Porphyry and epithermal systems of the Lesser Caucasus

Armenia-Georgia Field Trip

June 2019

Organized by the Geneva SEG Student Chapter and the Mineral Resources and Geofluids Research Group of the University of Geneva, in collaboration with the Institute of Geological Sciences of the Armenian National Academy of Sciences and the Faculty of Exact and Natural Sciences of Iv. Javakhishvili Tbilisi State University, Georgia
Acknowledgments

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Introduction

From June 19th to June 28th 2019, the SEG student Chapter of Geneva led a field trip across Armenia and Georgia to study the porphyry and epithermal systems of the Lesser Caucasus mountain belt. The goal of the fieldtrip was to understand the complex geodynamic and geological context of the mountain belt as well as understanding the emplacement of the deposits through time across the belt. During these 10 days, we were able to attend several mine visits in both countries and study different mineral occurrences and prospects.

This field trip was led by Prof. Robert Moritz who has been studying the metallogeny of the area with his students for the past 10 years. One professor, 2 post-doc fellows, 4 Ph.D students, 5 Master students from the University of Geneva as well as 3 persons from the industry (Eldorado Gold and Rio Tinto) attended this fieldtrip. The success of this fieldtrip was possible thanks to local scientist contact the team had on the field.

The idea of the fieldtrip was to travel through the Lesser Caucasus from the younger Cenozoic units to the older Mesozoic units. Particular interest was paid to the ophiolitic structures that help understanding the major tectonic structure and geodynamic history of the area. This report presents the different mines/prospects that have been visited and studied during the field trip on a day by day basis.

Additionally to the mine visits and geological stops, participants to the field trip attended two workshops, the first one in Yerevan with researchers from the Institute of Geological Sciences and the second one with employees from the Madneulli mine in Georgia. Each workshop consisted of presentations from both sides and discussion between people hosting the event and members from the Student Chapter.

Geological context

The Lesser Caucasus mountain belt is part of the Central Tethyan belt which runs across Georgia Armenia Azerbaijan and Iran. This mountain range formed as the result of two major collision. The first collision occurred during late Cretaceous times between the South Armenian block of the Gondwana derived terrane that subducted underneath the Eurasian continent toward the North East. The second collision took place during the Cenozoic between the Arabian plate and the Eurasian Margin. The ore deposits emplaced there can be assigned to these two distinct evolutionary stages and are typical of convergent margin tectonics (porphyry Cu-Mo and epithermal Au deposits).

The lesser Caucasus is therefore composed of three main tectonic units:
- the Somkheto Karabagh belt, a Mesozoic metallogenic and magmatic belt that resulted from the first collision
- the Amasia Sevan Aker a suture zone evidenced by an ophiolitic belt
- the Gondwana-derived South Armenian block hosting Cenozoic magmatic intrusion and ore deposit..

This fieldtrip started in the South Armenian block and first covered the Cenozoic deposits, whose emplacement was controlled by the strike slip movement created when the Arabian plate collided with the Eurasian margin. It ended up in the Mesozoic units (Alaverdi district and Georgia) where the deposits were emplaced contemporaneously. One distinctive feature is the location of the Kapan block, a Mesozoic block displaced by a major fault located within the Cenozoic units.
<table>
<thead>
<tr>
<th>Day</th>
<th>Name of the Deposit</th>
<th>Type of deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 21st</td>
<td>The Zangezur-Ordubad district</td>
<td>Porphyry and epithermal systems</td>
</tr>
<tr>
<td>June 22nd</td>
<td>The Kadjarian Mine</td>
<td>Porphyry Cu-Mo deposit</td>
</tr>
<tr>
<td>June 22nd</td>
<td>The Shahumyan mine (Kapan district)</td>
<td>Epithermal (intermediate sulfidation)</td>
</tr>
<tr>
<td>June 23rd</td>
<td>The Amulsar deposit</td>
<td>Epithermal Au mine + Polymetallic mine</td>
</tr>
<tr>
<td>June 24th</td>
<td>The Meghadzor mine + Hrazdan prospect</td>
<td>Epithermal Au mine + Fe-skarn prospect</td>
</tr>
<tr>
<td>June 25th</td>
<td>The Shamlugh mine (Alaverdi district)</td>
<td>Epithermal deposit</td>
</tr>
<tr>
<td>June 26th</td>
<td>The Madneulli mine</td>
<td>VMS- Epithermal deposit - Porphyry</td>
</tr>
<tr>
<td>June 26th</td>
<td>The Sakdrisi mine</td>
<td>Epithermal (Intermediate Sulphidation)</td>
</tr>
<tr>
<td>June 27th</td>
<td>The Kvemo Bolnisi prospect</td>
<td>Epithermal (Intermediate Sulphidation)</td>
</tr>
</tbody>
</table>

*Figure 1: Map of the itinerary*
June 20\textsuperscript{th}: Introduction day

The first day of the field trip was devoted to the drive from Yerevan to Kapan. It was a full day of driving and we used this day to introduce the geological context and background of the field trip. Additionally, the team enjoyed a stop at the Noravank monastery and had the chance to taste wine from the Areni area, one of the oldest wine making regions in the world.

![Figure 2: a. Noravank monastery b. Wine tasting experience](image)

June 21\textsuperscript{st}: The Zangezur-Ordubad district

This first day in the field was dedicated to the visit of the Zangezur-Ordubad mining district. The structural control was of major importance for the emplacement of deposits from the Early Eocene to the Miocene. During this period, several porphyry and epithermal deposits were emplaced, associated with the emplacement of deeper magmatic intrusions. There are three stages of ore deposits here: the first stage is subduction related and is dated as Eocene in age, the second and third event last from the Oligocene to the Miocene and formed in a collisional to post-collisional tectonic setting. The main deposits known to this day are the porphyry Cu-Mo deposits Agarak, Aygedzor and Kadjaran, one of the biggest deposit in Armenia; major epithermal Au gold deposits are Lichk and Tey Lichkvaz. The main focus for this day was the Eocene porphyry Cu deposit, the Agarak deposit, which is one of the oldest in this district, emplaced during the first subduction related episode.

**Agarak mine**

<table>
<thead>
<tr>
<th>Ownership</th>
<th>GeoProMining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>6km N from Agarak village, in the Syunik province, very close to the Iranian border, at an altitude of 1000m. GPS: 38.919906(^\circ)N, 46.185664(^\circ)E.</td>
</tr>
<tr>
<td><strong>Deposit type</strong></td>
<td>Porphyry Cu-Mo</td>
</tr>
<tr>
<td><strong>Principal Commodities</strong></td>
<td>Cu, Mo, Ag, Au.</td>
</tr>
<tr>
<td><strong>Resources/Reserves/ Cut off grades</strong></td>
<td>45Mt @0.5% Cu, 0.029% Mo, 0.025g/t Au, 1.19g/t Ag. (Hovakimyan et al., 2019)</td>
</tr>
<tr>
<td><strong>Metallurgical / Mineralogical info:</strong></td>
<td><strong>Ore minerals</strong>: Molybdenite, chalcopyrite, bornite, magnetite, sphalerite, galena, covellite, enargite. <strong>Gangue minerals</strong>: Quartz, pyrite, carbonates</td>
</tr>
</tbody>
</table>


Mine History

The mine has been active for decades, since Agarak town, previously called Banavan, was founded in 1949 as a base for the local mining operations and workers. Today, about 1000 people work at the Cu-Mo mine (envsec).

Regional Geological Setting

Agarak and Aygedzor are two deposits located within the Meghri-Ordubad Pluton (MOP). The MOP was emplaced in several stages over 30Ma, from mid-Eocene to early Miocene, contemporaneously to the Arabia-Eurasia collision.

Local geology

**Host Lithology (and ages)**
Host rocks in Agarak consist of granodiorite dated at 48.9±0.07Ma (Moritz et al., 2016b), granite dated at 44.03±0.02Ma (Moritz et al., 2016b) and hornblende gabbro, diorite and tonalite dated from 45.9±0.9 to 43.8±0.6Ma (Rezeau et al., 2016)

**Structure**
The Tashtun and Spetry normal and thrust faults (Fig.3), respectively, control magmatism, alteration and mineralization (Tayan et al., 2007). The Tashtun fault is 500m wide at Agarak, bounded by two N-S oriented faults characterized by a E 55-60° dip.

Main parts of the porphyry Cu-Mo stockwork, along with a porphyritic granodiorite are located west to the 55-75° W dipping Spetry fault, in the hanging wall (Figure 4)

Agarak was overprinted by younger tectonic events, and the syenogranite host has been thrust over the Early Pliocene Nor-Arevik sedimentary suite, in a west to east movement (Tayan, Karamyan et al., 1974). Some sub-parallel segments of the Spetry fault are observed to the east, in an “en-échelon” pattern, resulting in counter-clockwise displacement of the stockwork mineralization (Tayan).
**Figure 4:** Agarak open pit with middle Eocene syenogranite thrust over the Pliocene Nor-Arevik sedimentary suite (Hovakimyan et al., 2019).

**Alteration**
Potassic alteration (shreddy biotite), together with propylitic (epidote) and sericitic alterations. Silicification, disseminated pyrite, argillic alterations (kaolinite), carbonates, albitization and chloritization are also commonly observed.

**Mineralisation**

**Ages:**
44.2 ± 0.2 Ma (Re-Os on Molybdenite), data from Moritz et al., 2016b.
42 ± 2.5 Ma (K-Ar on sericite), data from Bagdasaryan, 1969.

**Mineralogy**
Copper as chalcopyrite, bornite, covellite, enargite
Molybdenum in molybdenite
Lead in galena
Zinc in sphalerite
Host mineral for gold and silver are not mentioned. Electrum? Free gold and silver? Tellurides?

**Controls**
Structural. Ore controlling structures: NE strike, dipping 65° towards NW (Fig.3), but the Eastern part of the open pit, along the Spetry fault is where the highest Cu and Mo grades were retrieved (Tayan et al., 2007).
June 22\textsuperscript{nd}: The Kadjaran mine

On June 22\textsuperscript{nd}, the group stayed in the Zangezur-Ordubad district. We visited a younger deposit, dated as Early Miocene in age, associated to the collisional to post-collisional tectonic setting in this region: the giant Kadjaran porphyry Cu-Mo deposit.

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Zangezur Copper and Molybdenum Combine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Town of Kadjaran (Syunik province, Armenia), Longitude: 46.1369 Latitude: 39.1403 (UTM WGS84 -38N)</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Porphyry-Cu-Mo-Re</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Cu-Mo-Re</td>
</tr>
<tr>
<td>Resources/Reserves/ Cut off grades</td>
<td>Total Reserves: 2244Mt @ 0.23%Cu , 0.03% Mo (Hovakimyan et al., 2019) Mine Life (since 1953 until 2037)</td>
</tr>
<tr>
<td>Metallurgical / Mineralogical info:</td>
<td><strong>Ore minerals</strong>: molybdenite, chalcopyrite, sphalerite, galena, covellite, tennantite, enargite, luzonite, bornite, chalcosite, gold, tellurides. <strong>Gangue Minerals</strong>: Quartz, carbonates, clay minerals, sericite.</td>
</tr>
</tbody>
</table>

Regional Geological Setting

Kadjaran is a deposit located within the Meghri-Ordubad Pluton (MOP) which consists of nested sub-volcanic intrusions emplaced over \~30 Ma from the middle Eocene to early Miocene during the Arabia-Eurasia collision.

Local Geology

**Host Lithology (and ages)**

This giant deposit is hosted by a 28.3 to 28.1 Ma-old monzonite intrusion (Rezeau et al., 2016), located to the east of the northwest oriented Tashtun fault and a porphyritic granite dated at 22.6 Ma (Moritz et al., 2016). The earliest dike generation, located in the eastern part of the Kadjaran district, consists of roughly north to northeast oriented quartz diorite dikes, and abundant fine-grained porphyritic granodioritic dikes (Tayan, 1984; Harutyunyan et al., 2002), also described as fine-grained andesitic dike and lamprophyre dikes dated between 26.6 and 24.5 Ma (Rezeau et al., 2016). Younger, 22.2 to 22.1 Ma-old, west to west-northwest oriented porphyritic granodiorite dikes crosscut the monzonitic host intrusion (Karamyan, 1978; Tayan, 1984; Tayan et al., 2002; Moritz et al., 2016; Rezeau et al., 2016).

**Structure**

Ore zones are controlled by an orthogonal system of steeply dipping (65-85\degree) east-west, north-south and northeast oriented (45-65\degree) sub-parallel fractures. The main ore-bearing zones are at the intersections of east-west oriented fractures and northeast oriented fractures. The majority of the ore-bearing stockwork zones of the Kadjaran deposit contain millimeter scale and up to 5 cm-thick veins, with some of them reaching a length of several tens of meters. They are mainly gently dipping (25-40\degree) sub-parallel sets of mineralized veins, forming stockwork systems, and dated at 27.28 ± 0.14 and 26.43 ± 0.13 Ma (Moritz et al., 2016; Rezeau et al., 2016).

**Alteration**

The alteration consists of sericitization, silicification and argillic alteration (kaolinite-illite).

Mineralisation

**Age**

27.2 ± 0.1 Ma to 26.43 ± 0.11 Re/Os molybdenite (porphyry event) (Moritz et al, 2016; Rezeau et al, 2016)

20.48 ± 0.10 Ma Re/Os molybdenite (epithermal event) (Moritz et al, 2016; Rezeau et al, 2016)
Mineralogy
- Copper as chalcopyrite, bornite, enargite, covellite, chalcosite, luzonite
- Gold as native gold and tellurides
- Lead in galena
- Zinc in sphalerite
- Molybdenum in molybdenite
- Rhenium in molybdenite

June 22nd: Kapan district: Shahumyan, Centralni East and West

The other half of the day was dedicated to the visit of the Shahumyan mine core shack belonging to the structural Kapan block unit. This stop acted as a large jump in geologic time, as the Kapan mining district is hosted in the Mesozoic units.

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Polymetal International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>In the eastern part of the Kapan district. Longitude: 46.432195 Latitude: 39.218500</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Epithermal (intermediate sulfidation)</td>
</tr>
<tr>
<td>Principal Commodity</td>
<td>Cu-Au-Ag-Zn±Pb (Shahumyan)</td>
</tr>
<tr>
<td></td>
<td>Cu (Centralni West)</td>
</tr>
<tr>
<td></td>
<td>Cu-Au (Centralni East)</td>
</tr>
<tr>
<td>Production</td>
<td>290,000 t of ore processed. 13.7 Koz of Au, 0.3 Moz of Ag, 615 t of Cu and 2,888 t of Zn (2016) (Mederer et al., 2019)</td>
</tr>
</tbody>
</table>

Exploration History

Mining in the Kapan district dates back to the Mid-19th century. In the past, the Centralni East and West were also exploited, but they ceased in 2005 and 2008 respectively. Now, the underground Shahumyan deposit remains the only active mine in the district.

Local Geology

Host Lithology (and ages)
The ore deposits of the Kapan district are hosted by Middle Jurassic andesitic to dacitic volcanic and volcaniclastic rocks of tholeiitic to transitional affinities below a late Oxfordian unconformity, which is covered by calc-alkaline to transitional Late Jurassic-Early Cretaceous volcanic rocks interlayered with sedimentary rocks.

Four geological units are distinguished in the Kapan district: the Middle Jurassic, Late Jurassic-Early Cretaceous and Paleogene magmatic complexes, overlain by Quaternary basanite flows.

The Shahumyan mineralization is hosted by the dominantly porphyritic subvolcanic quartz-dacite of the Middle Jurassic Barabatoom Formation that also consists of hyaloclastite and lava flows interlayered with ash fall deposits.
**Structure**
More than 100 steeply N and S dipping (75°–85°), E-W-oriented veins are found in the Shahumyan zone.

**Alteration.**
The main alteration in Shahumyan is phyllic and argillic, accompanied with advanced argillic (alunite) and poorly developed residual quartz alteration in the northeastern part of the deposit.

In Centralni West the alteration is characterized by chlorite, carbonate and epidote, with some sericite close to the ore. In Centralni East, there is silicification, residual quartz alteration and phyllic alteration.

**Mineralisation**

**Age**
146.2±3.4 Ma on pyrite from Centralni East (Re-Os) (Mederer et al., 2019)
156.14±0.79 Ma on alunite from Shahumyan (40Ar/39Ar) (Mederer et al., 2019)

**Mineralogy**
- Copper as chalcopyrite, enargite, chalcocite, bornite, digenite
- Gold and silver as Au-Ag tellurides, including calaverite, krennerite, sylvanite, petzite and hessite.
- Lead as galena.
- Zinc as sphalerite.
- Mercury as coloradoite.

*Figure 5: Students looking at the Shahumyan drill cores*
Controls

In the Kapan district, there is a deformation history with repeated reactivation of preexisting faults. Steeply dipping east-west striking extensional faults are the predominant structures in the Middle Jurassic magmatic complex. They formed early during the deformational history and are the host to mineralized veins in the Kapan district. These faults define the large-scale duplex-style geometry and control stratigraphic repetition in the district. Late north-south-oriented and steeply dipping normal faults and northwest-oriented strike-slip faults crosscut the thrust faults and the mineralized east-west striking extensional faults.

Oxidation Levels / Enrichment / Supergene upgrade

The host rock of the veins in Shahumyan is affected by hydrothermal brecciation with clasts cemented by ore and gangue minerals. In other places, pseudo-breccia is developed with alteration along micro-fractures.

From the most altered rocks to the least, minerals such alunite, diaspore, dickite and sericite with minor pyrite, hematite and supergene limonite are found.

Discussion (Formation model, Exploration implications etc.)

Mineralization is found in veins; Cu-sulfide quartz veins for Centralni West, Cu-Au, sulfide stockwork and veins for Centralni East and polymetallic veins for Shahumyan. In Shahumyan, the veins are zoned with an early barren quartz-pyrite stage, rimmed by a polymetallic stage, and filled by a late carbonate stage.

June 23rd: Amulsar deposit

After this step back in time, we kept going through Cenozoic units from the South Armenian Bloc

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Lydian International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Near the Jermuk city</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Epithermal (high sulfidation)</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Au-Ag</td>
</tr>
<tr>
<td>Resources/Reserves/ Cut off grades</td>
<td>102.7Mt @ 0.79g /T Au @3.9g/T Ag (Lydian website)</td>
</tr>
<tr>
<td>Metallurgical / Mineralogical info:</td>
<td>The high gold content is recorded is the oxidized matrix of a silica breccia. It is non visible gold and the matrix is mainly composed of goethite minerals.</td>
</tr>
</tbody>
</table>

Exploration history

The Amulsar deposit is a true greenfield discovery. However, during the 20th century, exploration has been done in the area for potential exploitation of quartz and Uranium. It is only in 2006 that exploration was launched for gold.

Regional Geological Setting

The emplacement of the Amulsar deposit is linked with the collision between the Arabian plate with the Eurasian margin. This collision controlled dextral strike slip tectonics in the South Armenian block, controlling the emplacement of magmatic intrusive and extrusive rocks as well as the ore deposit.

Local Geology

Host Lithology (and ages)

The deposit in Amulsar is characterized by 3 different units:

- An upper volcanic unit that is heavily oxidized and silicified and contains the ore.
- A lower volcanic unit which consist of a andesitic lava with strong argillic alteration
- An unaltered lower volcanic unit, andesite.

**Structure**
The deposit presents a complex structure. It shows pre-, syn-, and post-mineralisation structures with mainly both SW-NE and NW-SE thrust faults, faults and folds. The ore grade is the highest where the structure is the most complex.

**Alteration**
As mentioned previously, the upper volcanic unit is heavily silicified and oxidized. The silicification that affects the rock makes it impossible to define the nature of the clasts. The oxidized breccia is mainly composed of goethite.

![Figure 6: Map of the deposit and photographs of the main host rock lithologies](image)

**June 24th: Meghradzor mine**

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Armenian company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Meghradzor village</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Epithermal</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Au-Ag</td>
</tr>
<tr>
<td>Metallurgical / Mineralogical info:</td>
<td>The Au is present in quartz veins. Presence of galena, sphalerite, chalcopyrite as well in the veins</td>
</tr>
</tbody>
</table>
Exploration history

The Meghradzor mine is known from the ancient time (3500y BC). Modern exploration started in the 1960’s during Soviet times.

Regional Geological Setting

As with Amulsar, the emplacement of the Meghradzor deposit is linked with dextral strike slip movement in the SAB controlled by the collision between the Arabian plate and the Eurasian Margin.

Local Geology

Host Lithology (and ages)
The deposit is hosted in Eocene alkaline volcanogenic rocks as well as syenitic and monzonitic intrusions. Often, the veins are following emplacement of lamprophyre dikes.

Structure
The main veins are E-W oriented with a dipping angle of 65°-70° toward the N.

Figure 7: Pyrite veins sample from the mine tailings

June 24th: Hrazdan prospect

The following informations are extracted from the Armenian passport of the deposit.

Main mineralogy: magnetite, pyrite, chalcopyrite, martite, hematite, limonite;

Gangue: garnet, chlorite, calcite, quartz, epidote;

Ore grade: 26.46%;

Age: 42-38 Ma (the method is not indicated);

Host-rock geology: Eocene granodiorite and Cretaceous (Cenomanian) limestone and limestone-sandstone;

Deposit type: Contact-metasomatic (skarn), situated along the contact of Eocene granodiorite and Cretaceous limestone and limestone-sandstone;
June 25th: The Shamlugh mine (Alaverdi district)

On June 24th, we made a panorama stop to look at the ophiolites of the Sevan Akera Suture zone. On June 25th we went North on the other side of the suture zone in the Mesozoic units.

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Formerly operated by Metal Prince Ltd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Town of Shamlugh, Lori District</td>
</tr>
<tr>
<td></td>
<td>41.165272°N 44.719861°E</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Polymetallic with massive lenses, stockwork and veins</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Cu, Pb, Zn, Au, Ag</td>
</tr>
<tr>
<td>Resources/Reserves/Cut off grades</td>
<td>4. Mt @ 3.53% Cu, 1.7% Pb, 4.96% Zn, 8.1 g/t Ag and 1.0.3 g/t Au (Calder et al., 2019)</td>
</tr>
<tr>
<td>Metallurgical/Mineralogical info:</td>
<td>Main ore minerals are chalcopyrite, pyrite, sphalerite, bornite, and chalocite (Khatchaturyan 1977). Minor minerals include galena, tennantite, stannite, emplectite, argentite, and marcasite.</td>
</tr>
<tr>
<td>Mining methods</td>
<td>Underground and open pit mining (active)</td>
</tr>
</tbody>
</table>

Regional Geological Setting

The Shamlugh mine is hosted in a part the Alaverdi district dominated by Middle Jurassic magmatic rocks interlayered with sedimentary rocks. These units are overlain by Late Jurassic and Cretaceous volcanic and sedimentary rocks and Eocene and Quaternary rock units (Sopko 1961; Lebedev and Malkhasyan 1965; Ghazaryan 1971; Melkonyan 1976).

Local Geology

Host Lithology (and ages)
Mainly hosted by the Middle Jurassic dacitic to rhyolitic pyroclastic unit, which is a distinct ore-bearing marker unit in the district and which can be followed laterally from the Alaverdi to the Akhtala deposits (Nalbandyan and Paronikyan 1966; Nalbandyan 1968).
**Structure**
In the shallow parts of the deposits, the orebodies consist of stockwork and subhorizontal, stratabound lenses. In the deeper parts subvertical ore-bearing veins predominate.

**Mineralisation**

**Age**
155 ± 4 Ma (silicified, sericitized, ore-hosting pyroclastic rock) (Bagdasaryan et al., 1969)
142 ± 6 Ma (silicified, sericitized rhyolite sill) (Bagdasaryan et al., 1969)

**Mineralogy**
Chalcopyrite, pyrite, sphalerite, bornite, and chalcocite

**Controls**
Host rock alteration and ore bodies are controlled by an EW-oriented strike-slip fault and second order NNE oriented faults (Althunyan, 1973; Zohrabyan and Melkonyan 1999).

*Figure 9: Several features of what can be find in the surroundings of the mine*
June26th: The Madneulli mine

The final part of our trip was the visit of mines in the Bolnisi district, an area mainly hosting deposits in Cretaceous volcanogenic units and considered as the back arc basin of the Somkheto Karabagh belt.

<table>
<thead>
<tr>
<th>Ownership</th>
<th>RMG (Rich Metal Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>4km from Bolnisi, Georgia</td>
</tr>
<tr>
<td>Coordinates:</td>
<td>41°21'42&quot;N, 44°29'30&quot;E</td>
</tr>
<tr>
<td>Deposit type</td>
<td>VMS- Epithermal deposit- Porphyry</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Cu</td>
</tr>
<tr>
<td>Production:</td>
<td>85Mt @1.0g/tAu and 1%Cu in 30 years (Georgian mining corporation website)</td>
</tr>
<tr>
<td>Metallurgical/Mineralogical info:</td>
<td>Ore Minerals: chalcopyrite, bornite, chalcocite, covellite, native gold, sphalerite, galena, tennantite-tetrahedrite, tellurides</td>
</tr>
<tr>
<td></td>
<td>Gangue Minerals: pyrite, quartz, barite, sericite, clay minerals (kaolinite, alunite, pyrophyllite, jarosite, gypsum, chlorite,</td>
</tr>
<tr>
<td>Mining method/</td>
<td></td>
</tr>
<tr>
<td>processing method</td>
<td>Open pit / Mills and flotation and heap leaching (for Au in the silicified zones)</td>
</tr>
</tbody>
</table>

**Figure 10: Panoramic view of Madneuli deposit’s open pit**

**Exploration History**

Discovered in 1949. First, the found a Ba-rich lithocaps which later on led them to discover Pb-Zn mineralization, which evolved with continued extraction to Zn-Cu and lastly to Cu-Au at depth.

**Regional Geological Setting**

Madneuli deposit is part of Bolnisi mining district which belongs to the Artvin-Bolnisi zone located at the northwestern extremity of the Somkheto-Karabagh belt. It represents the transition between the Eastern Pontides magmatic arc in northeastern Anatolia and the Somkheto magmatic arc of the Lesser Caucasus. The Bolnisi district is a major copper and
gold producer in Georgia, where mining started as early as the Bronze Age. As an exception from the other deposits in the district, Madneuli has been controversially interpreted both as a transitional volcanogenic massive sulfide-epithermal system (Migineishvili, 2002, 2005) and as a porphyry-epithermal system (Gugushvili et al. 2014).

**Local Geology:**

**Host Lithology (and ages):**
The Madneuli deposit is hosted in three main complexes. The upper complexes consist of Madneuli and Kazreti volcano-sedimentary complexes. They are hosting the main mineralization and are separated from each other by a regional unconformity. At the same time these two complexes are separated by the E-W Madneuli fault from the Nabahrevi complex, which consist of ignimbrites, lavas, dacitic dykes and granodiorite (88-89Ma, K-Ar whole rock method; Rubinstein et al., 1983; Gugushvili and Omiadze, 1988).

**Structure**
The main structure is the Madneuli fault which is sub-vertical and trends E-W.

**Alteration**
The main alterations in the mine are: silicification (in which the highest gold concentration is hosted), sericitization (quartz-chlorite-sericite), argillic alteration (alunite, kaolinite, jarosite, pyrophyllite), quartz-sericite-pyrite

**Mineralisation**
There are two types of mineralization in the deposit: disseminated Au-Cu-Pb-Zn ore in stockworks and strongly silicified zone which consisting mainly Au.

**Mineralogy**
- Copper as chalcopyrite, bornite, chalcocite, covellite,
- Gold as native gold and tellurides
- Zinc as sphalerite
- Lead as galena

**Mineralogical zonation within the deposit**
A vertical distribution of mineralization styles have been recognized and studied at the Madneuli deposit. The main distribution trend is showing that the copper-rich ore bodies at depth are grading into sphalerite, galena, barite and gold-bearing mineralization in the shallower parts of the mineralized systems. The same distribution can be found in the other deposits of the Bolnisi district, like Sakdrisi, Kvemo Bolnisi and David Gareji (Gugushvili et al., 2014; Gugushvili, 2004).

**Discussion. (Formation model, Exploration implications etc.)**
The host-rock volcano-sedimentary successions were deposited under alternating subaqueous and subaerial conditions related to intermittent uplift and subsidence phases (Gugushvili et al., 2001, 2014; Migineishvili, 2002, 2005). Detailed field and petrographic studies by Popkhadze et al. (2014) support the subaqueous origin of the majority of the host rocks, including thick pyroclastic sequences. Although there are divergences about details, the proposed genetic models are consistent with a submarine magmatic-hydrothermal system, similar to a transitional VMS-epithermal setting with a potential porphyry system at depth (Gugushvili et al., 2001, 2014; Migineishvili, 2002, 2005; Gialli et al., 2012; Gialli, 2013).
June 26th: Sakdrisi mine

| Ownership | RMG (Rich Metals Group) since 2012 after Quartzite company ownership |
| Location | 16km southwest of Bolnisi and 50km southwest of Tbilisi, Georgia |
| Coordinates: Longitude- 44.375273°  Latitude- 41.379409° |
| Deposit type | Epithermal (Intermediate Sulfidation) |
| Principal Commodities | Au (Cu as by-product) |
| Production: | In www.docs.satvistomo.de/Gold_InTheCaucasus the following are mentioned: -10 ppm to 180 ppm Au in the mean rate 130g/t Au, 70g/t Ag |
| Resources/Reserves/ Cut off grades | -Potential 23.5 Mt Au bearing rocks with an average of 1.03 g/t Au (Gugushvili et al. 2004) |
| Metallurgical/ Mineralogical info: | Ore Minerals: Au-rich quartz-barite and quartz-chalcedony veins, occurring in the lithocap and Cu (as chalcopyrite)-rich quartz-amethyst and quartz-carbonate veins, occurring in the stock work |
| | Gangue Minerals: quartz, barite, chalcedony, hematite, goethite |
| Mining method/ processing method | Open pit / Heap leaching (for Au in silicified zones) |

Exploration History

The Sakdrisi-Kachagiani prehistoric mine is considered the oldest Au mine in the world, dating back to the 3rd millennium BC or to the 2nd half of the 4th millennium according to a large-scale investigation carried out from the Volkswagen Foundation starting the 2004 until the 2013 (www.docs.satvistomo.de/Gold_InTheCaucasus). Originally mined for Cu in pyrite and Ba-barite polymetallic ore. The deepest vertical extension of prehistoric mining activities reached 31 m below surface.

Principal techniques that can locate the mineralisation

1. Occurrence of older mining galleries, use of intersects:

   The ore deposit of Sakdrisi was explored and prospected in the 1980’s, when several exploration tunnels had been dug (see Omiadze 2007). These tunnels intersected ancient mining galleries underground, an important observation first described by Timur Mudshiri, a Georgian engineer and geologist (Mudshiri 1987). Intersection cuts with ancient tunnels are reported from both the 20m and 40m exploration horizons.

2. Silicification and Supergene Cu enrichment (e.g. azurite, malachite)

Local Geology

Host Lithology (and ages)

The Sakdrisi deposit is located within the Upper Cretaceous volcanic units.

The Upper stratigraphic horizon is represented by rhyolitic ignimbrites and pumiceous pyroclastic flows (K-Ar 77.6 Ma) which are intruded by rhyolitic and rhyodacitic lava flows, dikes and extrusive domes (K-Ar 72-71 Ma), all of
which are barren. Typical textures of welded ignimbrites may still be observed, as well as devitrified flattened pumices (called fiamme).

The underlying host rock within the mineralizing Au-rich envelope is composed of thick tuff sequence in which the deposit is found, is intensely disrupted, silicified and argillized forming phyllosilicates and clay minerals (K-Ar 83.6-82.1 Ma). The above ages are taken from Gugushvili et al., 2004.

**Structure**
The structure of Sakdrisi is controlled by a NE striking fault and the deposit consists of five block prospects (Sakdrisi I-V) characterized by a 2 km long cluster aligned along a NE-SW orientation. Secondary NW-SE oriented faulting explains the erosion of the uplifted blocks, while supergene enrichment is preserved in the open pit Sak-V. The stockwork found in the prehistoric Sakdrisi-Kachagianni mine is composed of vertical to irregularly quartz veins with a thickness of 10-30cm. A top-to-south thrust of barren ignimbrite atop the “reduced ore” has been evidenced in Sak-IV. This contact has been identified by the localizing of fluid flow responsible for intense alteration in the mine, as well as the sigmoidal shape of the barren ignimbrite over the mineralized host rocks.

**Alteration**
Chloritization is part of the regional alteration.

Near the top of Sak-IV’s oxidized brecciated zone intense silicification contrasts with the clay-altered rocks located closer to the main thrust zone.

Pyrite alteration is proximal to the vein system. Initial textures are preserved, resulting in rocks, which exhibit a vuggy texture. Some crystals recrystallized to quartz, while plagioclase is locally totally replaced by sericite.

Dickite was mainly deposited in the veins, but it is also found in their alteration haloes and in the zones of supergene advanced argillic alteration, due to weathering and oxidation of sulfides (top of Sak-V).

Jarosite was found at the bottom of the open pit Sak-V, in an area of supergene enrichment, from where the highest gold grades were recovered.

Some of the phyllosilicates, clay minerals and oxides observed are; illite, sericite, montmorillonite, dickite, chlorite, azurite, malachite, jarosite, siderite, ankerite and hematite.

*Figure 11: The team pointing out some structural features in the open pit*
Mineralisation

The two types of ore which are currently being exploited in Sakdrisi are (1) auriferous quartz-barite and quartz-chalcedony veins surrounded by illite siderite alteration haloes, in the brecciated, silicified and oxidized volcaniclastic rocks of the lithocap, and (2) subvertical chalcopyrite-rich quartz-amethyst and quartz-carbonate veins hosted in the stockwork of a more reduced zone. The latter is thought to represent a deeper part of the system directly overlain by the silicified zone, which underwent supergene enrichment, as suggested by the occurrence of minerals such as chalcocite.

According to K-Ar dating the deposit dates back to 77.6-83.5 Ma (Gugushvili et al. 2004).

Mineralogy

Gold as native gold. The Au accessible is extremely fine-grained flour gold hardly visible with the naked eye.

Cu-Copper as chalcopyrite, with economic values below 60m of stockwork depth.

June 27th: Kvemo Bolnisi prospect

<table>
<thead>
<tr>
<th>Ownership</th>
<th>100% Georgian Mining Corporation (GMC) With agreements on mineral rights with Rich Metals Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>5 km southeast of Bolnisi, Georgia</td>
</tr>
<tr>
<td>Deposit type</td>
<td>Epithermal (Intermediate Sulphidation)</td>
</tr>
<tr>
<td>Principal Commodities</td>
<td>Au (+ Cu)</td>
</tr>
<tr>
<td>Production:</td>
<td>Exploration Target</td>
</tr>
</tbody>
</table>
| Metallurgical/ Mineralogical info: | **Ore Minerals** Native Gold, Chalcopyrite, Chalcocite  
**Gangue Minerals** : Quartz. Pyrite, |
| Mining method/ processing method | Proposed Open pit / Mill and flotation |

Exploration History:

The Kvemo Bolnisi Exploration project lies on a NW-SE lineament that connects it to both the Sakdrisi and Madneuli deposits within a 10km section. A topographic high associated with the silicification and oxide precipitation that highlights the top of the Kvemo Bolnisi breccia pipe system.

In addition to the geological characteristics, ore bodies in the Kvemo Bolnisi district were identified using an aeromagnetic survey by a subcontractor. Additionally, a suite of 18 drill holes were recovered identifying two gold zones and a smaller, deeper breccia pipe with significant Au mineralization.

Principal techniques that can locate the mineralization:

Oxidation halo outline the surface expression of subsurface breccia pipes, which host Cu-sulfides and associated Au mineralization.

Regional Geological Setting:

Located adjacent to the Late Cretaceous part of the arc hosted by the Eurasian continent. Regional geology is composed of Jurassic to Cretaceous volcanoclastic-sedimentary sequences with ignimbrites and andesites intruded by Cretaceous and early Tertiary andesitic porphyry systems associated with ongoing subduction, prior to continental collision in the Eocene.
Local Geology:

**Host Lithology (and ages):**
Undifferentiated volcanic units identified primarily as ignimbrites and intermediate-felsic volcanic units. 87-80 Ma.

**Structure.**
Mineralization associated with two breccia pipes at the center of the KB system both of which sit below silicified oxidation zones

**Alteration.**
Hematite-goethite-limonite sequence of Fe(OH) group minerals associated with intense silicification above the breccia pipe. Supergene Cu enrichment in intermittent zones of the breccia pipe.

Mineralization

**Age**
Potentially coeval with nearby Madneuli and Sakdrisi systems dated between 80-87 Ma.

**Mineralogy**
Copper as Chalcopyrite,
Gold as Native Gold

Controls

Hydrothermal mineralization controlled by breccia pipe mineralization and supergene controls by oxidation limits

Oxidation Levels / Enrichment / Supergene upgrade

The current understanding of the KB system precludes information on the depth of the system. The breccia pipe are 60 m, and 20 m wide, respectively, and both are associated with Cu-Au mineralization. Highest Au concentrations are associated with oxidized zones, in which highest Cu grades are associated with supergene enrichment zones that extend laterally away from breccia pipes for hundreds of meters.

Geophysical responses

A magnetic anomaly was discovered using 1 km spaced aeromagnetic survey.

Discussion. (Formation model, Exploration implications etc.)

The Kvemo Bolnisi exploration project is interpreted to be an intermediate epithermal Cu-Au system related to some intrusive system at depth, similar to the Madneuli deposit. The deposit appears to have formed along a structural lineament which controlled Cretaceous alkalic intrusions hosted by older volcano-sedimentary units.
References


mineralization, economic potential and perspectives according to data for April 2014, in Natsvlishvili M.P., ed., Conference booklet, Tbilisi, Caucasus Mining Group, 55 p. (in Russian with English abs.).


