2022 AUTh SEG Student Chapter
Field Trip Report
Cyprus

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Society of Economic Geologists

School of Geology AUTh

Thessaloniki

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Field Trip Participants

From October 26th to 30th, the Student Chapter of the Society of Economic Geologists (SEG) of the Aristotle University of Thessaloniki (AUTh) organized a field trip to the ore deposits and the Troodos Geopark of Cyprus. The deposits are related with the opening and closure of the Tethys ocean during Mesozoic and the associated ophiolites, and include chromite, volcanogenic massive sulfide and asbestos mineralization. The field trip was financially supported by the SEG through the Foundation Round I 2022 from the Stewart R. Wallace Fund, while additional funds were available from the participation of the chapter at the 2nd AUTh Flea Market in December 2021 and the University of Nicosia, with contact person Associate Professor Ernestos Sarris.

Thirteen student members with different degrees of education, from undergraduate to Ph.D. level, took part in the field trip, accompaniedby the Academic Advisor, Professor Vasilios Melfos and Assistant Professor Grigorios-Aarne Sakellaris (Table 1). Each of the students held a small presentation about different topics regarding the geology and the ore deposits of Cyprus, after the field trip at the Aristotle University of Thessaloniki.

The continuous support of SEG is deeply appreciated. Through the generous financial funding of the SEG Stewart R. Wallace Fund of the Round I 2022, we have been able to accomplish this field trip. Special thanks are due to Dr. Ernestos Sarris for his support and guidance throughout the whole field trip. Also, we would like to thank Mr. Demetris Vattis, Quarries Director of Hellenic Mining Corporation, Mr. Konstantinos Xydas, Director of HellenicMinerals, Mr George Kalogeropoulos, Quarries Director of Hellenic Copper Mines, Dr. Nikos Adamides, Mrs Constantina Theofylaktou and Mrs Eleutheria Eleutheriou for the knowledge that provided us with and all the fruitful discussions about the geology of Cyprus and its mininghistory. Finally, we would like to thank our Academic Advisor and Professor Vasilios Melfos, and the Associate Professor Griorgios-Aarne Sakellaris for all the support throughout the trip and the knowledge exchange. Photo credits go to Vasilios Melfos and Margarita Melfou.

Most of the mines are inactive today, and it was safe for the student members approaching them. Therefore, no special activities and precautions were taken to improve safety.

Table 1. The field trip participants

Name	Academic Status	SEG Membership
Vasilios Melfos	Professor	Academic Advisor
Grigorios Aarne Sakellaris	Assistant Professor	
Christos Stergiou	Ph.D. student	SC[1] member, SEG Student[2]
Margarita Melfou	Ph.D. student	SC member, SEG student
Alexandros Mpampatzianis	Master student	SC member, SEG student
Anastasios Kyriakos	Master student	SC member, SEG student
Dimitra Perperi	Master student	SC member, SEG student
Elisavet Varvari	Master student	SC member
Eftychia Peristeridou	Master student	SC member, SEG student
Ioanna Alpi	Master student	SC member, SEG student
Niki Mandraveli	Master student	SC member
Eirini Margiola	Undergraduate Student	SC member, SEG student
Eleni Pegioudi	Undergraduate Student	SC member
Eleni Tsirigoti	Undergraduate Student	SC member
Nikoleta Passali	Undergraduate Student	SC member

[1] Student Chapter member, [2] Student member of the SEG

Introduction

The field trip to Cyprus was organized by the board of the AUTh SEG Student Chapter during the academic year 2021-2022 and mainly by Margarita Melfou (Secretary), Eftychia Peristeridou (Vice-President)and Dimitra Perperi (President). The participants were based in the old townof Nicosia, the capital of Cyprus. The distances between the visit sites were covered by a

minibus offered by the University of Nicosia.
Cyprus is located in the eastern Mediterranean Sea and has attracted many geologists from all over the world due to its mining history and unique geology. The name "Cyprus" meanscuprous, which is synonymous with copper.

The island of Cyprus is divided into four geological zones, as shown in Figure 1:

- The Kyreneia Terrane, which is primarily composed of the Pentadaktylos mountain range.
- The Troodos Terrane (or Troodos Ophiolite sequence).
- The circum Troodos sedimentary succession (including the Mesaoria Basin)
- The Mamonia Complex.

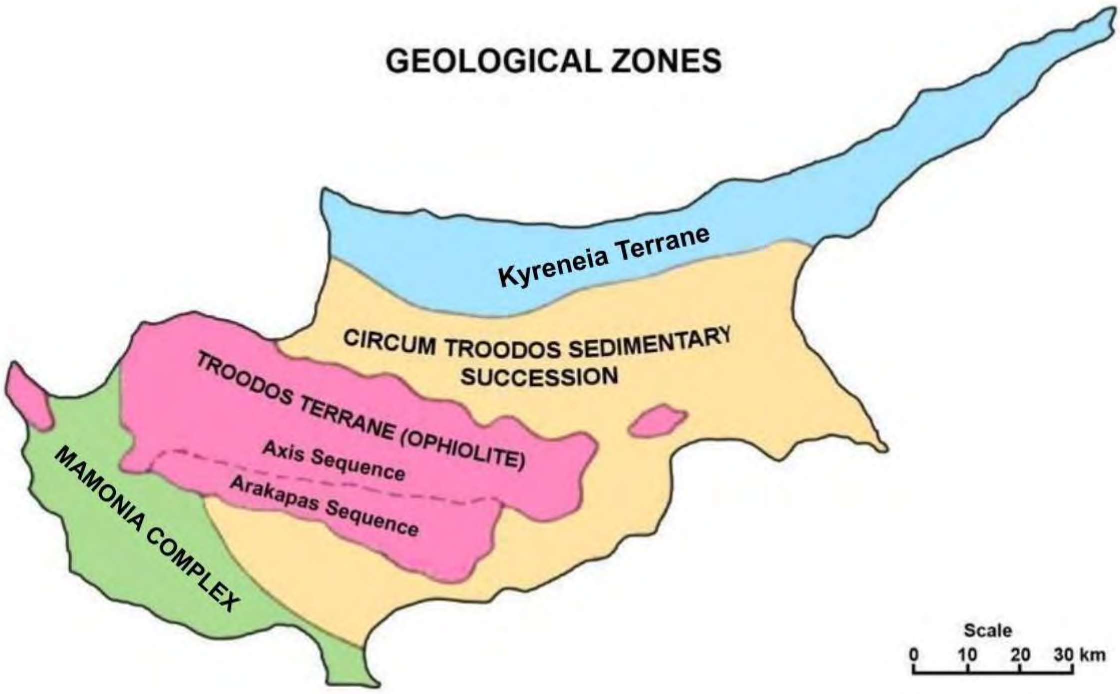

Figure 1. Geological map of Cyprus with the major geological zones (Mougiannou et al., 2019)

The Kyreneia Terrane is the northern-most geological zone of Cyprus and consists mainly of the Pentadaktylos mountain range, which runs 160 km along the north coast. The base of the zone consists of a series of recrystallized limestones, marbles and dolomites that date from Permian to Lower Cretaceous, followed by sedimentary rocks of Upper Cretaceous to Middle Miocene (Anonymous, 2015). The Troodos Terrane consists of a 10 to 20 km thick ophiolite sequence, composed of ultrabasic and basic plutonic rocks followed by intermediate magmatic rocks and lava flows. Numerous researchers have thoroughly examined this sequence in terms of mineralogy, petrology and geochemistry, because it is considered to be the most complete ophiolite sequencein the world. The area between the Kyreneia and the Troodos Terranes is covered by the Troodos sedimentary sequence, which is composed of clastic sediments, volcanoclastics, limestones, cherts, chalks, and clays. Southwest of Cyprus, the Mamonia Complex consists of Upper Triassic to Lower Cretaceous sedimentary rocks and Upper Triassic mafic igneous and metamorphic rocks that all lie close to the southwest margin of the Troodos Terrane and its Upper Cretaceous sedimentary cover.

Cyprus comprises metallic and industrial mineral deposits that are associated with the Troodos Ophiolite. The metallic mineral resources are mainly chromite and volcanogenic massive sulfides, such as copper and pyrite ores, whereas the industrial minerals include asbestos, gypsum, and natural pigments. The formation of chromite is directly associated with the dunite through the process of fractional crystallization of the magma that originated from the mantle.

The sulfide deposits, also known as Cyprus-type massive sulfide deposits, are associated with pillow basaltic lavas of the Troodos Ophiolite and were formed during seafloor spreading of the Tethys oceanic lithosphere. Chalcopyrite, bornite, chalcocite, covellite and cuprite represent the main copper minerals. Cyprus has been well-known for its copper production, which started around 3000 BC (Bronze Era) (Kassianidou, 2000). Several archaeological excavations on the island unearthed many slag heaps, which indicates that Cyprus was one of the largest producers of copper in Antiquity and the main supplier for the Roman Empire, until its downfall. Up to the 19th century, the mining industry in Cyprus was inactive. The need to produce sulfur in late 19th century led to the extraction of pyrite and chalcopyrite, while copper was also extracted for other purposes (Maliotis, 2021).

Asbestos is mainly of chrysotile type, a fibrous mineral found in veins, and was formed during the serpentinization of harzburgite. Asbestos has been mined from 1904 to 1988.

Activities Program

Day 1

1st stop - Agrokipia VMS deposit

The first stop of the field trip was at the Agrokipia VMS deposit (Fig. 2), where Dr. N. Adamides and Mr. D. Vattis introduced us the geology of the area and the history of the mine. The ore bodies in this area are covered by basaltic lavas of the Troodos ophiolite sequence. The deposit exhibits indications that the hydrothermal fluids reached the sea floor and deposited massive sulfides in the form of exhalative lenses comparable to those presently forming by black smokers at constructive margins (Adamides 2010a,b).

Due to oxidation these ore bodies were altered to a gossan, from which gold and silver were mined in the 1930s. In 1950, after exploration and drilling works in the area, the "Agrokipia A" deposit was discovered. The ore consisted mainly of pyrite and chalcopyrite and was mined with an open pit. Until 1971, when the mining activities stopped, a total of 442.000 tons of ore were mined, of which 139.000 tons of pyrite concentrate were produced. In 1954, about 200 meters northeast, the "Agrokipia B" deposit was discovered by gravimetric methods. The ore consists of pyrite, chalcopyrite and sphalerite with minor bornite, galena and tennantite. The exploitation started in 1958 and ended in 1964, with only 74.000 tons of ore being extracted (Catzipanagiotou, 2020; Maliotis, 2021).

2nd stop - Kokkinopezoula-Mitsero VMS deposit

Our second stop was at the Kokkinopezoula - Mitsero VMS deposit and the abandoned mine which is called "Red Lake" (Fig. 3) due to the intensive oxidation of the sulfides. The deposit is located close to the village of Mitsero, 28 km southwest of Nicosia. Dr. N. Adamides and Mr. D. Vattis guided us through the old facilities of the mine sites and gave us a presentation of the characteristics of the deposit and the mine. The deposit forms massive lenses and high-grade pyritic stockworks in altered pillow lavas with quartz gangue (Adamides 2010a,b, 2013).

In 1953 the exploration led to thediscovery of pyrite-chalcopyrite deposits and thus, the extraction of copper and sulfur started. Although the operation of the mine led to the economic development of the area, the workingconditions were very dangerous for the miners and as a result, the mine stopped its operation in 1966.

Furthermore, we discussed the environmental impact of the mine after its closure. The large open pit was filled with water, which caused extensive acid drainage (pH = ~3) from the oxidation of the sulfides, especially pyrite (Fig. 3). In the past, the contamination of the water and the soil caused significant harm to the fauna and flora, but in recent years due to environmental restoration works the scenery has changed, and trees have begun to grow giving hope that this area will be gradually recovered (Kostarelos et al., 2015).

Figure 2. The “Agrokipia A” VMS deposit and the members of the AUTH SEG student.

Figure 3. The Kokkinopezoula VMS deposit and the members of the AUTH SEG student.

3rd stop - Kokkinoyia VMS deposit

At Kokkinoyia (Fig. 4), the VMS deposit was formed by hydrothermal fluids that were discharged at the sea floor. The deposit is characterized by massive cupriferous lenses, and associated stockwork mineralization with pyrite and chalcopyrite, with local sphalerite enrichment (Adamides 2010a,b, 2013). The deposit attracted geologists in 1926, and the exploration works focused the intensive oxidation zones and the areas around the large slag heaps from Roman times. Mining started in the 1930’s, but intensive exploration and exploitation with underground galleries occurred during the 1970’s. In total, 475.000 tons of ore were extracted with an average content of 3.7% Cu and 35% S, from which about 80.000 tons of copper concentrates and 203.000 tons of pyrite concentrates were produced. Today the mine is abandoned (Maliotis, 2021).

Figure 4. The Kokkinoyia mine VMS deposit and the members of the AUTH SEG student.

4th stop - Pillow lavas and flows with celadonite at Kato Moni

Close to Kato Moni village, we observed impressive pillow lavas and flows (Fig.5) with celadonite, which is the predominant secondary mineral of the pillow lavas, replacing clinopyroxene. Celadonite is a blue-green phyllosilicate mineral of the mica group and usually forms aggregates of prismatic crystals. It is most commonly formed by low-temperature hydrothermal alteration of volcanic rocks. In the Troodos ophiolite sequence celadonite is found as a void-filling phase within porous basalts and other volcanic rocks, but it can be also found as a thin coating, or it may even replace phenocrysts (Laureijs et al., 2020).

5th stop - Alestos VMS deposit

At the next stop, we discussed briefly the VMS deposit of Alestos. The extensive interaction between the hydrothermal fluids and ambient seawater, associated with the presence of permeable pillowed flows, resulted in the deposition of sulfide mineralization surrounded by zones of extensive alteration (Adamides 2013). The main type of alteration is silicification with outer chlorite and epidote-hematite zones. The massive sulfide mineralization forms lenses and is underlain by stockworks. Significant supergene oxidation formed chalcocite and covellite, as the main secondary copper minerals. The exploitation started in 1971 and lasted almost 20 years. Approximately 661.000 tons of ore were extracted, with an average content of 0.9% Cu (Maliotis, 2021).

6th stop - Skouriotissa VMS deposit

Our next stop was at the Skouriotissa VMS deposits (Phoukasa and Phoenix), where Mr. K. Xydas, Director of Hellenic Minerals, gave us a brief presentation about the history and the operation of the mines, and focused on the formation of the ore bodies (Fig. 7). Skouriotissa is identified as a volcanogenic massive sulfide deposit and ore varies from 0.1-4.5 wt.% Cu (Adamides 2010a,b, 2013). Unusually, most Cu at Skouriotissa is supergene in nature (e.g. chalcocite, covellite, native Cu), and only minor hypogene mineralization exists in the form of chalcopyrite. Phoenix is a stockwork mineralization whilst Phoukasa is massive. Massive sulfide lenses are composed of pyrite and chalcopyrite, overlain by pyritic chert, with limited supergene enrichment at the upper levels associated with submarine weathering and formation of ochre, enriched in gold. A pipe-like stockwork zone underlies the deposit, which laterally away rests on unaltered lavas (Martin 2019).

Figure 5. Eleni Pegioudi, member of the AUTH SEG student chapter, examining celadonite in the altered pillow lavas close to Kato Moni village.

Figure 6. The Alestos VMS deposit and the homonym hill.

Faulting is well defined in the area with the Phoukasa and Skouriotissa faults cross-cutting the deposit. The mineralization occurs at the Upper Pillow Lavas and the seafloor boundary. The most spectacular umber situated directly overlying the VMS mound is also located at Skouriotissa allowing a complete cross-section through the VMS stratigraphy and sediments that overlie mineralization to be analyzed.

Skouriotissa is one of the oldest mines in Cyprus, since slag heaps and archaeological artifacts that were found in the area, were dated back to 1060 B.C. Today only the Phoenix mine is actively operating in Cyprus producing 99.99% pure Cu cathodes using heap leach extraction followed by a solvent extraction electrowinning (SXEW) process. Gold is also produced in minor quantities via cyanide leaching from gossan material.

Figure 7. The Skouriotissa mine which is a property of Hellenic Minerals, and the students with the staff of the company.

7th stop - Apliki VMS deposit

The final stop for the first day was at the Apliki VMS deposit, where we had the opportunity to learn about the geology and exploitation of this deposit, by Mr. G Kalogeropoulos, Quarries Director of Hellenic Copper Mines, accompanied by Dr. N. Adamides (Fig. 8). The Apliki mine, which is 5 km southwest of the Skouriotissa mine, is one of the most representative examples of Cu-bearing massive sulfide deposits globally.

Figure 8. Dr. N. Adamides explaining to the students the geological characteristics of the Apliki.

The mineralization in the Apliki mine is hosted within the sequence of the Lower Pillow Lavas of the Troodos ophiolite complex. The three main ore minerals are pyrite, marcasite, and chalcopyrite, while the most common magmatic minerals include plagioclase, augite and sometimes olivine. Celadonite, calcite, analcime, and quartz are the predominant alteration minerals and can be found dispersed throughout the rock matrix (Antivachis, 2015).

The Apliki deposit was detected during gold exploration in the 1930s and initially was mined underground, followed later by opencut mining. Operations ceased in 1973, however low-grade resource remains (Maliotis, 2021). However, a small part of the oxidized ore was stored separately and is now an important resource for Hellenic Copper Mines for hydrometallurgical purposes (Antivachis, 2015).

Day 2

1st stop - Troodos UNESCO Global Geopark Visitor Centre

In the second day we visited the Troodos UNESCO Global Geopark Visitor Centre where Mrs. Constantina Theofylaktou, the geological officer of the Geopark, presented the spectacular Troodos ophiolite sequence and the related geology of Cyprus (Fig. 9). At the entrance of the Visitor Centre there is a small geological garden that contains the all the representative rock types of the Troodos ophiolite sequence, arranged in stratigraphic order. We had the opportunity to examine all these samples and discuss the details with Mrs. Theofylaktou and our Academic Advisors.

Figure 9. Mrs. Constantina Theofylaktou, the geological officer of the Geopark, presenting the spectacular Troodos ophiolite sequence and the related geology of Cyprus.

The visit at the Troodos UNESCO Global Geopark was a unique experience for us to explore the complex geological processes which have made Cyprus a geological model for researchers from around the world, contributing to a better understanding of the development of the oceans and the planet in general. The Troodos ophiolite is recognized as the most complete and studied ophiolitesequence in the world. It is a part of a completely developed oceanic crust, composed of plutonic,volcanic and intrusive rocks, as well as chemical sediments. It was formed during the ocean spreading and the oceanic crust evolution. It emerged and moved into its current position through a series of intricate tectonic processes, associated with the collision of the African plate to the south and the Eurasian plate to the north (Pearce and Robinson 2010).

2nd stop - Abandoned Amiantos (Asbestos) mine

After the Geopark Visitor Centre, we spent considerable time at the rehabilitated abandoned Amiantos (Asbestos) mine, where Dr. Ernestos Sarris, Associate Professor at the Department of

Engineering at the University of Nicosia, guided us through the old facilities and talked about the history of the mine, focusing on the formation processes of asbestos and the restoration methods of the mine (Fig. 10). The Amiantos mine is of an opencast type, where chrysotile asbestos has been exploited from 1904 until 1988 (Maliotis, 2021). Chrysotile is the most common type of asbestos and resulted from the serpentinization of the Troodos ultramafic rocks.

From 1904 until 1988, 130 million tons of asbestos are estimated to have been extracted.In the 1980s, when it was discovered that asbestos exposure is linked with a rare type of lung cancer called mesothelioma, caused by the inhalation of asbestos fibers, there was a decrease in its demand and thus eventually the production ended. All those years of asbestos exploitation resulted not only in many health problems for the workers, but the environment and the area were affected too. Pollution of the soil and the water, extensive waste tips and a huge open pit are some of the problems that the operation of the mine has left behind (Poyatzi et al., 2018).

Figure 10. Associate Professor Ernestos Sarris discussing with the students about the history of the mine and the formation processes of asbestos.

Day 3

1st stop - Maroullena River - Lower pillow lavas

On the last day of the field trip, we visited different geosites of the Troodos Geopark, with the guidance and support of Mrs. Eleutheria Eleutheriou, an experienced geologist. The first stop was at the Maroullena River with a spectacular exposure of the Lower and the Upper pillow lavas of the Troodos ophiolite sequence, cut by vertical dykes (Fig. 11). Samples of greenish celadonite and chalcedony veins were also found while exploring the area.

2nd stop - Columnar joints

At the second stop we observed the columnar joints from afar, as they were not approachable, and discussed their formation (Fig. 12). These joints are formed when structured contraction cracks propagate into cooling lava flows. As these lava flows solidify, the fracture tips follow the solidification front and leave behind long vertical prismatic columns as a record of this ordering process (Goehring et al., 2008). Although columnar jointing is prominent in lava flows,it can also be observed in andesites and rhyolites. This structure can be found in sills and dykestoo, but the columns are not so well developed.

Figure 11. The students examining the Lower pillow lavas with greenish celadonite and chalcedony veins.

Figure 12. Columnar joints.

3rd stop - Memi mine, Xyliatos

At the Memi VMS deposit, close to village Xyliatos, we had the opportunity to collect beautiful samples of pyrite (Fig. 13). The deposit consists of two massive sulfide lenses that are associated with high-grade pyritic stockworks in altered lavas with quartz gangue. The mine operated from 1954 until 1971, and then again from 1987 until 1990.

Figure 13. The students looking for pyrite samples at the massive sulfide deposit of Memi.

4th stop - "Teisia tis Madaris"- Sheeted dykes, Gabbro, Diabase

One of the most impressive geotrails of the Troodos Geopark is at the "Teisia tis Madaris" with a sheeted dyke complex (Fig.14). This complex consists mainly of diabase and microgabbro, and the dykes are epidotized due to the low degree of alteration, caused by the circulation of hydrothermal fluids at temperatures around 350°C. In many dykes, there are some cooling surfaces known as chilled margins, that indicate that the dyke has solidified in between another cold material.

Figure 14. The geologist Mrs. Eleutheria Eleutheriou and the students at the "Teisia tis Madaris", one of the most impressive geotrails of the Troodos Geopark.

5th stop - Lagoudera - Plagiogranites

At Lagoudera we observed some plagiogranites. Plagiogranites are leukocratic rocks that are found in the upper parts of gabbros and in sheeted complexes of the ophiolite sequences. They consist of quartz and plagioclase; epidote and chlorite can be found as secondary minerals resulting from the low-temperature hydrothermal alteration (Coleman et al., 2013).

6th stop - Chandria Village - Cumulate rocks - Gabbro outcrop

At Chandria we observed cumulate rocks of the Troodos ophiolite sequence, intruded repeatedly by dykes. This exposure provides a perfect example of multiple magmatic activity and magma chambers at Troodos. The cumulate rocks consist of olivine gabbro, pale gabbro and wehrlite. The gabbro is crosscut by younger intrusions, e.g. plagiogranite dykes with poorly developed chilled margins, near vertical gray microgabbroic dykes with developed chilledmargins and vertical basaltic dykes.

7th stop - Upper mantle igneous rocks - Dunite with chromite

At the final stop of the field trip we observed dunites (Fig. 15), which hosted layers and lenses ofchromite. In the Troodos ophiolite sequence chromite can be found both as podiform bodies within harzburgites and as lenses and layers within dunites.

Figure 15. Altered ultrabasic rocks from the last stop.

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