Cardiff University SEG Student Chapter

Balkans Field Trip Report, June 13th-20th 2018

Jamie Price, President

Society of Economic Geologists Student Chapter

Following the success of our previous international field trips to Finland in 2016 and Sweden in 2017, this year we decided to head further southeast in Europe to visit some of the Balkan nations, namely Bulgaria, Serbia and Macedonia. These Balkan nations have only been the subject of commercial exploration for the last 15-20 years, with some impressive discoveries made over the past few years. In addition to this, there are also several well established larger mines that have been in operation for many decades. We thought this combination of new exploration projects and established operating mines would be ideal for a student fieldtrip, since it gives an insight into the full exploration and mining cycle for the participants.

The 8-day field trip was organised by the Cardiff SEG President Jamie Price for a total of twelve participants, comprising five undergraduate students from Cardiff University, an undergraduate from Brighton University, three PhD students from Cardiff University, University of Edinburgh and Durham University, and two recent graduates working in the industry. Having participants from four universities (including both undergrad and postgrad) as well as two industry professionals was great as it allowed for a wider knowledge base, as well as a chance for networking and setting up collaborations in the future.

We gratefully acknolwedge SRK Consulting and the SEG Stewart R. Wallace fund, both of which provided financial support for the trip. Our thanks also extend to the companies visited during the course of the trip – Assarel Medet, Nevsun Resources, SGS Laboratories, Dundee Precious Metals, Avala Resources and Central Asia Metals.

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Field Trip Participants

Name	Year of Study	Institution
Jamie Price	2nd year PhD	Cardiff University
Ben Williams	-1st year PhD	Cardiff University
Andrew Dobrzanski	3rd year PhD	University of Edinburgh
Josh Hughes	2nd year PhD	Durham University
Vlad Simov	MSc Graduate	Cardiff University/Sanctus
Huw Edwards	BSc Exploration Graduate	Cardiff University/RPS
Jake Garland	3rd year BSc Exploration	Cardiff University
Josh Mallett	2nd year BSc Exploration	Cardiff University
Jamie Fallows	3rd year BSc Exploration	Cardiff University
Chris Bowrey	2nd year BSc Geology	Cardiff University
Sam Bruce	2nd year BSc Exploration	Cardiff University
Marcus Skelton	3rd year BSc Geology	University of Brighton

Geological Overview

Bulgaria is situated in the south-eastern part of the Balkan Peninsula and lies almost entirely within the Alpine geosynclinal belt. Many of the rocks in the region have been subject to both Tethyan and Alpine deformation following closure of the Neothethys and Alpine Tethys oceans. Closure of these oceans involved multiple subduction events and subsequent collision between the African, Arabian and Indian plates with the Eurasian plate and resulted in intense orogenesis and magmatism. Bulgaria is host to a diverse geology and as such, is also host to a diverse range of mineralization styles, including porphyry copper and epithermal Cu-Au mineralisation, skarn-copper, sediment-hosted polymetallic deposits and vein-type gold deposits. Bulgaria occupies a leading position in European mining, ranking second in gold and third in copper production on the continent. Recent data from the World Gold Council showed that Bulgaria has the seventh richest gold reserve across Central and Eastern Europe

Field Trip Rationale

The Balkan nations were chosen as the destination for our 2018 International Field Trip for a number of reasons. Firstly, the area has recently been the focus of renewed exploration, with some very interesting discoveries of late. Secondly, the area also has quite a few established mines, which have been in operation for many decades. And thirdly, there is a significant variation in the style and type of mineralisation found in the region. The field trip was structured such that the participants could see each of the stages involved in the exploration and mining cycle; from initial exploration and assaying, to mature exploration, to mining (both open cast and underground) and lastly mineral processing. Firstly, we started by visiting two exploration projects in Serbia, one of which is likely to make it to production in the next few years. We also visited the SGS laboratories in Serbia to see the process involved in assaying samples - a key component of exploration. We then made our way to southeastern Bulgaria, to see a deposit that has been brought through the exploration and resource evaluation phase, and is due to be mined within months of our visit. In the latter part of the trip, we visited two mature mine sites, one open cast Cu-Au and the other underground Pb-Zn-Ag, for participants to see each of the mining techniques in action. We were also able to have tours of the processing facilities at these two sites, completing the overall mining cycle and providing an excellent, industry focussed insight into the mining and exploration industry for all those in attendance.

This report outlines our activities over the duration of the trip, with some images of the group in action.

Field Trip Outline

Day 1 *Wed 13th June:* Depart Cardiff for London Heathrow. Flight from London Heathrow to Sofia. Drive to Bor, Serbia.

Day 2 *Thu 14th June:* Visit to Timok Au Project (Avala/Dundee). **8:30** Arrival to Avala office and safety induction

Day 3 Fri *15th June:* AM Visit to Cukaru Peki Project (Nevsun). PM Visit and tour of SGS Laboratories.

Day 4 *Sat 16th June:* Long drive from Bor, Serbia to Krumovgrad, Bulgaria.

Day 5 Sun *17th June:* Ada Tepe Mine visit.

Day 6 Mon *18th June:* Long drive from Krumovgrad, Bulgaria to Vinica, Macedonia.

Day 7 Tue *19th June:* Sasa underground Pb-Zn mine visit. Drive to Sofia, Bulgaria.

Day 8 Wed *20th June:* Assarel Mine visit. Late PM return to Sofia Airport. Depart Sofia to London Heathrow. Return to Cardiff.

Day 1: Wednesday 13th June

An early start was required to commence the trip, departing Cardiff at midnight and making our way to London Heathrow for a 6:30am flight to Sofia, Bulgaria. Upon arrival just before lunchtime, we collected the hire cars and our belongings and embarked on the first leg of our journey – a 240 kilometre drive across the border to the industrial town of Bor, Serbia. A visit on the way to some friends of one of the participants gave us a great insight into the local culture. A family we had never met before took us into their home, gave us a traditional Bulgarian lunch and a taste of some home-brewed Bulgarian alcohol (the latter not consumed by drivers of course!), before we continued on our way. We arrived into Bor at about 6pm, giving us just enough time for delicious Serbian buffet of grilled meats and an early night ready for a busy week.

Timok Au Project - Introduction

Owned by: Avala Resources (Dundee Precious Metals)

Commodity: Au

Development Stage: Exploration

Geological Setting/Genetic Model: Sed-hosted Au/Carbonate Replacement Au

Location and Access: 270 km southeast of Belgrade, near Bor

Geological Domain: Timok Magmatic Complex

The Timok Magmatic Complex (TMC) is a northerly orientated, 85 x 25 km volcanic and intrusive complex located in eastern Serbia (Figure 1, 2). It represents a fragment of a Late Cretaceous Alpine magmatic arc caught up within the Carpathian-Balkan orogenic belt, which formed during closure of the Neotethyan ocean (Neubauer, 2002). From its base, the complex typically comprises clastic sedimentary rocks and Cretaceous limestones, overlain by andesitic volcanic and volcaniclastic rocks, all of which are intruded by several generations of high K, calc-alkaline intrusives (typically diorites and monzonites; Figure 3). The TMC is structurally complex and broadly deformed into a large-scale synclinal fold (Knaak et al., 2016). Magmatism has been documented over a 12 Ma period from 89 Ma to 77 Ma, and typically youngs from east to west. Several models have been proposed for the tectonic setting of the TMC, including rifting of the Variscan basement, a back-arc/pull apart basin developed due to late Cretaceous subduction and a pull apart basin formed due to oblique subduction via transpression (Knaak et al., 2016).

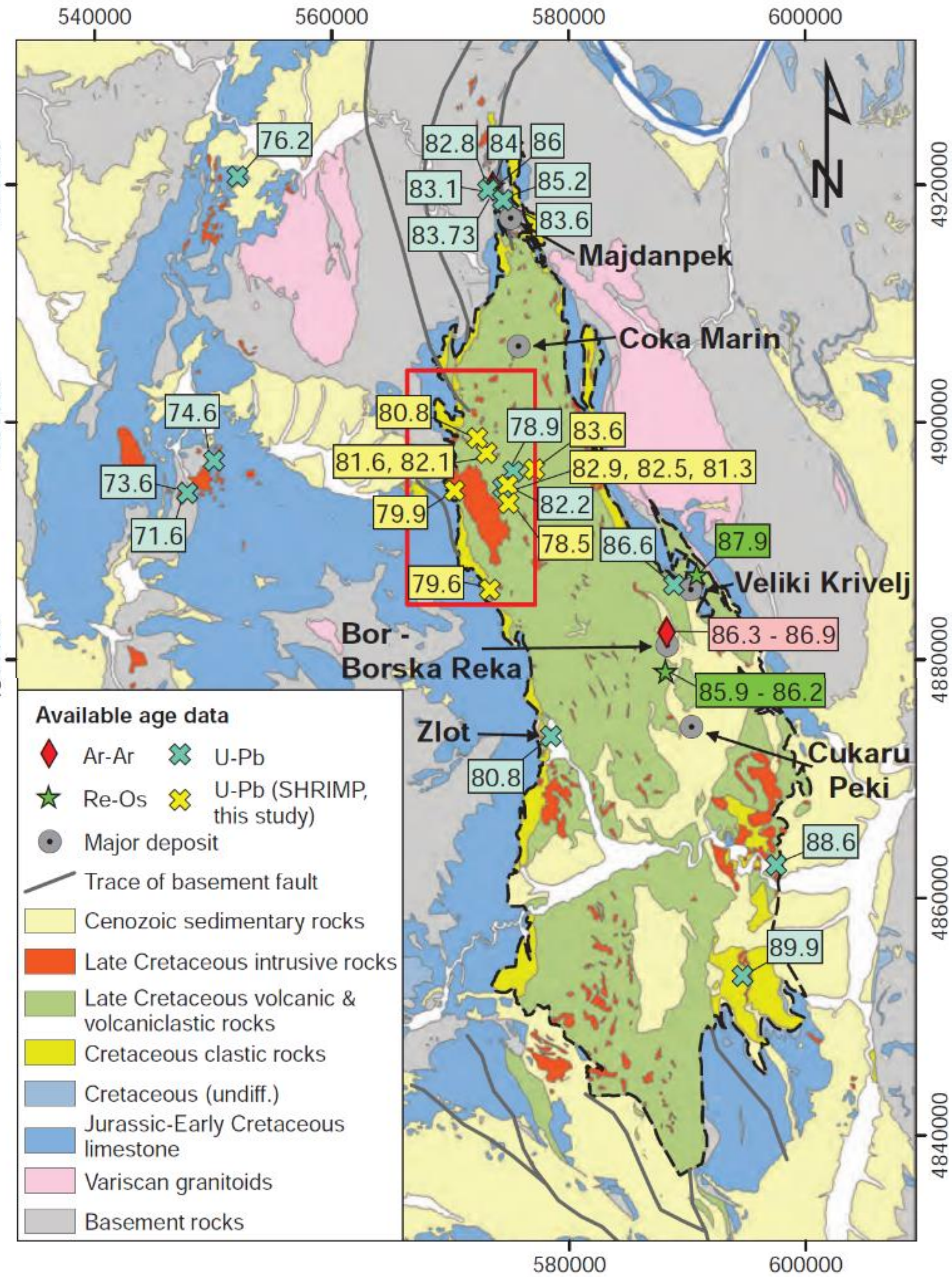
Most importantly, the TMC forms an important part of the Balkan metallogenic belt and is host to a range of mineralisation styles and some world class deposits. The eastern margin is host to *high-sulphidation Cu-Au* and *porphyry Cu-Au deposits* of the Bor metallogenic zone, whereas the rest of the complex is host to smaller porphyry Cu-Au, high sulphidation epithermal, polymetallic replacement and skarn-type deposits (Knaak et al., 2016; Figure 2). A subsidiary of Dundee Precious Metals, Avala Resources, are operating in the area and are exploring primarily for sedimentary-hosted Au-Ag deposits.

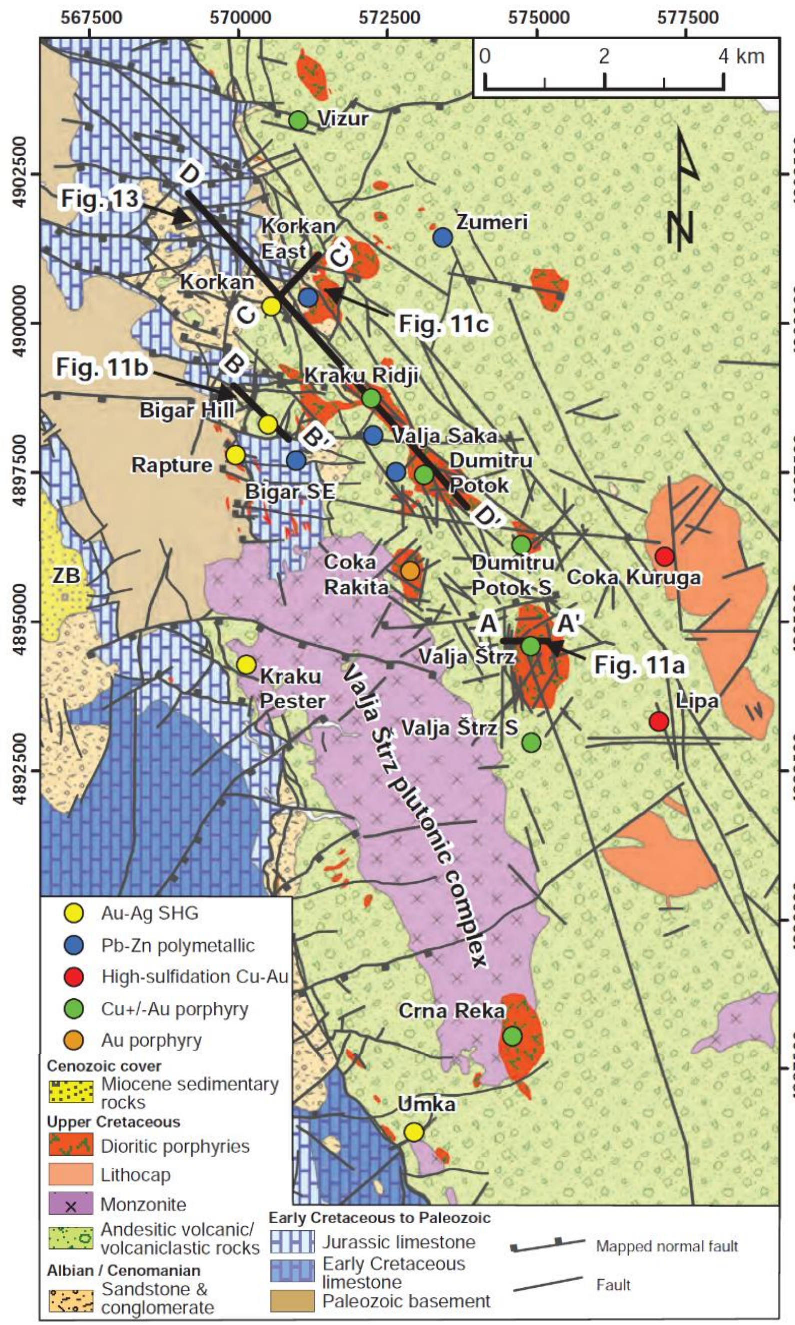
Local Geology

Gold and silver in sedimentary rocks have been identified at several prospects along the northwest margin of the TMC, including **Bigar Hill**, **Korkan** and Kraku Pester prospects (Figure 2). At these locations, gold is primarily located along two major stratigraphic contacts in the basal clastic sedimentary sequence underlying the volcanics. Gold is located primarily along two major stratigraphic contacts (informally S1, S2) in the clastic sedimentary sequence underlying the andesitic volcanic rocks (Knaak et al., 2016). At Korkan and Bigar Hill, the lower Au-bearing horizon is located at the unconformable breccia/karstic contact between a lower Cretaceous limestone and a calcareous quartz-rich sandstone (Figure 3) At Bigar Hill, the more continuous upper Au-bearing horizon lies between a grey quartz-rich sandstone and a red, volcanic-rich sandstone – this zone is largely missing from the Korkan prospect due to erosion. Though less significant, gold is also found in steeply dipping faults and fracture zones cross cutting the clastic units. At Bigar Hill, gold is also found in quartz vein replacement zones in a hydrothermally altered dioritic sill (Knaak et al., 2016).

Mineralogy

Mineralisation within the auriferous horizons is characterised by micron-sized gold grains, typically associated with fine-grained pyrite in decarbonated clastic sedimentary rocks, or as part of the karst infill. Gold and silver are also closely associated with clay minerals (including kaolinite, illite, smectite), with an ore assemblage containing pyrite, As-rich pyrite, marcasite, stibnite and tellurides (Knaak et al., 2016). Elevated gold concentrations tend to occur in Fe-rich rocks, suggesting that sulphidation reactions had an important role in controlling Au deposition. High gold concentrations also coincide with low Ca, due to hydrothermal activity removing diagenetic carbonate (Knaak et al., 2016). Au displays a low temperature metal association with As, Hg, Tl, S and Sb, with minor base metals and a high





Figures 1 and 2: 12 = Simplified geological map of the Timok Magmatic Complex (black dashed), with ages frovided for multiple units. Red box outlines Figure 13. 13 = Generalised geological map of the northwestern area of the Timok magmatic complex, eastern Serbia. From Knaak et al. (2016).

Au/Ag ratio. At Kraku Pestar, native sulphur and realgar (As_4S_4) are identified – minerals which are only stable at temperatures of less than 200°C. These minerals and element associations indicate a relatively shallow depth of formation, or one that is distal to a high temperature hydrothermal fluid source (Knaak et al., 2016).

In 2017, Avala Resources carried out a total of 9335 metres of diamond drilling at the Timok Gold Project, including 6770 metres at Korkan West (41 holes), in addition to ground magnetics, induced polarisation and resistivity geophysical surveying, an extensive soil sampling program and almost 7km of trenching (DPM, 2018). Decent intersects from the Korkan deposit include 64m @ 1.15 g/t Au and 57m @ 1.21 g/t Au. Recent drilling at Korkan and Bigar hill has served to confirm the structural setting, stratigraphy and the lithological relationships of the gold mineralisation present (DPM, 2018).

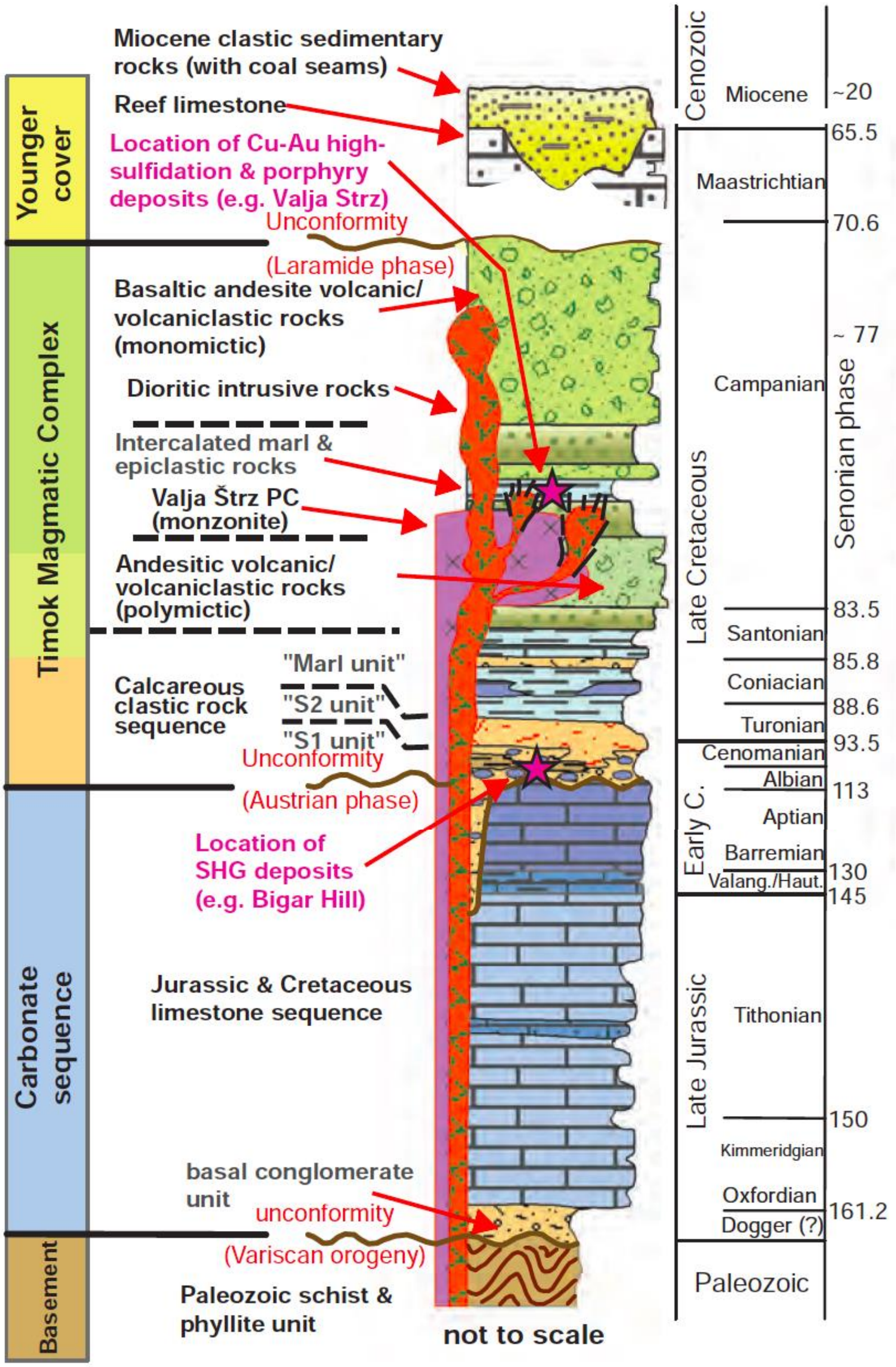


Figure 3: Generalised stratigraphic columns for the northwest Timok Magmatic Complex (TMC), eastern Serbia. The location of sedimentary-hosted Au deposits and porphyry Cu-Au deposits is shown. From Knaak et al. (2016) after Jelenkovic et al., 2016).

Day 2: Timok Au, Thursday 14th June

On the second day of the trip, we undertook our first visit to the Timok Au Project, currently operated by Avala Resources, a subsidiary of Dundee Precious Metals. The company are exploring primarily for sedimentary-hosted Au-Ag deposit associated with the Timok Magmatic Complex (TMC) of eastern Serbia. Gold and silver anomalies have been identified at several prospects along the northwest margin of the TMC, including **Bigar Hill**, **Korkan** and Kraku Pester prospects. At these locations, gold is primarily located along two major stratigraphic contacts in the basal clastic sedimentary sequence underlying a volcanic package.

We had the opportunity to visit the active exploration area and got to see the intense alteration associated with mineralisation in the field. Sedimentary-hosted Au is not a deposit type that is taught in detail in undergraduate geology programs, so it was great for the students to see this style of mineralisation in the field. We continued to the coreshed to see some of the best intercepts, and to see exactly what a section through the ore zone looked like. During the visit, two participants, Jamie Price and Josh Hughes, gave presentations to the Avala staff, providing them with an insight into their PhD research on gold mineralisation.

Towards the end of the visit in the late afternoon, the Avala team invited us to their monthly BBQ outside the core shed, which we accepted in a heartbeat. With a range of delicious BBQ food, we spent the rest of the evening chatting with the staff and trying some of the local delicacy, Rakija, before heading back to the hotel.

Jake enjoying the alteration present in one of the high grade ore zones

Participants checking out the outcrop

Looking at alteration in drillcore

Relaxing in front of the BBQ with some of the locals

Cukaru Peki Project - Introduction

Owned by: Nevsun Resources

Commodity: Cu-Au

Development Stage: Exploration/Resource Definition

Geological Setting/Genetic Model: Porphyry Cu-Au

Location and Access: 5km south of Bor, access by road

Geological Domain: Timok Magmatic Complex

First Operational: Not yet…

See Regional Geology for Timok Au Project

Cukaru Peki is a copper-gold mineralised deposit located within the Bor district of the Timok Magmatic Complex, situated about 5 kilometres south of the mining town of Bor. The deposit consists of two different styles of copper-gold mineralisation, namely the Upper Zone and the Lower Zone. The Upper Zone comprises high sulphidation epithermal Cu-Au mineralisation and occurs at depths of 450-850m below surface, whereas the Lower Zone consists of porphyry Cu-Au style mineralisation and is found from 700 to at least 2200m depth. As of March 2018, the deepest drillhole drilled terminated in porphyry mineralisation at 2268m depth (Nevsun, 2018).

Local Geology

The Cukaru Peki deposit is hosted by Upper Cretaceous andesitic volcanics (89-84 Ma), overlain by a clastic sequence of siltstones, conglomerates and sandstones. Up to 500m of poorly consolidated Miocene sedimentary rocks unconformably overlie the Cretaceous clastic sequence, essentially blanketing the deposit (Figure 4). The largest porphyry and porphyry epithermal deposits in the area, the Majdanpek and Bor Cu-Au deposits, are also hosted in Upper Cretaceous andesitic volcanic units. Andesitic volcanics within the Timok Magmatic Complex are typically calc-alkaline in composition, with a geochemical signature similar to adakites, and are interpreted to have been erupted within a rift basin. At Cukaru Peki, the Cretaceous sedimentary sequence is intruded by multi-stage plutonic intrusions, typically monzogranitic, dioritic and granodioritic in composition (Figure 4).

Mineralogy

Upper Zone epithermal mineralisation is associated with strong advanced argillic alteration. The top third is characterised by a massive sulphide lens overlying a volcanic-volcaniclastic sequence, with a change to vein- and stockwork-hosted mineralisation with depth in more coherent andesite (Nevsun, 2018; Figure 5). The massive sulphide assemblage consists primarily of multiple pyrite phases and covellite (CuS), with lesser chalcocite and bornite, and hosts the highest concentrations of gold and copper. Enargite is also frequently identified, and is often rimmed by covellite (interpreted as later in the paragenetic sequence). Minor disseminated or veinlets of galena and sphalerite are observed around the margins of mineralisation. The Upper Zone also contains mineralised hydrothermal breccias in places, with multiple phases of brecciation evident. Native gold is rare and when found is very small (2-6 µm); instead, gold is present as telluride minerals such as calaverite ($AuTe_2$), sylvanite ($(Au,Ag)Te_2$) and kostovite ($AuCuTe_4$), typically hosted in pyrite but locally observed enclosed within bornite (Nevsun, 2018; Cornejo, 2017).

In contrast, the Lower Zone porphyry Cu-Au mineralisation comprises quartz-sulphide veins and disseminated sulphides, associated with a multi-stage dioritic intrusion. The alteration footprint of the Lower Zone is much larger, with a much large alteration footprint, including potassic alteration overprinted by quartz-sericite alteration. It is thought that the Lower zone represents the source of hydrothermal fluids for the overlying Upper Zone mineralisation (Nevsun, 2018).

The Measured and Indicated Resource for the Upper Zone is estimated at 29 Mt at an average grade of 3.7% Cu and 2.4 g/t Au, containing 1.1 million tonnes Cu and 2.2 million ounces of Au. Furthermore, the Inferred Resource for the Upper Zone is estimated at 14 Mt at 1.6% Cu and 0.9 g/t Au containing 0.23 million tonnes of Cu and 0.42 million ounces of Au. Currently, the deposit boasts a 10-year mine life, that would produce over £1.7 billion of payable copper. The Upper Zone is owned entirely by Nevsun, whereas the Lower Zone is divided in ownership between Nevsun (60.4%) and Freeport-McMoRan Exploration (39.6%).

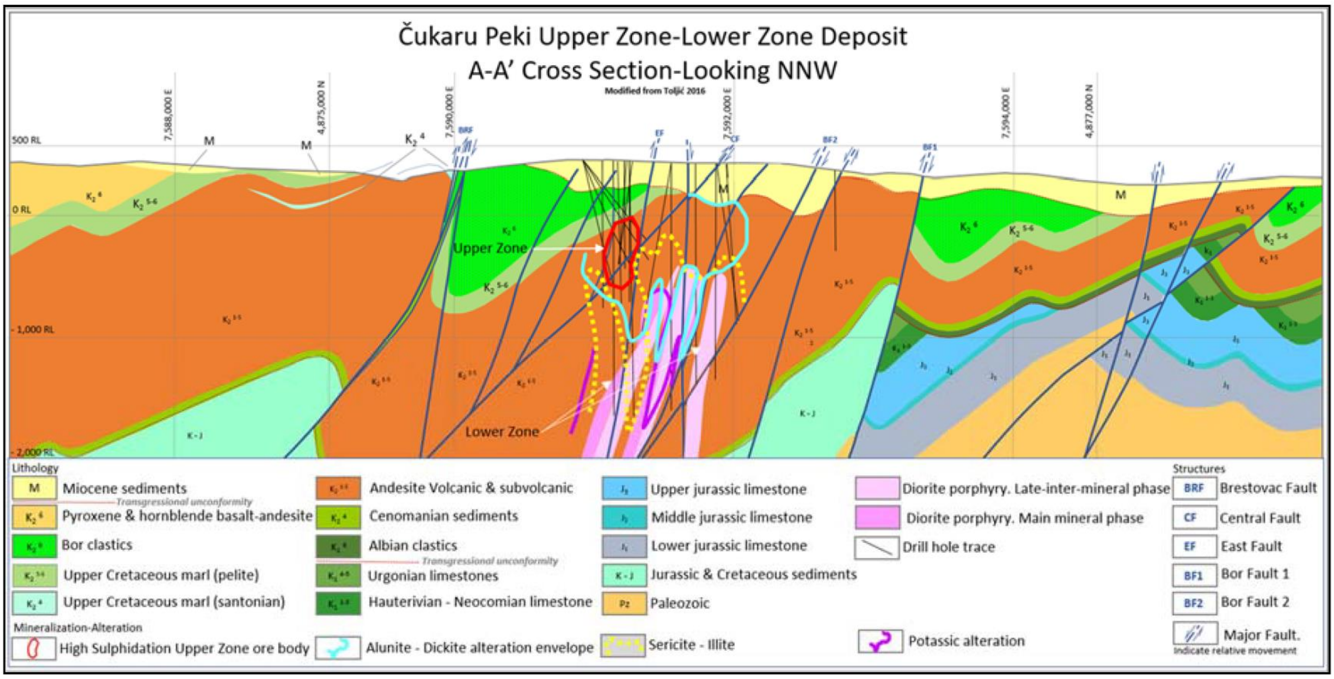


Figure 4: Cross Section through the Cukaru Peki deposit (both the Upper Zone and the Lower Zone.

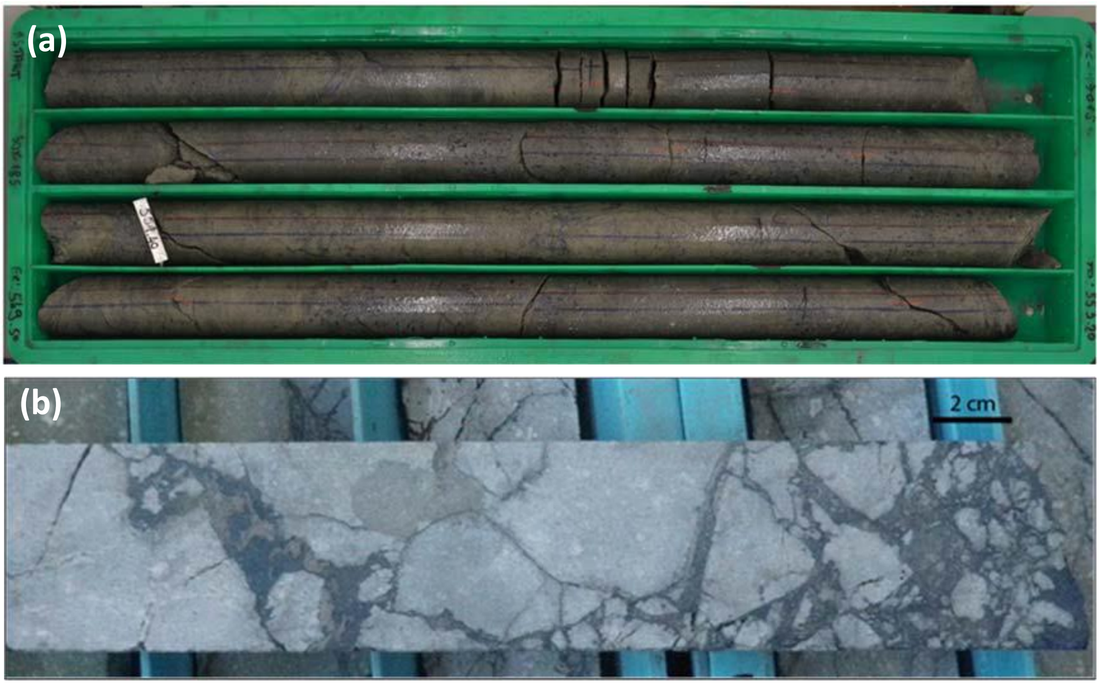


Figure 5: Examples of different types of ore from the Cukaru peki Upper Zone. (a) Massive sulphide, veins and stockwork in a coherent andesitic rock. (b) Hydrothermal breccia infilled with covellite-pyrite mineralisation in an advance argillic altered andesite (Nevsun, 2018).

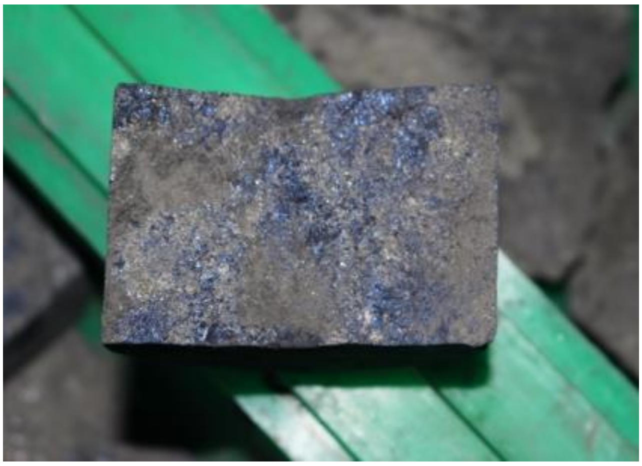
Day 3: Cukaru Peki Cu-Au, Friday 15th June

Our second day in Bor started with an excellent visit to review drillcore at the recently discovered (and very impressive) Cukaru Peki deposit, owned by Nevsun Resources. Cukaru Peki is a copper-gold mineralised deposit located within the Bor district of the Timok Magmatic Complex, situated about 5 kilometres south of the mining town of Bor. The deposit consists of two different styles of copper-gold mineralisation, namely the Upper Zone and the Lower Zone. The Upper Zone comprises high sulphidation epithermal Cu-Au mineralisation and occurs at depths of 450-850m below surface, whereas the Lower Zone consists of porphyry Cu-Au style mineralisation and is found from 700 to at least 2200m depth.

The participants had the chance to inspect some 'super high-grade' intersections, containing copper minerals such as chalcocite and bornite, from a deposit that is yet to be mined. We also were able to see the difference in the styles of alteration and mineralisation between epithermal Cu-Au and porphyry Cu-Au, both of which are present at Cukaru Peki. The staff at Nevsun then took us to see outcrops of the volcanic host rocks, then onward to have a panoramic view of the Bor open cast Cu pit, which has been in operation for over half a century. And of course, we also got to visit part of the waste dump to collect some samples!

In the afternoon, we headed back into town to visit the SGS Geochemistry labs, with a full guided tour from the lab manager, George Daher. As part of the visit, we got to see the entire process starting with the crushing and milling or rock samples, through the melting and dissolution, to the analysis and data processing, giving the participants an appreciation of the process undertaken when assaying rock/soil samples. George also emphasised the importance of QAQC and running blanks/standards during analysis. A very interesting and eventful day, bringing our stay at Bor, Serbia to a close!

First stop – the core shed to look for copper mineralisation



A very high grade intercept, dominated by the blue Cu sulphide covellite

The group looking out over the industrial town of Bor

And the historical Bor open pit and active plant

Day 4: Saturday 16th June

Saturday was the first of two planned driving days, owing to the significant distances between the sites we were visiting. We commenced on our mammoth 600 kilometre journey back over the Bulgarian border and across the spine of the country, to the town of Krumovgrad in the southeast. We were treated to some beautiful scenery, and enjoyed some tourist stops during the course of the day.

Ada Tepe Mine - Introduction

Owned by: Dundee Precious Metals

Commodity: Au-Ag

Development Stage: Mining/Pre-Production

Geological Setting/Genetic Model: Low-Sulphidation Epithermal

Location and Access: 3km S of Krumovgrad, SE Bulgaria

Geological Domain: Rhodope Metamorphic Terrane

First Operational: Mining - 2016, Production – late 2018

The Ada Tepe Au mine is located approximately 3km south of the town of Krumovgrad, in the Rhodope Mountains of SE Bulgaria. It is claimed that Ada Tepe is the oldest gold mine in Europe, with pottery and pyrite-rich slag indicating that mining dates back to over ~1500 BC (Popov, 2011). Despite this history, gold mining in the region was largely forgotten until the mid-1990's, when the state undertook an extensive regional geological mapping, soil sampling and airborne geophysics program (Marton et al., 2016). From this work, a strong geochemical anomaly and multiple geophysical anomalies were noted, but not followed up until 2000, when more detailed mapping was undertaken and channel sampling returned assays of over 100g/t Au. The first drill hole drilled in 2000 returned significant intercepts including 62.8m @ 3.4 g/t Au and individual 1m samples returning up to 81 g/t Au. Since then, over 100km of diamond and RC drilling has been completed and the Ada Tepe deposit has been located and its extent determined (Marton et al., 2016). Construction of the open cast operation started in the fourth quarter of 2016, with first concentrate production on track for the fourth quarter of 2018 (DPM, 2018).

The Krumovgrad region is located within the Rhodope metamorphic terrane of southern Bulgaria and northern Greece and forms part of the Alpine-Himalayan orogenic belt (Figure 6). In the Cretaceous, the region formed part of the Eurasian convergent margin, and so endured multiple continental collisional events. This was followed in the late-Cretaceous-Paleogene by significant post-orogenic extension in a back-arc setting, resulting in rapid stretching of the crust and exhumation of lower crust exposed as metamorphic core complexes, including the Kessebir-Kardamos dome in the Krumovgrad area (DPM, 2018). This basement metamorphic dome consists of gneisses, metasedimentary rocks such as metapelites and marbles, and metaigneous rocks such as amphibolites and metagabbros (Bonev et al., 2006a). This major extensional episode was accompanied by low-angle detachment faulting, development of half-grabens and sedimentary basin formation (DPM, 2018). Consequently, coarse clastic sedimentary rocks of the Paleogene-age Shavar Formation (Krumovgrad Group) were deposited in the fault-bounded half-grabens (Marton et al., 2016), which act as the primary host of mineralisation. The principal structure at Ada Tepe is a low angle (10-15°) detachment fault separating metamorphic basement rocks from the overlying mineralised sedimentary rocks. Crucially, this structure acts as the lower bounding surface to mineralisation.

The Ada Tepe deposit is an Oligocene-age low sulphidation epithermal Au-Ag deposit. The geometry of the ore bodies present indicate that mineralisation is both structurally and lithologically controlled (Marton et al., 2016). As such, mineralisation at Ada Tepe can be subdivided into the following two main types (DPM, 2018; Figure 7):

1) ***"Wall Zone" mineralisation*** – a massive, shallowly dipping, quartz-rich body forming the hanging-wall to the detachment and essentially defining the meta core complex-sedimentary boundary. Interpreted to be associated with early silica flooding along the fault zone and relatively low Au grades (~5-7 g/t Au).
2) ***"Upper Zone" mineralisation*** – a set of E-W trending and steeply dipping veins extending upward into the sedimentary breccias overlying the "Wall Zone". Strongly faulted, permeable sedimentary rocks provided a pathway for fluid circulation and open-space filling, resulting in bonanza-type mineralisation, with grades of over 100 g/t Au.

The most favourable units for gold mineralisation are coarse conglomerates (containing decimetre scale marble blocks) and fine grained sandstones and siltstones (Marton et al., 2016). An association of high gold grades with features including AuAg-bearing, open space filled silica-carbonate-adularia veins with colloform-banded and lattice-bladed textures, as well as hydrothermal breccias and the presence of sinter, all support the low-sulphidation nature of the deposit and also suggest a close proximity to the paleosurface (DPM, 2018). Ar/Ar adularia dating of gold mineralisation at Ada Tepe return ages of **34.7-35.4 Ma** (Marchev et al., 2004b; Marton et al., 2010). In contrast, Ar/Ar dating of metamorphic basement rocks show that exhumation (cooling to lower than 350°C) took place between 36.9-37.3 Ma, about 2 million years prior to mineralisation (Marton et al., 2010).

Alteration assemblages in the area vary considerably, reflecting the very heterogenous composition of the host-rocks. Silica alteration and open-space quartz crystallisation exhibit a number of different textures, including colloform-crustiform banding, drusy and sugary, massive chalcedony and rarely lattice-bladed (Figure 8). Rocks originally containing alumina-silicate minerals are subject to argillic and sericitie alteration, whereby illite, kaolinite and sericite join quartz in the alteration assemblage (Marton et al., 2016). The distribution of alteration assemblages and vein textures indicate that boiling was a very important process, particularly for 'bonanza' high-grade gold mineralisation at Ada Tepe. Sulphidation associated with cooling of the mineralising fluids is thought to have had an active, albeit lesser, role (Marton et al., 2016). Over the course of the last year of so, exploration has been focussed at the Kupel prospect, where mineralisation is situated 200m above the detachment contact. Here, gold is associated with quartz-chalcedony veining, often exhibiting a stockwork character, in addition to dark siliceous mud deposited in a sinter environment and anomalous Sb-W-Te. As such, the Kupel Prospect indicates the presence of a high-level epithermal gold system (Marton et al., 2016).

Based on the current Mineral Reserve, the Ada Tepe deposit is expected to produce an average of 85,700 ounces of Au per annum and has a current mine life of 8 years (DPM, 2018). The project is expected to employ approximately 230 people, and the processing plant is scheduled to operate 24 hours a day, 7 days a week.

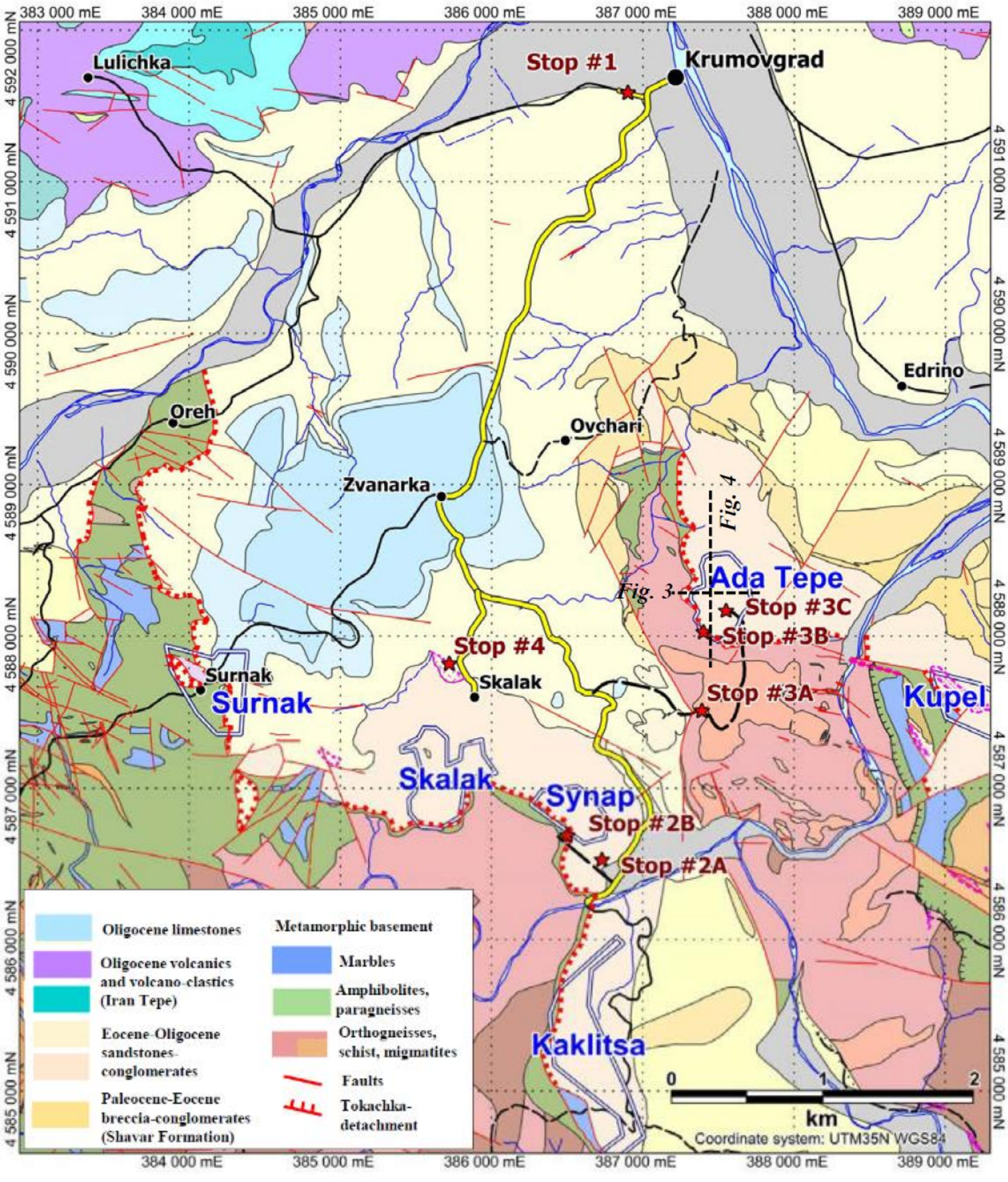


Figure 6: Geologic map of Krumovgrad project area, showing the bedrock geology, structural features and current Au prospects (DPM, 2018).

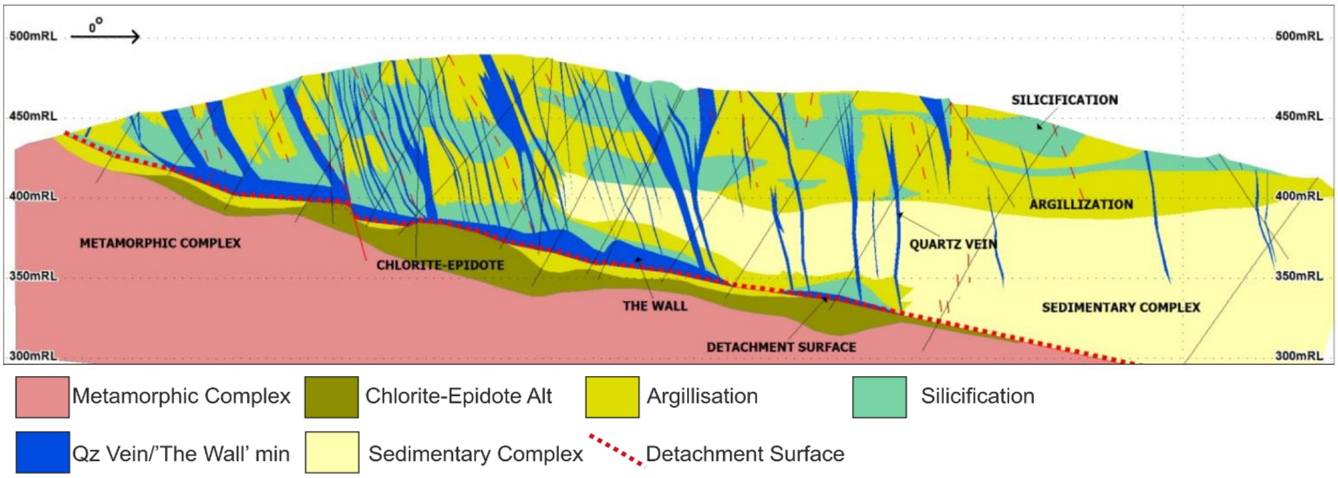


Figure 7: Representative N–S section (looking to West) through the Ada Tepe deposit, showing the interpreted lithological units, ore types and the main alteration zones.

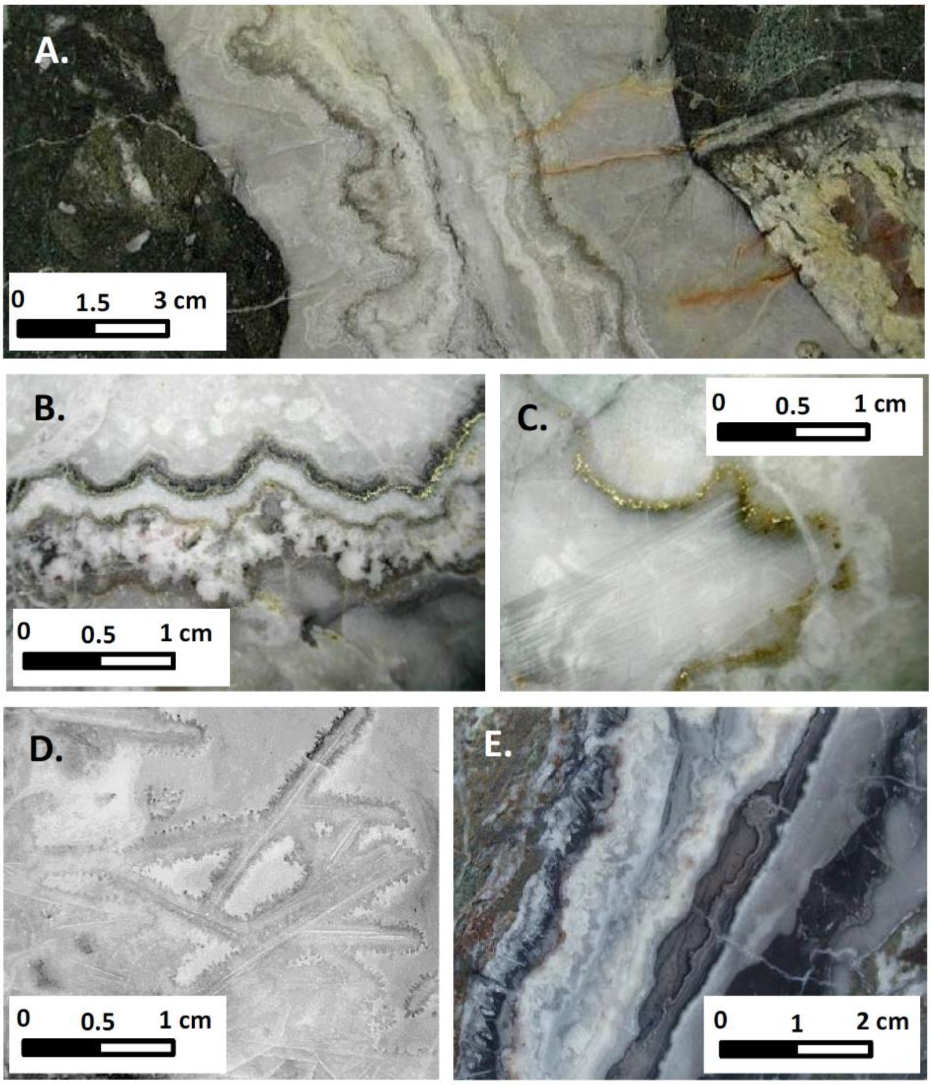


Figure 8: Representative vein textures from Ada Tepe: A. Crustifrom-colloform banded vein of cryptocrystalline silica (chalcedony), moss adularia, and sulfide; B. Subparallel bands of microcrystalline silica, moss adularia and electrum separated by a carbonate zone; C. Electrum in cryptocrystalline silica and moss adularia vein; D. Lattice-bladed vein with silica forming pseudomorphs of former carbonate blades; E. Crustifrom-colloform banded vein of with bands of chalcedony (gray), moss adularia, and chalcedony (white) and lattice bladed quartz pseudomorphs.

Day 5: Ada Tepe, Sunday 17th June

The next visit was to the Ada Tepe Au deposit, where initial mining was planned to start in a matter of months. It is claimed that Ada Tepe is the oldest gold mining area in Europe, with pottery and pyrite-rich slag indicating that mining dates back to over ~1500 BC. The Ada Tepe deposit is an Oligocene-age low sulphidation epithermal Au-Ag deposit, currently operated by Dundee Precious Metals. Alteration assemblages in the area vary considerably, reflecting the very heterogenous composition of the host-rocks. Silica alteration and open-space quartz crystallisation exhibit a number of different textures, including colloform-crustiform banding, drusy and sugary, massive chalcedony and rarely lattice-bladed.

We met with Geology Manager first thing in the morning, before walking over to the DPM offices. First, we had the chance to review some of the companies drillcore, observing some magnificent vein textures that typify epithermal gold deposits. We were lucky enough to have two academics from the Geneva on site, who are currently researching the deposit. They gave us an overview of their findings to date and showed us some key features in the drillcore. Jamie Price and Josh Hughes once aain gave two presentations to the staff and trip participants, which was received well by those present. After lunch, we were able to get out in the field and see the deposit for ourselves, which unusuallyis outcropping at the surface on the top of a hill. Our group was the last planned guests on site before mining was due to commence, so it was fantastic to see a deposit in all its glory. Even better, the staff geologists showed us some visible gold on the outcrop, and gave us the go ahead to take samples! The visit to the main Ada Tepe deposit as followed by a visit to another prospect, including a sinter, which was an added bonus. An excellent visit, made even better by the exposure present prior to mining.

Identifying different epithermal vein textures on the outcrop (visible gold here!!!).

Dundee geologists discussing the geological setting of the deposit.

Fantastic epithermal veins in drillcore

An outcropping sinter – marking the paleosurface..

Day 6: Monday 18th June

Our second driving day involved a 500 kilometre route that took us across the mountainous area of southern Bulgaria. Along the way, we visited a working monastery, the spa town of Velingrad, and had a tour of the Belitsa Bear Santuary. In the early evening, we crossed over the border to Macedonia, and eventually arrived at the town of Vinica, our destination for the evening. Having found a very nice restaurant that sold large pizzas for ~£3 and large beers for ~70 p, we got together as a group to discuss the days adventures and the plans for the final two days of the trip.

A visit to the Monastery and meeting the monks

Checking out the local wildlife (in an enclosure of course…)

Sasa Mine - Introduction

Owned by: Central Asia Metals

Commodity: Pb-Zn-Ag

Development Stage: Mine

Geological Setting/Genetic Model: Porphyry Stockwork Related – Deposits derived from Metasomatic Skarn-Hydrothermal Processes

Location and Access: F.Y.R.O. Macedonia, 90 km E of Skopje. Access by road.

Geological Domain: Serbo-Macedonian Massif

First Operational: 1966

The Sasa Mine comprises the Svinja Reka, Golema Reka and Kozja Reka Pb-Zn-Ag deposits, which lie within the Serbo-Macedonian Massif of northeastern Macedonia. This massif extends through Serbia, Macedonia, Bulgaria, and eastern Greece into Turkey and hosts a large number of lead-zinc deposits (Figure 9). The massif comprises metamorphic rocks of Precambrian, Cambrian and Palaeozoic ages, within which a lower complex (amphibolite-grade gneisses, schists and meta-sediments) and upper complex (greenschist facies volcanoclastics) have been recognised.

The Sasa deposits are located on the eastern flank of a Tertiary intermediate intrusive complex and related porphyry Cu-Mo system, within which a northwest striking stockwork alteration zone is developed. The mineralisation is considered to relate to the intrusion of Tertiary volcanics (Peltekovski et al 2012). High-temperature hydrothermal 'fluids' along bedding-parallel faulting were responsible for metasomatism of the host metasediments, producing skarn within marbles and base metal mineralisation within open-voids.

Geology

The Pb-Zn-Ag mineralisation occurs as stratiform deposits hosted predominantly by quartz-graphite schist and marbles of Lower Palaeozoic age at Svinja Reka and by gneisses at Golema Reka. The well-defined lenses of Pb-Zn-Ag mineralisation dip at approximately 35° to the south-west and typically range in true thickness from between 2 and 30 m (Figure 10). The mineralised lenses are present in parallel sheets (typically two or three bodies, namely the hanging wall, central and footwall orebodies), separated by an interburden with thicknesses of 1 to 10 m.

Mineralogy

High-temperature hydrothermal fluids and bedding-parallel faulting are responsible for metasomatism of the (Mn-bearing) host sediments producing skarn (calc-silicate minerals including calcite, actinolite, chlorite and epidote) and base metal mineralisation (Serafimovski et al. 2006). The skarn association has a characteristic zonal structure and contains calc-silicate minerals (Fe-Mn-pyroxenes, Fe-Mn-pyroxenoids, garnets, ilvaite, epidote), magnetite, pyrite and pyrrhotite. The hydrothermal association, which is superimposed onto the skarn assemblages, contains argentiferous galena, sphalerite, pyrite and minor chalcopyrite (Palinkas et al. 2013).

The Sasa deposit was discovered during a period of exploration between 1954 and 1965, with production commencing in 1966. The mine was closed in 2002 and was placed into bankruptcy due to funding issues, however, operations resumed in 2006 when the Solway Group purchased the mine and invested in new equipment. In 2017, the current owners Central Asia Metals mined 793,000 tonnes of ore at average grades of 3.83% Pb and 3.3% Zn, to produce 9587 tonnes of Pb concentrate and 11384 tonnes of Zn (CAM, 2018). Current reserves are 10.9 million tonnes at 3.9~% Pb, 3.1% Zn and 22 g/t Ag.

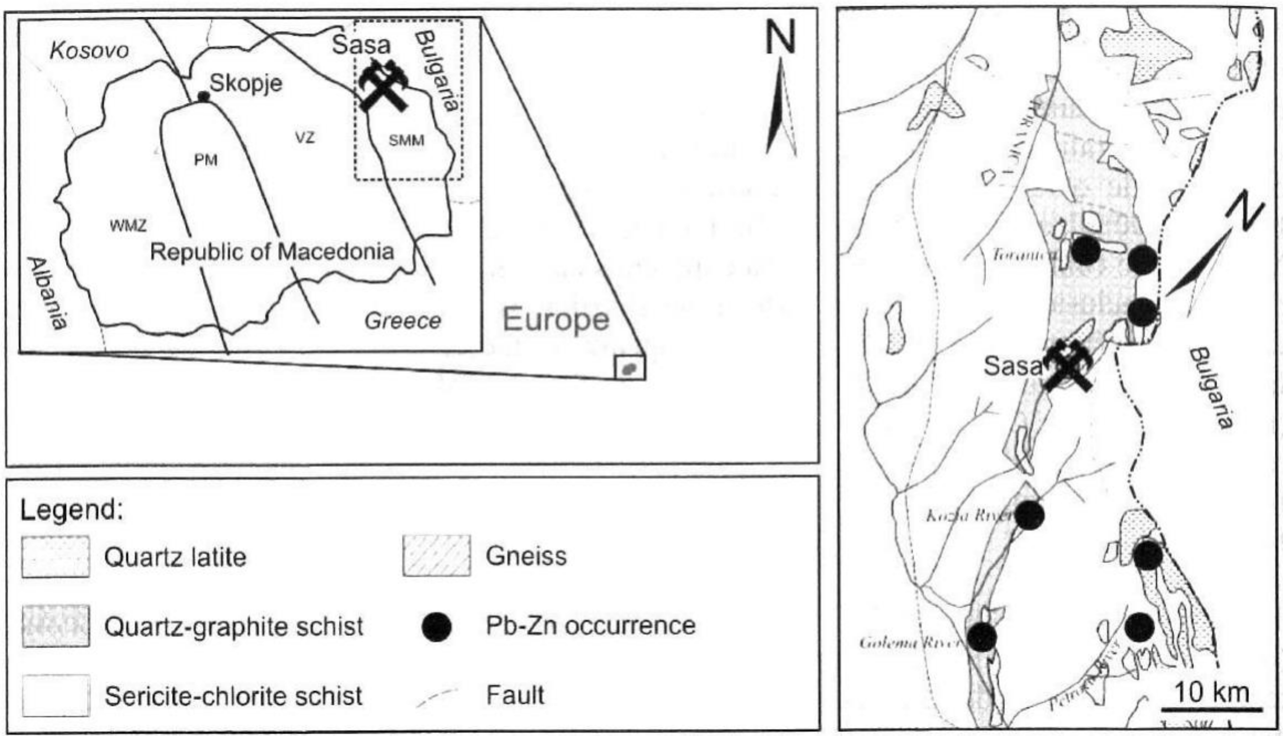


Figure 9: Regional geological setting of the SASA Pb-Zn skarn deposit within the Serbo-macedonian massif (simplified after Dimitrijevic, 1995, and Serafimovski and Aleksandrov, 1995). WMZ - Western Macedonian zone; PM - Pelagonian massif; VZ - Vardar zone; SMM - Serbo-Macedonian massif (from Palinkas et al. 2013).

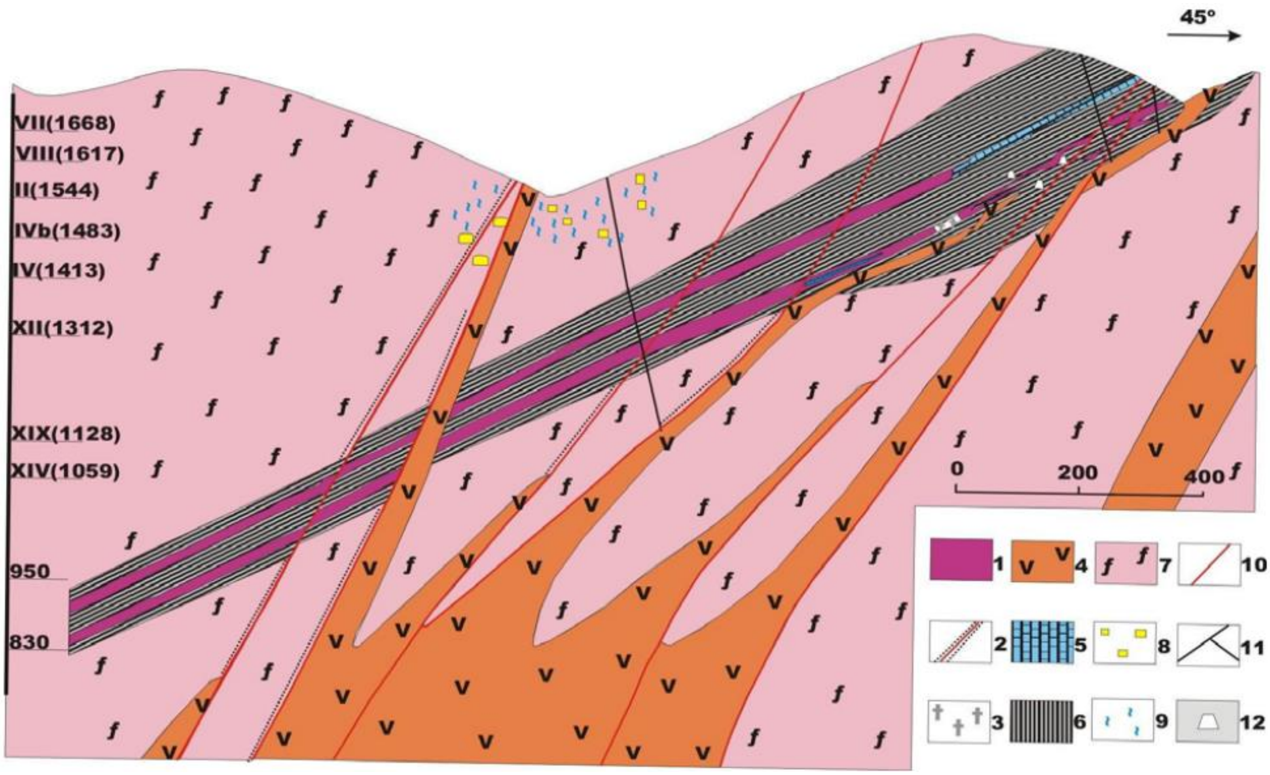


Figure 10: Geological cross section of the Sasa deposit (from Peltekovski et al 2012): 1. Ore-metasomatic type; 2. Mineralization around ore; 3. Skarn; 4. Dacite; 5. Cipoline; 6. Quartz-graphite schist; 7. Gneiss; 8. Pyritization; 9. Silicification; 10. Faults; 11. Drill holes; 12. Mine workings

Day 7: Sasa Pb-Zn mine, Tuesday 19th June

The penultimate day of the trip started with a visit to the Sasa Pb-Zn underground mine in northern Macedonia, currently operated by Central Asia Metals. This was our visit visit to an active mine as part of the trip, and for some of the participants, their first visit to an active minesite! The Sasa deposit was discovered during a period of exploration between 1954 and 1965, with production commencing in 1966. It has been in operation for most of the >50 years since.

The Sasa Mine comprises the Svinja Reka, Golema Reka and Kozja Reka Pb-Zn-Ag deposits, which lie within the Serbo-Macedonian Massif of northeastern Macedonia. The Pb-Zn-Ag mineralisation occurs as stratiform deposits hosted predominantly by quartz-graphite schist and marbles of Lower Palaeozoic age at Svinja Reka and by gneisses at Golema Reka.

Upon our arrival, we were greeted by the Senior Geologist, who gave us an introduction to the deposit, before we traversed the minesite whilst he described what we were looking at. Next stop was the coreshed, where we examined the mineralised core and compared it to that seen at the previous deposits. Unfortunately, we were unable to go underground due to safety reasons, but we were rewarded with a look at an active drill rig and a superb tour of the processing facility. The group was able to get up close an personal with the processing plant, including standing on top of the froth flotation tanks and seeing the forming of the concentrate which leaves the facility for smelting elsewhere.

Following the tour of Sasa, we returned to Bulgaria and descended on the capital Sofia, where we went for food and a few celebratory beers on our last night of the trip. We also met with Chris Bray of SRK Consulting, who was instrumental in helping us with contacts during planning of the field trip, and showed him our appreciation as well as sharing some of our stories from the trip to date.

Students admiring the processing plant..

And look at those froth flotation tanks!!

An active drill rig at the Sasa mine alongside fresh drillcore, with a local Macedonian man for scale

Assarel Mine - Introduction

Owned by: Assarel Medet

Commodity: Cu

Development Stage: Mine

Geological Setting/Genetic Model: Porphyry Cu

Location and Access: Bulgaria, 65 km ESE of Sofia. Access by road.

Geological Domain: Central Srednogorie Zone

First Operational:

The Assarel Cu deposit lies within the Panagyurishte district which is a part of the Central Srednogorie zone. This zone includes three, relatively large porphyry-copper deposits (Assarel, Medet and Elatsite), several smaller ones (Tsar Assen, Vlaikov Vruh, Karlievo, and others) and numerous ore occurrences of the same type (Fig.22). Individual porphyry-type deposits are closely associated with volcanic-hosted, medium- to high-sulphidation epithermal deposits mined for gold and copper, including Chelopech near Elatsite, and Elshitsa near Vlaikov Vruh (Bogdanov 1987).

Geology

The Assarel granodiorite porphyry deposit is located in the central part of the Assarel volcano, in an area of intensive radial and concentric faulting and jointing. The mineralisation is associated with and partly hosted by coeval volcanic rocks erupted from the Assarel Volcano. The central part of the volcano is predominantly composed of massive and brecciated lava sheets, and pyroclastics of dominantly andesite and latite-andesite composition. The eastern part of the structure is uplifted due to post-ore faulting, such that weakly altered basement metamorphic rocks are now exposed at the same structural level as the volcanic rocks with advanced argillic alteration (Figure 12). The ore mineralisation forms a cone whose top is inclined by 80–85 towards the south or south-west. The horizontal cross section of the deposit, therefore, has an ellipsoidal shape with a long axis oriented in a N-S direction (Strashimirov et al., 2002).

Mineralogy

Qz + chpy ± py as the main hypogene ore stage is temporally associated with sericitic and transitional sericitic-propylitic alteration. Qz-Py with minor chpy is prominent in the central and marginal parts of the deposit. The qz-gal-sph association is rarely developed and found mainly in the upper part of the deposit. Galena and sphalerite are found in well-defined veins with chalcopyrite at depth. Several mineral assemblages representative of high-sulphidation style are established in the upper levels. These include enargite, goldfieldite (Cu-As±Te assemblage), colusite, As-sulvanite and sulvanite (Cu-Sn-V assemblage), aikinite and wittichenite (Cu-Bi assemblage), hessite and tetradymite (Bi-Ag-Te assemblage) found as fine mineral inclusions in chalcopyrite. They are spatially related to sericitic and advanced argillic alterations of the volcanic rocks in the highest parts of the deposit. Assarel therefore combines typical features of porphyry copper at depth with an overprint of high-sulphidation style of mineralisation in the upper parts of the system.

Enargite and numerous rare minerals including tellurides and selenides occur at Assarel, emphasising the transitional nature of this deposit to the high-sulphidation epithermal environment. The relatively shallow volcanic level of the Assarel system facilitated intensive reworking of the host rocks, in an environment which was affected by the incursion of meteoric water (Strashimirov et al., 2002). Assarel is the only major deposit in the district with a well-developed supergene enrichment blanket of chalcocite and covellite, which is of major importance for the economics of the deposit. The zone of supergene enrichment is 60–70 m thick above primary quartz-pyrite-chalcopyrite ore, and below a zone of complete oxidation which usually comprises the first 10–15 m below the present-day land surface (Strashimirov et al., 2002).

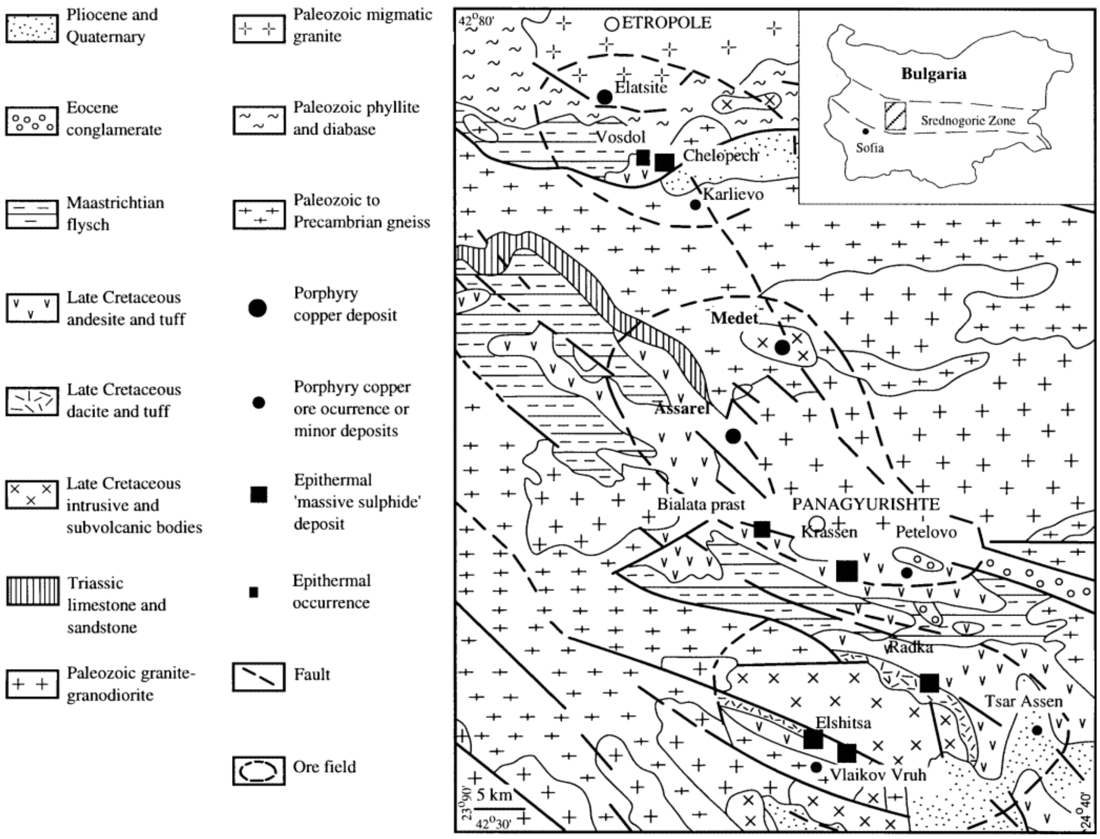


Figure 11: Geological map of the Panagyurishte ore district. All of Bulgaria's major porphyry-copper and volcanic-hosted 'massive sulphide' epithermal deposits are aligned along the NNW-SSEtrending Panagyurishte corridor cutting the Late Cretaceous Srednogorie magmatic zone of broadly E–W orientation (modified after Bogdanov 1987) (from Strashimirov et al. 2002).

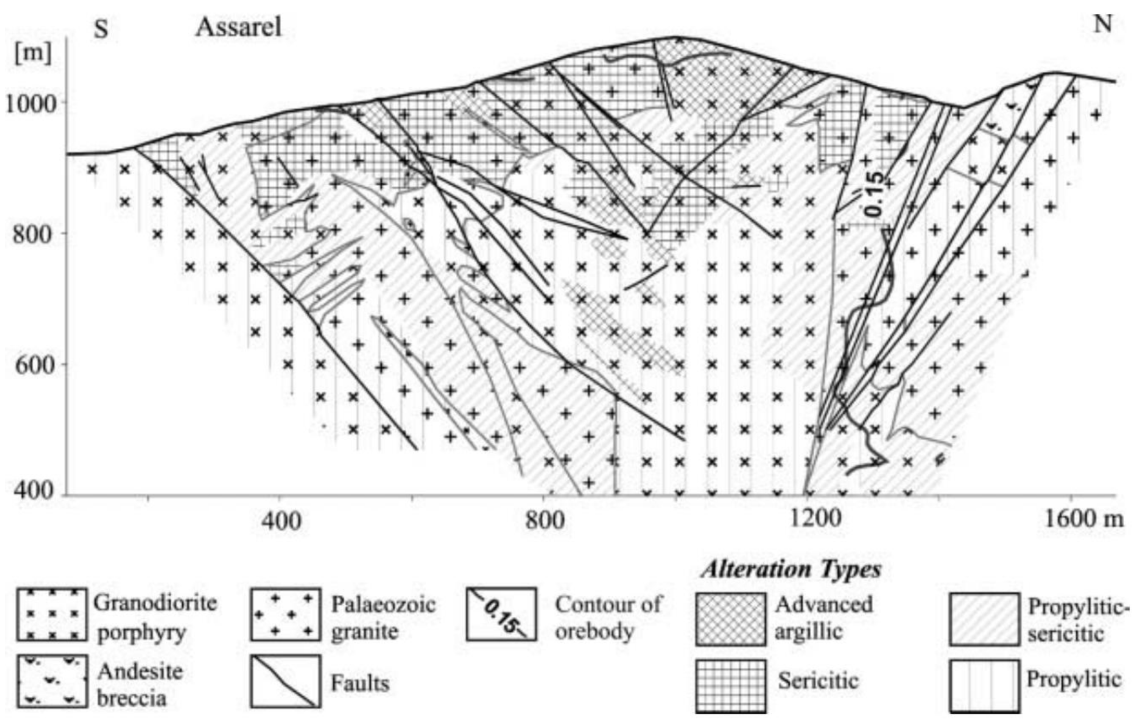


Figure 12: Geological section through the central part of the Assarel deposit. Economic chalcocite-covellite mineralisation is associated with an irregular subhorizontal zone of supergene enrichment overprinting sericitic and advanced argillic alteration. The southern limit of the orebody (cut-off grade 0.15% Cu) is to the left of the depicted section (from Strashimirov et al. 2002).

Day 8: Assarel Cu Mine, Wednesday 20th June

The final day of our trip was upon us and it did not disappoint. We left Sofia first thing, and made our way to the vast Assarel open-cast Cu mine (operated by Assarel Medet), currently the largest copper deposit in Bulgaria. The Assarel granodiorite porphyry deposit is located in the central part of the Assarel volcano, in an area of intensive radial and concentric faulting and jointing. The mineralisation is associated with and partly hosted by coeval volcanic rocks erupted from the Assarel Volcano.

At Assarel, we were fortunate to have a full tour of the on-site museum – celebrating the history of the minesite with lots of interesting exhibits on show. During our visit, we also had a panoramic view of the large open cast pit, with explanations from the staff geologists, and had a fantastic tour of the brand new, state of the art froth flotation processing plant. It was fantastic for the students to see such a new facility with up to date technology. We were also very kindly hosted for lunch by the minesite, including a delicious three course meal – the perfect end to a successful trip. After a few more visits to tourist hotspots on the way back to Sofia airport, we departed the Balkans having had a very memorable trip.

Brand new froth flotation facility for participants to explore..

Standing in front of the massive Assarel open pit

The group posing in the bucket of a large excavator..

Enjoying a delicious three course meal on site, courtesy of Assarel Medet

We would once again like to extend our sincerest thanks to all of the companies and individuals that hosted us, and to those who sponsored the trip and made it possible.

Jamie Price, September 2018