, crushing, "pulling" and sub-stratum tearing of the Upper Permian beds is observed in the thrust area.

The second largest sub-meridian fault is localised in folded rocks, east of the Central area of the Aynak deposit. It is traced by the series of positive linear magnetic anomalies. In the orefield area, many small tectonic dislocations occur, trending in an east-west and east-northeast direction.

In the Dashtak Valley area, two tectonic slices of gneiss and schist were also mapped, thrust over the Upper Proterozoic Schist Formation (PR_3^2D) and Vendian-Cambrian marbles. The thrust surface is parallel to the rock bedding in the tectonic slices, dipping to north at 50 to 60 degrees. The thickness of the brecciated zones along these faults does not exceed 1 to 2 m.

A zone of dislocation occurs in the wide belt between the Western and Central areas. It is represented by a series of steeply dipping faults with different amplitudes. The zone is 200 to 300 m wide and about 10 km long. In places the rocks are intensively brecciated and mylonitized. A tectonic slice of schist was found in the Pache occurrence area, thrust over Vendian-Cambrian marble. The plane of dislocation dips to the northwest at 45 degrees, parallel to the bedding of the marble.

The fault zone in the Pache valley divides two blocks: the uplifted southern block composed of metavolcanics and the downthrown northern block represented by carbonate-schist rocks and quartzite schists resting on crystalline basement. The zone extents sub-latitudinally and is about 5 km long, between 10–15 to 60–100 m wide and steeply inclined (65 to 75 degrees) to the north with a throw of 300 m. The rocks in this zone are represented by diaphtoritic green schist.

Small and concordant inter-bedding thrusts or under-thrusts in plastic Vendian-Cambrian carbonate-schist rocks are common. They typically follow undulating flexures in the beds, rarely cutting them at a steep angle. Plastic deformation, such as squeezing and flowing of plastic material can be observed at the contact of the marble and carbonaceous schist. Displacement of plastic material attains several tens of meters. Similar inter-bedding thrusts are distinct in curves of folds, gradually disappearing in the limbs.

4.4 COMMERCIAL MINERALS IN THE REGION

In the Aynak orefield and adjacent regions two genetic types of copper deposits and occurrences occur:

1) Sedimentary type corresponding to stratiform sandstone-hosted copper deposits; and
2) Hydrothermal-metasomatic type hosted in faults within metavolcanics, gneiss and schist formations.

In the Aynak region, Darband is the largest deposit and Tobagi, Pache and Gargav the most significant occurrences.

4.4.1 Darband deposit

The Darband deposit is situated 5 km east of the Aynak deposit and is connected by an earth surfaced road. The deposit area has a distinctive broken rocky relief between 2550 m to 2900 m in altitude. It has a relative altitude of up to 300 m above the deeply cut narrow valley. The deposit is limited to the southern limb of a large syncline which is composed of Upper

Proterozoic metamorphic rocks flanked on the east by weakly faulted Upper Permian-Upper Triassic carbonate deposits. The Upper Proterozoic rocks are overlain to the north and west by Neogene clayey, sandy, gravel deposits.

The main ore zone can be broadly traced for 7 km and its width varies between 50 to 200 m. Distinct geological boundaries or contacts with non-mineralized rocks have not been observed. In two parts of the central area, the copper-bearing rocks are overlapped by Neogene deposits. Continuity of the mineralised zone under cover was proved by mapping, drilling and geophysical surveys. Copper mineralisation is hosted in calcite and dolomite marble and also in Upper Proterozoic carbonate-mica, mica, mica-quartz-feldspar and hornblende-mica-feldspar schists.

Economic concentrations of mineralisation are limited to quartz-feldspar rocks with only weak mineralisation occurring within mica bearing schist; carbonaceous schist proves to be barren. Within the ore zone the copper mineralisation distribution is discontinuous with economic grades interleaved with low-grade mineralisation and barren areas. Overall copper grades die out with depth. However, in some areas, thin bands of ore at surface merge with thicker high-grade orebodies at depth. In some places, interfingering of ore horizons with barren horizons occurs in plan as well as in section.

The mineralisation occurs within veins and disseminated through the host rock. Chalcopyrite is the main ore mineral in carbonate rocks and bornite the main ore mineral in terrigenous rocks (mica-hornblende-quartz and feldspar schist). A weak oxidized zone occurs within which the dominant mineral is malachite with minor chalcocite and azurite.

The extent of the orebodies varies between 150 and 680 m with an average thickness of between 10 and 40 m and the average copper contents vary between 0.8 and 1.22 %. Research into the extent of the deposit at depth is in progress.

Copper resources for the orebodies within the main zone of the Darband deposit have been evaluated at 1 million tons as at 1 January 1977.

4.4.2 Tobagi occurrence

The Tobagi occurrence is situated 7.5 km south of the Aynak deposit, 60 to 80 m above the surrounding plane, which is composed of Neogene and Quaternary deposits.

The occurrence is situated within a geosynclinal structure composed of Upper Proterozoic basic and intermediate metavolcanics and tuffs. They are cut by gabbro-diabase, quartz-porphyry dykes and stockwork and Vendian-Cambrian marble, mica, carbonaceous, carbonate-actinolite (tremolite)-mica schist. The schists and microquartzite are synclinally folded. The axis of the syncline mainly strikes east–west with the northern limb cut by a latitudinal fault, dividing the carbonate-schist and metavolcanic formations. The copper mineralisation occurs within a metasomatic albititic body, 600 m in length, within a steep angled (60 to 80 degrees) southerly dipping zone of the latitudinal fault. The metasomatic body varies in thickness from 8–10 to 35–40 m and occurs on the eastern end of the fault. To the west, the body divides into two branches. One of the branches is an extension of the above described steeply dipping orebody. The other is an extension, which can be traced in an easterly direction for 500 m. It has a northeast to east inclination dipping between 30 and 60 degrees. The metasomatic body is composed of fine-grained albite aggregates with abundant zones of brecciation and fissures. 8 to 15 m albitized zones occur along fissures parallel to the main fault within marble schist. Quartz and carbonate veinlets occur at steep angles to the metasomatic body and are the product of later processes.

The ore mineralisation occurs throughout the entire metasomatic body. The copper content of the ore intersections varies from 0.48 to 2.97 % (Table 4). Fine disseminated clusters of ore minerals dominate with mineralised veins being less common. The minerals making up the clusters vary in size from 1–2 mm to 3–4 cm and the lenticular veinlets vary in thickness from 1 to 1.5 cm. The main ore mineral present is chalcopyrite with rare disseminations of bornite and chalcocite. Supergene minerals present include malachite, azurite and less commonly chrysocolla. Cuprite and tenorite have been observed crosscutting the rocks and are often associated with limonite.

Eight trenches, 500 m long and 30 to 80 m apart were cut along the length of the orebody.

Table 4 Mineralisation intersected by trenches at the Tobagi occurrence

	Main orebody								Southern orebody		
No of trench	203	204	205	202	206	201	207	198	208	199	209
Thickness in m	16.0	10.0	8.0	12.5	35.5	44.0	7.0; 11.7	10	37.2	10.0	7.0; 4.0
Average Cu content %	0.95	0.75	1.01	0.83	1.15	0.72	0.5; 0.7	2.97	0.95	1.06	0.54; 0.7

4.4.3 Pache occurrence

The Pache occurrence is situated 3.5 km south of the Aynak deposit on the southern slope of the mountain range, 150 to 170 m above the valley floor. The occurrence is situated within a NE trending thrust zone. The orebody occurs within a metasomatic albitic body and the mineralisation is localised within the schists on the eastern limb.

The internal structure of the orebody is complicated with variable thickness from 4–5 m to 48–49 m. The orebody is commonly branched with a traced extend of 800 m. The main part of the orebody trends NE and is steeply dipping (60 to 70 degrees) with a NW inclination. The southeastern limb of the orebody is cut by a fault and the northwestern limb is overlain by unconsolidated deposits.

The main ore minerals present are chalcopyrite with rare chalcocite occurring disseminated within the host rock. Supergene minerals (malachite, azurite) can be found in fissures as veinlets, coatings and crusts.

Twelve trenches, 800 m long and 40 to 80 m apart were cut along the length of the orebody (Table 5).

Table 5 Mineralisation intersected by trenches at the Tobagi occurrence

No of trench	181	113	182	112	183	111	184	185	186	110	187	109
Thickness, m	5.0	6.0	14.2	49.4	27.5	478.9	13.3	10.0	14.4	1.8; 13.7	5.0; 9.0	18.3
Cu content %	0.55	1.32	0.83	1.10	1.15	1.16	0.61	0.42	0.87	4.4; 0.37	0.5; 0.38	0.94

4.4.4 Gargav occurrence

The Gargav occurrence is situated 7 km southwest of Aynak. The mineralisation occurs within a crush zone of a N–S trending fault. The wallrocks are Vendian-Cambrian inter-layered marbles, carbonaceous schists and microquartzites. Evidence of hydrothermal alteration includes irregular silicification, ferruginisation and carbonatisaton. The alteration zone is 20 to 25 m thick and 300 m in length and is steeply inclined. The ore forming minerals include finely disseminated chalcopyrite, rare chalcocite, and veinlets of malachite, azurite and cuprite. Three trenches, 200 m in length, were dug to expose the mineralisation (Table 6).

Table 6 Mineralisation intersected by trenches at the Gragav occurrence

No of trench	178	179	180
Thickness, m	19.6	16.3	12.3
Cu content %	0.61	0.6	0.8

Finely disseminated cobalt minerals, in particular erythrite, accompany the copper mineralisation. In some areas large crystals (to 8 mm) of disseminated cobaltite were found. In such places, the cobalt content reaches 3 %.

In addition to the above mentioned occurrences, a further 50 mineralised localities have been documented and are listed in Volume 2, Annexe 4,

5 Geological characteristic of the Aynak deposit

5.1 LITHOLOGY AND STRATIGRAPHY OF ROCKS OF THE DEPOSIT

The copper deposits at Aynak are hosted within the metamorphosed Vendian-Cambrian Carbonate-Schist Formation. They unconformably overlie folded basement comprising metamorphosed Upper Proterozoic volcano-sedimentary rocks. The copper-bearing rocks are exposed at a number of localities and are surrounded by thick (400m) Neogene molasse deposits.

The Upper Proterozoic rocks predominantly outcrop west of the Central and Western areas of the deposit. They are divided into three formations (from bottom to top): amphibolite and gneiss, metabasite and volcanic breccia.

The Amphibolite and Gneiss Formation has three members. The lower member is 300 m thick and comprises hornblende gneiss and microgneiss with intercalations of muscovite schist and less common hornblende orthogneiss. The middle member is represented by muscovite-garnet gneiss with minor intercalations of two-mica-garnet, hornblende-garnet and hornblende gneiss, and muscovite schist up to 300 m in thickness. The upper member consists of plagioclase-hornblende para-amphibolite with rare intercalations of hornblende schist up to 200 m thick.

The Metabasite Formation has four members (from bottom to top): 1 – aphyric amygdaloidal basalt with tuff intercalations (total thickness of 120 m thick); 2 – plagioclase porphyrite of andesite-basalt composition and amygdaloidal basalt with intercalations of hornblende porphyrite and tuffite (total thickness of 250 m); 3 – hornblende porphyrite and basalt with intercalations of carbonate tuff-breccia (total thickness of 150 m); 4 – tuff and tuffite of andesite-basalt composition with intercalations of basalt (total thickness of 100m).

The Volcanic Breccia Formation is predominantly composed of coarse fragments of volcanic rocks, actinolite-plagioclase schist, biotite schist and dolomite marble with a brecciated appearance. The formation is 20 to 200 m thick.

The above mentioned Upper Proterozoic formations contain gabbro-amphibolite and keratophyre bodies of Upper Proterozoic age, cut by Vendian-Cambrian andesite and syenite dykes.

The ore-bearing Vendian-Cambrian Carbonate-Schist Formation is prevalent across the ore deposit area, in particular in the Central area and to a lesser extent in the Western area, where it is exposed in small areas of elevated folded structures.

The Carbonate-Schist Formation is exposed in the Central area along a rocky ridge, 140 m above the valley floor. The area of outcrop is 1400 m long and 30 to 400 m wide. Exploratory boreholes (up to 1300 m) have been drilled through the overlying Neogene sediments into the formation. From this, it is clear that the copper-bearing Carbonate-Schist Formation extends north and northeast beyond the perimeter of the explored area. In addition, to the southeast, the extent of mineralisation remains undefined. The Carbonate-Schist Formation is characterised by rocks of variable composition thus allowed 8 different members to be distinguished, with members 6, 7 and 8 further divided into several beds. Colour is the key diagnostic feature of the members and beds.

The lower part of formation (Members 1 to 6) is 65 to 225 m thick and is composed of dolomite marble with minor intercalations of carbonate-feldspar-quartz schist and an admixture of micas and carbonaceous material. The upper part of the section (Member 6) contains horizons and lenses of chalcopyrite ore.

The middle part of the formation (Member 7) represents terrigenous rocks of quartz-feldspathic composition with minor intercalations of dolomite marble. This part of the formation is 50 to 180 m thick. The lower beds (7^1) of this member contain discontinuous chalcopyrite mineralisation and the upper beds (7^2) contain continuous bornite and chalcopyrite-bornite mineralisation representing the main economic horizon within the Aynak deposit.

The upper part of the formation (Member 8) is composed of carbonate-feldspar-quartz schist and carbonaceous schist with low-grade pyrrhotite-pyrite mineralisation and infrequent layers of weakly pyritised dolomite marble. This member is up to 200 m thick.

A description of all members within the ore-bearing ("productive") Carbonate-Schist Formation is provided below.

Member 1 occurs at the base of the formation and overlies different beds of the Upper Proterozoic Amphibolite and Gneiss Formations. The member is represented by three beds with a total thickness of 3 to 12 m. They are (from bottom to top):

a) chlorite-actinolite-biotite, biotite-feldspar, hornblende-feldspar, biotite-hornblende and garnet schist with thin (3 to 5 cm) intercalations of carbonaceous-quartz schist;

b) tremolite-carbonate schist and dolomite marble containing tremolite and an admixture of terrigenous plagioclase and quartz, with thin (1 to 7 cm) intercalations of microquartzite; and

c) sericite-carbonaceous, sericite-quartz-carbonaceous and actinolite-quartz-carbonaceous schist. Layers "a" and "b" are often missing.

Member 2 is composed of dark-grey, fine-grained, quartz-bearing dolomite marble, with numerous intercalations (2 to 3 cm), lenses and “boudins” of dark microquartzite. Fine alternations of dolomite marble and quartz-mica-carbonate schist can be observed in the thinnest parts of the member. Microquartzite can occur concentrated in individual layers, intercalated with marble on a 1:1 ratio. Rare disseminated pyrite can also be observed. The thickness of the member varies from 3 to 35 m.

Member 3 is composed of light-brown to brownish-grey biotite-phlogopite-feldspar and carbonate-mica schist with characteristic small loop-shaped and veined carbonates and quartz boudins. Occasional intercalations of mica-dolomite marble occur. In areas of increased thickness, rhythmical bedding can be observed. Carbonate-mica schist and mica-dolomite marble are concentrated in the floor and roof of the member between exploration sections XXI and XXIV (1 to 3 m) and to a lesser extent in the middle part (2 to 10 m). The marble thins out towards the north, and towards the south it merges with the upper layer of carbonate-mica schist. The rocks are pyritised and occasionally chalcopyrite and bornite grains associated with quartz boudins can be seen. The total thickness of the member is between 10 and 30 m.

Member 4 is represented by dark-grey and black carbonaceous-carbonate schist and grey quartz-bearing dolomite marble, frequently alternating with thin (to 1 mm) intercalations of carbonaceous material. In some places, intercalations (0.5 to 1 m) of mica-quartz schist can be observed. Rare disseminated pyrite and chalcopyrite occurs. This member is thinner (2 to 8 m) than member 1 but more consistent.

Member 5 is composed of light grey, homogeneous, fine- to medium-grained, coarse bedded, quartz-bearing marble. Dark-grey marble can be observed in the roof and floor of the member. Rare disseminated small grains of pyrite, sphalerite or chalcopyrite can be seen in places. The marble within this member is relatively consistent and marks the lower boundary of economic copper mineralisation. The thickness of the member varies from 10 to 25 m.

Member 6 is 35 to 115 m thick. It has a heterogeneous composition and can be divided into 7 individual beds (6^1 to 6^7). They are composed of dolomite marble with frequent intercalations of microquartzite, quartz-containing dolomite marble and carbonaceous and mica schist of quartz-carbonate-feldspar composition. The main bodies and lenses of chalcopyrite ore in the Central area occur in the middle and upper part of this member (6^3 to $6^{7)}$.

Bed 6^1 is represented by dark-grey, fine-grained, quartz-bearing dolomite marble frequently alternating (2 to 10 cm) with dark microquartzite. Carbonaceous schist may occur in the roof and floor of the beds. Mica enriched layers can be seen in the upper part of the bed. The thickness of the bed is between 3 and 8 m.

Bed 6^2 is composed of brownish-grey phlogopite-carbonate and phlogopite (biotite)-feldspar schist with characteristic thin loop-shaped carbonate veinlets, or nest-like accumulations of phlogopite. Phlogopite-carbonate schist forms individual intercalations, 1 to 3 m thick, in the middle part of the member. Thin intercalations of phlogopite bearing dolomite marble occur in parts. The rocks are pyritised with rare disseminated chalcopyrite occurring. Bed 6^{2} is a marker bed within member 6 and its thickness varies between 2 and 10 m.

Bed 6^3 consists of grey quartz-bearing dolomite marble containing minor quantities of mica and rare thin intercalations (3 to 10 cm) of disseminated fine-grained pyrite alternating with bands and boudins (2 cm x 5 cm to 30 cm x 50 cm) of dark-grey microquartzite and carbonaceous-quartz schist. In some areas, (between exploration sections XXIV and XXV) schist prevails over dolomite. The thickness of the bed varies between 2 and 12 m.

Horizons of chalcopyrite ore occur in beds 6^3 and 6^4 on the southern limb of the Central area, northeast of section XX. Several further small ore lenses occur on the northern limb.

Bed 6^4 is represented by dark-grey (to black) carbonaceous-quartz and rare phlogopite-carbonaceous schist, with fine and less prominent carbonate veinlets. Thin (3 to 10 cm) intercalations of dolomite marble with an admixture of carbonaceous matter can be observed in the schist. Disseminated or nest-like accumulations of pyrrhotite-pyrite mineralisation are common. Chalcopyrite is disseminated in some places and in other places it attains economic accumulations (orebody No 8, lens No 12). The thickness of the bed is 10 m.

Bed 6^5 is composed of dark-grey fine-grained, quartz-bearing dolomite marble, 10 to 30 m thick. Thin (1 to 5 cm) intercalations of dark-grey microquartzite with rare carbonaceous-quartz schist occur. Rocks of these beds contain irregularly distributed copper mineralisation. They locally form part of No 2, 3 and 7 (3) orebodies and also an important part of ore lenses in the Central area (No 3, 5, 11, 13, 14, 16, 17 and 19).

Bed 6^6 consists of light-grey, quartz-bearing, medium grained dolomite marble, with large (1 to 3 cm) metablasts of dolomite. Layers of oriented actinolite and tremolite grains and thin (1 to 5 cm) intercalations of light microquartzite can be observed in the marble. Ore-bearing beds contain disseminated layers of chalcopyrite, and to a lesser extent bornite mineralisation. Bed 6^6 forms part of No. 2, 3 and 7 (3) orebodies and are between 5 and 20 m thick.

Bed 6^7 are represented by frequent (over 2-3 cm) alternations of grey and dark-grey fine-grained dolomite marble (occasionally with metablasts of dolomite and an admixture of terrigenous plagioclase) with dark microquartzite and carbonaceous-quartz schist. Layers of irregularly disseminated chalcopyrite mineralisation is common, forming parts of No 2, 3, 4 and 6 (4) orebodies and also ore lenses within No 9 and 10 (exploration sections XXIX and XXX). The thickness of the bed varies between 5 and 25 m.

Member 7 is between 50 and 180 m thick and is dominantly composed of terrigenous rocks of quartz-feldspathic composition with minor intercalations of dolomite marble. It is divided into two beds: lower 7^1 and upper 7^2.

The lower bed (7^1) contains the entire No 1 orebody, No 2, 4, 6 (4) and part of No. 5 orebody. It also contains lenses of chalcopyrite ore within No 4, 6, 7, 8 and 18 orebodies. The upper bed (7^2) hosts the main bornite and chalcopyrite-bornite mineralisation and the main part of No. 5 orebody (chalcopyrite ore).

The rocks of this member contain economic chalcopyrite mineralisation with some bornite in the Western area.

Bed 7^1 consists of dark-grey phlogopite-carbonate-carbonaceous-quartz schist with a characteristic breccia-like appearance due to the loop-shaped pattern of dolomite and calcite veinlets. Carbonaceous-carbonate and phlogopite-carbonate-feldspar schist prevail in the lower part. Thin (to 1 mm) intercalations of grey mica-dolomite marble with an admixture of altered terrigenous plagioclase and carbonaceous-quartz schist and layers (1 to 7 m) of relatively homogenous light-grey dolomite marble (in the lowest part of section) occur. The maximum thickness of the beds (up to 60 m) is observed in the central part of the Central area and minimum thickness (up to 10 m) in the limbs.

In the Western area, brecciated carbonaceous-feldspar schist with fragments of microquartzite and dolomite marble represents the beds. A layer (1 to 1.5 m) of dolomite marble with an admixture of carbonaceous-quartz schist and microquartzite fragments occurs. In this area, the bed in 15 to 80 m thick.

Bed 7^2 is predominantly represented by light-grey feldspar and mica-feldspar schist with less frequent quartz-feldspar schist and quartzite. Layers (up to 10–15 m) of dolomite marble with an admixture of terrigenous plagioclase (in the lower parts of section) and intercalations (up to 2 m) of microquartzite occur. In addition, massive mica marble with an admixture of terrigenous quartz-feldspar and carbonaceous-quartz materials and intercalations (in the southern part of the Central area) of phlogopite-carbonate-carbonaceous-quartz schist can be observed.

The maximum thickness of the beds (up to120 m) is observed in the central part of the Central area, and the minimum thickness (to 40 m) in the limbs, where changes in facies occur. Mica-feldspar-quartz schist and quartzite, alternating with dolomite marble and containing an admixture of terrigenous plagioclase, are dominant in the southern limb of the Central area. Phlogopite-carbonate-carbonaceous-quartz schist with intercalations (0.5 to 1.5 m) of massive dolomite marble prevails in the middle part of the area. In addition, the composition of the copper mineralisation changes from bornite and chalcopyrite-bornite ores in the central part of the Central area to predominantly chalcopyrite ore in the limbs.

The main part of bed 7^2 is represented by feldspar schist and carbonaceous and carbonates varieties. Layers of quartzite and dolomite marble are relatively thin (1-2 m). Chalcopyrite mineralisation substantially prevails over bornite. The bed varies between 40 and 125 m in thickness.

Member 8 is up to 200 m thick and overlies part of the ore mineralisation within the Carbonate-Schist Formation. Lithologically, Member 8 can be divided into two parts. Rocks of the member are covered by Neogene molasse sediments and were only intersected in boreholes.

Bed 8^1 is composed mainly of dark-grey phlogopite-carbonaceous-quartz schist with a typical admixture of terrigenous plagioclase. Intercalations of mica-feldspar schist with an admixture of small fragmental grains of plagioclase and rare intercalations of microquartzite and dolomite marble are present within the schist. The rocks are pyritised and contain low-grade layers of disseminated chalcopyrite mineralisation. On top of the beds layer (5 to 10 m) of black carbonaceous schist occur with occasional thin layers (0.1–0.5 cm) of quartz-feldspar and carbonate material. The bed is 30 to 70 m thick.

Bed 8^2 consists of grey and dark-grey weakly pyritised dolomite marble, fine- to medium-grained, low in mica and at times containing an admixture of small plagioclase and quartz fragments. Intercalations (from 1 mm to 1–2 m) of phlogopite-carbonate-carbonaceous-quartz schist (occasionally with an admixture of terrigenous plagioclase), carbonaceous and quartz-feldspar schist (in the lower part) and mica and carbonaceous microquartzite occur within the marble.

A layer (10–35 m) of black carbonaceous schist with layers of intensive disseminated aggregates of pyrite-pyrrhotite mineralisation occurs within the middle part of beds. Disseminated chalcopyrite has been observed in places (more in the upper part of beds). The bed is in excess of 125 m thick.

Neogene sediments are widespread in the deposit area unconformably overlying older rocks. They are represented by sand, marl, clay, weakly cemented sandstone and cobble-pebble material. They are up to 400 m thick. At the base of the Neogene sediments, coarse ore breccia (up to block size) occurs adjacent to the ore bearing ("productive") formations. **Quaternary sediments** are less extensive. They are represented by alluvial-prolluvial valley and slope deposits and delluvial-colluvial slopes and foot-hills deposits. They are up to 20 m thick.

Large dumps of low-grade ore and slag from ancient smelting furnaces can be found near the ancient mine works.

5.2 STRUCTURE OF THE DEPOSIT

The Aynak deposit is situated on the northeastern part of an upland area with the same name, one of the structures of the folded Baykal basement in the central part of Kabul tectonic block.

As discussed previously, the metamorphic basement of the region is composed of three structural-formational complexes: *the lower* – joining the Upper Proterozoic gneiss and schists cut by gabbro-amphibolite and keratophyre intrusions; *the middle* – composed of Upper Proterozoic metavolcanics of varying composition, cut by small intrusions of hornblende-gabbro and gabbro-diabase; and the *upper* – represented by Vendian-Cambrian copper-bearing rocks of the Carbonate-Schist Formation, forming the cover of the epi-Baykal platform.

The metamorphic rocks of the first two complexes are compressed into narrow isoclinal, frequently reversed folds with complicated forms. The third complex forms more simple plunging synclinal folds with more complicated structure occurring only in the limbs and close to large dislocations.

The Central and Western areas of the Aynak deposit occur within two plunging synclines of the upper Vendian-Cambrian structural-formational complex. These folds are probably divided by complexes of older metamorphic rocks covered by Neogene molasse sediments.

The plunging syncline of the Central area is the largest, most tightly folded structure, similar to those within the Aynak orefield area. The axis of the syncline plunges to the northeast (25-40 degrees) with its lower bend continuously plunging to the northeast at an angle of about 20 degrees. The fold has been explored in this direction over a length of more than 2 km. It has a maximum width (in a east-southeast direction) of about 1.5 km. The plunged syncline has only been outlined to the west. On the north, east and south it is covered by thick (more than 300 m) Neogene cover. Recent erosion has exposed a section of the western limb of the fold and its southwest curve.

The western limb of the plunging syncline was explored by exploration mining adits and by core drilling in a north-easterly direction (20 degrees) over a distance of 1800 m (from section XX to XL). It is composed of rocks from Members 1 to 7, inclining to the east-southeast at different angles. On the western limb of the northern part of the fold (north from section XXXII), the beds incline from 30 to 45 degrees; 500 to 700 m to the east of the western margin of the fold the beds flatten out. South from section XXXII, the inclination of the beds is steeper, between 50 and 70 degrees, and south from section XXV the fold closes to the southwest. The direction of dip of the beds in the southwestern extension changes rapidly to the southeast, and after to the northeast (50 to 60 degrees). The structure of the plunged syncline in its southwestern closure is complicated. Two small high order synclinal folds can be seen here outcropping in the northwest and divided by an anticlinal bend. The small folds plunge towards the northeast to the base of the plunging syncline.

The southwestern limb of the plunging syncline and its southwestern closure has a complicated structure, due to appearance of a high order narrow asymmetric anticline. This anticline was explored in a northeasterly direction from section XX to XXXIV for a distance of about 1.5 km. The lower members (1 to 5) of the Vendian-Cambrian Carbonate-Schist Formation are exposed in its core (below the Neogene sediments). The northwestern limb is relatively flat, dipping to the northwest at 30 to 50 degrees. The southeastern limb is steep, almost vertical. Both limbs of the anticline are composed by copper-bearing rocks belonging to the 7th member. In the southeastern limb, the ore bearing rocks are complicated dipping to the southeast, almost vertically (between sections XX and XXVII) to a postulated depth of more than 500-600 m.

North from section XXVII, the southeastern limb of the anticline gradually flattens and inclines to the southeast. The anticline obtains a symmetric structure close to section XXXIV and gradually closes (disappearing) as confirmed by exploration boreholes No 590 and 97 (section XXXIV). In the southeast limb of the plunged syncline, the limit of the copper-bearing formation is unclear as it is covered by a thick cover of Neogene sediments.

The complicated internal structure of the plunged syncline of the Central area can be divided into two parts based on character and intensity of folding (section XXXI): the southwestern part, 1000 m in length and the northeastern part more than 1000 m in length.

The southwestern part of the plunged syncline is a higher order fold structure and thus more complicated, formed by the intensive compression of the Carbonate-Schist Formation accompanied by faulting of internal beds and squeezing of more plastic material from the higher order limbs to closed parts. Folds with limb amplitudes from tens of meters to 200-450 m are observed together with intensive small traction folds (with amplitude in meters) on the floor of the ore-bearing formation, with pleating and wrinkling of layers occurring in the most strained parts.

In the northeastern part of the plunged syncline (north from section XXXI) the setting of the ore-bearing Carbonate-Schist Formation is relatively simple and is complicated only by a series of flat undulated folds, the limbs of which incline at 10 to 30 degrees.

In addition to folded structures in the plunged syncline of the Central area, faults are widespread particularly in the limbs. They are represented by concordant, internal tear faults cutting bedding and small thrusts. In the western and southeastern limbs of the plunged syncline, interlayer faulting is represented by a series of sub-parallel tear faults up to 1000 m long with amplitudes not exceeding tens of meters. Typically they occur at the contact of layers with different competence. Smaller faults cut dislocations in the axis of the high order folds and shallow reverse faults in the western limb of the plunged syncline. They are less than 100 m long with an amplitude shift of between 10 and 20 m.

The main fold and fault structures of the Central area of the Aynak deposit are long and complicated. According to changes in facies and thickness of different members in the ore-bearing Carbonate-Schist Formation, the plunged syncline had started to form at the time of sedimentation (synsedimentary). This is evidenced by the maximum thickness of the main ore bearing beds 7^2 occurring in the most folded part of the plunged syncline (sections XXXIV-XXXVI) and the minimum in the limbs (sections XXXVIII-XL) in the north and southeast. However, the northwestern limb of the asymmetric anticline complicates the main fold. The formation of the plunged syncline and secondary dislocations continued during the post Vendian-Cambrian period. Tectonic movements on main faults continued much later forming the Neogene depressions, which are related to the plunged syncline structures of the Vendian-Cambrian structural-formational complex.

The Western area synclinal structure is less well studied as the surface, exploration mining works and sparse exploration boreholes only exposed a small part of the structure. Where intersected it comprised mineralised carbonate-terrigenous rocks, similar to Member 7 of the Central area. The mineralised rocks extend in an east-northeast direction and are steeply, almost vertically dipping to the north-northwest. They are intensively deformed and are cut by numerous mainly longitudinal faults, concordant to bedding.

In the west, the ore-bearing member (7) is cut by a large northwest striking fault and to the east, the fault is covered by Neogene deposits. The fault has been traced (with interruptions) for about 400 m and its thickness is estimated between 30 to 60 m. The ore member presumably continues under the Neogene cover for a distance of at least 600 to 700 m.

Metamorphic rocks, situated to the north of the ore member, were previously regarded as analogous to the underlying lower members (1-6) of the Carbonate-Schist Formation of the Central area. They were mapped as such (see enclosed geological maps) at a scale of 1:10000 (orefield area) and at a scale 1:2000 (deposit areas).

Based on the most recent geological information, these rocks can be equated with the overlying Member 8 of the Central area. The ore zone occurs in the southern limb of the near latitudinal synclinal structure, dipping almost vertically. In the north, the above mentioned rocks of

Member 8, which form the central part of this syncline structure, are cut by large faults. The older Upper Proterozoic metamorphic rocks must have been moved by a thrust structure onto the ore-bearing Vendian-Cambrian Carbonate-Schist Formation.

The lower members (6-1) of the Carbonate-Schist Formation, analogous to the Central area, are expected to the south of the ore-bearing member.

5.3 DISTRIBUTION AND MORPHOLOGY OF OREBODIES

The Aynak deposit is characterised by stratiform mineralisation in which the mineralisation is distinctly related to many specific stratigraphical horizons within the Carbonate-Schist Formation. Thirty orebodies have been delineated in the Central area. They are distributed within five horizons, divided by intercalations of waste rock or rock with sub-economic mineralisation.

The extent of the orebodies is extremely variable: the directional length varies from 15–30 m to 1500 m and the width from 30 m to 1000 m. The thickness of ore horizons, as well as the intercalations dividing them, changes gradually and usually varies from several meters to several tens of meters, attaining a maximum thickness in the central parts and minimum in the limbs. The edges of the orebodies in plan and section are determined by the contoured ore values and the outline varies substantially according to the cut-off grade.

All the orebodies are conformable with wall rock bedding, following later bends and displacements.

The orebodies are divided into three groups based on their size and form:

a) large layers – the Main orebody;

b) medium size layers – orebodies No. 1 to 8; and

c) small lenticular bodies – ore lenses No. 1 to19.

All of the orebodies occur within distinct stratigraphical horizons within the copper-bearing formation as described below (from top to bottom by section):

The first horizon extends throughout the entire of Bed 7^2 in the north (sections XXXIII-XL) and in the Central area it occurs in Bed 7^1 on the southeastern limb of the plunged syncline. It is represented by three orebodies: Main orebody, orebody No 5 and ore lens No. 1. The latter occurs at the base of Bed 8^1 and is divided from the Main orebody by a 12 m thick intercalation of waste rock (section XXXVIII). According to sections XX to XL, the first ore horizon is the most continuous and widespread throughout the Central area.

The second horizon is situated below the first one and occurs in Bed 7^1. It contains orebody No. 1 and five ore lenses (No. 4, 6, 7, 8 and 18). This horizon occurs on sections XXVIII-XXXII and it is separated from the Main orebody by intercalations of waste rock up to 30 m thick (sections XXX-XXXI). North of section XXXII and south of section XXVIII, the second horizon is absent and is stratigraphically replaced by the overlying orebodies of the first horizon – the Main orebody in the north and orebody No. 5 in the south.

The third horizon is the second most widespread as demonstrated from section XX in the south to XXXVIII in the north. The horizon is made up of three orebodies (No. 2, 4 and 6) and three lenses (No. 2, 9 and 10), all situated in Beds 6^6 and 6^7. In the north, where the orebodies of the second horizon are absent, orebody No. 2 partially occurs at the base of Bed 7^1. According to sections XXXV-XXXVIII it directly adjoins the Main orebody of the first horizon. South from section XXVIII, where the second horizon is absent, the intercalated waste rock dividing the first and the third horizons (i.e. the Main orebody and orebody No. 4) attains a maximum thickness of 65 m (section XXVI).

The fourth horizon, containing orebodies No. 3 and 7 and ore lens No. 3, extends for about 1200 m (from section XX to XXXIV) and occupies Bed 6^5. In places where the orebody swells, it occupies part of Bed 6^6. The intercalations of waste rocks that divide the orebodies in the fourth and third ore horizons are not continuous and vary from 0 m (in the areas where the orebodies are joined) to 15 m in thickness. In the southeastern limb of the plunged syncline, intercalations of waste rock between the orebodies of the fourth (No. 7) and the third (No. 6) ore horizons are absent.

The fifth horizon is the most intermittent of all the horizons. It contains orebody No. 8 and nine ore lenses (No. 5, 11 to 17 and 19), which mainly hosted by Beds 6^3 and 6^4. Single lenses partly transfer to the overlying Bed 6^5 (No. 11, 13, 16, 17 and 19) and the underlying Bed 6^2 (No. 15). Continuous intercalations of waste rock, 5 to 10 m thick, divide the orebodies of the fifth and the fourth ore horizons. In the southeastern limb of the plunged syncline (between orebodies No. 7 and 8) it attains 15 to 20 m in thickness.

The first ore horizon is the most important of all five horizons containing more than 80 % of the copper reserves of the Central area. It differs from the others ore horizons as it is dominantly composed of bornite and has a high copper content (> 2 %). The others ore horizons are predominantly chalcopyrite bearing and have a copper content of around 1 %.

The Western area ore zone belongs to Member 7 of the Carbonate-Schist Formation and has yet to be studied in detail. As a result, it has not been sub-divided into different ore horizons.

The orebodies of all above mentioned horizons differ by size and morphology and are all briefly characterised below.

The Main orebody is situated in the first ore horizon. It is a layered body occurring within Bed 7^2 which is represented by terrigenous quartz-feldspar rocks with minor intercalations of dolomite marble, containing quartz-feldspar clastic material. In some places, the orebody extends to the lower part of Bed 7^1 comprising mica-carbonate-carbonaceous-quartz schist.

The orebody differs by its dominantly bornite composition and high copper content, rarely below 1 % throughout. The contours defining the orebody outline do not fluctuate much with varying copper cut-off grades (from 0.2 to 0.9 %). This suggests that the orebody boundaries are sharp and well defined with the exception of localised areas in the floor and roof where thin rims of low-grade chalcopyrite ore occur. Only one small “window” of waste rock (7 m thick) has been identified in the orebody (section XXV).

The Main orebody was traced for 1500 m along strike (from section XXII in the south to XL in north) and for 1000 m across strike (section XXXIV). It varies from 70 m in width (section XXIV) in the south to 900 m in the centre (section XXXIV) to 600 m in the north (section XXXVIII), in the explored part of the plunged syncline.

The maximum thickness of the orebody (100 to 150 m) occurs in the central part (for 500 m between sections XXI and XXXVI) and the minimum (> 30 m) in the limbs. The deepest intersection of the orebody was attained by borehole 138 (section XXXVIII), 680 m below the surface.

In detail, the Main orebody follows the features, bends and internal structure of the plunged syncline of the Central area, plunging to the northeast at an angle of 20 degrees. In the majority of the Central area, it is covered by Neogene deposits up to 350 m thick. The orebody is only exposed for 700 m on the northwestern limb of the plunged syncline (between sections XXIII-XXXIII). The orebody extent remains open to the north and east.

In the same horizon as the Main orebody, but on the southeastern limb, orebody No 5 is situated. In the north, in section XL, the thickness of the orebody reduces substantially, gradually thinning to the northwestern of the plunged syncline. In borehole 97 (section XXXIV), thinning out of the orebody is observed towards the southeast where ore thicknesses are reduced to 30 m and the mineral composition changes from predominantly bornite to chalcopyrite. It is apparent that the orebody continues towards the northeastern part of the plunged syncline, to the north of the marginal ore intersected in borehole 133 (section XXXVIII).

In the Central Area, four of the eight layered medium size orebodies (No. 1 to 4) are situated in the central part of the plunged syncline, three (No. 5 to 7) in its southeastern limb and one (No. 8) occurring in both. The parameters of these orebodies are shown in table 7.

Orebody No. 5 is situated in the same geological horizon as the Main orebody in the southeastern limb of the plunged syncline of the Central area. It occurs within Beds 7^2 comprising terrigenous quartz-feldspar rocks with minor intercalations of dolomite marble and quartz-feldspar clastic material and Beds 7^1 comprising carbonate-carbonaceous-quartz schist. The orebody can be traced in an east–northeast direction and is steeply (nearly vertically) dipping to the south-southeast. In comparison to the Main orebody, orebody No. 5 is thinner and is characterised by chalcopyrite ore and by a more irregular distribution of mineralisation. Three barren "windows" (sections XXII, XXIII and XXV) 5 to 15 m thick occur. The continuity of the orebody is disrupted when the copper cut-off grade is increased above 0.4 %.

Orebody No 1 is the main orebody in the second horizon occurring solely within the phlogopite-carbonate-feldspar schists of Bed 7^1. It is generally underlain by the Main orebody and the orebody extent has been fully defined, determined by the cut-off grade. Orebody continuity is preserved with increasing copper cut-off grades (from 0.2 to 0.7 %), however the size slightly decreases.

Orebody No. 2, together with orebodies No. 4 and 6, are situated within the third horizon. They occur in Beds 6^5-6^7 and partly 7^1 (on the hangingwall), represented by quartz-bearing marble and also by carbonaceous and mica schist of quartz-carbonate-feldspar composition.

Orebody No. 2 is exposed at the surface only on the western limb of the plunging syncline, between sections XXX and XXXII. North of section XXXV it joins the Main orebody. Southwards, it gradually diverges from the Main orebody (from section XXXV) divided by intercalations of Bed 7^1 waste rocks. In the southwest, orebody No. 2 thins out between sections XXIX and XXX.

When the copper cut-off grade is increased above 0.4 %, continuity of orebody No 2 is satisfactory preserved in its northern part but is disrupted in the southern part.

Immediately south from the section XXX, an elongated orebody No. 2 appears in the same geological horizon. After a short interruption, orebody No. 4 appears within the dolomite marble of Bed 6^7, frequently alternating with carbonaceous-carbonate and phlogopite-carbonate-feldspar schists from the base of Bed 7^1. Orebody No. 4 is exposed at the surface for 150 m between sections XXIII and XXV. The mineralisation in orebody No. 4 is extremely irregularly distributed in comparison to the others orebodies. Three barren "windows", 5 to 7 m thick (sections XXIV and XXV) were distinguished within its boundaries. An increase in copper cut-off grade above 0.4 % disrupts the continuity of the orebody. The orebody is fully outlined in plan.

In the southeastern limb of the plunged syncline, in the same geological horizon, orebodies No. 2, 4, % and **6** occur extending in an east-northeast direction, steeply (almost vertically) dipping to the south-southeast.

Orebody No 3 together with orebody No. 7 occurs in the fourth ore horizon. It occurs within the rocks of Beds 6^5-6^7 represented by quartz-bearing dolomite marble and also by carbonaceous mica schist of quartz-carbonate-feldspar composition. It outcrops on the western limb of the plunged syncline between sections XXIII-XXXI.

Table 7 Main parameters of the medium-size layered orebodies, Central area

Orebody No.	Location section	Depth (altitude) from–to, m	Size, m from–to, average		Thickness, m from–to average	Stratigraphic members and beds containing bodies
			in direction	by inclination		
1	XXVIII–XXX	2380–2200	250	80–345 215	5–28 10.7	7^1 (floor)
2	XXX–XXXIX	2530–1925	960	600–1180 890	5–38 15.0	6^5–6^7 and 7^1 (floor)
3	XXIII–XXXII	2520–2048	800	390–765 600	2–51 20.7	6^5–6^7
4	XXIV–XIX	2520–2325	460	130–420 310	5–32 16.5	6^7 and 7^1 (floor)
5	XX–XXXI	2475–2150	1000	30–250 170	30–135 67.0	7^2 and 7^1 (roof)
6(4)	XXI–XXVI	2435–2260	600	50–150 105	7–20 12.5	6^7 and 7^1
7(3)	XX–XXVII	2463–2260	670	70–180 120	4–40 13.0	6^5–6^6
8	XXI–XXX	2467–2183	720	120–450 235	3–16 8.5	6^3–6^4

Orebody No. 3 is situated beneath orebodies No. 2 and 4 and is separated from them by a more or less continuous intercalation of waste-rock up to 20 m thick (section XXX). Ore mineralisation in orebody No. 3 is discontinuous and irregular. Two barren "windows" 6 to 8 m thick have been identified in sections XXIV and XXIX. An increase in copper cut-off grade above 0.4 % disrupts the continuity of the orebody in parts. The orebody is outlined in plan.

Orebody No. 7 is situated within the southeastern limb of the plunged syncline in the same geological horizon as orebody No. 3. It extends in an east–northeasterly direction and is steeply (almost vertically) dipping to the south-southeast.

Orebody No. 8 is an important body within the fifth and lowest ore horizon. Its mineralisation is hosted by quartz bearing dolomite marble, alternating with thin intercalations (3 to 10 cm thick) of microquartzite and carbonaceous-quartz with rare phlogopite-carbonaceous schist (Beds 6^3–6^4). The orebody is situated in the southeastern keeled closure of the plunged syncline and in the southeastern limb. In the former, the mineralisation is relatively consistent and compressed into two high order symmetric synclinal folds. In the latter, the mineralisation is steeply (almost vertically) dipping to the south-southeast, parallel to orebodies No. 5 to 7.

Small lenticular bodies belonging to the third group occur in all five ore horizons. The list of bodies is enclosed in table 8. Among the 19 small ore lenses, only four (No 4, 7, 10 and 16) are cut by 2 or 3 exploration intersections. The others have been identified on just one exploration intersection. The largest (thickest) ore lenses (No 1, 3 to 7, 10 to 12, 16, 17 and 19) have evaluated reserves of category C_2.

In the Western area of the deposit, the copper-bearing rocks of the Carbonate-Schist Formation are represented by a variety of lithologies: feldspar-schist and its carbonaceous and carbonate-containing varieties with minor intercalations of quartzite and dolomite marble (Bed 7^2); brecciated carbonaceous-feldspar schist with fragments of microquartzite and dolomite marble (Bed 7^1); and to a lesser extent by dolomitic marble with intercalations of carbonaceous-quartz schist (Members 6 and 8). Chalcopyrite is the main ore forming mineral.

In the area of the western limb, outcrops occur (with 200 m interruptions) 600 m in length and between 30 to 100 m wide (in the area of adits No. 3 and 7). Further small isolated outcrops occur within the Neogene deposits, 700 m further to the east-northeast (in area of boreholes No. 94 and 95, section XIV). In the western limb, the orebodies are layered and strike east-northeast with a near vertical inclination to the north-northwest. Limited borehole information occurs for this area.

Table 8.The main parameters of the small lenticular bodies in the Central area

No of ore lens	Localisation in exploration section	No. of ore inter-sections	Depth extent in altitude from–to, m	Size, m from–to, average		Thickness, m from–to average	No of stratigraphic members and beds containing bodies
				in direction	by inclination		
1	XXXVIII	1	2058–2005	100	80	6–13 9.5	8^1 (floor)
2	XXXIV	1	2145–2075	50	115	2–4 3.0	6^6
3	XXXIV	1	1985–1940	100	135	0–10 4.8	6^5
4	XXXI–XXXII	3	2305–2108	160	70–335 200	0–15 6.4	7^1 (middle part)
5	XXXII	1	2140–2026	100	200	0–5 3.5	6^5 (middle part)
6	XXXI	1	2280–2155	100	190	0–5 2.8	7^1 (middle part)
7	XXVIII–XXX	8	2447–2282	290	105–240 153	3–20 6.2	7^1 (floor)
8	XXX	1	2395–2353	50	60	3–4 3.0	7^1 (middle part)
9	XXIX	1	2470–2410	50	85	3–7 5	6^7 (roof)
10	XXIX–XXX	3	2320–2190	200	115–160 135	3–6 4.0	6^7 (roof)
11	XXX	1	2130–2070	100	170	4–38 20.8	6^5 (floor)
12	XXX	1	2340–2235	100	140	3–7 4.4	6^3–6^4 and 6^5 (floor)
13	XXIX	1	2415–2355	15	60	1–4 3.0	6^5 (floor)
14	XXIX	1	2215–2185	30	50	1–3 2.0	6^5 (middle part)
15	XXIX	1	2240–2210	30	50	2–3 2.0	6^3 and 6^2 (roof)
16	XXVI–XXVIII	3	2290–2181	120	165–190 175	2–24 10.3	6^5 (floor)
17	XXVIII	1	2232–2000	50	75	3–7 5.0	6^5 (roof)
18	XXIV	1	2236–2293	50	70	2	7^1 (floor)
19	XXIV	1	2430–2350	100	110	8	6^5 (floor)

5.4 MINERAL AND CHEMICAL COMPOSITION OF ORES

5.4.1 Mineralogy of ores

Approximately 60 primary and secondary minerals, including more than 30 ore minerals, have been distinguished in the Aynak deposit. The dominant ore minerals are bornite and chalcopyrite. Within the supergene zone of the deposit, chalcocite, native copper, cuprite and malachite dominate. Frequent, yet less abundant minerals include pyrite and sphalerite. Rare minerals include cobaltite, smaltite, pentlandite, molybdenite amongst others.

The most common rock forming minerals are dolomite, quartz, biotite and oligoclase-andesine in the wallrock. **Bornite** is the most abundant copper mineral within the deposit, in particular within the Main orebody of the Central area. It occurs in rocks rich in quartz and feldspar although it can often be seen associated with dolomite. Bornite mainly forms compact linear or broken up aggregates with irregular margins, parallel to wallrock bedding. As a rule, the size of the aggregates does not exceed several millimetres; more rarely bornite can be seen as irregular disseminations or as layered disseminations. Quartzite is typically barren although rare disseminations of bornite and fine grains of isolated and isometric bornite (hundredths or tenths of mm) can occur. Disseminated bornite attains several mm in size or even cm in others rocks and its form is mostly irregular. Commonly, the grain size varies from 0.004 to 1.0–1.2 mm. Rarely, in different rocks, brecciated bornite aggregates from 5 to 40 cm in diameter with an almost monomineralic bornite cement can be seen. Spectral analysis of bornite confirms the following admixture: Ni – 0.0001 to 0.0003 %, Co – 0.004 to 0.01 %, V – 0.001 %, Ag – 0.0002 %, As – 0.005 %, Zn – 0.0003 % and In – 0.001 %.

Bornite is frequently intergrown with chalcopyrite. Their contacts suggest that they formed contemporaneously. Supergene chalcocite can occasionally be seen as close intergrowths (sub-graphic) in the Central area (boreholes 6, 128 and others). In addition to primary bornite, which displays a yellowish tint (as a result of forming in solid solution with chalcopyrite), supergene bornite occurs replacing chalcopyrite in the form of rims or veinlets.

Chalcopyrite is the second main ore mineral of the deposit. It occurs mainly in orebodies 1 to 8 underlying the Main orebody. Chalcopyrite is the main primary copper mineral in the Western area. It occurs in a disseminated form at varying levels of concentration. The size of the grains and clusters varies from tenths of millimetre to several centimetres. Chalcopyrite also forms compact or sporadic clusters rhythmically alternating in layers, 1 to 2 mm thick. Rarely, chalcopyrite layered ore up to 80 cm thick with 30 to 70 % volume of chalcopyrite occurs. Spectral analysis of chalcopyrite confirms the following admixture: Ni – 0.0001–0.0002 %, Co – 0.002–0.05 %, Ag – 0.0003–0.001 %, As – 0.003–0.01 %, In – 0.002 %, Sn – 0.0003 %, V – 0.002 % and Ga – 0.0003 %.

In the Central area, chalcopyrite is closely associated with bornite and more rarely with pyrite, cobaltite, smaltite and gersdorffite. Bornite and pyrite are very rarely associated together with chalcopyrite. Sometimes in polished section, trellis exsolution of chalcopyrite in bornite, due to solid solution breakdown, can be observed. In the supergene zone, chalcopyrite is replaced by chalcocite, digenite, bornite, cuprite and limonite.

Cobaltite crystals or irregular grains, 0.1 to 1.5 mm in size, can be seen in relatively low-grade or medium-grade disseminated chalcopyrite ore. On rare occasions, it is associated with ***smaltite, pentlandite*** and other cobalt minerals.

Common, but in small quantities, ***sphalerite*** and ***pyrite*** occur. ***Pyrrhotite*** also occurs in intercalations of carbonaceous schist. Pyrite crystals, 1–1.5 mm in size, are common in overlying and underlying parts of the copper-bearing formations. Occasionally, it occurs in low-grade chalcopyrite ore and as a rule it is missing in high-grade dominantly bornite ore.

Scaly crystals of ***molybdenite*** can be seen at intervals within the bornite and chalcopyrite ore.

Chalcocite, replacing bornite and chalcopyrite is common within the oxidation zone and less so within the unoxidized ores. Typically it is accompanied by native copper, which occurs as irregular disseminations or forming irregular clusters and dendrites. Associated carmine-red ***cuprite*** forms powdered or solid fine-grained masses and mixtures with iron hydroxides.

At surface, ***Malachite*** is the most common copper mineral, forming unconsolidated masses and crystalline crusts along fissures of varying direction. ***Chrysocolla*** occasionally forms pseudomorphs after malachite or occurs as isolated clusters. Other relatively common minerals in the oxidising zone are minerals of the ***asbolane–psilomelane–wad*** *group.*

Dolomite is the most widespread rock-forming mineral accompanying copper mineralisation, accounting for 80–99 % of the dolomite marble. The second most widespread non-ore mineral is quartz, forming micro- to coarse-grained compact masses or occurring in later Alpine veins in association with coarse-grained dolomite, chalcopyrite and bornite. Oligoclase-andesine commonly occurs in feldspar, quartz-feldspar and feldspar-carbonate wallrocks. Biotite is one of the main minerals in the copper-bearing mica-carbonate schist and is widespread in dolomite marble. Other frequent minerals in the ore-bearing rocks are tremolite, muscovite, scapolite, graphite and calcite. Calcite occurs in veinlets either on its own or accompanied by quartz, rare pyrite, chalcopyrite and bornite and cross cuts ore-bearing, overlying and underlying rocks. Supergene calcite can be found in oxidising zones accompanied by cuprite and native copper.

5.4.2 Ore type and quality

Ore types occurring in the deposit are classified as bornite ore or chalcopyrite ore based on the ratio of the main copper minerals. Bornite ore is high-grade with copper contents in excess of 1.5–3 % (average content is 2.36 % in the deposit) and chalcopyrite ore is low- to medium-grade with copper contents of about 1 % or less. Both ores are classified into 3 types according to their degree of oxidation: sulphide (with less than 10 % oxidised copper), mixed (10 to 50 %) and oxidised (more than 50 %).

To a large degree, **bornite ore** is the main ore type and is the characteristic ore within the Main orebody. In comparison, chalcopyrite forms only minor parts in the lower and middle part of this body although it increases in the hanging wall, prevailing in places over bornite. However, the relative volume of this ore is insignificant. The transition from bornite to chalcopyrite is characteristic in the footwall. The chalcopyrite content in the bornite ore does not exceed 10 to 15 %.

The distribution of bornite ore in the Main orebody is relatively regular. The highest copper contents occur in the central part of the plunged syncline (between sections XXXI-XXXVIII) and the lowest in the limbs. In detail the copper content varies from 1.32 to 4.34 % between the above-mentioned sections (Table 9) with an average of 2.4 %. In further intersections, the maximum copper content again occurs in the central parts with the minimum grades occurring at the hangingwall and footwall. The coefficient of variation of the copper content in the sulphide ore of the Main orebody is 33 %. This was calculated from 35 ore intersections (with an average content of 2.22% and σ =0.73 %).

In the Main orebody, bornite ore occurring close to the surface is oxidized to varying degrees, replaced by mixed and oxidised varieties of ore. In the mixed ore zone, chalcocite, native copper and cuprite occur together with primary sulphide minerals. The boundary between mixed and sulphide ore is usually relatively distinct and is readily distinguished in borehole core and in geological documentation of exploration adits. In places, the mixed ore is absent and in such places, the sulphide ores occur in direct contact with oxidised ores.

Oxidised ores, in comparison to mixed ores, contain accumulations of malachite and are absent of native copper. The abundance of chalcocite and cuprite is also substantially lower. Occasionally azurite, chrysocolla, chalcantite and brochantite can be observed. The boundary between oxidized and mixed ores is not absolute and is defined according to geochemical analyses. According to 35 samples, the copper content and its variability in mixed and oxidised ores is almost the same as in sulphide ores:

	Copper content %			Standard deviation σ	Coefficient of variation V
	from	to	average		
a) sulphide	0.69	4.34	2.20	0.73	33
b) mixed	0.76	3.69	2.15	0.75	35
c) oxidised	1.15	3.51	2.21	0.90	41

Chalcopyrite ore is substantially less important than bornite. In the Central area, it is characteristic in orebodies occurring within the lower parts of the copper-bearing beds in the central part of the plunged syncline (ore lenses No. 1 to 4). In the Western area, chalcopyrite mineralisation occurs in all orebodies situated in the southeastern limb of the plunged syncline (No. 5 to 8). In these ores, bornite occurs in small amounts and as a rule does not exceed 10 to 15 % of the total ore mineral content. Pyrite, cobaltite and other arsenides of cobalt and nickel occur more frequently in chalcopyrite ore than bornite ore. Cobalt content (0.011 to 0.020 %) in chalcopyrite ore is higher than in bornite ore (0.004 %). Silver on the contrary is almost absent in chalcopyrite ore.

Table 9 Variability of copper content in sulphide bornite ores of the Main orebody

Section No.	Borehole No.	No. of analyses	Average copper content in %	Interval of content in %	
				from	to
1	2	3	4	5	6
XXXVIII	75	20	2.67	1.08	3.87
	10	51	1.71	0.35	3.93
	74	37	2.10	1.00	3.85
XXXVI	111	29	2.45	1.13	3.42
	84	51	2.62	1.05	3.72
	73	68	2.52	0.42	4.80
	87	94	2.49	0.63	5.52
XXXV	82	11	1.32	0.49	2.54
	77	72	1.96	0.87	3.85
XXXIV	72	13	2.27	1.16	3.62
	1	65	2.43	1.15	3.86
	69	75	2.78	1.10	5.18
	6	81	4.34	1.15	7.98
	70	97	2.36	0.51	4.63
	71	75	2.89	0.72	4.98
	590	48	1.70	0.50	3.46
	97	17	0.59	0.44	1.22
XXXIII	56	60	2.30	0.80	3.92
	57	83	3.74	1.20	8.18
	137	71	2.47	0.51	4.83
	136	39	1.96	0.44	3.54
XXXII	11	21	2.13	1.14	3.62
	2	31	2.65	0.99	3.80
	134	39	2.69	1.73	4.73
	3	15	2.98	1.44	3.60

The copper content in chalcopyrite ore (average content from 0.82 to 1.28 % in different orebodies) is substantially lower than in bornite ore (2.36 %). It varies usually from tenths to 1.5 % and is low- to medium-grade in quality. The distribution of copper in different orebodies is relatively regular, as well as in different ore horizons. The variation coefficient of the copper content within the sulphide ore of orebody No. 2 is 34 % (average content = 0.90 % and σ = 0.31%).

The copper content of sulphide chalcopyrite ore varies from 0.44 to 1.95 % with an average of 0.87 %. Mixed ores replacing chalcopyrite ore show corresponding copper contents from 0.45 to 1.52 % with a 0.83 % average. The copper content of oxidised ores varies between 0.41 to 2.61 % with a slightly higher average of 0.91 %.

The mineral composition of the oxidised and mixed ores is generally the same as in analogous types of bornite ore, with the exception of the nearly exclusive occurrence of chalcopyrite as the primary sulphide.

The special occurrence of the Neogene basal ore breccias amongst the oxidised ores should be noted. They form separate lenses that differ from common ores by their lower mechanical hardness and higher amounts of clay-carbonate material cementing the ore fragments. Newly-formed malachite and cuprite commonly occurs within the breccia cement. The copper content of the ore breccia is directly related to the primary ore. Ore breccia overlying bornite ore is higher-grade than breccia overlying chalcopyrite ore.

Structures and textures within the bornite and chalcopyrite ores (and their types) do not display a large degree of variability. The most common structures are disseminated, banded-disseminated, lenticular-banded, linear-banded, plicated, veined, veined-disseminated, brecciated, massive and branching. The most common textures are xenomorphic, mutual boundaries and granoblastic. Rare textures include trellis, hypidiomorphic, fine-grained, rimming, thread-like, dendritic, netted-replacement and colloform.

The comparative characteristics of the different ore types is shown in Table 9a.

Bornite ore, as well as chalcopyrite ore, is almost monometallic. In addition to copper and sulphur, only increased contents of cobalt, molybdenum and silver occur. The cobalt content in technological samples varies from 0.008 to 0.18 %, with 0.004 % being the average content in bornite ore and the average content in chalcopyrite ore in different orebodies varying from 0.011 to 0.020 %. The highest cobalt content occurs in common sulphide and oxidised chalcopyrite ore and the lowest in bornite ore (high-grade oxidised, common and high-grade sulphide ore). The main cobalt minerals in unoxidised ores are cobaltite, with minor smaltite and in oxidized ores, asbolane and erythrite. Negligible amounts of molybdenite (several ppm) occur. The maximum silver content is found in bornite ore (up to 8 ppm) and the minimum in chalcopyrite ore. The content varies from less than 1 ppm to 30–50 ppm. Silver minerals were not identified in the ore.

5.4.3 Zoning and distribution of mineralisation

In the Aynak deposit, the mineralisation distribution displays primary and secondary zoning. Primary zoning occurs vertically (by thickness of ore-bearing beds) and horizontally (in plan).

Primary vertical zoning is characteristic throughout all the ore-bearing beds and different orebodies. The centre of the Main orebody is represented by bornite mineralisation and it passes into chalcopyrite and then pyrite mineralisation upwards and downwards from the centre. By mineral sequence, the vertical zoning is symmetric but the thickness of individual zones in the hangingwall and footwall is asymmetric.

Bornite, the dominant ore mineral in the centre of the Main orebody, is accompanied by minor primary chalcocite and chalcopyrite. Chalcopyrite content increases upwards, attaining 20 % of the total ore content in the hangingwall. However, in some parts of the hangingwall, chalcopyrite and bornite are equal or bornite even prevails. Pyrite and cobalt minerals appear in small amounts. The thickness of the bornite-chalcopyrite ore zone does not exceed 10 to 15 m. Within the Main orebody, areas with dominant chalcopyrite ore in the hangingwall are rare. In higher parts of the section, beyond the economic limits of the orebody, fine disseminated pyrite with negligible chalcopyrite and cobalt minerals are common in the wallrocks.

Vertical zoning is even more distinct downwards from the centre of the Main orebody. The chalcopyrite content gradually increases upwards but it does not exceed 15–20 % of the total ore mineral content. The lower contact of the orebody is more distinct than the upper. It is abruptly defined by waste-rock or it is in direct contact with chalcopyrite ore from underlying orebodies. Transitional (bornite-chalcopyrite) ore is not characteristic for this part of the copper-bearing beds. Below the dominantly bornite ore of the Main orebody, a thick (up to 100 m) zone of dominantly chalcopyrite ore with minor bornite (less than 10 to 15 %) occurs merging orebodies and lenses of the four underlying horizons (orebodies No. 1 to 4, 6 to 8 and lenses No. 2 to 19). The bornite content gradually decreases and disappears in this zone. Conversely, the amount of pyrite and cobalt minerals increases displaying small thin areas of associated cobaltite-pyrite-chalcopyrite (orebody No. 8). This zoning is distinctly reflected in the orebodies (except orebody No. 8) by the decrease in copper content and increase in Co content with depth (Table 10).

Below the economically defined footwall (under orebody No. 8) fine disseminated pyrite is widespread, particularly in the carbonaceous-quartz schist (Member 5), similar to the upper part of copper-bearing beds.

Primary horizontal zoning is less distinct than vertical zoning. In the Main orebody, it is displayed by the replacement of dominantly bornite ore by bornite-chalcopyrite ore and in the limbs by chalcopyrite ore (together with a decrease in thickness) as observed in borehole 97 (section XXXIV). It is also reflected in the dominantly chalcopyrite ore of orebody No. 5, situated in the southeastern limb of the plunged syncline of the Central area which belongs to the same horizon as the bornite ore within the Main orebody.

Table 10. Average copper and cobalt content in the orebodies of the Central area of the Aynak deposit

No. of ore horizon	Central part of the plunged syncline			Southeast limb of the plunged syncline		
	Orebody No.	Copper content %	Cobalt content %	Orebody No.	Copper content %	Cobalt content %
1	The Main orebody	2.36	0.004	5	0.94	0.013
2	1	1.28	0.011			
3	2, 4	0.98-0.85	0.013-0.015	6	0.96	0.011
4	3	0.83	0.015	7	0.82	0.019
5	8	1.19	0.020	8	1.03	0.020

Secondary zoning occurs in the oxidised zone of the deposit and is visually distinct at surface in the outcropping orebodies on the west margin of the plunged syncline as well under the Neogene deposits to the north and south of the Central area.

The depth of the oxidised zone is variable with the deepest (250 m beneath the surface) oxidation occurring (section XXXVIII) where the orebodies outcrop at surface (sections XXII-XXV). The total length of the oxidation zone in the Central area is in excess of 1500 m. The width in plan is directly related to the area of exposed orebodies at surface or below the Neogene rocks. The maximum thickness of the oxidising zone (up to 160 m) in the southern sections is up to 160 m (XXIV-XXV) and it thins towards the north. The thinning of the oxidising zone can be seen also from the west toward the east (below the outcropping orebodies as well as below the Neogene cover). In areas covered by the Neogene rocks, the thickness of the oxidising zone distinctly dies out and as a rule it displays an inverse relationship to the thickness of the overlying Neogene rocks.

The oxidised zone is divided into two sub-zones according to copper oxide content; oxidised and mixed ores. The oxidized ore is situated in the upper part of the zone and gradually alternates downwards with mixed ore. The maximum thickness of the oxidized ore occurs in the south (sections XXII-XXIV), thinning to the north and eventually disappearing north of section XXXV (Table 11). The mixed ore was traced further north under the Neogene deposits than the oxidized ore and vanishes north of section XXXVIII. As for oxidized ore, the maximum thickness of mixed ore occurs in the south (section XXVII) and the minimum in the north.

Table11. Parameters of the oxidized zone of the Central area of the Aynak deposit

No of section	Sub-zone of oxidized ore						Sub-zone of mixed ore					
	Thickness, m						Thickness, m					
	Surface outcrop		Under the Neogene deposits		Width in plan, m	Altitude m	Surface outcrop		Under the Neogene deposits		Width in plan, m	Altitude m
	from	to	from	to			from	to	from	to		
1	2	3	4	5	6	7	8	9	10	11	12	13
XXXVIII	-	-	-	-	-	-	-	-	15	20	110	2240-2220
XXXVI	-	-	-	-	-	-	-	-	30	52	170	2322-2240
XXXV	-	-	21	25	200	2308-2278	-	-	0	29	190	2278-2253
XXXIV	-	-	5	22	160	2352-2330	-	-	8	40	250	2330-2298
XXXIII	-	-	0	18	140	2410-2385	-	-	10	45	310	2385-2335
XXXII	30	70	2	30	320	2480-2410	10	30	6	25	440	2435-2230
XXXI	50	110	5	50	435	2530-2307	0	35	10	30	340	2420-2293
XXX	-	-	10	40	445	2500-2298	-	-	4	65	470	2394-2245
XXIX	70	100	10	20	-	2387-2270	-	-	17	34	-	2382-2270
XXVIII	30	60	10	30	-	2475-2397	-	-	3	55	-	2397-2280
XXVII	-	-	0	43	-	2365-2315	-	-	15	80	-	2350-2265
XXVI	50	75	30	47	-	2425-2340	-	-	30	50	-	2340-2310
XXV	50	105	-	-	-	2500-2385	28	70	-	-	-	2385-2330
XXIV	15	135	-	-	-	2520-2378		30	-	-	-	2378-2347
XXIII		>120	-	-	-	2510-2370	n/d	n/d	-	-	-	
XXII	30	>125				2510-2370	n/d	n/d	-	-	-	

Visually, the boundary between the sulphide and mixed ores is readily distinguishable. The transition between the mixed and the oxidized ore is gradual and can be only distinguished by chemical analysis.

Secondary sulphide enrichment (cementation) characteristic in many copper deposits was not identified in the Aynak deposit. Chalcocite and native copper, the typical secondary minerals in the deposit can be found in oxidised as well as in mixed ores. Due to carbonate environment, there is no evidence of copper migration in the oxidised zone. In addition, the copper content in the sulphide, mixed and oxidised ores does not show significant variation. For example, in the Main orebody, the corresponding copper contents (with a 0.4% copper cut-off grade) are 2.39, 2.17 and 2.28 % respectively.

5.4.4 Deposit origin

The following are the key characteristics of the Aynak deposit and provide clues to its genesis:

- distinct relationship of mineralisation to particular stratigraphic horizons and lithological facies;
- layered form of the orebodies, their large extent in both plan and in thickness and multi-horizontal distribution;
- tectonic control of mineralisation, i.e., the relationship of the copper-bearing formation to the superposed synsedimentary basin and the numerous copper occurrences at its base;
- primary vertical and horizontal zoning of the mineralisation;
- simple chalcopyrite-bornite composition of the ore;
- distinct features of ore recrystallisation including the presence of structures such as brecciation, intersection, veining and clusters and textures such as granoblastic, inequigranular, coarse-crystalline xenomorphic, euhedral amongst others;
- weak metamorphic alteration of the ore-bearing formation (to greenschist facies);
- presence of fine disseminated syngenetic copper mineralisation in the overlying and underlying rocks of the copper-bearing formation;
- copper-bearing veins are exposed only within ore-bearing horizons;
- layered structure of the ores is widespread;
- presence of residual organic carbon in the copper-bearing rocks; and
- lack of relationship between the mineralisation and magmatic activity or faults.

All these characteristic features confirm that the Aynak deposit is a distinctive, economic and important metamorphosed representative of sandstone-hosted copper deposit type. The controversial origin of this type of deposit is well documented.

The distinct division of the ore-bearing Carbonate-Schist Formation into three large rhythms, the lower dominantly carbonate, the middle dominantly terrigenous and the upper again dominantly carbonate, indicate the complicated history of these copper-bearing deposits.

Initial deposition occurred within an open basin in a near-shore marine environment, with low denudation and negligible removal of material from the source area (the lower rhythm). Substantial uplift of the source area and subsequent active erosion led to the distinct increase in sedimentation of terrigenous material in the basin (probably lagoonal-deltaic type). Continued accumulation of sediments resulted in basin floor subsidence, providing further space for continued sedimentation (the middle rhythm). The period of erosion and near flattening of the source area gradually changed the sedimentation environment to a near-shore open-sea basin (the upper rhythm). It is thought that the primary accumulation of copper occurred during the middle rhythm of sedimentation, in a lagoonal-deltaic type basin. Diagenetic and catagenetic processes on the copper-bearing schist resulted in the recrystallisation and redistribution of the ore forming minerals. The later carbonate environment prevented copper migration during the formation of the deep oxidised zone.

6 Conclusions

1. The Aynak deposit represents one of the most important worldwide economic deposits of the sandstone-hosted copper deposit type, characterised by extensive multi-horizon mineralisation and high ore quality.
2. Thirty orebodies have been delineated differing in size, morphology and by the composition of the ores. Amongst them, one large Main orebody, eight medium-size stratiform orebodies and nineteen ore lenses occur.
3. The Main orebody ore is over 1500 m in length and up to 1000 m wide. Orebody thickness varies from 30 m in the traceable marginal parts to 150 m in the central part. The medium-sized orebodies vary from 250 to 1000 m in length and from 100 to 850 m wide, with an average thickness of between 10 and 70 m. The small lenses range from 15 to 290 m in length, 50 to 200 m in width and 2 to 20 m in thickness.

   The Main orebody forms the greater part of the plunging syncline of the Central area. It is sub-horizontally inclined in the centre of the fold and is steeply dipping (50 to 70 degrees) on the limbs. Orebodies No. 1 to 4, which occur underneath the Main orebody, have a similar orientation. Orebodies No. 5 to 8 in the SE side of the plunging syncline are steep-dipping (near vertical).
4. Total copper reserves in the Central area (with a 0.4 % copper cut-off) as at 1st March 1977 were estimated to be 4790.1 kt with an average grade of 1.88 %, including 2735 kt (57.1 %) of C_1 category. 84.0 % of the total reserves (4 023.2 kt) are high-grade (with average copper content 2.36 %) bornite ores of the Main orebody and 16.0 % (766.9 kt) are relatively low-grade chalcopyrite ores (with average copper content of 0.91 %) of the medium-size orebodies and small lenses.
5. The mineral composition of the primary ores is simple. The main ore minerals are bornite and chalcopyrite. Close to the surface oxidised ores (> 50% oxidised ore content) and mixed ores (50-10 %) occur. Of the total copper reserves, sulphide ores represent 84.5 %, mixed ores 8 % and oxidised ores 7.5 %.
6. According to the preliminary results of the laboratory technologic tests, the sulphide ores are easily processed while the mixed ore are moderately easy to process.
7. The technical conditions of the deposit make it amenable to open-pit mining to a maximum depth of 600 to 650 m with potential annual production of between 6 to 8 millions tons of ore. Potential flooding of the deposit is negligible. Supply of water for industrial and communal needs can be provided by waters from the Logar River.
8. The Central area of the deposit is only fully delineated to the west. The extent of the mineralisation to the north, east and south has yet to be outlined. The most prospective area for increasing reserves appears to be the northeastern part, in the dip direction of the lower limb of the ore-bearing plunging syncline, where the thickest parts of economic mineralisation was found.
9. The Western area has not been delineated in extent or in depth. According to recent data, reserves of C_2 category in this area are 427.5 kt of ore with a copper content of 1.13 % and prognosis reserves 380 kt of the same quality of ore.
10. Further synclinal structures with ore-bearing ("productive") Carbonate-Schist Formation can be found in the region underlying Neogene deposits.
11. The main aim of further geological exploration in the Aynak deposit and the surrounding area should be:

i) Drilling of boreholes sited using morphological data, position of the orebodies and composition of ore with the aim of upgrading the reserves from C_1 and C_2 categories into B and C_1 categories respectively. This data is also required for the construction of large mining and processing plant at the Aynak deposit;

ii) Following the trace and outlining the main orebodies in the Central area towards the north, northeast, east and southeast. This will improve the perspective of the area and increase the reserves of C_1 and C_2 categories for potential future exploitation by open pit or underground mining methods;

iii) Preliminary exploration and delineation of the copper-bearing formation in the Western area; and

iv) Investigate the potential for identifying new ore-bearing structures underneath the Neogene formations in the Aynak orefield, using drilling and other exploration techniques.

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