Aynak Information Package
Part I Introduction

Compiled by the Afghanistan Geological Survey and the British Geological Survey

Contents

1 Introduction

This CD provides a summary of the geological information available in Afghanistan on the Aynak Copper Deposit and has been produced by the British Geological Survey (BGS) and Afghanistan Geological Survey (AGS) with the purpose of promoting the Nation's mineral industry. Afghanistan is a developing country with a very low per capita income and a recent history of conflict that has prevented any development of the mining industry. The present government of the Islamic Republic of Afghanistan has placed an emphasis on encouraging the mining sector and ranks the Aynak Copper Deposit as one of its highest priorities for encouraging inward investment. Accordingly a new Minerals Law has been promulgated and the Ministry of Mines and Industries (MMI) is currently setting up Mining Cadastre and Mines Inspectorate Offices to administer the law. A copy of the new Minerals Law is included on the CD. Aynak will be the subject of a Public Tender exercise and interested investors will be notified of the terms and conditions.

1.1 HISTORY OF EXPLORATION

The Aynak Copper Deposit was worked in prehistoric times as evident from a number of small adits and surface excavations. During recent exploration copper coins and skeletons were also found and old workings were intersected during the course of the drilling operations. There are also old copper-smelting furnaces and an extensive surface deposit of slag covers much of the central area of the deposit. Copper coins were issued in the 1st to 4th Centuries AD by the Kushan dynasty, which covered modern Afghanistan and much of northern India, and it can be speculated that the copper came from Aynak. It is not known when these operations ceased but there has been no recorded history of recent exploitation.

The deposit was rediscovered in 1973-4 by Russian and Afghan geologists, who carried out prospecting and geological mapping at a 1:100,000 scale (Shcherbina, Petrov and Silkin, 1975). Subsequently the Soviet Geological Mission "Technoexport" conducted a systematic exploration programme of Aynak in two main phases: from 1974-1976 (Part III Preliminary Report) and from 1978-1989 (Part II Geological setting of Aynak and summary of exploration). This exploration was exceedingly thorough and well documented in a number of reports which are listed in the Bibliography. Their work included the drilling of several hundred exploration, geotechnical and hydrogeological boreholes, nine underground adits, 70 trenches, and geophysical and topographic surveys. It is important to acknowledge the thoroughness and high standard of this work and its very large contribution to the understanding the geology of the deposit. The exploration ceased in 1989 with the withdrawal of Soviet forces and advisors and the subsequent civil war halted any further work by AGS. During the civil war the AGS offices were in the front line between the warring factions. AGS staff, however, managed to preserve the bulk of the Russian reports but, inevitably, some volumes were destroyed. BGS will continue to try and locate the missing volumes in Russia or elsewhere.

In addition to Aynak, numerous other copper occurrences are found within the region. Notable amongst these are Darband, and Jawkhar, which are situated a short distance to the north and northeast of Aynak. Considerable exploration was undertaken by Soviet geologists on both prospects, although little information survives in the AGS archives on Jawkhar. A brief summary is however included in this information package on Darband and the Other Occurrences.

1.2 LOCATION OF THE DEPOSIT

Aynak is situated about 30km SSE of Kabul and is approached along a 15km motorable track which branches off the surfaced road between Kabul and Gardez, some 30km south of the capital. The centre of the deposit is located at approximately longitude 69°18’18” latitude 34°15’58” with reference to the Herat North Datum.

1.3 OVERVIEW OF THE GEOLOGY OF AFGHANISTAN

Afghanistan has some of the most complex and varied geology in the world. The oldest rocks are of Archean age and these are succeeded by rocks from the Proterozoic and from all of Phanerozoic system up to the present day. The country also has a long and complicated tectonic history, partly related to its position at the western end of the Himalaya. This diverse geological foundation has resulted in a significant mineral heritage with over 1400 mineral occurrences recorded to date. Historical mining concentrated mostly on precious stone production, with some of the oldest known mines in the world believed to have been established in Afghanistan to produce lapis lazuli for the Egyptian Pharaohs. More recent exploration in the 1960s and 70s resulted in the discovery of significant resources of metallic and non-metallic minerals.

The tectonic evolution of Afghanistan from Late Palaeozoic times onwards is best explained in terms of accretion of fragments of Gondwana to the active margin of Laurasia from late Palaeozoic times onwards (Tapponnier et al., 1981). During the Triassic, parts of the northern edge of the Gondwanaland supercontinent broke away and began drifting north, before colliding with the Tadjik block, resulting in the Cimmeride Orogeny. The orogeny is marked by two distinct collisions which brought first the Farad block against the Tadjik block, followed closely by the Helmand block against the Farad block. The Herat Fault system marks the suture line of this first collision, which had taken place and was completed by the beginning of the Cretaceous, and the Panjao Suture marks the line of the second collision that was completed by early Cretaceous times. Both suture zones are ophiolite bearing, and the Herat Fault system in particular has had a long history of sedimentation and igneous activity, up to the present. The Farad block was subsequently overlain by Upper Jurassic-Cretaceous sediments and the Helmand block by Cretaceous sediments only. During this period the Pamir and West Nuristan blocks of northeast Afghanistan were also accreted to Eurasia. These four blocks, together with the Tadjik block are collectively known as the Afghan Block. Due to processes discussed below, the southeastern margin of this Block is considered prospective for precious and base metal mineralisation, as well as rare metals in the numerous pegmatite fields.

Following a brief period of quiescence, tectonic activity once again began as India drifted north, away from Gondwanaland and towards the enlarged Eurasian plate with the Afghan block at its southern margin. The first evidence of this is preserved as the Kandahar volcanics, which marked the beginning of the development of a volcanic arc along the southern margins of the Eurasian plate. These were intruded by subduction-related, 'I-type' granitoids in the Helmand and West Nuristan blocks (during the Cretaceous to early Tertiary). This geological setting is highly prospective for a number of different mineralisation styles and the large number of mineral discoveries to date only reinforces the potential of the East-Central Afghanistan region. Igneous activity was not confined to this region, with younger (Oligocene) alkaline intrusions and basaltic extrusions in the Farad block and the sedimentary basins within the Herat Fault Zone. The chemistry of these rocks suggests derivation from a mantle source beneath a zone of continental extension (within an overall setting of dextral transtension). Oligocene granitoids were also intruded into the thickened continental crust of Northeast Afghanistan. By the start of the Tertiary, the widespread marine sedimentation that had preceded the Himalayan Orogeny had become restricted to the Tadjik block and by Neogene times even this had become localised as the collision of India began to raise the area above sea level. Himalayan deformation of the Afghan block resulted in the reactivation of many of the internal block boundaries including the

Herat Fault system (as discussed above, but not active since the Miocene) and the Chaman Fault system (which marks the southeast edge of the Afghan Block and is still active to the present day). Folding and thrusting of the Mesozoic sediments also led to basin inversion and imbrication with the Palaeozoic basement.

To the east of the Afghan block a complex collage of tectonic units marks the collision zone with the Indian plate. During the Cretaceous period, the East Nuristan volcanic arc was accreted to the margin of Eurasia (although magamatisn continued in the Eocene). This was followed by the docking of the Kabul block. The Kabul block is somewhat of an enigma in Afghan geology. It is composed of Proterozoic and Lower Palaeozoic basement overlain by Mesozoic sedimentary sequences, and is bounded along its western and eastern margins by ophiolitic rocks of Cretaceous age. It is believed that the block was a sliver of continental crust, separated from the Indian and Afghan blocks by oceanic crust, which got caught up in the collision and was accreted to the edge of the Afghan Block before final collision with India. The Kabul block is particularly prospective for stratiform copper deposits hosted in Vendian – Cambrian metasedimentary rocks, and for chromite in the ophiolitic sequences. The final piece in the Afghanistan jigsaw is the Katawaz basin in Southeast Afghanistan. This is interpreted as a flexural basin on the western margin of the Indian Plate, where subsidence synchronous with sedimentation resulted in the deposition of more than 10km of Tertiary sediments before shortening and inversion in the late Tertiary as India finally collided with Afghanistan. Sedimentation across the country since this time has been continental in nature, with large areas of Quaternary deposits particularly across the very north and south of the country.

1.4 GEOLOGY OF THE KABUL BLOCK

The Kabul block is a NNE-trending lenticular shaped fault block, approximately 200 km long and up to 50 km wide, which is bounded on the west by the *Pagman fault* and on the east by the *Altimur fault*. The block has a broad anticlinal structure exposing a core of Precambrian metamorphic rocks flanked by Late Palaeozoic and Mesozoic sequences. Poorly consolidated fluvial and fluvial-lacustrine intermountain basin deposits of Neogene age cover large areas of the block. A fuller description of the regional setting is given in Part II.

Figure 1. Schematic map of Afghanistan showing the location of the Kabul block.

The Precambrian basement of the Kabul block consists of Early to Middle Proterozoic metamorphic rocks of the *Sherdarwaza* and *Kharog Formations* and the Late Proterozoic *Welayati Formation*. The *Sherdarwaza Formation* consists of gneisses, migmatites, granite gneisses and schists with subordinate marbles, quartzites and amphibolites, which reach a thickness of more than 3000 m in the area of Kabul city. These are unconformably overlain by the *Kharog Formation*, which mainly consists of quartzites, with interbedded conglomerates at the base and schists, gneisses, amphibolites and marbles near the top. The thickness of the formation is 2500 m. The *Welayati Formation* conformably overlies the Kharog Formation. The lower part of the formation is composed mainly of amphibolites and the upper part by mica schists, staurolite-garnet-mica schists and amphibolites, with layers of plagio-gneisses, quartzites and marbles. The thickness of the formation is 1200 – 1500 m.

These basement rocks are deformed by isoclinal, grading to brachyform and gneissdomal folds. In the centre of the block, most of the folds strike almost to the east, while at the periphery the minor structures are parallel with the boundaries of the block. The presence of extensive low-angle thrust sheets in the Precambrian basement of the Kabul block has been described by Mennessier (1961), who suggested that the thrust sheets moved from the north to the south.

The cover rocks of the Kabul block rest unconformably on the Proterozoic basement and include a number of stratigraphical units of widely varying age ranging from the Neoproterozoic through to the Neogene.

The oldest cover units are reported to be the *Loy Khwar* and *Gulkhamid* formations which are thought to be of Vendian – Cambrian age (Slavin et al., 1978). These have been metamorphosed to greenschist and lowermost amphibolite facies and are of lower metamorphic grade than the underlying Proterozoic basement. The *Loy Khwar Formation* mainly consists of a repetitive cyclical sequence of dolomite marbles, carbonaceous quartz schists and quartz-biotite-dolomite schists between 700 to 2000 meters thick, and is the host to the copper mineralisation at Aynak and to other copper deposits elsewhere in the region.

The *Gulkhamid Formation* overlies the *Loy Khwar Formation* and consists mainly of a metavolcanic sequence. Conglomerates and sandstones occur at the base and pass up into a thick sequence of metamorphosed lavas and volcaniclastic rocks of basalt-andesite-dacite composition. These rocks have also been termed the “Complex of Gulkhamid” (Yashchinin et. al., 1978), which is considered to be stratigraphically younger than Loy Khwar formation; although Shcherbina et al. (1978) and Gusev et al. (1979) considered them to be part of the *Welayati Formation*.

Palaeozoic and Mesozoic sequences occur around the margins of the Kabul block. In the south a sequence of volcano-terrigenous formations up to 5500 metres in thickness occurs. The stratigraphic relationship of these rocks to the *Loy Khwar Formation* remains unknown, although they are assumed to be younger and of possible Carboniferous to Early Permian age. Elsewhere thick limestone, dolomite and terriginous sedimentary sequences of Permian, Triassic, Jurassic and Cretaceous age occur. Early Cretaceous ultrabasic rocks including harzburgites with pyroxenites, dunites and associated chromite deposits occur along the margins of the Kabul block and probably represent the vestiges of ophiolitic complexes that were tectonically emplaced during accretionary events related to the evolution of the block.

Poorly consolidated coarse fluvial and fluvial-lacustrine intermountain basin deposits of the Neogene *Latabang Formation* cover large areas of the Kabul block and reach thicknesses of up to 600 metres.

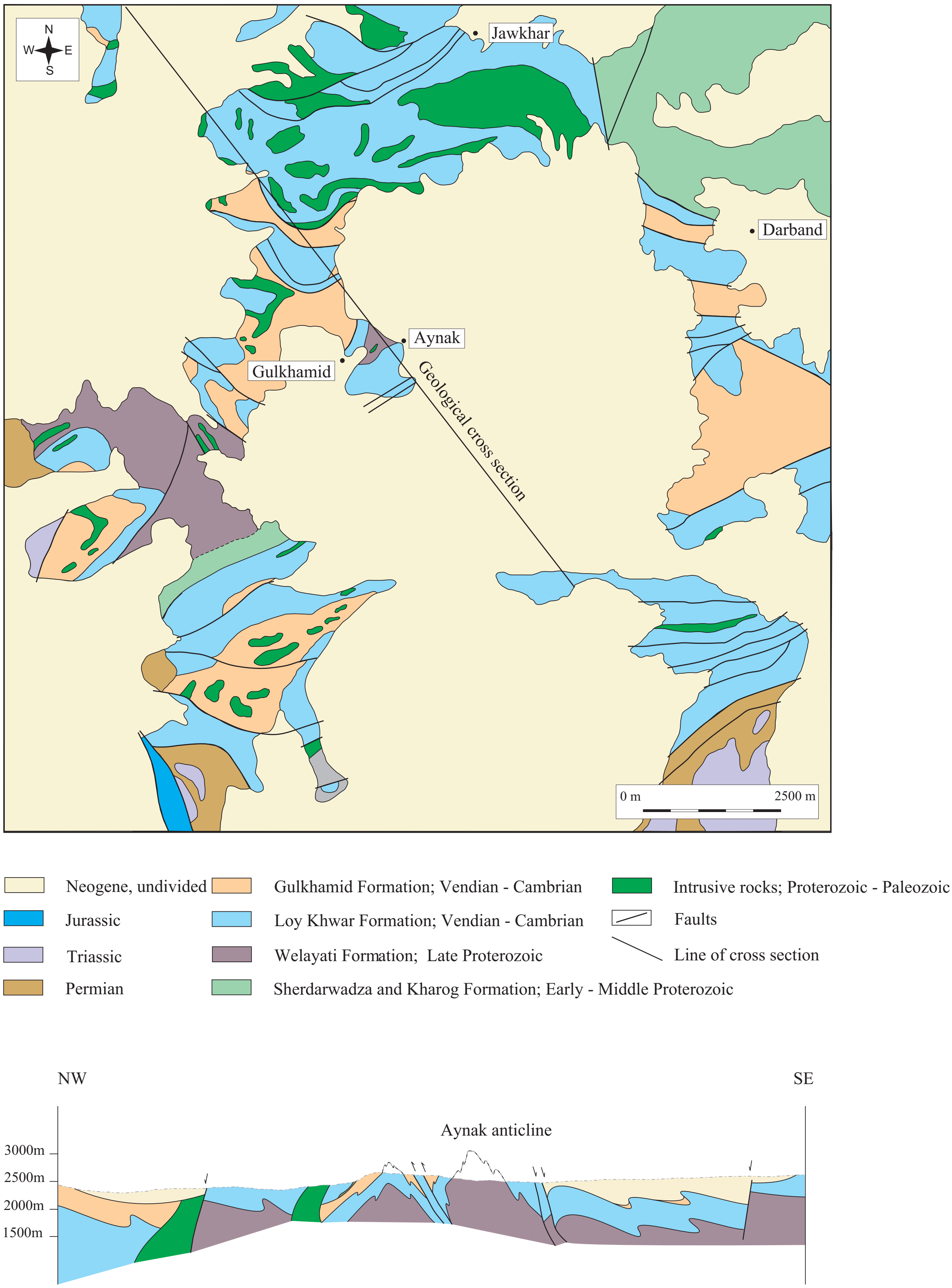

Figure 2 Simplified geological map and cross sections of the Aynak area.

2 The Aynak Copper Deposit

2.1 STRATIGRAPHY

The oldest rocks exposed in the Aynak area have been assigned to the *Welayati Formation*. Early exploration work at Aynak by Akocdzhanyan et al. (1977) investigated these rocks in detail and divided them into three main lithological – structural units. The oldest unit is exposed in the cores of anticlinal structures in the south and north of the prospect and consists of garnetiferous gneisses, amphibolitic gneisses and schists, containing staurolite, andalusite and silliminite. This is overlain with angular unconformity by a sequence of metavolcanic rocks predominantly of basaltic to andesitic composition with intercalations of quartzitic and carbonate schists. These rocks have low-grade greenschist facies metamorphic mineral assemblages and retain primary volcanic textures and fabrics. The uppermost, or third unit, is represented by quartzitic schists and carbonate schists that conformably overlie the metavolcanic unit.

The rocks assigned to the *Welayati Formation* by Akocdzhanyan, et al. (1977) are overlain by a thick metasedimentary sequence of the *Loy Khwar Formation*, which is the host to the copper mineralisation. This is a cyclical sequence composed of repetitive units, both on the macro and micro-scale, of dolomite marble, carbonaceous quartz schist and quartz-biotite-dolomite schist. Scapolite is also present within the schists. Fine rhythmic layering of schist and dolomite marble is common. Stromatolite remnants within the formation elsewhere in the Kabul block point to an Upper Proterozoic age (Mennesier, 1968; Slavin, 1972; Feruz, 1973), although the presence of the algae *Tannuofia* also suggests an Early Cambrian age. Based on this palaeontological evidence the formation has been assigned a Vendian (sic) to Cambrian age.

Exploration at Aynak has played an important role in elucidating the stratigraphy of the *Loy Khwar Formation* (Yashchinin et al., 1978; Gusev et al., 1979). Seven members were originally defined during the first phase of exploratory drilling at central and eastern Aynak, and eight were defined during later exploration at western Aynak. A summary of the stratigraphy of the formation is given in Table 1, which presents a unified scheme equating the work from both phases of exploration.

The *Loy Khwar Formation* is post-dated by basaltic to dacitic metavolcanic rocks of the *Gulkhamid Formation*, which are assumed to be of Vendian – Cambrian age.

Upper Permian limestones and dolomites of the *Khingil Formation* occur at Aynak in small outcrops in the western and the southern part of the area. They rest with strong unconformity on the older rocks and have a thin basal layer of conglomerate and coarse sandstone.

Poorly consolidated coarse fluvial and fluvial-lacustrine intermountain basin deposits of Neogene *Latabang Formation* infill valleys and depressions in the Aynak area where they reach maximum thicknesses of about 600 metres.

Table 1 Stratigraphic units of the Loy Khwar Formation in the Aynak area.

Unified scheme	Early C and E. part	Later W. part	Estimated thickness (m)	Major Lithologies
7	7	8.2	>125	Dolomitic marble with intercalations of carbonaceous quartz schist
6	6	8.1	30-70	Carbonaceous quartz schist with interbanded biotite-dolomite-quartz schist
5	5	7.2	40-120	Dolomite marble ± quartz ± feldspar ± biotite, dolomite-quartz-feldspar rock, biotite-dolomite-quartz schist
4	4	7.1	10-60	Biotite-dolomite-carbonaceous quartz schist, breccia texture
3	3.7	6.7	5-25	Grey dolomite marble with black quartz schist and microquartzite
	3.6	6.6	5-20	Light grey dolomite marble with dolomite porphyroblasts
	3.5	6.5	10-30	Dark grey dolomite marble with microquartzite bands
	3.4	6.4	1-10	Black quartz schist
	3.3	6.3	2-12	Grey dolomite marble with microquartzite and schist bands
	3.2	6.2	2-10	Biotite-dolomite schist and dolomite marble
	3.1	6.1	3-8	Dark dolomite marble with microquartzite bands
2	2	5	10-25	Dark grey dolomite marble with interbedded black quartz schist and microquartzite (chert)
1	1.4	4	2-8	Black carbonaceous quartz schist
	1.3	3	10-30	Sericite-carbonaceous quartz schist, biotite-quartz schist
	1.2	2	5-35	Dolomite marble with tremolite, tremolite carbonate schist
	1.1	1	3-12	Chlorite-biotite schist ± actinolite ±hornblende, basal with garnet

Information in column 2 taken from borehole logs and sections in the 1974-6 drilling and column 3 from the later 1978-1988 drilling in the western part of the deposit.

2.2 RELATIONSHIP BETWEEN THE LOY KHWAR FORMATION AND UNDERLYING METAVOLCANIC VOLCANIC ROCKS

The relationship between the metasedimentary sequence of the *Loy Khwar Formation* and the underlying metavolcanic rocks assigned to the *Welayati Formation* is not clearly understood, but deserves discussion as it is considered to have important implications for metallogenesis of the Aynak copper deposit and other deposits in the Kabul block.

Regional geological surveys of the Kabul block assigned the *Welayati Formation* to the Proterozoic basement. This would imply a significant time span between the volcanism of the *Welayati Formation* and deposition of the overlying Vendian – Cambrian *Loy Khwar Formation*. Contrary to this view, the descriptions provided by Akocdzhanyan et al. (1977) indicate that at Aynak two contrasting lithological sequences of significantly different metamorphic grade, structural style and age have been grouped within the *Welayati Formation*. The lower part of the formation at Aynak consists of structurally complex, relatively high grade gneissic and schistose basement rocks of amphibolite grade (almandine, siliminite, andalusite and staurolite-bearing). These are unconformably overlain by a basic–intermediate metavolcanic sequence, also assigned to the *Welayati Formation* by Akocdzhanyan et al. (*op. cit.*), which is of considerably lower metamorphic grade (greenschsist facies) and retains primary volcanic textures and fabrics. Basal breccias of this low-grade metavolcanic sequence contain clasts of the underlying higher grade gneissic sequence.

It is here proposed that the high-grade gneissic rocks are typical of the *Welayati Formation*, as found elsewhere in the Proterozoic basement of the Kabul block. The unconformably overlying low-grade metavolcanic sequence at Aynak is however considered to be significantly younger and is not part of the *Welayati Formation*. Evidence from Aynak suggests that the metavolcanic sequence and the overlying metasedimentary rocks of the *Loy Khwar Formation* are broadly conformable. Carbonate and quartzitic schists are intercalated within the upper parts of the metavolcanic sequence and the basal unit (1.1) of the *Loy Khwar Formation* consists of actinolite or hornblende-bearing chlorite-biotite schists that are believed to represent intercalated basic volcaniclastic material incorporated in the initial sediments. There appears therefore to be a broadly transitional and conformable contact between the metavolcanic sequence and the overlying *Loy Khwar Formation*.

2.3 STRUCTURE OF THE AYNAK DEPOSIT

The structure at Aynak is dominated by the Aynak anticline, the core of which is composed of amphibolites and gneisess of the Welayati Formation flanked on the limbs by the Loy Khwar Formation. The axis of the anticline mainly strikes north-east, but towards the south-western closure the axis swings around to an east-west direction (Figure 3). This change in orientation is probably due to two different phases of folding. The structure is approximately 4 km in length and up to 2.5 km wide and is asymmetrical. The south-eastern limb dips gently and consists of several secondary anticlines and synclines. The north-western limb is steeply dipping and in places overturned with dips of 45–70° to the south-east.

The periclinal closure of the anticline at its western end is asymmetrical. Here the southern limb is overturned and the axial plane is inclined towards the north-north-east, suggesting tectonic movement towards the south-south-west (see Figure 3). This is compatible with low-angle thrust sheets in the Pre-Cambrian basement which Mennessier (1961) suggested moved from the north to the south.

A distinctive north-east trending reverse fault (thrust fault?) occurs along the northwestern limb of the Aynak Anticline in the west of the area (Zaycev et al., 1988). The footwall is represented by rocks of the Gulkhamid formation; whereas the hanging wall is composed of the Welayati and Loy Khwar formations. The fault zone is manifested by a calcareous polylithic breccia zone ranging from 12 m up to 150 m in width. Several secondary faults occur in parallel with the main structure and are likewise filled by calcareous breccias. Several sets of later faults cut across the folds. These trend approximately north-south, east-west and northeast-southwest.

As a result of folding the copper deposit is divided into two prospects, with Central Aynak located on the eastern limb of the anticline and Western Aynak occurring in the area of the periclinal closure at the western end of the structure (Figure 3).

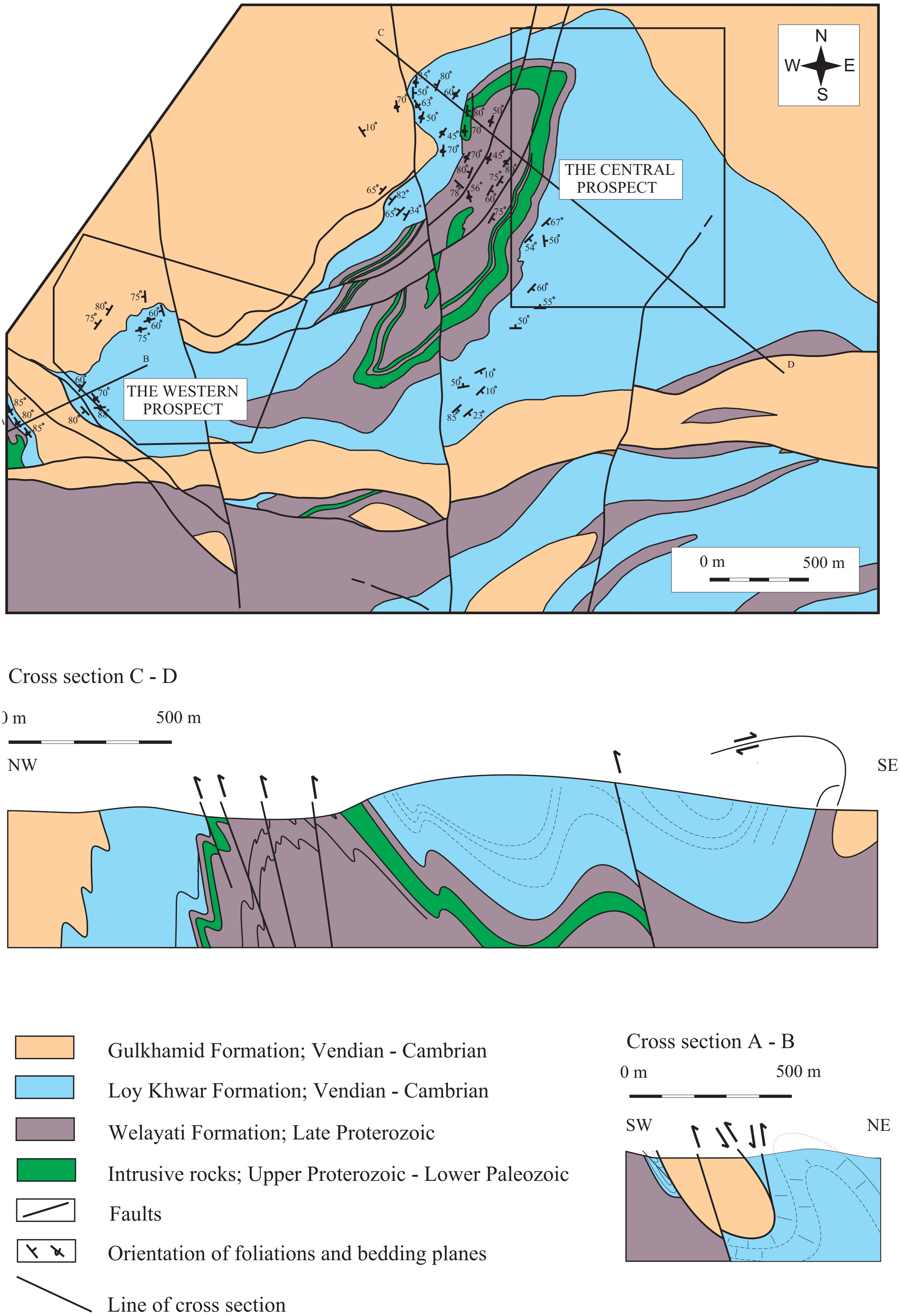

Figure 3 Simplified geological map and cross sections of the Aynak deposit.

2.4 MINERALISATION

The copper mineralisation at Aynak is stratabound and characterised by chalcopyrite and bornite disseminated in dolomite marble and quartz-biotite-dolomite schists of the *Loy Khwar*

Formation. The mineralisation is mainly concentrated in members 3–5 of the Formation, as illustrated in Figure 4. Cross-cutting quartz-carbonate veins with chalcopyrite and bornite also occur but are only of minor extent and confined to the zones of stratabound mineralisation. They are believed to be due to later metamorphic segregation.

The assessment of ore reserves and dimensions of ore bodies is outside the remit of this current work, although according to Russian exploratory drilling several large ore bodies and a considerable number of smaller bodies occur. At both Central and Western Aynak most of the mineralisation is contained in a large, main orebody. Based on a cut-off grade of 0.4% Cu the main orebody at Central Aynak was reported to extend 1850 m along strike and 1200 metres down dip and have a maximum thickness of 210 m. At Western Aynak the main body is reported to extend 2230 m along strike and 1640 m down dip, and to have a maximum thickness of 214 m, based on a cut-off grade of 0.4% Cu. The smaller bodies have dip and strike dimensions of a few tens to a few hundred metres and thicknesses of a few metres up to tens of metres.

The main ore body at Central Aynak is characterised predominantly by bornite. Chalcopyrite occurs in only minor amounts in the middle and lower parts of the body, but increases in the upper parts where in places it predominates over bornite. In contrast, about 80% of the mineralisation at Western Aynak is represented by chalcopyrite with bornite only accounting for about 20% of the mineralisation.

Primary mineral zoning is apparent within the deposit. The central part of the deposit contains mainly bornite grading out to chalcopyrite and then pyrite and pyrrhotite. Cobalt concentrations also increase in peripheral areas and in places traces of cobaltite and, to a lesser extent, smaltite occur in association with pyrite and chalcopyrite. Overall cobalt concentrations in the deposit are very low, with average concentrations of 0.004 and 0.013% being reported for the central and southeastern parts of the main orebody of Central Aynak. Traces of sphalerite also occur in peripheral parts of the deposit. The primary mineral zoning at Western Aynak is illustrated in Figure 4 and is as follows:

bornite > bornite + chalcopyrite > chalcopyrite > pyrite + pyrrhotite.

Secondary zoning occurs in the oxidised parts of the deposit. The depth of the oxidised zone is variable. The deepest zone of oxidation occurs at a depth of 250 m below the surface, beneath thick Neogene deposits in the northern part of Central Aynak. In areas where mineralised bodies crop out at surface, the zone of oxidation reaches a maximum depth of 160 m. The oxidised zone passes downwards into a mixed zone, which is partially oxidised and also contains primary sulphides. Secondary malachite with minor amounts of azurite, chalcocite, covellite, cuprite and native copper are typically found in the oxidized as well as in the mixed zone. There is no indication however of net migration of copper in the oxidized zone of the Aynak deposit and a zone of supergene enrichment does not occur beneath it. This is probably a reflection of the carbonate-rich nature of the deposit.

Limited information is available on gold in the Aynak deposit. Gusev et al. (1979) report that 606 samples of “ore” from the main ore-body (presumably of Central Aynak) were analysed for gold, of which 256 samples contained concentrations above detection. Of these, 141 samples contained 0.2 ppm (g/t), 78 contained 0.4ppm, 24 contained 0.6 ppm, 14 contained 0.8 ppm and one sample contained 1.0 ppm Au.

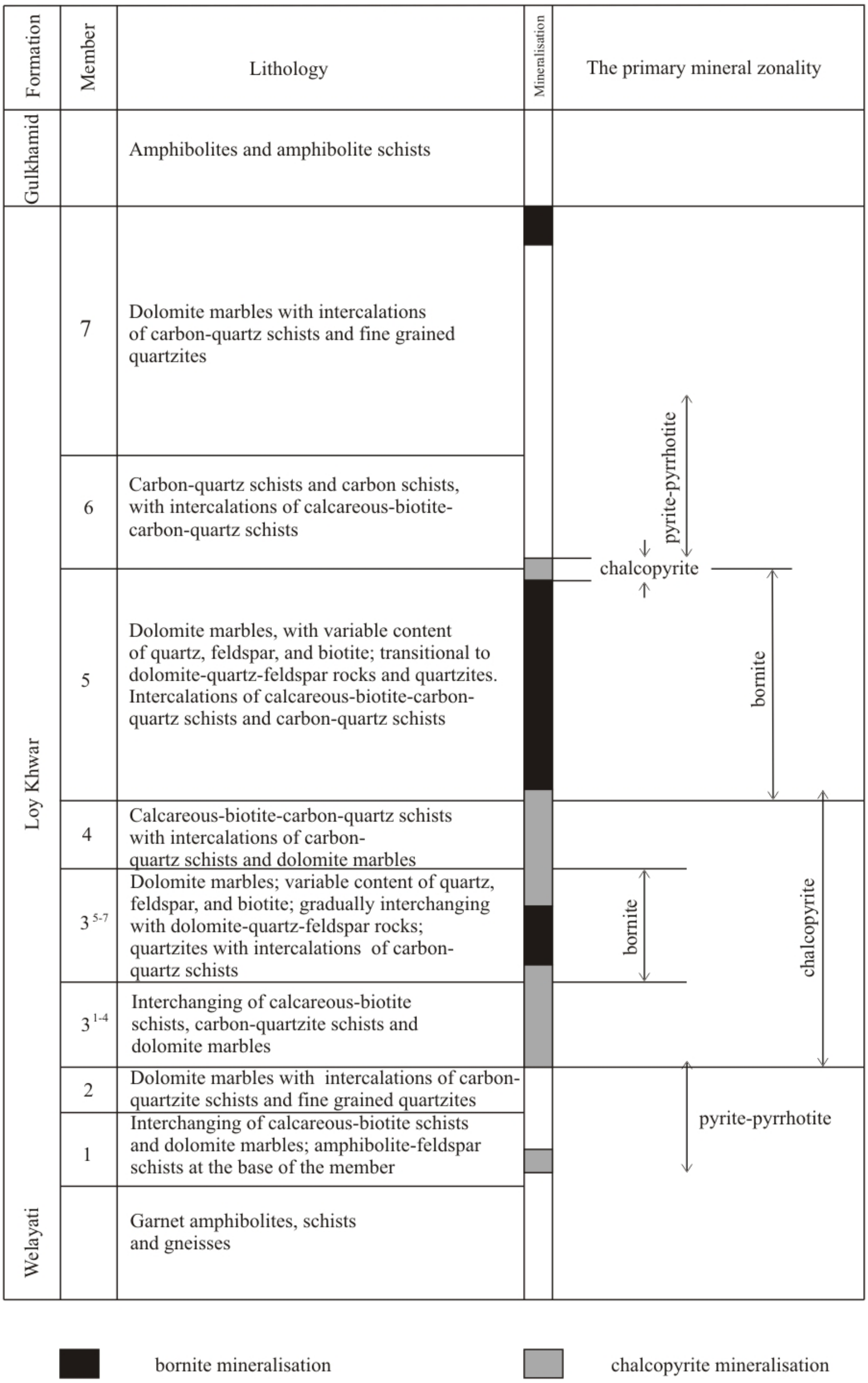

Figure 4 Schematic diagram of primary mineral zonation at Western Aynak (after Zaycev et al., 1988)

3 Metallogenic Model for the Aynak Copper Deposit

After the end of the late-Proterozoic glaciation there was a global marine transgression with the formation of extensive, shallow marine shelf areas fringing the major continents. In the Kabul block this was preceded by a period of basic to intermediate volcanism and the marine transgression spread over a series of lavas and volcaniclastic rocks, which have been assigned (spuriously) to the Welayati Formation. The time interval between the volcanism and transgression appears to have been short, given that the contact between the volcanic rocks and overlying marine sedimentary sequence of the Loy Khwar Formation is broadly conformable and possibly transitional. The Loy Khwar Formation is dominated by dolomite marbles with subsidiary black, carbonaceous-quartz schist, quartzite and a variety of quartz, biotite, dolomite and feldspar-bearing schists.

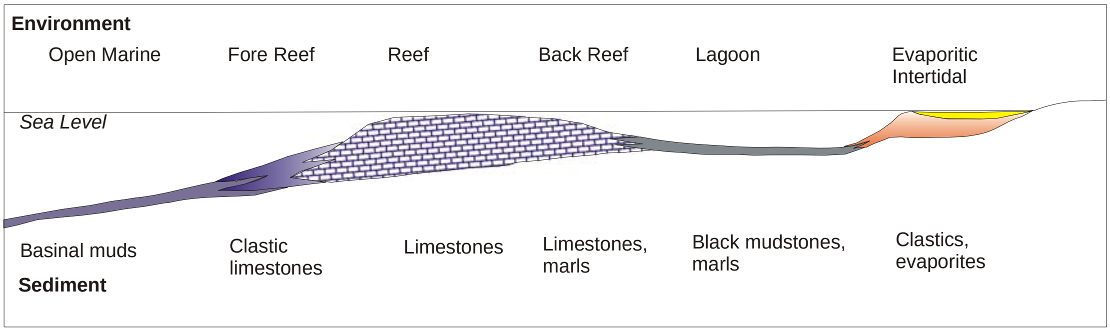

Figure 5 Simple carbonate reef model for the deposition of the Loy Khwar Formation

The sedimentary sequence of the Loy Khwar Formation is cyclical on a macro and micro scale with rhythmic units of dolomite marble, carbonaceous quartz schist and quartz-biotite-dolomite schist throughout the sequence. This cyclical sequence is interpreted as having been deposited in sub-tidal shelf to tidal flat environments, with alternating transgressions and retreats of the shoreline in response to sea level changes (Figure 5). Most of the black schists are carbonaceous and probably represent organic-rich mud deposited in a shallow, lagoonal or back-reef, low-energy environment. The dolomite marbles were possibly deposited as open water and patch reefs on the seaward side (a 'carbonate ramp') or, alternatively, as stromatolite mats on extensive tidal-supratidal flats to the landward side of the lagoon. The variable quartz-biotite-dolomite schist units possibly represent tidal channel deposits or sediments deposited on shallow shoals to the seaward side of the lagoon where carbonate and quartz sand mixed with the clay-rich lagoonal sediments. The cyclic sedimentation and the rapid alternation of the lithologies in the lower and middle parts of the Loy Khwar formation point to shallow water deposition with oscillating sea level changes. In contrast the uppermost units in the formation are dominated by carbonate rocks, which indicates that, in this area at least, the reef facies transgressed over the whole area and carbonate deposition continued until the volcanic rocks of the succeeding *Gulkhamid Formation* were erupted.

The copper mineralisation at Aynak is predominantly stratabound with disseminations and clots of chalcopyrite and bornite in the dolomite marble and variable quartz-biotite-dolomite schist units. As seen in Figure 4 the mineralisation is concentrated in Units 3–5 with a thinner mineralised body in Unit 1. Minor sulphide mineralisation in the form of disseminations and veinlets also occur in the metavolcanic rocks underlying the Loy Khwar Formation.

Aynak clearly belongs to the class of sediment-hosted copper deposits (Cox et al., 2003) as it is stratabound and restricted to a relatively narrow range of layers within a sedimentary sequence.

The protolithic host rocks were dolomitic siltstones, carbonate rocks and shales of marine origin, in contrast to sediments in redbed copper deposits, which are hosted by sandstones, arkoses and conglomerates of continental origin. It therefore forms part of the reduced-facies sediment-hosted copper deposits (subtype 30b.2) of Cox et al., (*op. cit.*). It is believed that the presence of dolomitic carbonates and the metamorphic mineral scapolite indicate evaporitic conditions existed in the shallow marine basin, which would have been situated near to the Vendian equator.

The source of the copper in sediment-hosted copper deposits has been the subject of some debate but the absence of any continental redbed sequences in the Vendian of the Kabul block indicates that weathering of hematite-bearing sandstones is not a likely source for the metal. The underlying volcanic rocks are likely to have been the source for the copper and leaching of the ferromagnesium minerals could have liberated the metal (Figure 6). In the absence of any analyses of the volcanic rocks to discover if they were a potentially fertile source, this must remain a supposition. A suitable equation for this leaching would be as follows:

$$Cu_2O + 6Cl^- + 2H^+ = 2CuCl_3^{2-} + H_2O$$

This equation requires a chloride-rich brine to mobilise the copper into solution. Evaporitic brines may well have been present in the shallow marine basin and these are likely to have been sodium-rich and poorer in potassium and calcium because of the formation of shales and carbonates. The chloride brine would also have had the capacity to leach Mg by similar reactions. Downward percolating brine would have circulated through the underlying volcanic pile until it either reached an impermeable barrier, perhaps the base of the Neoproterozoic, or until it had gained sufficient heat to rise in a convective current cell. Such heated hydrothermal brines would migrate to the basin margins or rise along listric faults, which may have formed the marginal structures to the carbonate reefs (Figure 6).

In order to precipitate the copper as a sulphide and to form the deposit there must have been a source of reduced sulphur. The abundant carbonaceous-quartz and black quartz schist indicate that biological activity was very high in these sediments and that reduction of seawater sulphate to sulphide took place at the base of the water column or within the bottom sediments. These reactions can be summarised as:

$$SO_4^{2-} + 2CH_2O(\text{organic}) = H_2S + 2HCO_3^-$$

$$SO_4^{2-} + CH_4 = S^{2-} + CO_2 + 2H_2O$$

The reaction of the copper chloride complex with the sulphide produces chalcocite.

$$CuCl_3^{2-} + S^{2-} = Cu_2S + 6Cl^-$$

The observed mineral zoning at Aynak probably relates to the spreading of copper-rich fluids away from the main conduits and mixing with reducing fluids in the sub-surface sediment. No evidence is presented for the replacement of synsedimentary framboidal pyrite but it may have been destroyed by metamorphism. The mineralisation is believed to be syndepositional diagenetic in origin and to have taken place within the bottom sediments prior to lithification. This allows the disseminated texture of the chalcopyrite in small, bedding-parallel grains to be formed in, for example, the biotite-quartz-dolomite schist (Figure 7). There is no evidence for primary, massive-sulphide layers being formed on the seafloor.

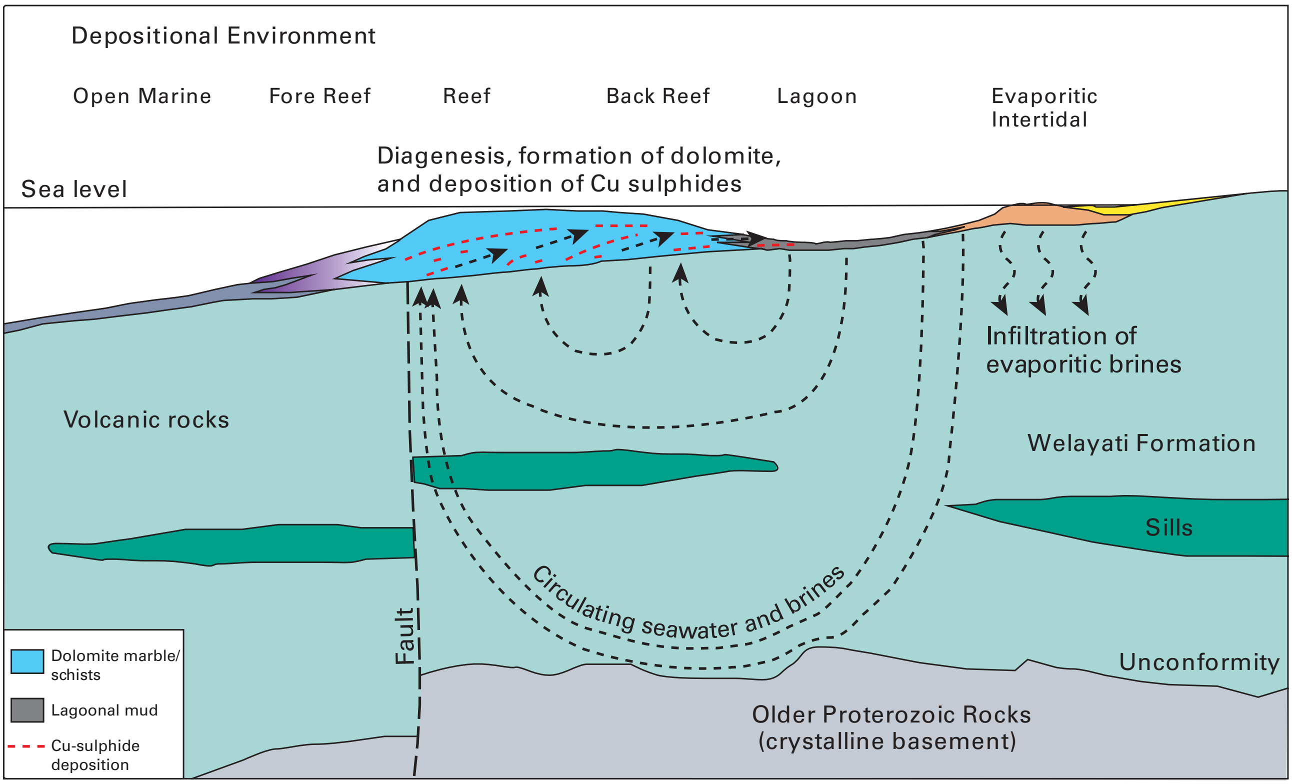

Figure 6 Model for the circulation of evaporitic brines through volcanic rocks and convective flow into the overlying sedimentary sequence.

The carbonate rocks of Aynak are recorded throughout the exploration reports as dolomitic marble, although it has not been possible to perform detailed tests to confirm this. Dolomite in carbonate successions can have a complex polyphase history but the widespread dolomite in both the thick carbonate units and the thinner biotite-dolomite schists (Figure 7) indicates a syndepositional diagenetic or shallow burial diagenetic origin, rather than a much later hydrothermal one. Once lithified the protolith to the schists would be unlikely to retain sufficient permeability to allow the conversion of the calcium carbonate to dolomite. Dolomitisation of the carbonate rocks in the succession may have taken place at the same time as the copper mineralisation, with the Mg-rich evaporitic brines altering aragonite or calcite to dolomite. Silicification of the carbonate rocks could also have occurred at about the same time. Further mineralogical or chemical work will be needed to prove that the copper mineralisation and the dolomitisation are coeval. Some of the present metamorphic textures such as the light grey, porphyroblastic dolomite marble, which is characteristic of Unit 3.6, may have replaced an earlier dolosparite texture (Figure 8).

Mineralisation appears to have ceased before the thicker carbonate succession of Unit 7 was deposited. This may have been due to eustatic sea level rise and influx of open marine water into the shelf lagoon. Evaporation in the area would have ceased, thereby cutting off the supply of chloride-rich brines, but ideal conditions for carbonate deposition would have proceeded rapidly in the oxygenated, open marine conditions.

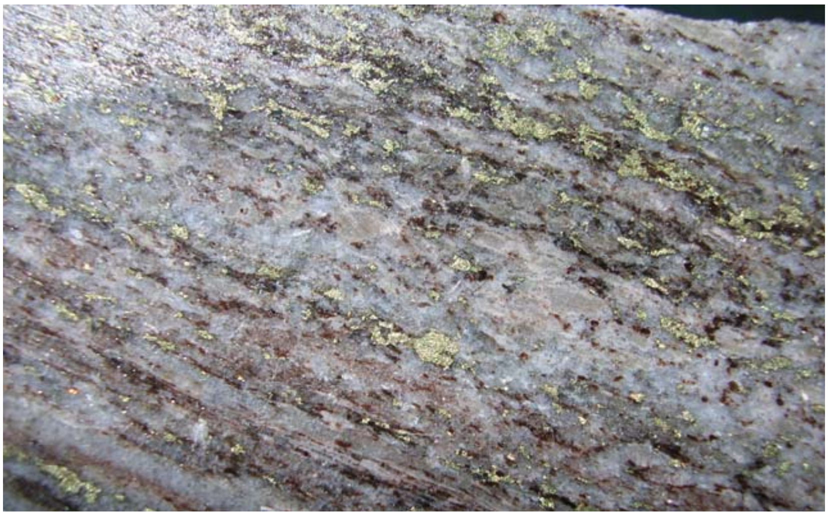

Figure 7 Biotite-quartz-dolomite schist with chalcopyrite crystals aligned along the foliation. The foliation may mimic earlier sedimentary layers

Figure 8 Light grey, porphyroblastic dolomite marble with chalcopyrite grains

4 Bibliography

The information present in the Records Office in AGS is extensive and includes reports in Dari, Russian, German and English. The Aynak data is almost exclusively in Russian with, in some cases, English summaries. BGS has translated all the report titles and limited metadata into English and created a bibliographic database. This CD includes a Bibliography of relevant reports on Aynak, which has been extracted from the database.

5 Geological Maps

Two geological maps are included in the data package. The first is the 1:50 000 scale geological map (Map 1) which shows the general geology of the Aynak area and the position of the

Darband and Jawkhwar prospects. This map was drawn up by the Aynak team but also uses much of the geological information produced by the Ardeskan geological group on their 1:100 000 prospecting map (Shcherbina et al., 1975).

The second map included in the data package is the 1:5 000 scale geological map of the sub-Neogene rocks of the Aynak deposit (Map 2). This is the key map of the deposit and shows the position of all the boreholes, adits, trenches and geological cross-sections. A geological key to symbols used on the map is provided as Geological key 1.

Detailed geological maps at a 1:2000 scale for parts of the deposit are also available and have been scanned into the data archive. Level plans were also drawn for the Central area and these have been used in part to validate the 3D model

6 Subsurface Exploration

6.1 BOREHOLES

The Russian exploration is reported to have drilled several hundred boreholes, including holes for geotechnical and hydrogeological investigations. Because of the incomplete nature of the AGS archive the precise number of boreholes is unknown, but it is believed that the majority were drilled for mineral exploration and resource assessment and it has been possible to locate borehole logs for 150 of these. Also included are the logs of a number of horizontal holes drilled from the adits and these have been incorporated in the database. Chemical data from the adits and the trenches has not been included in the database. The graphic logs of the boreholes have been scanned and are now available in digital format as *tif* or *jpeg2000* files. The borehole logs contain information on interpreted lithostratigraphic age, depth intervals, core diameter, core recovery, dip and azimuth values at specified depths, geological description of each unit, banding angle to the core axis, SP, EP and Apparent Resistance, geochemical sample intervals and sample numbers, total and oxidised Cu in %, Cu oxidation ratio, and grouped geochemical samples with Cu, Co and S determinations in percent.

Data relevant to the construction of a 3D geological and resource model has been abstracted from these logs and entered into a Microsoft Access database, a copy of which Aynak_Boreholes.mdb has been included on this CD-ROM. The database has been prepared in Microsoft Access 2000 format and should be readable in later versions of the software. Data from Access can be exported or linked to a variety of other software packages for display of the borehole data. The database contains four tables:

Table 2 Tables in the borehole database (Aynak_Boreholes.mdb)

Table name	Description of contents	Number of Records
tblBorehole	Borehole name, X, Y, Z coordinates, Starting dip and azimuth, total depth, % recovery of ore horizon, start and finish dates	150
tblDownhole_azim_dip	Borehole name, Depth, Inclination, Azimuth	2355
tblGeology	Borehole name, Unit number, Top depth, Bottom depth, Thickness, Age, Lithology, Description, Banding angle	2322
tblAnalyses	Borehole name, Top depth, Bottom depth, Interval, Sample number, Copper total, Copper oxidised, Oxidation ratio	12471

Most of the data was entered by staff of the AGS and validated by BGS staff. Further validation was carried out during the preparation of the Vulcan 3D model.

6.2 ADITS

Nine adits were constructed during the early phase of the exploration and the entrances of these are open. Their underground condition is not known and they may have been used as ordnance stores. At least one is currently being used as a human habitation. After checking for UXO re-examination of the geology of the adits and resampling for chemical analysis is advised as a relatively straightforward method of checking the accuracy of the earlier work.

6.3 CROSS SECTIONS

A number of section lines are drawn on the 1:5 000 scale geological map in several orientations and the Russian reports (Akocdzhanyan et al., 1977, Yashchinin et al., 1978 and Zaycev et al., 1988) include several interpreted sections along these lines. These show the boreholes and the interpreted geology derived from surface outcrops and the borehole logs. These sections are labelled from I – XLII in the Central area and 1 – 7 in the Western area. In the Central area the density of the drilling is sufficient to allow the 3D modelling to be based on the drill logs but in the Western part the 3D model relies more on the Russian interpretation shown on the sections.

6.4 3D MODEL

The validated Access borehole database was sent to BGS Keyworth and entered into the Maptek Vulcan 3D modelling system, along with raster scans of the geological maps, cross sections, level plans and surface topography. Geological linework was digitised from these scans within Vulcan and triangulations created for key surfaces. The chemical analyses were used to create ‘stick models’ of the copper distribution in the boreholes and preliminary block models were created (Figures 9 and 10). It should be emphasised that this model is for illustrative purposes and is not a resource estimation. The accuracy of the copper analyses is unknown and the core is not available for relogging.

Copies of the Vulcan 3D model of Aynak are available on DVD for companies that have the software and data can also be exported to a variety of other 3D display packages.

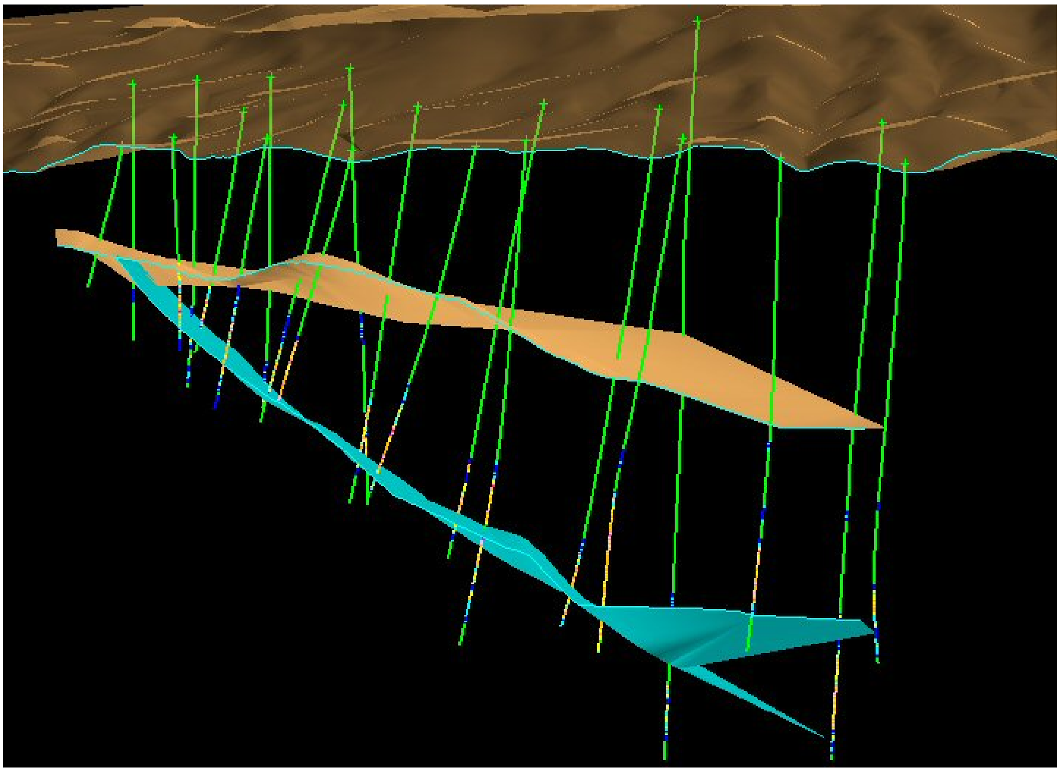

Figure 9 Screen image of part of the central Aynak model showing boreholes coloured by Cu content. The dark brown surface is the current topography; the light brown the sub-Neogene unconformity and the light blue the base of Unit 4.

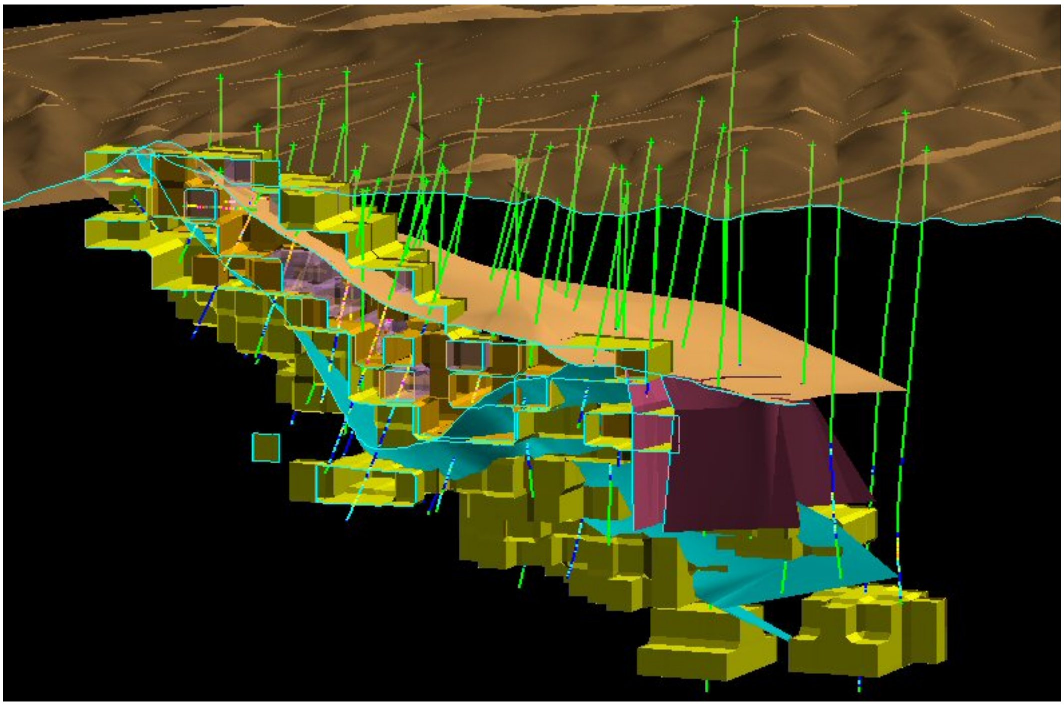

Figure 10 Screen image of the Aynak deposit showing example 50m blocks (Cu blocks >50th percentile in yellow, >75th percentile in orange and >90^{th} percentile in purple). Other surfaces as in Figure 9.

7 Conclusions

The aim of this information package is to provide an inventory and interpretation of the geological data on the Aynak copper deposit that is available in the archives of the Afghanistan Geological Survey. Modern information technology has been used to create databases of the unpublished reports held by AGS and of key geological information such as the borehole logs of the deposit. We have scanned many of the important documents, such as the borehole logs and sections, and also translated from the original Russian those key documents that summarize the economic geology of the deposit. We have also used a three dimensional modelling package to demonstrate completeness of the information package still available and to demonstrate the morphology of the deposit. The package does not include new data and is not an economic assessment of the deposit. We leave this task to those mining companies, who are interested in developing the deposit and who are better qualified to assess the economic feasibility of mining the deposit. During the course of these activities we have applied modern metallogenic modelling to the deposit with the aim of classifying the deposit in comparison with other sediment-hosted copper deposits. Inevitably this requires some interpretation of the information contained in the reports, but we have tried to keep this to a minimum and not to alter the basic data. There is much still to discover about the deposit and it is hoped that the scientific community will also be encouraged to unravel many of the unanswered questions about the deposit and its origin.

Aynak is one of the largest unworked copper deposits in the world and bears comparison with those in the Zambian Copperbelt in grade and tonnage. Without the upheavals that have taken place in Afghanistan over the past two decades it may well have begun operation and been a major part of the industrial economy of the country. We hope this CD will encourage the rapid development of the deposit and the start of production in the near future.

Finally we have included a list of Acknowledgements on this CD and we would like to thank all the previous Afghan, Russian and other geologists who have worked on the deposit or in the AGS data archive. Without all their hard work and perseverance none of the contents of this CD would have been available.

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