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THE MAJDANPEK PORPHYRY Cu-Au DEPOSIT OF EASTERN SERBIA A REVIEW

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Abstract - The approximately 1000 Mt @ 0.6% Cu, 0.3-0.4 g/t Au Majdanpek porphyry copper is the most northerly deposit within the Timok Magmatic Complex (TMC) which also hosts the exploited Bor and producing Veliki Krivelj deposits. Slightly older, but similar magmatic rocks southeast of the region host the significant porphyry-high sulphidation mineralisation at Elatsite and Chelopech in neighbouring Bulgaria. Similar porphyry deposits are also known in Romania, across the Danube river to the north of Majdanpek. The TMC igneous rocks show clear evidence of crustal contamination and thus likely relate to an eastward dipping subduction zone beneath a continental margin located to the west. Mineralisation is related to sparse and narrow north-south trending andesitic dykes dated at 83 Ma. These dykes intrude along a north-south trending fracture zone cutting Proterozoic and Palaeozoic metamorphic rocks, and Jurassic limestones. Extrusive facies of the TMC are rare at Majdanpek, although they are common farther to the south of the region. Mineralisation is typicaly developed as stockworks, the bulk of which are actually within the metamorphic aureole of the andesitic dykes. There are also numerous skarns and replacement bodies flanking the intrusives, while more distal replacement bodies are found in the Jurassic limestones. The highest copper grades relate to K-silicate alteration and zones of strong silicification. Mo grades are very low throughout the deposit, while the Cu%:Au g/t ratio is approximately 2:1. PGEs occur as minor phases accompanying the copper mineralisation and are recovered at the smelter. Significant supergene upgrading is recorded in an oxidation blanket that was 25 m thick in the north and covered the deposit.

Introduction

The giant Majdanpek porphyry copper deposit, which had an estimated total pre-mining resource of ca. 1000 million tonnes (Mt) @ 0.6% Cu, 0.3-0.4g/t Au, is located in the Timok Mountains of eastern Serbia, approximately 120 km SE of the capital, Beograd (Belgrade). The deposit shares its name with the town that is situated close to the eastern side of the main open pit (Plate 1). Majdenpek is served by a good transport infrastructure with road links to the Danube and to the Bor mining centre to the south. A railway line was used to transport ore and concentrate to the Bor metallurgical plant. The mine site is currently under licence to RTB Bor, the Serbian State owned mining company. Porphyry copper style mineralisation was first discovered at Majdanpek in 1961, with production commencing in 1962.

Modern mining started prior to 1962 with the exploitation of massive pyrite-limonite bodies within Jurassic limestone marginal to the porphyry system, although archaeological evidence indicates that mining activity has taken place in the local region for approximately 3000 years (Jankovic, 1990). The limestone hosted massive pyrite-limonite mineralisation originally contained 3 to 15 g/t Au in a total resource of approximately 15 Mt of ore. Production at Majdanpek reached its peak in the period 1962-1990 when 12 to 14 Mt of ore were mined per annum from two open pits, North and South Revir. The initial porphyry operation in the 1960s commenced with grades of 0.82% Cu and close to 0.8 g/t Au. Historic production has amounted to 1.55 Mt of Cu and 100 t of Au from approximately 500 Mt of ore with an average recovered grade of 0.31% Cu, 0.2 g/t Au. After 1999, Majdanpek has encountered a number of production problems as a result of the NATO bombing, diminishing grade and geotechnical problems. Current feasibility studies indicate a remaining resource of 108 Mt @ 0.424 wt% Cu, 0.273 g/t Au and 1.49 g/t Ag in the South Revir (open pit), which is currently not in production. Sporadic operations have continued up to the present from North Revir.

Setting and Geology of the Timok Magmatic Complex

Majdanpek is the most northerly of the porphyry copper deposits associated with the Timok Magmatic Complex (TMC). The TMC is part of the greater geological framework that comprises the Alpine-Balkan-Carpathian-Dinaride metallogenic-geodynamic province (Heinrich and Neubauer, 2002), also elsewhere referred to as the Carpatho-Balkan Magmatic Belt (see Herrington *et al.*, 2003 and references therein).

The Alpine-Balkan-Carpathian-Dinaride (ABCD) Province (Fig. 1) is in turn, part of the Alpine-Himalayan (or Tethyan) orogenic system that extends from western Europe to southeast Asia and resulted from the convergence and collision of the Indian, Arabian and African plates with Eurasia. This on-going collision was for the greater part initiated during the Cretaceous. The complex geometry of the collision interface and the presence of several microplates within the orogenic collage resulted in a variety of collision products, notably some segments characterised by extensive regional metamorphism and others by calc-alkaline igneous activity (Heinrich and Neubauer, 2002). This segmentation has resulted in discontinuous distribution of mineral deposits within the ABCD province (Mitchell, 1996 and Jankovic, 1997) and the limited lateral extent of the various metallogenic belts along the trace of the orogen.

While magmatic activity is evident within the ABCD from the Cretaceous to the present, two overlapping, arcuate segments have been delineated representing the bulk of the magmatism, one to the south in which the majority of the intrusion and volcanism is Late Cretaceous and a second to the north, where Late Miocene activity predominates (Fig. 1). These and adjacent segments of the ABCD host a series of significant porphyry Cu-Au deposits and related

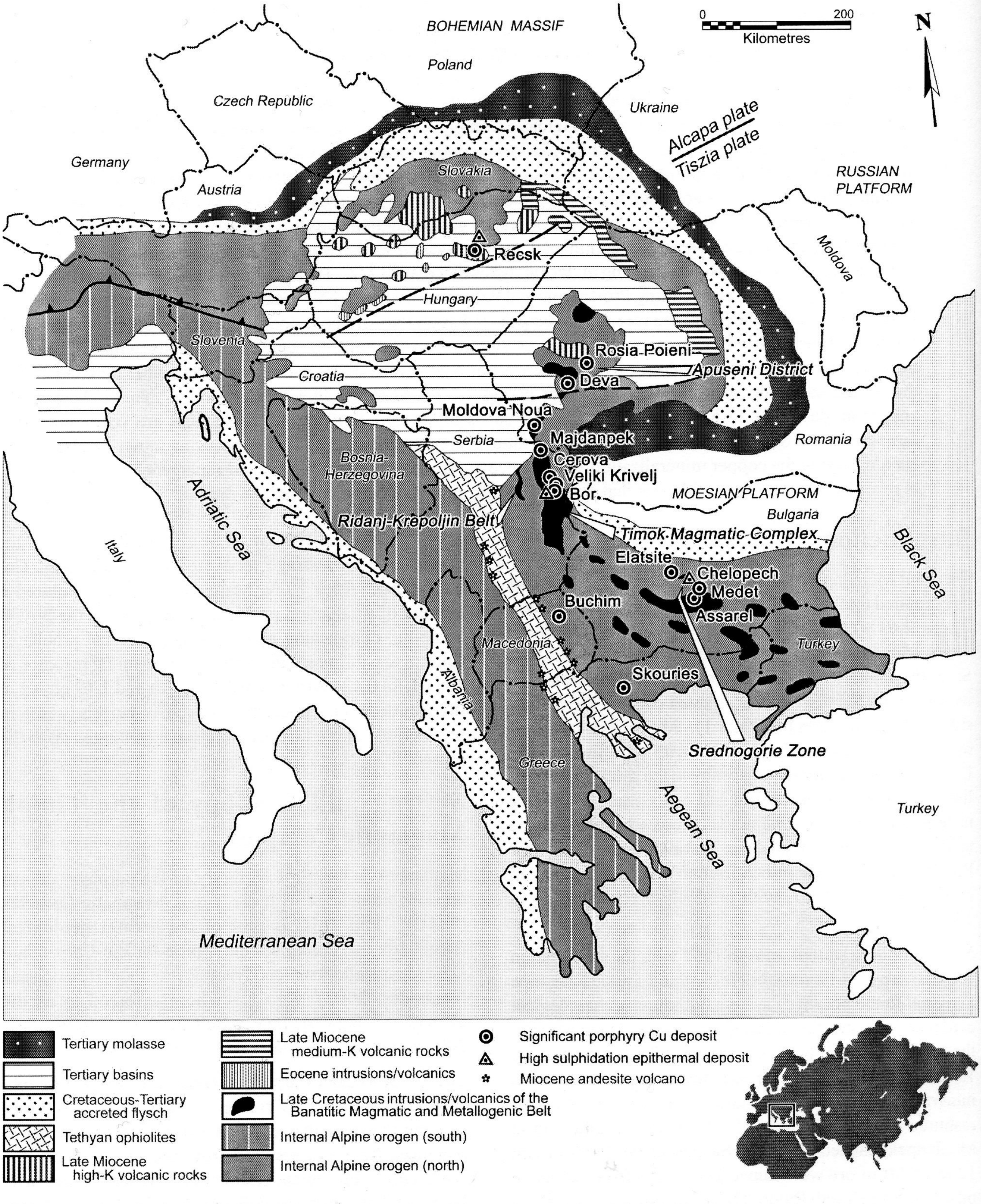

Figure 1: ***The tectonic and geologic setting, and principal magmatic arc rocks hosting porphyry copper deposits in the Alpine-Balkan-Carpathian-Dinaride (ABCD) Province*** (modified from Herrington *et al.*, 2003).

Table 1: ***Tonnage (production + resources), grade and age details of a representative selection of the porphyry Cu-Au/Mo deposits of the Alpine-Balkan-Carpathian-Dinaride metallogenic-geodynamic province.*** See Fig. 1 for locations.

Deposit	Country	Tonnage @ Grade	Age
Recsk (porphyry/skarn)	Hungary	109.4 Mt at 0.96 % Cu / 36 Mt at 2.19 % Cu (historic production); 700 Mt @ 0.66% Cu, 0.006% Mo (potential resource) (a,e)	Late Eocene
Rosia Poieni	Romania	350 Mt @ 0.36% Cu, 0.5 g/t Au (a)	Late Miocene
Deva	Romania	Not known (e)	Late Miocene
Moldova Noua	Romania	500 Mt @ 0.35% Cu (e)	Late Cretaceous
Majdanpek	Serbia	~1000 Mt @ 0.4 to 0.8% Cu, 0.25-1.0 g/t Au	Late Cretaceous
Veliki and Mali Krivelj	Serbia	>840 Mt @ 0.4% Cu, 0.1 g/t Au	Late Cretaceous
Bor - Borska Reka porphyry - High sulphidation	Serbia	600 Mt @ 0.6% Cu, 0.25 g/t Au (f) 200 Mt @ 1.5% Cu, 0.8 g/t Au (f)	Late Cretaceous
Elatsite	Bulgaria	320 Mt @ 0.36% Cu, 0.21g/t Au (Au historic grade) (b)	Late Cretaceous
Medet	Bulgaria	163 Mt @ 0.32% Cu, 0.1 g/t Au (b)	Late Cretaceous
Assarel	Bulgaria	354 Mt @ 0.44% Cu (b)	Late Cretaceous
Chelopach (high sulphidation)	Bulgaria	61.5 Mt @ 1.32% Cu, 3.24 g/t Au (b,c)	Late Cretaceous
Buchim	Macedonia	85 Mt @ 0.3%Cu, 0.3g/tAu (a)	Early Miocene
Skouries	Greece	500 Mt @ 0.37% Cu, 0.47 g/t Au (d)	Early Miocene

a – GEODE Database, http://www.gl.rhbnc.ac.uk/geode/ABCD.html; b – Strashimirov *et al.*, 2002; c – Bonev, *et al.*, 2002; d – Tobey *et al.*, 1998; e – Herrington *et al.*, 1998; f - Monthel *et al.*, 2002.

high sulphidation Cu-Au mineralisation, as shown on Fig. 1 and listed in Table 1.

Within the ABCD province the most economically significant segment comprises the Upper Cretaceous subduction-related magmatic rocks and mineral deposits referred to by various authors as the Banatitic Magmatic and Metallogenic Belt, BMMB, or the Apuseni-Banat-Timok-Srednogorie belt (Berza *et al.*, 1998; Strashimirov and Popov, 2000). This belt forms an L-shape extending from Romania through Serbia and into Bulgaria (see Fig.1). The BMMB intrusive and extrusive rocks were emplaced during a 30 M.y. period from ~90 Ma to 60 Ma and may have been the result of several different subduction zones of varying polarity (Ciobanu *et al.*, 2002). Lips (2002) suggests that the subduction regime that produced the BMMB commenced with the convergence between Africa and Eurasia at c.110 Ma. Due to the relatively slow rate of this convergence, there was a lag of 10 to 20 M.y. before the initiation of the melting that led to the emplacement of the BMMB magmatic rocks.

Temporal variations in the ages of mineral deposits within the belt are attributed to variations in convergence direction relative to the geometry of the active margin (Lips 2002). Specifically the deposits in south-western Romania, eastern Serbia and in central Bulgaria have been dated at 77, 85 and 91 to 80 Ma respectively (Lips, *et al.*, 2004). The distribution of related igneous rocks along this belt is nearly continuous, although in eastern Serbia they appear to be restricted to the TMC and a narrower, sub-parallel belt which is some 30 to 40 km to the west of the TMC (see Fig. 1), known as the Ridanj-Krepoljin Belt (RKJ) (Karamata *et al.*, 1997). Only minor bodies of andesite are exposed northwards from the TMC towards the Danube (which forms the Serbian-Romanian frontier north of Majdanpek – Fig. 1) (Karamata *et al.*, 1997). These two magmatic belts have petrological and geochemical characteristics similar to the West and East Banatite zones defined to the north of the Danube in Romania (Karamata *et al.*, 1997). The RKJ is an extension of the West Banatite belt that includes the Moldova Noua porphyry Cu deposit (Fig. 1) (Cioflica and Vlad, 1984; Vlad 1984; Karamata *et al.*, 1997), while the TMC is thought to be the southerly extension of the eastern belt (not sufficiently significant to appear on Fig. 1) that contains some porphyry and related skarn mineralisation in Romania.

The RKJ lies to the west of the TMC and is predominantly composed of dacite with subordinate andesite, that have been dated at 70-74 Ma by K/Ar methods (Pecskay *et al.*, cited in Karamata *et al.*, 1997). The rocks of the TMC are predominantly intermediate to felsic (subordinate) in composition with medium to high K-series calc-alkaline affinities (Jankovic *et al.*, 2002; Karamata *et al.*, 1997; Banjesevic *et al.*,2002). Magmatic activity is dated at between 82.73±0.03 and 86.29±0.32 Ma by U/Pb methods (von Quadt *et al.*, 2002),and 84 ± 1.5 Ma using Ar-Ar methods (Lips *et al.*, 2004). The westerly younging direction of these magmatic complexes suggests that they formed as a result of westerly migrating subduction of the oceanic lithosphere of the Vadar Sea during the late Cretaceous north-south convergence between Africa and Eurasia that resulted in the closure of the Neotethys Ocean (Ciobanu *et al.*, 2002; Lips, 2002; Banjesevic *et al.*, Karamata *et al.*, 1997).

The TMC is an approximately north-south, lozenge shaped belt of extrusive and intrusive units emplaced during the late Cretaceous (see Figs. 1 and 2). The complex is approximately 100 km in length north-south, up to 25 km at it's widest, and has a total area of around 1130 square kilometres (Cocic *et al.*, 2002).

The country rocks of the TMC comprise a basement of Proterozoic metamorphics overlain by Palaeozoic metamorphic and sedimentary formations intruded by Hercynian granitoids (Cocic *et al.*, 2002). Xenoliths of these units have been observed within the TMC volcanic succession. For the most part, the Mesozoic of the region is dominated by carbonate units of Triassic, Jurassic and lower Cretaceous ages. These units are folded with a broad regional NW-SE strike.

To the west, the TMC is bounded by the approximately north-south trending Zlot fault zone and by the Belorecko-Bucje fault zone in the east (Jankovic *et al.*, 2002). Both are interpreted from geophysical data as being deep-seated structures that converge at depth contributing to the graben-like character of the TMC (Andric *et al.*, 1972; Karamata *et al.*, 2002). This graben-like structure is often referred to in the Serbian literature as a 'rift-dyke complex' or 'dyke syncline' (Jankovic *et al.*, 2002; Cocic *et al.*, 2002; Andric *et al.*, 1972). Other large scale NNW-SSE striking longitudinal faults are also reported within the TMC, cut by numerous WNW-ESE to NW-SE and ENE-WSW to NE-SW striking transverse faults (Fig. 2), described by Kozelj (2002) as a result of subsidence within the 'rift-dyke complex'. The observed spatial distribution of these faults may be interpreted as evidence of the TMC graben being a pull-apart basin (Richards, 2003), consistent with the observed discontinuity in mineralisation and magmatism trends along the length of the BMMB.

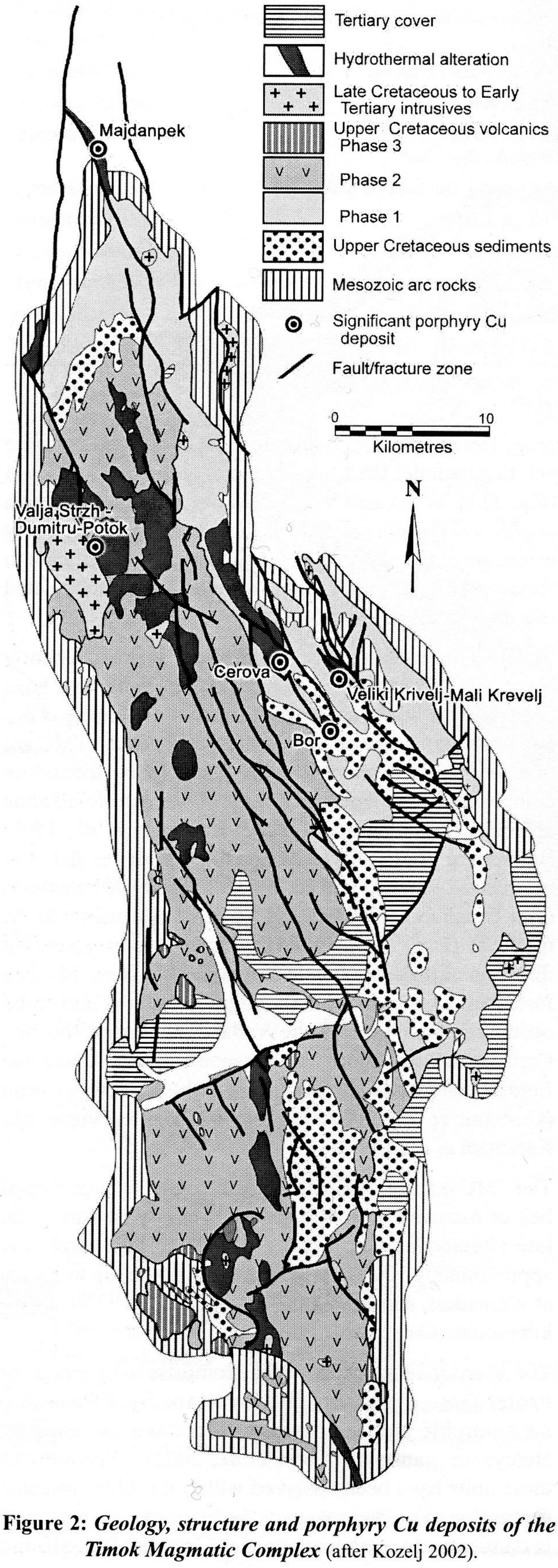

Figure 2: ***Geology, structure and porphyry Cu deposits of the Timok Magmatic Complex*** (after Kozelj 2002).

The igneous rocks of the TMC have historically been the subject of extensive study, in part due to the occurrence of Timocite, an andesite containing large phenocrysts of hornblende and biotite in an idomorphic matrix (Historic reference Breithaupt, 1861, cited by Jankovic, 2002). Later studies by Drovenik (1960) and Drovenik *et al.*, (1962) were the first to describe three phases of volcanism in the late Cretaceous. For a number of years the view persisted that the TMC consisted of three distinct phases of volcanism, with the intrusion of plutonic bodies following the cessation of eruptive activity. Karamata *et al.*'s review (2002) reinterpretted the magmatic history to comprise four main phases, the first two characterised by volcanic activity, followed by two dominated by intrusion, all related to several large stratovolcanic edifices (See Table 2). Volcanic facies analysis of the TMC volcanic successions describe the presence of andesitic crypto-domes with hyaloclastic margins, autobrecciated andesitic flows, epiclastics and tuffs. The wide range of facies and their variation with time suggests periods of both sub-aerial explosive, and relatively quiescent sub-aqueous volcanism, which lasted from the Turonian to the Campanian. Absolute ages of the TMC igneous suite indicate a tight range from 86 to 83 Ma. Quartz diorite close to the Majdanpek Dolovi-1 orebody (Fig. 3) was dated at 83 Ma while sub-volcanic andesite from the Veliki Krivelj deposit yielded an age of 86 Ma, both from U-Pb dating of zircons (Von Quadt *et al.*, 2002). In addition, fresh andesite from Bor was dated at 84±1.5 Ma using Ar-Ar methods (Lips *et al.*, 2004). Earlier studies indicated much younger dates using less reliable K-Ar methods. Strontium isotope data from various TMC rocks range from 0.7039 to 0.7060, inferring that the magmas show significant modification by continental crust material, either through subduction fluids or via high-level chamber processes (Von Quadt *et al.*, 2002).

For detailed descriptions of the TMC volcanic succession the reader is referred to Djordjevic and Banjesevic (1997, 1998) and Banjesevic (1998).

On a more regional scale, preliminary U-Pb zircon dates of the arc volcanic rocks in the Ridanj-Krepoljin (RKJ) zone suggest an age of about 70 Ma for the andesite-dacite at Krepoljin (M. Banjesevic pers comm.). These data support the proposal for a trenchward migration of Late Cretaceous magmatism westwards from the TMC, possibly

Table 2: ***Summary of main periods of magmatism in the Timok Magmatic Complex*** (Karamata *et al.*, 2002).

Magmatic phase	Rock types and lithologies	Age
1st phase volcanics	Hornblende ± biotite ± pyroxene andesites with subordinate dacite lavas, volcanoclastics and pyroclastics	Turonian – Coniacian
1st phase intrusives	Hornblende ± biotite ± pyroxene andesite and dacite porphyries, and porphyritic diorites and quartz diorites. These rock types mostly form N-S striking dykes which are tens of metres wide and subvolcanic intrusions of dimensions ~1 km^2.	Turonian - Coniacian
2nd phase volcanics	Basaltic-andesites and minor andesites. Abundant volcanoclastic material, lava flows and tuffs.	Senonian
2nd phase intrusives	Monzonites, monzodiorites, diorites, granodiorites, quartz diorites and their porphyritic facies. These rocks are mostly found in dykes and subvolcanic intrusions. The only intrusive body of any size is the Valja Strz monzonite that which has an exposed surface area of ~20 km^2.	Campanian

in response to steepening of the subduction angle (Von Quadt *et al.,* 2002). This steepening may have been the initiator of the extension resulting in eruption of the TMC.

Mineralisation in the Timok Magmatic Complex

The TMC contains some of the largest examples of porphyry style mineralisation in Europe, including Veliki Krivelj, Majdanpek and the gold-rich Bor deposit. Total tonnage and grade figures for these deposits and others are listed in Table 3. Despite porphyry copper style mineralisation being restricted to a relatively small geographical area in the northern part of the TMC, there are a variety of mineralisation morphologies and significant variations in Cu and Au grade (Jelenkovic and Kozelj, 2002; Herrington *et al.,* 1998). The TMC also contains high sulphidation epithermal Cu-Au deposits, none of which are currently being mined, with the exception of care and maintenance work at Bor. A detailed review of epithermal gold mineralisation is given by (Kozelj, 2002a, 2002b).

The following are summaries of other key porphyry style deposits within the TMC, after Herrington *et al.,* (1998).

Bor Porphyry and High Sulphidation Cu-Au

Sub-cropping massive, high sulphidation mineralisation was discovered at Bor at the turn of the 20th century with mining commencing in 1903. Subsequent mining and exploration drilling has shown that the massive sulphide orebodies are spatially related to deeper porphyry style mineralisation, the Borska Reka deposit. The two styles are continuous, linked by a transitional stockwork zone (Fig. 3). The length of the altered and mineralised structural zone exceeds 2000 m with a width of around 1000 m, while the mineralised zone, which dips at 50° to the west, has been drill tested to a depth of at least 1500 m below surface. Past production + current reserves of the high sulphidation Cu-Au zone is estimated to total 3 Mt Cu, 160 t Au and 600 t Ag from 200 Mt of ore with an average grade of 1.5% Cu and 0.8 g/t Au (Monthel *et al.,* 2002).

The host sequence at Bor is dominated by porphyritic hornblende-biotite andesites, andesitic tuffs and minor dacites. These volcanic rocks are overlain by pelitic sediments, and are underlain by a series of Late Cretaceous conglomerates and sandstones, which are nowhere mineralised.

High sulphidation mineralisation is characterised by a series of massive, cigar-shaped, or pipe-like bodies, together with mineralisation in fracture zones and in volcanic breccias. The largest of the sulphide bodies is Tilva Rosh with other major bodies such as Choka Dulkan and Tilva Mika (Fig 3). Tilva Rosh, which had maximum plan dimensions of 650 x 300 m and extended vertically for as much as 800 m, comprised both massive and disseminated sulphide mineralisation. The massive sulphide orebody of Choka Dulkan has a strike of some 150 m, thickness of 60-70 m and a vertical extent of around 300 m.

Table 3: ***Summary of the total resources for differing styles of porphyry copper related mineralisation in the Timok Magmatic Complex*** (Jelenkovic and Kozelj, 2002; Jankovic, 1990; Herrington *et al.,* 1998).

Deposit	Total Size (Mt) Production+resource	Cu (%)	Au (g/t)	Morphological Type (Jelenkovic and Kozelj, 2002)
Bor - Porphyry - High sulphidation	600 200	0.62 1.5	0.25 0.8	Porphyry copper and high sulphidation massive sulphide.
Veliki Krivelj	>540	0.35	0.068	Porphyry copper related to high-level dyke swarms.
Mali Krivelj	>300	0.5	0.147	Porphyry copper related to high-level dyke swarms.
Valja Strzh	482	0.2	0.04	Porphyry copper hosted by composite pluton.
Dumitru Potok	290	0.21	0.1	Porphyry copper hosted by composite pluton.
Majdanpek	~1000	0.4-0.8	0.25 - 1.0	Porphyry copper related to an initial rift structure.

The massive copper ore at Bor contains 3 to 6% Cu and comprises up to 70% (by volume) fine-grained pyrite, accompanied by up to 2.5 to 3.75 (locally to 18) g/t Au and 10 g/t Ag (Jankovic, 1982; Monthel *et al.,* 2002). The principal copper minerals are chalcocite, covellite and enargite, with associated marcasite, chalcopyrite, tetrahedrite and sulvanite. Spectacularly bladed hypogene covellite is common in the massive sulphide ore. Traces of galena and sphalerite are present in the massive sulphides, although these minerals form a major component of the Choka Marin high-sulphidation body which lies to the north of Bor. Associated gangue minerals are significant amounts of silica, barite, ubiquitous anhydrite and native sulphur. Barite is more common in the upper sections of the system, while the predominant sulphate mineral in the lower levels is anhydrite. Native sulphur accompanies high-grade enargite and covellite veining in one of the orebodies. Very late gypsum veins are also common.

There is a suggestion of a sulphide mineralogy zonation within the massive ore to a pyrite-chalcopyrite-bornite (occasionally pyrrhotite) association in the lower levels, possibly indicating a change in sulphur activity. The massive ores grade laterally and at depth to disseminated mineralisation. A system of thin sub-parallel veins is developed beneath the large Tilva Rosh body although post-ore faulting has removed the lower sections of bodies such as Choka Dulkan. The disseminated zones also carry significant sulphide mineralisation (>0.6% Cu) and form part of the ore reserves.

Alteration is distinctive around the high-sulphidation deposits with a change at depth towards the porphyry style mineralisation. In the upper parts of the high-sulphidation system, silicification is the common alteration with vuggy silica developed close to the interpreted palaeosurface. Outward zoned advanced argillic alteration, characterised by in an inner envelope of kaolinisation and peripheral chlorite surrounds the orebodies, in places accompanied by pyrophyllite, diaspore and alunite, and locally with andalusite, zunyite, sericite and some corundum. Alunite is most abundant in the upper parts of the alteration. Kaolinite is commonly associated with the alunite (Karamata *et al.,* 1983).

The porphyry style disseminated and stockwork mineralisation of Borska Reka is associated with dykes and minor intrusions of diorite which are restricted to its lower sections. The bulk of the mineralisation is hosted by altered andesite which has a distinct porphyritic texture. Alteration

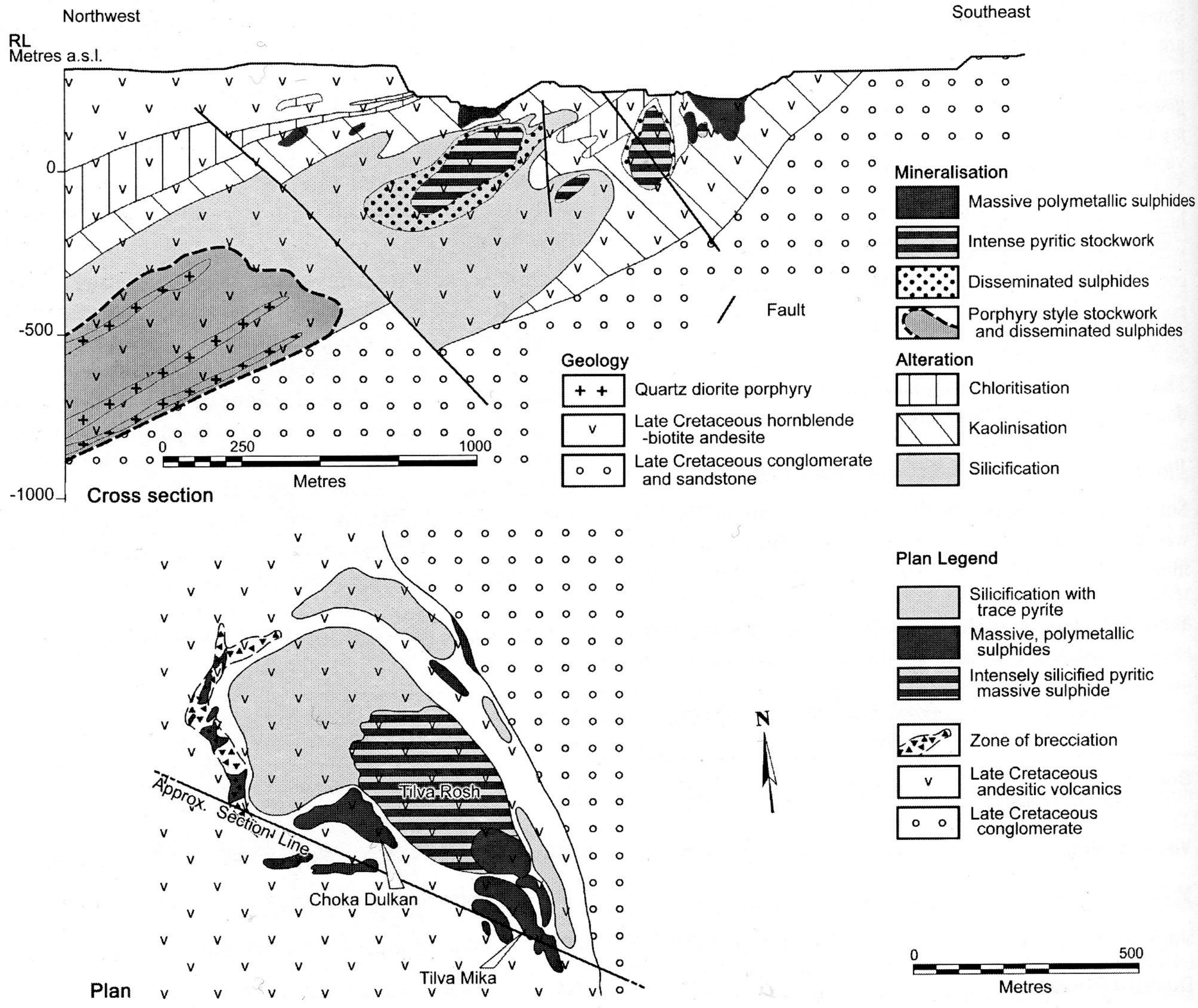

Figure 3: ***Geological cross section through the Bor high sulphidation and porphyry Cu-Au deposits (top) and sub-crop geological map of the high sulphidation deposits and alteration (bottom).***

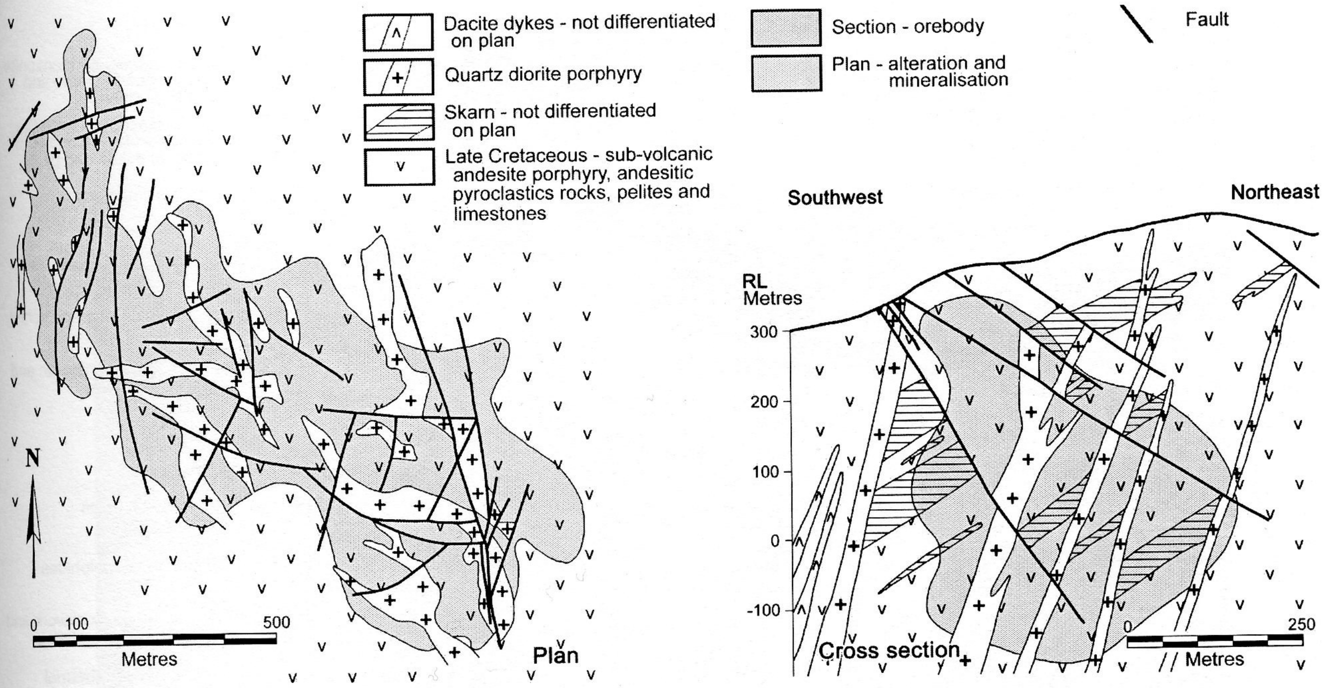

Figure 4: ***Simplified geological plan (left) and cross section (right) through the Veliki Krivelj porphyry Cu deposit***

is characterised by silicification and illite-argillisation, accompanied by chlorite, alunite and carbonates, although alunite is widespread in parts of the deposit. The principal Cu sulphide is chalcopyrite with up to 6% (by volume) pyrite, and in the lower levels, molybdenite. These sulphides are accompanied by magnetite, minor pyrrhotite, enargite and bornite, and are overprinted in parts by chalcocite and covellite. This porphyry deposits contains around 600 Mt @ 0.6% Cu, 0.25 g/t Au.

Veliki Krivelj Porphyry Cu

The Veliki Krivelj deposit is approximately 3 km to the northeast of Bor. It has maximum sub-surface plan dimensions of 1500 x 700 m and a vertical extent of more than 800 m as indicated by diamond drilling. Historic production since operations commenced in 1982 has amounted to 0.51 Mt Cu, 120 Kt Mo, 60 t Ag and 10 t Au from ore with a recovered grade of 0.34% Cu, 0.4 g/t Ag and 0.07 g/t Au (Monthel *et al.,* 2002). At a cut-off grade of 0.15% Cu, the deposit is quoted as originally containing a mineable reserve of approximately 2.5 Mt of Cu from ore averaging 0.44% Cu, within a larger geologic resource. The Mo content of the ore is generally only 0.003 to 0.005%, although it may locally reach 0.02 to 0.03%. The deposit has been previously described by Aleksic (1969, 1979); Jankovic *et al.,* (1980); Jankovic (1990, 1990b).

The porphyry style mineralisation at Veliki Krivelj occurs in hydrothermally altered Upper Cretaceous sub-volcanic hornblende andesite and pyroclastic equivalent breccias, tuffs and agglomerates as well as the Upper Cretaceous volcano-sedimentary series of pelites and limestones. This mineralisation, prominent Late Cretaceous to Early Tertiary diorite and quartz diorite porphyry dykes as well as andesite dyke swarms, are all superimposed on earlier skarns formed in the Upper Cretaceous pelites and limestones.

Hydrothermal alteration is mainly developed in the pyroclastic facies of the host hornblende biotite andesite, predominantly as a potassic assemblage characterised by secondary biotite, accompanied by widespread silicification and by sericite on the margins. Pyrophyllite is found locally. On the periphery of the porphyry copper mineralisation, where silicification is weak, chlorite, epidote and calcite are developed. Late intense zeolite, gypsum and sporadically anhydrite are also apparent. Strong pyritisation is associated with the silicification.

Porphyry style mineralisation is dominated by chalcopyrite, pyrite, minor molybdenite, magnetite, pyrrhotite, hematite, traces of cubanite, enargite, bornite, covellite, chalcocite, galena and sphalerite. The occurrence of up to 50 m thick zones of pyrophyllite, alunite and kaolinisation in parts of the alteration system indicates the presence of advanced argillite alteration, although this has not been studied systematically.

The early skarn assemblage includes garnet, calcite, epidote, quartz, biotite, pyrite and sporadically wollastonite, with disseminated chalcopyrite.

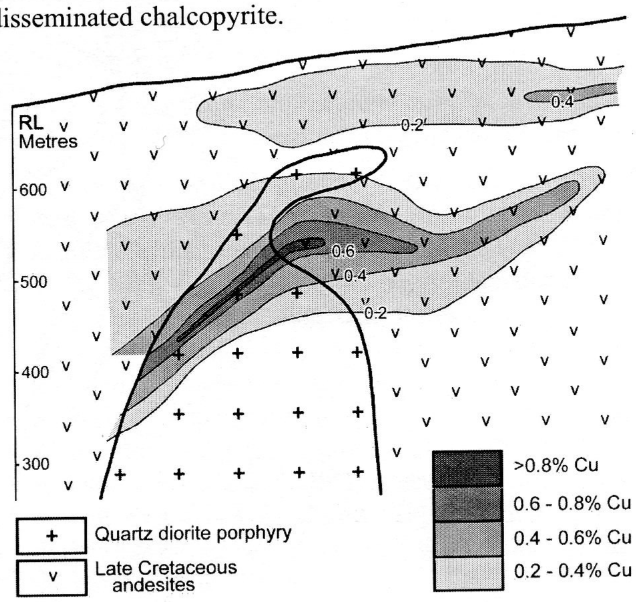

Figure 5: ***Sketch geological section through the Valja Strzh porphyry Cu deposit showing Cu grades.*** Other data suggest the deposit thickens and widens along trend.

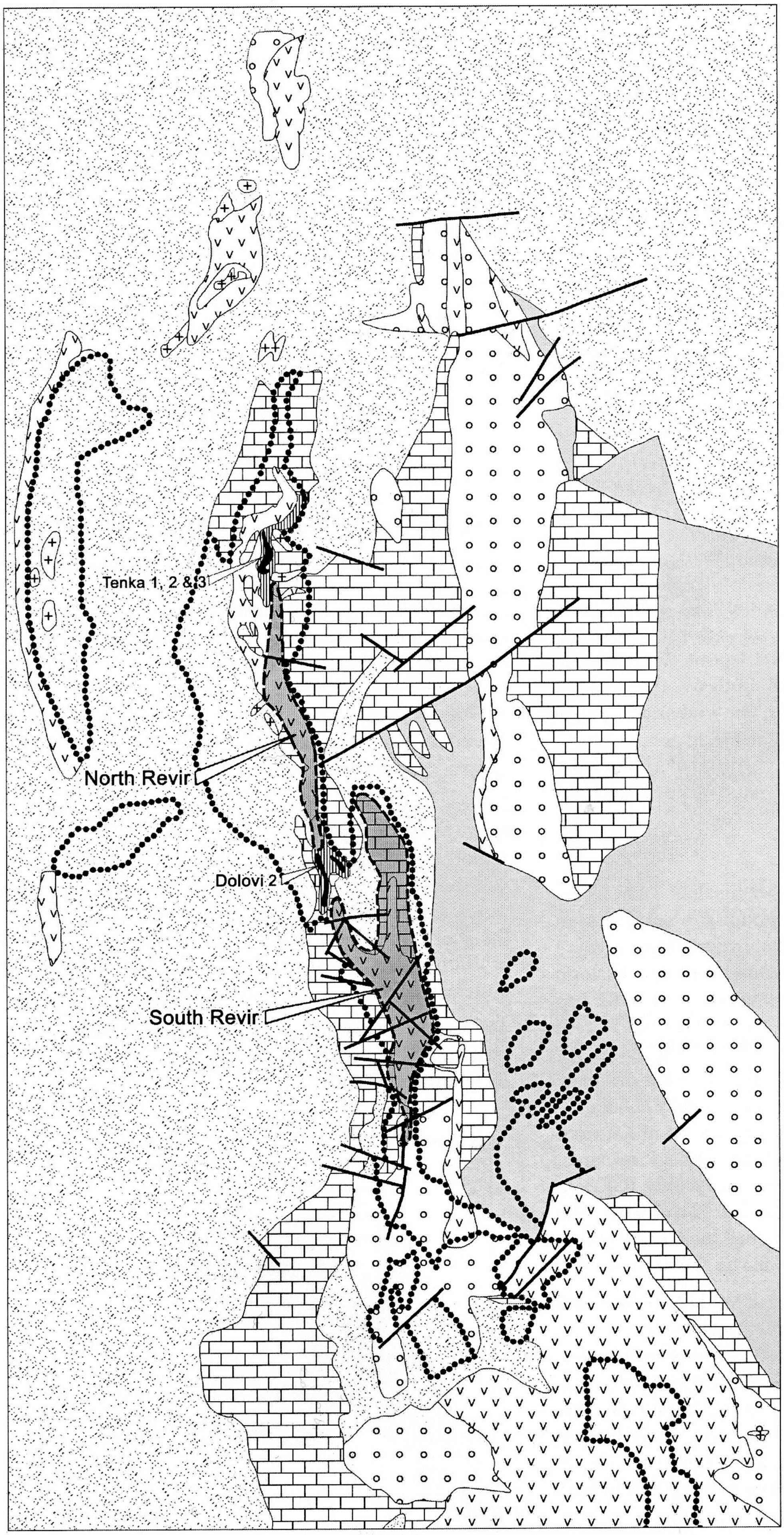

Figure 6: ***Geological map of the Majdanpek copper deposits and surrounding district.*** The sub-volcanic andesitic dyke complex on which the orebodies are centred lie within a pre-intrusive, 300 to 600 m wide, north to north-north-west trending zone of fracturing. This early fracturing is not shown on this plan. The structures illustrated are predominantly post-mineralisation (after Herrington *et al.*, 1998, Cocic *et al.*, 2002).

Footnote: The precise outline of the Dolovi-1 orebody and associated sub-volcanic andesite dykes could not be obtained to plot on this plan. These are believed to be located in the alteration zone to the west of the main North Revir orebody. They are illustrated on the geological cross section (Fig. 7), and are described in the text on page 464.

Plate 1: ***View looking north over Majdanpek South Revir*** (flooded in foreground – autumn 2002) with North Revir visible in the background behind ridge of trees left of centre. Majdanpek town is visible in the valley centre right. Mesozoic limestones form the background hills.

Valja Strzh and Dumitru Potok

The Valja Strzh and Dumitru Potok zones of porphyry style mineralisation are developed adjacent to the Late Cretaceous to Early Tertiary Crni Vrh plutonic complex which was emplaced along a regional fracture zone on the western margin of the TMC. This complex intruded Late Cretaceous (Turonian) andesites and in part into clay-rich sediments of similar age. The plutons are composite magmatic complexes represented by a potassic intrusive series. Initial strontium ratios ($^{17}Sr/^{16}Sr$) show variations between 0.708 and 0.714, indicating a continental crust contaminated mantle source. In the deeper parts of the complex, monzonite and granodiorite prevail, while syenite, quartz diorite and quartz diorite porphyry are developed along the margin (Terzic, 1966)

Copper mineralisation is related to hydrothermally altered intrusives and to andesitic sub-volcanic and extrusive complexes. Extensive zones of alteration occur at the margins and in the central parts of the plutonic complex in a zone which is over 8 km in length. Alteration facies include propylitic, dominated by chlorite and epidote with silicification and pyritisation (Jovanovic, 1974). Several occurrences of copper mineralisation have been so far identified but only two large, sub-marginal grade deposits of are known, namely Valja Strz and Dumitru Potok (see Fig. 5 and Table 3). There are some indications of epithermal mineralisation developed at the margins of these bodies (Jovanovic 1974).

Cerova

Cerova is a small porphyry copper deposit to the north of Bor, worked for its secondary enrichment zone.

The Majdanpek Deposit.

The Majdanpek deposit is located at the most northerly tip of the TMC (Fig. 2). The deposit is approximately 5 km in length with an average width of 300 m. Weak copper mineralisation (>0.1% Cu) has been detected to a depth of at least 1000 m (Cocic *et al.,* 2002). The elongate morphology of the mineralised system results from the mineralisation being focused on a Late Cretaceous andesitic dyke complex which was intruded into a 300 to 600 m wide zone of fracturing and pre-existing faulting which cuts Proterozoic to Cambrian metamorphic suites, Triassic clastic rocks and Jurassic limestone (Jelenkovic and Kozelj, 2002; Jankovic *et al.,* 1980).

Jelenkovic and Kozelj (2002) outline three tectonic stages key to the formation and location of the Majdanpek deposit:

i) *A pre-ore stage* consisting of the folding of the Proterozoic to Early Mesozoic basement, commencing in the Hercynian and involving the initiation of faulting. These faults underwent further reactivation during the Alpine orgeny, cumulating in the intrusion of the TMC along pre-existing north-south faults.
ii) *An intra-ore stage* saw the further reactivation of the major north-south fault zone that controls the spatial distribution of magmatic bodies and ore mineralisation. Jelenkovic and Kozelj (2002) suggest that during this period extensive localised faulting took place, improving the structural permeability and facilitating the passage of ore forming fluids.
iii) *A post-ore tectonic stage* resulted in the re-faulting of the newly emplaced orebody and was responsible for the structure observed today.

The country rocks to the deposit consist of Proterozoic amphibolites and gneisses; Cambrian phyllites, schists and subordinate amounts of marble with serpentinised lenses that are assumed to be metamorphosed igneous sheets (Cocic *et al.,* 2002). This metamorphic basement is unconformably overlain by a series of Mesozoic formations comprising Triassic conglomerates and sandstones, Upper Jurassic limestones and Senonian (Upper Cretaceous) Flysh deposits. The TMC is represented in the area by numerous smaller andesite dykes which follow the strike of the main north-south structural trend, and a number of minor diorite and quartz diorite intrusions and dykes. The presence of the diorite and quartz diorite bodies has been inferred to indicate a larger intrusion at depth (Jankovic, 1990). The relationship between the dyke complex and the mineralised stockwork shows that dyke emplacement took place pre-, syn- and post- the major stockwork forming event (Clarke and Ullrich, 2004).

Porphyry Copper Style Mineralisation at Majdanpek

The Majdanpek deposit is divided into two mining areas, North and South Revir. North Revir is characterised by the presence of polymetallic Pb-Zn-rich limestone replacement ores and smaller porphyry copper style bodies. In contrast, South Revir comprises the large porphyry copper occurrence, the Cu-Au-rich massive sulphide Knez Lazar body, and a number of contact skarns.

A total of 10 orebodies have been recognised at Majdanpek, including porphyry style, massive sulphide-limestone replacement and skarn ores. The locations of a selection of these bodies are shown on Fig. 6. The styles of mineralisation found in the Majdanpek deposit are described in Cocic *et al.,* (2002). The volumetrically most significant mineralisation types are the disseminated-stockwork-veinlet porphyry ores, the most significant of which is the South Revir orebody.

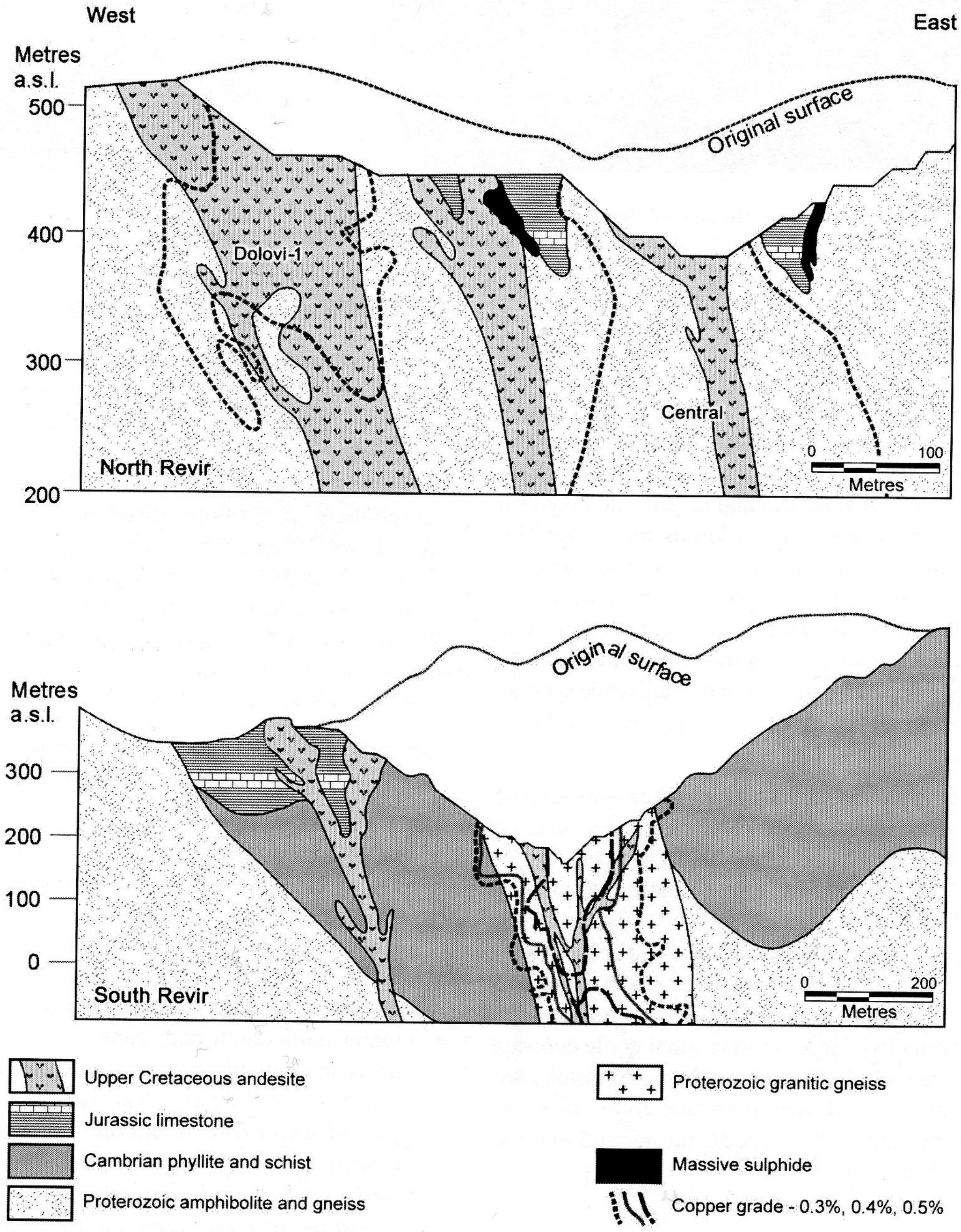

Figure 7: ***Typical cross sections through North Revir, Central Orebody (Top) and South Revir, Main Orebody (bottom)*** showing copper grade contours (after Herrington *et al.,* 2003).

South Revir Porphyry Copper

The main porphyry-copper mineralisation at South Revir has a prismatic form, with a north-south strike length of more than 2 km. The orebody width in a generally east-west direction ranges between 270 m and 350 m at the +110 m level (Cocic *et al.*, 2002). This reduces to a width of between 170 m and 250 m at the -100 m level (the current deepest level of exploration). Data from the Mine Geological Department indicates that there is an observed decrease in Cu grade with depth and it is postulated that overall, the orebody has a funnel shaped cross section (Fig. 7). Historic mine records show that the original vertical extent of the porphyry style mineralisation was approximately 800 m (from the +600 m to the –200 m level). While there is a consensus on the east-west limits of the mineralisation, there currently appears to be little knowledge of its north-south extent, particularly to the south (Cocic *et al.*, 2002; Zivkovic and Momcilovic, 2002).

The morphology of the orebody roughly follows that of the porphyritic dykes that intruded along the main north-south fracture zone. Two styles of porphyry-copper mineralisation are recorded from the South Revir orebody, namely a "stockwork" and an "impregnation-metasomatic" (disseminated) type (Cocic *et al.*, 2002). Reported grades show that the richest parts of the orebody were located in the higher sections of the system (+200 m level) and are associated with stockwork style mineralisation, averaging 1.5% Cu and 0.8 g/t Au. The grade diminishes as the stockwork is replaced by disseminated mineralisation, with grades averaging around 0.4% Cu and 0.25 g/t Au.

The ore mineralogy is dominated by chalcopyrite, accompanied by pyrite, magnetite and molybdenite. The overall Mo content of the deposit is low, averaging 0.003 to 0.008%. Minor minerals recorded include bornite, galena, sphalerite, marcasite, tetrahedrite, arsenopyrite, enargite, stannite and colusite, along with Ag-tellurides and Ag-selenides. Gold occurs in the native form and/or with sulphides. Of note is that minor amounts of PGE have historically been recovered from the concentrate. Jankovic (1990b) reported the occurrence of Pd-tellurides with traces of silver of the composition $Pd(Ag)Te_2$ up to $PdAgTe_2$.

The highest copper grades are found in the areas of K-silicate alteration close to the central parts of the orebody. This potassic alteration is spatially associated with strong silicification (Herrington *et al.*, 2003; Jelenkovic and Kozelj, 2002). The alteration mineralogy is characterised by an association of quartz, sericite, biotite, hydro-biotite and rare but poorly preserved K-feldspars. $^{40}Ar/^{39}Ar$ analysis of biotite samples from the potassic alteration yielded an age of 83.6 to 84.0±0.6 Ma, placing the main mineralisation at the Santonian-Campanian boundary in the Upper Cretaceous (Clarke and Ullrich, 2004).

The silicification of the potassic alteration is manifested by fine grained quartz veinlets and disseminations. Sericite is found as thin threads and appears to be closely associated with the silicification. The potassic alteration is surrounded by a zone of sericite-quartz-chlorite-calcite (Cocic *et al.*, 2002). The transition from potassic to sericite (phyllic) dominated alteration appears to correlate with the change from stockwork- to more disseminated-type pyrite-dominated mineralisation. Further from the core of the orebody alteration is represented by a more distal propylitic facies characterised by a chlorite-calcite ± sericite/epidote assemblage.

Skarn mineralisation is also developed at South Revir, following the contact between the andesite and quartz-diorite intrusives and Jurassic limestone. The skarn bodies, which consists of garnet, epidote, chlorite, calcite, magnetite

Table 4: *Summary of the types of mineralisation described at the Majdanpek deposit* (Cocic *et al.*, 2002).

Cu ore types	Description	Mineralogy
Impregnation-metasomatic (i.e. disseminated)	A finely disseminated ore consisting of very fine grained aggregates of predominantly pyrite and chalcopyrite with minor concentrations of rutile & magnetite. Sulphide deposition can be strongly correlated with altered former Fe-Mg silicates.	Mt-py-cp
Stockwork	Veinlets of pyrite, chalcopyrite, and magnetite with quartz ± carbonate ± sericite ± chlorite. Some veins show evidence of multiple deposition events. Veinlet thickness rarely exceeds 2 mm.	Py-cp-mt
Vein (stockwork)	Similar mineralisation to that of Stockwork-type, the key difference being vein widths of up to 20 mm. Non-ore minerals include quartz, carbonate, anhydrite and gypsum. It is from these veins that the most native gold has been observed in association with chalcopyrite.	Py-cp-mt
Massive sulphide	Massive pyrite bodies with subordinate chalcopyrite, sphalerite, and galena with quartz and carbonate gangue.	Py-cp-sl-gn
Oxidation zone	An oxidized zone of variable thickness (max 50 m), dominated by limonite with subordinate lazurite, malachite, native copper, cerussite, smithsonite, jarosite and cuprite. No gold has been observed.	Limonite
Supergene	Found in the highest levels of fault zones to a maximum depth of 15 m from surface with widths of up to 15 m. Cu-minerals includes chalcocite, covellite, bornite and idaite.	Co-cc-bn
Skarn	This style of mineralisation is very localised and occurs at contact zones between both andesites and quartz-diorite-porphyries with Jurassic limestones. Skarn bodies are generally of limited size and are dominated by magnetite with minor chalcopyrite, sphalerite and galena. Bornite is occasionally present..	Mt-(cp-sl-gn)

mt = magnetite; py = pyrite; cp = chalcopyrite; bn = bornite; co = covellite; cc = chalcocite; sl = sphalerite; gn = galena;

and hematite are small, with widths rarely exceeding a few metres before passing into marble and limestone. The metallic mineralisation associated with the skarns is predominantly magnetite with subordinate amounts of hematite, pyrite, chalcopyrite, and minor Pb-Zn sulphides and Pb-Sb sulphosalts (Herrington *et al.*, 2003; Cocic *et al.*, 2002). Grades of the order of 42% Fe, 2.35% Cu, 1.75 g/t Au and 4.2 g/t Ag have been reported from skarn ore (Jankovic,1990b).

North Revir Porphyry Copper

The North Revir area is located approximately 1 km north to northwest from the town of Majdanpek and comprises a number of orebodies. Porphyry copper mineralisation at North Revir consists of several small orebodies, none of which have either the tonnage or grade of those at South Revir. As a consequence, the North Revir area has not been as extensively explored or exploited. The two main examples of porphyry-style mineralisation at North Revir are the Central (North Revir) Orebody and Dolovi-1 (Fig. 7).

The Central Orebody has dimensions of approximately 1500 x 150 m and is ellipsoidal in plan. The remaining resource is estimated to have a grade of 0.29% Cu, 0.25 g/t Au at a 0.1% Cu cut-off. Its morphology and orientation is strongly controlled by a NNW-SSE striking fault zone along which a number of amphibole-biotite andesite dykes and quartz-diorite porphyries have intruded into the basement gneisses (Fig. 7). The known mineralisation extends over a vertical interval of approximately 600 m and comprises a stockwork of quartz-pyrite-chalcopyrite veins, with chalcopyrite being the main ore mineral. Other minerals present include minor amounts of magnetite, hematite, pyrite, arsenopyrite, marcasite, bornite, tetrahedrite, molybdenite, sphalerite, galena and native gold (Cocic *et al.*, 2002).

The stockwork is similar to that of the South Revir porphyry-style orebody and is characterised by a potassic K-feldspar-biotite altered core, with marginal silicification and sericite alteration. These alteration types in turn grade outwards to a peripheral propylitic zone, dominated by chlorite-calcite-epidote (Cocic *et al.*, 2002). The hypogene mineralisation is blanketed by an oxidation zone with a mean thickness of 25 m and mean grades of 0.45% Cu and 0.4 g/t Au. A striking feature of the Central Orebody is the development of smaller polymetallic and Cu-rich massive sulphide bodies that have formed at the contact zone between the intrusive andesites and Jurassic limestones (Cocic *et al.*, 2002).

The Dolovi-1 deposit is located approximately 200 m west of the Central Orebody and is another example of porphyry copper style mineralisation. At a 0.2% Cu cut-off, it is estimated to comprise 150 Mt @ 0.313% Cu, 0.109 g/t Au. In plan, the mineralised body is roughly ovoid in shape with a maximum strike length of 430 m and a width of up to 140 m. It is centred on a hornblende-biotite andesite that has been intruded into basement gneisses and amphibolites. All of the observed contacts are tectonic (Momclovic *et al.*, 2002). The host andesite is strongly silicified and propylitically altered, and is cross cut by quartz veins. In contrast to the Central Orebody and South Revir porphyry copper, no potassic core is observed (Momclovic *et al.*, 2002). The mineralisation comprises both stockwork and disseminated sulphides. Higher grades are associated with a stockwork of chalcopyrite-pyrite-quartz veins at the centre of the mineralised mass, which grades outward into lower grade disseminated sulphides.

Significant massive sulphide developments are hosted by Jurassic limestone units marginal to the porphyry mineralisation at the northeastern end of the North Revir pit. The Tenka polymetallic sulphide bodies (Fig. 6) contain a geological resource of approximately 4 Mt @ 8% Pb+Zn and 3 to 4 g/t Au, with a Zn:Pb ratio of around 5:1. The ore mineralogy comprises major sphalerite and galena, with associated pyrite, chalcopyrite, arsenopyrite and marcasite. Collomorphic sulphide textures are very common. Pb and Sb sulphosalts are present with Ag-rich tetrahedrite, freibergite and native gold. Quartz, calcite and rare barite are the main gangue minerals. These same limestones hosted the historically important Blanchard Fe-Cu-Au deposits, which originally comprised massive auriferous pyrite that was largely weathered to goethite with free gold. These small bodies outcropped and were exploited in the 19^{th} Century. The remnant ore has a grade of 1.1% Cu, 3.1 g/t Au. Systematic exploration for further carbonate-hosted deposits has not been carried out (P. Zivkovic, pers. comm.)

Summary

- The Majdanpek porphyry copper orebody is the largest and the most northerly deposit within the Timok Magmatic Complex (TMC) of eastern Serbia.
- Related magmatic rocks host significant porphyry-high sulphidation mineralisation to the southeast in Bulgaria (e.g., the Elatsite and Chelopech deposits of the Srednogorie district), and across the Danube river to the north of Majdanpek in Romania.
- The 86 to 83 Ma igneous rocks of the TMC show evidence for crustal contamination and are related to an eastward dipping continental subduction zone located to the west.
- Mineralisation, which has been dated at 83 Ma, is associated with sparse, narrow north-south trending, sub-volcanic andesitic dykes intruding a north-south fracture zone cutting Proterozoic and Palaeozoic metamorphic rocks and inliers of Jurassic limestone.
- Mineralisation is developed as stockworks, and disseminations, and as skarns and replacement bodies flanking the intrusives.
- The highest copper grades are found in zones of K silicate and silica alteration.
- The Majdanpek deposit has low Mo, contains PGE and has a Cu%:Au g/t ratio of around 2:1. Significant supergene upgrading is recorded over parts of the deposit.
- Numerous porphyry and high sulphidation prospects define a 20 km-wide corridor within the TMC, running for 40 km from Majdanpek in the north to Bor in the south.

References

Aleksic, D., 1969 - Results of two years of exploration at Veliki Krivelj (Rezultati dvogodisnjeg istrazivanja u Velikom Krivelju) *Zb. rad. Rud. met. fak. Inst., Bor,* za bakar IX, pp. 27-40 (*in Serbian*).

Aleksic, D., 1979 - The deposit Veliki Krivelj - Guide for Field Excursion, *Int. Conf. of European Copper Deposits,* RTB Bor, Bor, pp. 39-51.

Andric, B., Antonijevic, I., Grubic, A., Dragasevic, T., Djordjevic, M., and Terzic, M., 1972 - Analiza Geoloska grade Timockog Sinklorijum u svertosti novih geoloskih istrazivnja. III Savetovanje o istrazivnja bakrove mineralizacje na teritriji *SFRJ, RTB*, Bor.

Banjesevic, M., Cocic, S. and Radovic, M., 2002 - Petrographic-Geochemical characters and K-Ar ages of late Cretaceous volcanic rocks in the Bor Zone part of the Timok Magmatic Complex (Eastern Serbia*). Rev Roum. Geolgie.* v. 46, pp. 47-59.

Banjesevic, M., Cvetkovic, D., Kozelj, D., Peytcheva, I. and von Quadt, A., 2002 - The Timok magmatic complex and Ridanj-Krepoljin Zone: Geodynamic Evolution; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference; Abstracts Bor 100 years, 2002.

Berza, T., Constantinescu, E. and Vlad, S.N., 1998 - Upper Cretaceous magmatic series and associated mineralisation in the Carpatho-Balkan Orogen. *Resource Geology,* v. 48, pp. 291-306.

Bonev, I.K., Kerestedjian, T., Atanassova, R. and Andrew, C.J., 2002 – Morphogenesis and composition of native gold in the Chelopech volcanic-hosted Au-Cu epithermal deposit, Srednogorie zone, Bulgaria; *Mineralium Deposita,* v. 37, pp 614-629.

Breithaupt, J.F.A., 1861 - Timazit, eine neue Gesteinart, und Gamsigradit, ein neuer Amphibol. *Berg-und-Hüttenmännische Zeitung.* Freiberg, Leipzig. v. 20, pp. 51-54.

Ciobanu, C.L., Cook, N.J. and Stein, H., 2002 - Regional setting and geochronology of the Late Cretaceous Banatitic Magmatic and Metallogenetic Belt. *Mineralium Deposita*, v. 37, pp. 541-567.

Cioflica, G. and Vlad, S., 1984 - Alpine metallogeny in Romania. *An Inst Geol, Geofiz,* Bucharest, v. LXIV, pp. 174-175.

Clark, A.H. and Ullrich, T.D., 2004 - ^{40}Ar-^{39}Ar age data for andesitic mamgatism and hydrothermal activity in the Timok Massif, eastern Serbia: Implications for metallogenic relationships in the Bor copper-gold subprovince; *Mineralium Deposita,* v. 39, pp. 256-262.

Cocic, S., Jelenkovic, R.J. and Zivkovic, P., 2002 - Excursion Guide: Symposia Bor 100 years 24-25 October 2002, Bor, Serbia, ISBN 86-84265-00-9.

Djordjevic, M. and Banjesevic, M., 1997 - Geology of the southern part of the Timok Magmatic Complex. Booklet and Geological Map 1:50 000, *Federal Ministry of Economy*, Belgrade, *(in Serbian).*

Djordjevic, M. and Banjesevic, M., 1998 - Development of the Cretaceous volcanism in the Timok-Sredja Gora belt southwardly from the Bor Mine (Eastern Serbia), *Carpathian-Balkan Geological Association* XVI Congress – Abstracts Vienna, Austria, p. 132.

Drovenik, M., 1960 - Geolosko-petroloska studija sire okoline rudnika Bor / Istocna Srbija/, Doktorska disertacija, Fond strucnih dokumentacija *RTB Bor*, Bor.

Drovenik, M., Antonijevic I. and Mici, I. 1962 - Novi pogledni na magmatiza I geolosku gradju Timocke eruptivne oblasti. *Vesnik Geozavoda*, Ser. A. Knj. XX, Beograd, pp. 67-79.

Heinrich, C.A. and Neubauer, F. 2002 - Cu-Au-Pb-Zn-Ag metallogeny of the Alpine-Balkan-Carpathian-Dinaride geodynamic province, *Mineralium Deposita,* v. 37, pp. 533-540.

Herrington, R.J., Jankovic, S.R. and Kozelj, D.I., 1988 - The Bor and Majdanpek copper-gold deposits in the context of the Bor Metallogenic Zone (Serbia, Yugoslavia): *in* Porter, T.M., (Ed.), Porphyry and Hydrothermal Copper and Gold Deposits - A Global Perspective, *PGC Publishing,* Adelaide, pp. 185-194.

Herrington, R.J., First, D.M. and Kozelj, D.I., 2003 - Copper porphyry deposits of Hungary, Serbia, Macedonia, Romania and Bulgaria. *in* Europe's Major Base Metal Deposits. *Irish Association for Economic Geology*, Dublin, pp. 303-322.

Jankovic, S., Terzic, M., Aleksic, D., Karamata, S., Spasov, T., Jovanovic, M., Milicic, M., Miskovic, V., Grubic, A. and Antoniievic, I., 1980 - Metallogenic features of copper deposits in the volcano-intrusive complexes of the Bor district, Yugoslavia; *in* Jankovic, S. and Sillitoe, R., (Eds.), European Copper Deposits, *SGA* Special Publication 1 and *Department of Economic Geology, Faculty of Mining and Geology,* Belgrade University, pp. 42-49.

Jankovic, S.R., 1982 - Yugoslavia; in Dunning, F.W., Mykura, W. and Slater, D., 1982 - Mineral Deposits of Europe, v. 2 Southeast Europe, *The IMM, and The Mineralogical Society,* London, pp. 143-202.

Jankovic, S.R., 1990 - Types of ore deposits related to volcanic environments in the Bor district, Yugoslavia. *Geologische Rundschau*, v. 79, pp. 456-478.

Jankovic, S.R., 1990b - Ore deposits of Serbia: Regional metallogenic settings and types of deposit. *Rud. Geol. Fak.* Beograd, 760p.

Jankovic, S.R., Jelenkovic, R.J. and Kozelj, D., 2002 - The Bor Copper and Gold Deposit, Mining & Smelting Basin Bor and the Copper Institute Bor, Bor, Serbia ISBN 86-84265-01-7.

Jelenkovic, R.J. and Kozelj, D.I., 2002 - Morphogenetical types of porphyry copper mineralisation in the Bor Metallogenic Zone; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference Abstracts, Bor 100 years, 2002; pp. 29-56.

Jovanovic, M., 1974 - Porphyry copper deposits of the Dumitru Potok - Valja Strz area (Porofiska rudista bakra u reonu Dumitru Potok - Valja Strz), Mag. Thesis, *Faculty of Mining and Geology, Belgrade University*, pp. 143-202.

Karamata, S., Knezevic-Djordjevic, V. and Milovanovic, 2002 - A review of the evolution of upper Cretaceous-Paleogene magmatism in the Timok Magmatic Complex and the associated mineralization; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference Abstracts, Bor 100 years, 2002; pp. 15-28.

Karamata, S., Knezevic, V., Pécskay, Z. and Djordjevic, M., 1997 - Magmatism and metallogeny of the Ridanj-Krepoljin belt (eastern Serbia) and their correlation with northern and eastern analogues. *Mineralium Deposita,* v. 32, pp 452-458.

Kozelj, D., 2002a - Epithermal Gold Mineralization in the Bor Metallogenic Zone. *Pub of The Copper Institute, RTB Bor,* Bor, *(in Serbian with English Summary).*

Kozelj, D., 2002b - Morphogenetical types of epithermal gold mineralization in the Bor Metallogenic Zone; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference Abstracts, Bor 100 years, 2002; pp. 57-70.

Lips, A.L.W., 2002 - Correlating magmatic-hydrothermal ore deposit formation over time with geodynamic processes in SE Europe. *in* Blundel, D.J., Neubauer, F. and von Quadt, (Eds.) - The Timing and Location of Major Ore Deposits in an Evolving Orogeny. *Geological Society of London,* Special Publication 204, pp. 69-79.

Lips, A., Herrington, R., Stein, G., Kozelj. D., Popov, K. and Wijbrans, J., 2004 - Refined timing of porphyry copper formation in the Serbian and Bulgarian portions of the Cretaceous Carpatho-Balkan Belt, *Economic Geology,* v. 99, pp. 601-609.

Mitchell, A.H.G., 1996 - Distribution and Genesis of some epizonal Zn-Pb and Au provinces in the Carpathian-Balkan Region. *Trans. Inst. Min. Metall.* B105: pp. 127-138.

Momclovic, S., Zivkovic, P. and Krstic, S., 2002 - Geological characteristics of the ore body Dolovi-1 copper deposit Majdenpek; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference Abstracts, Bor 100 years, 2002; pp. 181-187.

Monthel, J., Vadala, P., Leistel, J.M. and Cottard, F., 2002 - Mineral deposits and mining districts of Serbia, compilation map and GIS databases; *Republic of Serbia, Ministry of Mining and Energy;* Publication BRGM/RC-51448-FR. Also available from http://www.mineralinfo.org/Cartes/Serbie/serbie.htm.

Pécskay, Z., Djordjevic, M., Karamata, S. and Knezevic, V., 1992 - First Data on the age of the volcanic rocks from the Ridanj-Krepoljin zone. *Zapisnici SGD,* zbor 24.12.1992. Beograd *(In Serbian).*

Ralevic, B., Antonijevic, I. and Zivkovic, P., 1997 - Mineral Deposits of the Derdap Region, Serbia. International Symposium - *Geology in the Danube Gorges,* Yugoslavia and Romania. pp. 155-161.

Richards, J.P., 2003 - Tecton-magmatic precursors for porphyry Cu-(Mo-Au) deposit formation. *Economic Geology,* v. 98, pp. 1515-1533.

Strashimirov, S., Petrunov, R. and Kanazirski, M., 2002 – Porphyry-copper mineralisation in the central Srednogorie zone, Bulgaria; *Mineralium Deposita,* v. 37, pp. 587-598.

Strashimirov, S. and Popov, P., (Eds.), 2000 - Geology and metallogeny of the Panagyurishte ore region (Srednogorie Zone, Bulgaria). Geodynamics and ore deposits evolution of the Alpine-Balkan-Carpathian-Dinaride Province. ABCD-GEODE Workshop, Borovets, Bulgaria, Guide to excursions *A and C. Publishing House*, St. Ivan Riliski, Sofia.

Terzic, M., 1966 - Dimitru Potok - Valja Strz; *in* Review of Detailed Exploration of the Timok Volcanic Massif (Dimitru Potok - Valja Strz; *u* Prikaz detaljnije istarzivanih zona u Timockom eruptivnom masivu) - *Conference on the results of exploration of copper mineralisation on the territory of SFRJ;* Bor, pp. 1-29 (*in Serbian*)

Tobey, E., Schneider, A., Alegria, A., Olcay, L., Perantonis, G. and Quiroga, J, 1998 – Skouries porphyry copper-gold deposit, Chalkidiki, Greece: Setting, mineralization and resources: *in* Porter, T.M., (Ed.), Porphyry and Hydrothermal Copper and Gold Deposits - A Global Perspective, *PGC Publishing,* Adelaide, pp. 175-184.

Vlad, S (1984) Alpine porphyry copper occurrences in Romania. *Bull. Acad. Serbe. Sci. Arts,* LXXXIV, Class Sci Nat Math, v. 25, pp. 111-127.

Von Quadt, A., Peytcheva, I., Cvetkovic, D. and Banjesevic, M., 2002 - Geochronology, geochemistry, and isotope tracing of the Cretaceous magmatism of East-Serbia and part of the Apuseni-Timok-Srednogorie metallogenic belt. *Geologica Carpathica,* v. 53, pp. 175-177 (Special Issue).

Zivkovic, P. and Momcilovic, S., 2002 - Vertical distribution of gold and silver in different types of Cu-Au and polymetallic ore bodies of the North Revir Deposit Majdenpek; *in* Geology and Metallogeny of Copper and Gold Deposits in the Bor Metallogenic Zone, Conference Abstracts, Bor 100 years, 2002; pp. 173-180.