The Geology and Genesis of the Chelopech Au-Cu Deposit, Bulgaria; Europe’s largest gold resource.

Introduction

The Chelopech gold-copper mine is located in west-central Bulgaria 80km east of Sofia on the southern flank of the Balkan Range at Chelopech village adjacent to the towns of Zlatitsa and Pirdop. Bulgaria’s major copper smelter, an Outokumpu flash-process smelter with an annual capacity of 170 000 tonnes, recently privatized by Union Miniere, is situated 7km east of Chelopech at Pirdop. The Chelopech deposit lies to the north of the Panagyurishte mining district where a number of cupriferous massive sulphide and porphyry copper deposits exist The open-pit mines of Elatsite and Assarel - Medet, each with an annual throughput of approximately 10Mtpa of ores grading 0.3 - 0.4% Cu are located 5km west and 10km south of Chelopech respectively

Chelopech is probably Europe’s largest gold deposit containing well in excess of 5.5 million ounces of gold (>10 million ounces gold equivalent) with ore reserves and resources (at a 4 g/t Au Equivalent cutoff) total 52.1Mt grading 1.40% Cu, 3.30 g/t Au. Chelopech can be classified as a “gold-enargite high-sulphidation epithermal mineralizing system” similar to the deposits mined at Lepanto in the Philippines, El Indio in Chile, Freda River in Papua-New Guinea and Nansatsu in Japan. The deposit is hosted in Sennonian-aged (Upper Cretaceous) andesitic to rhyodacitic pyroclastics and sub-volcanic intrusives and can be classified as being a high sulphidation gold-enargite epithermal system..

Regional Geology

Bulgaria is situated in the south-eastern part of the Balkan peninsula which lies entirely within the Alpine geosynclinal belt. In the southern Balkans two branches of this belt can be distinguished: the Carpathian-Balkan branch to the north and the Dinaric-Hellenic branch to the south. Between these tectonic belts the country can be subdivided into four primary tectono-stratigraphic zones: the northern part of the country in the Danube basin comprises non-folded Palaeozoic to Mesozoic sediments of the Moisian Platform overlying a complicated basement of Baikalian consolidation; southwards tectonism and magmatism increase in the Balkanides which are dominated by pre-Mesozoic basement and Laramide-age magmatism and volcanism. The West Rhodope - Srednogorie geoblock comprises crystalline granitic crust overlain by Cretaceous-aged island-arc and back-arc subduction related geosynclinal volcano-sedimentary sequences. The East Rhodope - Strandja block comprises subcontinental crystalline basic rocks overlain by Mesozoic to Recent marginal marine to terrestrial volcano-sedimentary cover.

Bulgaria can be sub-divided into a number of structural and metallogenetic zones. These are the Rhodope Zone (East, West and Serbo-Macedonian districts), the Srednogorie Zone (Central, Sacar-Strandja, East Thracian and Black Sea Rift districts), the Krashtide, the Moisian and the Balkan Zones.

Within each of these metallogenetic zones specific types and ages of mineralization occur. The Rhodope Zone is characterized by dominantly vein and replacement type lead-zinc and fluorite deposits, by Alpine-type chromite deposits and by granite skarn-type scheelite deposits; the Srednogorie Zone by porphyry copper, skarn-copper and volcanogenic massive pyrite deposits; the Balkan Zone by Bleiberg-type sediment-hosted polymetallic deposits and by vein-type gold deposits; the Krashtide Zone by granite-associated vein gold-arsenopyrite deposits and the Moisian Zone by sedimentary deposits of salt, gypsum, kaolin and manganese.

The structural-metallogenetic zones are separated from each other by major structural discontinuities or deep faults. Thus the Moisian Platform and Balkan Zones are separated from the Srednogorie Zone by the Balkan and Yambol Faults and their associated splays and the Rhodope Zone from the Srednogorie Zone by the Maritsa, Struma and Yantra Faults.

Geology of the Panagyurishte Mining District

The Chelopech deposit is located within the so-called Panagyurishte metallogenetic district within the central part of the Srednogorie zone some 80km east-south-east of Sofia. Mineralization is dominated by porphyry copper type deposits as at Assarel, Medet, Elatsite, Vlaikov Vrah, Tzar Assen, Popovo Dere, Petelovo, Sivata, Orlovo Gnezdo and Gorna Kamenitsa; and by so-called 'cupriferous massive pyrite' deposits as at Radka, Elshitsa, Krassen and Chelopech.

Alluvial (Topolnitsa and Luda Yana) and vein-hosted (Svishti Plas) gold mineralization is also known in the area and has been previously exploited in a minor way.

The geology of the Panagyurishte mining district comprises a basement of Pre-Cambrian granitoid gneisses injected by Palaeozoic granites and overlain by Upper Cretaceous magmatic and sedimentary sequences. In some parts of the district these rocks are overlain by late Cretaceous flysch and by Palaeogene and Neogene molasse.

The basement rocks form a series of uplifted horst-anticlinal structures between which a series of three north-east trending sub-parallel grabens contain the Cretaceous sequences. To the north, towards Chelopech, the Srednogorie massif forms the basement.

Mineralization in the Panagyurishte district is intimately related to the Cretaceous magmatic activity. In general terms the cupriferous massive pyrite deposits are associated with the Upper Cretaceous (Sennonian) volcanics of andesitic and dacitic affinity whilst the porphyry deposits are generally associated with plugs and stocks of monzodioritic and quartz-syenodioritic intrusives. The massive sulphide deposits comprise lens or stock-like bodies enclosed within the volcanics and are generally elongated along the principal structural grain. The porphyry copper deposits are located either within the volcano-sedimentary sequences in the grabens or in the horst blocks and are all proximally related to areas with intense development of sub-volcanic intrusive bodies and dykes.

Mineralization Types - The Porphyry Copper Deposits

The porphyry deposits of the Panagyurishte district occur as classic sub-volcanic copper porphyries within volcanics cut by granodiorite porphyries, quartz diorite porphyries and acid dykes (Assarel, Tzar Assen. Popovo Dere and Vlaikov Vrah); as copper-molybdenum porphyries within hypabyssal intrusions of quartz-monzodiorite (Medet); and as copper porphyries at the contact of major plutons with metamorphic wall rocks (Elatsite and Urlovo Gnezdo).

All deposits of the first type are located within the graben-like volcano-sedimentary belts whilst deposits of the second and third type all occur within the horst blocks cutting crystalline basement.

All of the deposits are spatially and genetically associated with the emplacement of small sub-volcanic to hypabyssal porphyritic quartz-diorite, monzodiorite to quartz-syenodiorite composition intrusions of subduction related magmatism (circa 80Ma) which succeeded the island-arc andesitic to dacitic volcanism in the Srednogorie Zone. Typically the deposits show a stock-like shape and occupy the apical parts of the hypabyssal intrusions (Medet), or penetrate the edifice of effusive rocks above sub-volcanic bodies (Vlaikov Vrah and Assarel). In the case of Elatsite the mineralization is localized adjacent to the contact of the intrusion with Carboniferous granodiorites and Pre-Cambrian schists within a wide replacement and alteration zone.

Mineralization in all the deposits comprises veinlets and disseminations consisting mainly of pyrite and chalcopyrite. Magnetite, hematite and minor sphalerite and galena also occur as do secondary copper sulphides in the upper parts of the orebodies. Molybdenite occurs in all of the deposits but is only of economic significance at Medet. Alteration assemblages are typical of porphyry systems and include K-feldspathization, biotitization, chloritization, argillitization and zeolitization.

The Cupriferous Massive Pyrite Deposits

The massive sulphide deposits in the Panagyurishte district include massive pyrite (+Au) orebodies (Elshitsa, Tsar Assen and Chervena Mogila), cupriferous massive pyrite deposits (Krassen and Chelopech) and polymetallic (Cu-Au-Pb-Zn) massive sulphide deposits (Radka, Vozdol and Dolna Kamenitsa).

All of these massive sulphide deposits occur within Upper Cretaceous (Sennonian) volcanic edifices as lenticular to stock-like bodies proximally located adjacent to radial and concentric faults, or to rhyodacitic dykes injected along them, cutting dacitic agglomerates and tuffs. Massive pyrite predates metallic mineralization and is thought to be related to a phase of dacitic volcanism; whilst Cu, Cu-Au, Cu-Au-Pb-Zn and Pb-Zn is later and is temporally related to a phase of injection of subvolcanic rhyodacites during the late Cretaceous.

Mineralization shows a complex paragenesis with the main minerals comprising pyrite, quartz, chalcopyrite, tennantite and bornite whilst enargite, luzonite, tetrahedrite, gold, bournonite, chalcocite, sphalerite, galena, gypsum and barite are subordinate. In addition a large number of rare and exotic sulphosalts and tellurides have been identified from these deposits. All of the deposits show a similar paragenesis which has been shown to be, in order of deposition:

(1) Pyrite - Quartz
(2) Chalcopyrite - Pyrite
(3) Enargite - Pyrite
(4) Bornite - Tennantite
(5) Sphalerite - Galena
(6) Late Quartz - Pyrite
(7) Pyrite - Marcasite
(8) Anhydrite - Gypsum

Genetically, three phases of mineralization can be recognized in the Panagyurishte district:

(1) Massive Pyrite
(2) Polymetallic Massive Sulphides
(3) Porphyry Coppers

The formation of the massive pyrite ores is associated with the second, dacitic, phase of volcanism. These ores were formed by replacement along and outward from steeply dipping fractures at the end of the dacitic phase, but before its completion, as clasts of massive pyrite can be found within tuffs of the uppermost parts of the dacitic sequence.

The main copper-polymetallic mineralization occurred after the intrusion of sub-volcanic rhyodacites but before a phase of tectonic activity leading to regional folding. This phase of tectonism also appears to be related to initiation of caldera and volcanic edifice collapse.

The porphyry copper and copper-molybdenum deposits are associated with sub-volcanic intrusions during the third phase of magmatic activity.

Local Geology

The pre-Mesozoic basement in the vicinity of Chelopech is comprised by Pre-Cambrian granite gneisses, crystalline two-mica schists, quartzites and amphibolites. This basement is unconformably overlain by Permian terrigenous volcanics and in turn by a terrigenous and transgressive marginal marine sequence of Triassic, Jurassic and Lower Cretaceous age. The stratigraphy of the mine area is dominated by Middle and Upper Cretaceous siliciclastics, volcanics and volcaniclastics, and flysch-type calcareous turbidites contained within an E-W trending syncline centered to the west of Chelopech village.

The lowest Cretaceous comprises Turonian-age polymict conglomerates which thin away from the Petrovden Fault which appears to have been active at this time shedding detritus to the north. The Lower Chelopech Formation of Coniacian-Santonian age comprises a basal sequence of siltstones and calcareous argillites with subordinate terrigenous sandstones and angular breccio-conglomerates.

Upwards these sediments become intercalated and eventually superseded by andesitic agglomerates, andesitic lavas, andesitic lapilli and psammitic tuffs. This complex injected by sub-volcanic bodies of porphyritic andesites with sub-vertically imbricated phenocrysts. The andesites are typically mesocratic and, volumetrically, approximately 60% are porphyritic with phenocrysts of feldspar, biotite, amphibole and, rarely, quartz. The Lower Chelopech Formation predates mineralization. The Upper Chelopech Formation is post-mineralization and overlies an angular diastem passing from mixed terrigenous-volcanigenous gritty sandstones with volcanogenic exhalative iron-manganese oxide horizons up and laterally into volcanogenic talus breccias and agglomeratic tuffs of andesitic affinity.

Above the volcano-sedimentary complex of the Chelopech Formation lies a thin sequence of red to gray argillaceous limestones and gray to dark blue calcareous argillites. Minor interbeds of silty and sandy limestones also occur in the upper parts of the sequence which contains microfaunal evidence of an Upper Turonian to Campanian age.

During the Santonian Stage sub-volcanic porphyritic andesites, porphyritic syenogranodiorites and intrusive rhyodacites where injected into the pre-Mesozoic basement and into the Middle and Upper Cretaceous. These bodies host and localize several large copper porphyry deposits such the Elatsite stock 10km NW of Chelopech which hosts a substantial orthomagmatic porphyry copper deposit.

Chelopech Mineralization

Mineralization consists of sulphide-rich zones of anastomosing veins and replacive massive sulphide bodies within enveloping haloes of pervasive silica-sericite alteration. The orebodies, which comprise steeply dipping lenses, branched converging mantos and discrete pipes extend from surface at about 700m above sea level, to below sea-level. The lenses vary from 150-300m in length, are 30-120m thick and extend for up to 350m down plunge and comprise the bulk of the presently known ore-reserves. The branched mantos and pipes are approximately 20-60m in diameter and extend for between 100 and 250m down plunge. Silica-sulphide mineralization is tectonically controlled and predominantly located along, and proximally to, radial and concentric faults and, in the case of the larger orebodies, at their intersections.

Ore mineralogy is complex but in abundance pyrite dominates followed by enargite-luzonite, tennantite, bornite and chalcopyrite. In very simple terms the central part of each orebody is dominated by fine-grained massive sulphides (predominantly pyrite and chalcopyrite) which passes outwards into a zone of gradually diminishing pyrite content and increasingly complex sulphides. Peripherally to the pyrite dominated zone is a chalcedonic silica-rich zone with galena, sphalerite and other sulphides.

The gross paragenesis of the deposit has been defined as:

Early: Gold-Pyrite
Gold-Copper-Pyrite
Copper-Gold-Pyrite
Copper-Pyrite
Late: Polymetallic

It has also been noted that gold distribution is closely controlled by zone of intense silicification adjacent to active structures.

This relatively simple chemical evolution has, however given rise to a very complex paragenesis and, as a result, a complex of ore types. Six different ore-types exist all of which contain pyrite as the dominant sulphide but are characterized by the presence of the subordinate minerals as set out below:

Inner: Pyrite
Chalcopyrite -Tennantite -Bornite
Enargite - Luzonite
Complex Sulphides and Arsenides
Sphalerite - Galena
Outer: Barite - Polymetallic

The ore mineralogy of the Chelopech deposits is dominated by pyrite (and marcasite, melknikovite etc) which forms, on average, some 20% by volume of the orebodies. The principal ore minerals comprise chalcopyrite, tennantite, enargite and luzonite together with subordinate famatinite, sphalerite and galena. Quartz, barite and kaolinite are the dominant gangue minerals with chlorite, ankerite and gypsum subordinate. However the mineralogy is very complex and to date some 71 mineral species have been identified

The main economic copper bearing minerals are (in order of abundance) chalcopyrite, tennantite, enargite, tetrahedrite, luzonite, bornite and famatinite. In gross terms about 65% of the copper is in the form of arsenides and sulphosalts, and about 35% as chalcopyrite.

Gold occurs in a variety of forms both as native metal with admixed silver in a stoichiometric form approximating to Au_3Ag and in auriferous tellurides such as nagyagite, sylvanite and kostovite.

Gold occurs as fine (5 to 300 microns, with 5 to 20 microns the norm) flattened elongate irregular or amoebae-like blebs and its distribution is irregular within the host grains. Approximately 10% of the total gold is free with a further 20% finely intergrown with chalcedonic silica; 25% occurs intergrown with enargite, luzonite, tennantite, tetrahedrite and bornite with the majority (45%) intergrown within pyrite, chalcopyrite and sphalerite. The highest gold contents within the orebody, reaching 100 g/t occur in association with silica-rich mixed Pb/Zn ore-types and in the high grade Cu zones dominated by chalcopyrite and enargite.

Texturally and microtexturally the massive sulphide mineralization exhibits a range of complex fabrics and textures. Pyrite is by far the most common mineral and is intimately associated with copper minerals and sulphosalts. Pyrite is the earliest sulphide and occurs in a number of forms: as single well formed cubic metacrysts 0.1-2mm in diameter, as grains and granules formed by the gradual and partial or complete replacement of mafic minerals such as pyroxene and amphibole, as collomorph and radial forms of non-stoichiometric iron sulphides such as melknikovite up to 10cm in diameter with each layer up to 2-3mm in thickness; as dense massive pyrite aggregates of irregular form and comprising all of the other forms described earlier. The non-stoichiometric iron-sulphides contain significant amounts of arsenic (up to 1%) as well as trace amounts of bismuth and antimony.

The other major sulphides and arsenides exhibit simple crystalline and intergrown forms with the pyrite and occur in infra-crystal spaces as replacements, as replacements of pyrite, as crosscutting veinlets and as overgrowths. Intergrowths of the cupriferous minerals are commonplace both as aggregates and as complex textures with several intergrown minerals.

Arsenic occurs in a number of mineral phases in typical Chelopech ore. The most abundant arsenic-bearing minerals are enargite, luzonite and tennantite, which may be zincian (with minor amounts of colusite and arsenian renierite. Non-stoichiometric iron sulphides (dominantly pyrite) may also contain up to 1% arsenic.

Ore Genesis

The Chelopech deposit has been studied extensively by Bulgarian geologists with regard to possible genetic models. Four distinct stages of mineralization can, to varying degrees, be recognized throughout the Panagyurishte ore district.

The first stage is manifested during sub-marine volcanism and caldera formation when sea-water circulation in the volcanic pile mixing with primary magmatic waters enriched in calcium and oxidized sulphur led to the precipitation of anhydrite at depth. Higher in the edifice at lower lithostatic pressures and lower pH reduction occurred to lead to pyrite precipitation as diffuse crystals and disseminations. These fluids apparently reached surface and exhaled precipitating finely laminated non-stoichiometric iron sulphides in topographic lows. Clasts of such material are found in water-winnowed volcanic sediments indicating that reworking occurred within the caldera in anaerobic conditions.

The second phase of mineralization occurred following uplift of the volcanic edifice into the sub-aerial environment accompanying the intrusion of late sub-volcanic porphyritic andesites. These intrusions were particularly gas-rich which led to the generation and heat driven circulation of acidic fluids which caused extensive leaching and silicification. This phase is typical of an epithermal acid-sulphate system and alteration zoning is strongly developed from the outer propylitic halo via argillic to advanced argillic alteration and pervasive silicification. A well developed zonation is seen over the known 1200m vertical extent of the mineralizing system with alunite giving way to alunite and dickite, to dickite, to dickite and diaspore and to diaspore and andalusite in the deepest parts of the system. Within this alteration system hydraulic fracturing within the brittle silicified zones enabled the ascent of metal-bearing solutions and sulphur. At depth and at temperatures above 300^{o}C these fluids precipitated pyrite with inclusions of bornite, digenite and, rarely, gold.

Higher in the system at depths of about 800m reduction in pressure led to boiling and the release of gaseous sulphur and arsenic leading to the generation of a high sulphidation environment and the precipitation of pyrite and enargite (highly oxidized As valency 5) along with goldfieldite, colusite, bornite and germanite.

This mineralization was localized where the solutions encountered earlier exhalative and diagenetic pyrite where dissolution of pyrite occurred leading to the precipitation of replacive enargite and luzonite.

Evolution of this hydrothermal system appears to have occurred with a lowering of the oxidation potential and a resultant change in the mineral species being precipitated. In addition the depth of boiling and sulphur release appears to have been greater, perhaps down to 1300m as the association of chalcopyrite and zincian tennantite dominates along with tellurides, selenides and native metals. In the uppermost oxidizing fringes of the system sea-water influx led to the precipitation of barite.

The waning stages of the hydrothermal system appears to have coincided with tectonic instability and minor faulting, especially on the edges of the massive silica bodies. Late stage lead-zinc-copper-gold low sulphidation type mineralization occurred over almost 2000m of vertical extent and dominated by galena, sphalerite, pyrite, rare chalcopyrite and native gold. Minor zonation is seen with barite increasing in the uppermost parts of the system and chalcopyrite increasing at the expense of galena at depth.

Late Sennonian tectonics and further uplift demarked the cessation of hydrothermal activity prior to the second volcanic phase (unmineralized) of the Upper Chelopech Formation.

31st March 1998
Sofia, Bulgaria