Field trip participants with the Llullaillaco volcano behind. Left to right: Morena Pagola, Agustina Esnal, Priscilla Myburgh, Julieta Palomeque, Camila Ferreyra, Florencia Pereyra, Diego Palma, Agustín Ulloa, Alejandro Toloy, Andrea Muñoz and Camila Riffo (Prof. Chong’s students), Patricio Arias (Prof. Chong’s long time field partner), Erick Montenegro (Prof. Chong’s student), Prof. Chong and Facundo De Martino
Trip Leader:
Dr. Guillermo Chong

Trip Participants:
De Martino, Facundo Julián
Esnal, Agustina
Ferreyra, Camila
Myburgh, Priscilla Solange
Pagola, Morena Lucía Sonia
Palma, Diego Sebastián
Palomeque, Julieta
Pereyra, Florencia
Toloy, Alejandro Daniel
Ulloa, Agustín

The Student chapter is deeply thankful to Prof. Guillermo Chong from UCN for organizing the visits to the mines and for all other support during the field trip. We also like to thank Guanaco Mine, Mining company Mantos de la Luna, Mining company El Peñón and Mining company Antucoya for providing meal and lodging, and the Society of Economic Geologist for providing financial support.

Introduction
From June 11th to the 16th the UNLP-SEG Student Chapter visited the II Region in northern Chile, where important gold&silver and copper mines are located. The schedule, detailed below, included Antucoya Mine, El Peñón, Mina Guanaco, Mina Mantos de La Luna, and a geologic tour led by Prof. Guillermo Chong, which included the Atacama Salt Flats. The first is a Cu porphyry mine, Peñón is a low sulphidation epithermal Au-Ag deposit whereas Guanaco is a high sulphidation Au-Cu deposit. Mantos de la Luna corresponds to a stratabound Cu deposit and the Atacama Salt Flat which is exploited for Li and nitrate.

Field Trip Schedule
- **First Day (June 11th):** Arrival at Antucoya mine (Cu Porphyry) where we were given the mine induction talk, geological-mining model introduction and later visit to one open pit and then a dynamic leaching pile.
- **Second day (June 12th):** Visit to El Peñón underground mine (Au&Ag LS epithermal), after induction and geological-mining model introduction. Afterwards, further talks about the project’s history were given in the complex’s panoramic viewpoint.
- **Third day (June 13th):** Guanaco Mine. After geological-mining model introduction we were taken to a panoramic viewpoint and then to Dumbo Pit, now inactive, to visualize the mineralizing ledges.
- **Fourth day (June 14th):** In the morning we arrived in the town of Tocopilla where Mantos de La Luna mining company gave us the mine induction and geological introduction at the company’s administrative facilities. Afterwards we were taken to the camp and mine where more specifics talks were given about the mine, and then we visited open pit exploitation.
Fifth day (June 15th): geological tour starting in Antofagasta City, passing through Mina La Escondida (Cu porphyry), Atacama Salt Flat, short visit to San Pedro de Atacama town and Salt Range, return to Antofagasta passing nearby the city of Calama and Chuquicamata Mine and a short stop at La Escondida iron sulphates deposit.

Regional Geology

The II Region of Chilean topography is dominated by three main ranges, Coastal, Domeyko and Main Range (Picture 1). Most of the nearby basins in northern Chile are formed as the result of late Tertiary to Holocene faulting, and fault movement has affected the configuration of salt flats and the morphology of their crusts. In general, the major subregions containing salt flats are closely related to major tectonic elements of northern Chile. The Coastal Range and Central Valley subregion are within a zone of intensive block faulting associated with uplifting of the Coastal Range. The Atacama Basin and nearby subregion lies to the east and partly within a fault zone trending north-northeast, associated with the uplifted tectonic block of Domeyko Range. The Andean Highlands subregion is in the western Andes, an area of intensive volcanism and faulting during the late Tertiary and Quaternary period.

Northern Chile is underlain chiefly by marine sedimentary rocks, volcanic rocks, and plutonic rocks of Jurassic and Cretaceous periods, which are mostly widespread in the Coastal Range, and by rhyolitic to basaltic volcanic rocks of Tertiary and Quaternary periods, which are most widespread in the Andean Highlands. Extensive areas are covered with thick alluvium and lacustrine sediments of late Tertiary and Quaternary periods.
Figure 1. Regional Geology of II Region, Chile.

ANTUCOYA
The mine is located in the Antofagasta Region (Picture 2), also known as the II Region, 125 km northeast of Antofagasta City, with an altitude of 1700 masl. The main characteristics of this mine are the use of sea water in the leaching process and the low copper grade within the mineralized rocks.
Antucoya’s annual production consists of 85,000 tons of fine copper through open pit exploitation and dynamic piles leaching since 2015, which final product is the copper cathode. The actual measured resources exceed 1,000 million tons with 0.33% copper.

The ore deposit is linked to cretaceous porphyries (140-142 Ma) (Maksaev et al., 2006) hosted in Jurassic rocks from La Negra Formation. Such ore is emplaced also following two structural trains consisting in two main fault zones. The first one is N-S oriented corresponding to Buey Muerto, and the second one is Antucoya, NW-SE oriented. Both define a horseshoe shaped zone (Picture 3) and both are linked to the Antofagasta Fault Zone (ZFA) (Dallmeyer et al., 1996; Scheuber and Andriessen 1990).
Antucoya’s ore minerals consist on Pyrite, Chalcopryrite, Chrysocolla, Brochantite, and some Cu oxides, with potassic alteration development in the nucleus and phyllic alteration towards the edges. The porphyry’s root was located 700 meters below drill collar, being interpreted as the system’s deep zone. On the other hand, Buey Muerto zone presents pyrite as it’s characteristic mineral, and quartz-sericite alteration, with acid pH hydrothermal fluids. In this sector the system’s root hasn’t been found so it has been interpreted as a shallower zone than Antucoya’s. The differences between both sectors seem to rely on a block tectonic with a relative vertical displacement between them (Picture 4).

![Geological block diagram. Left: Antucoya block. Right: Buey Muerto block.](image)

The deposit exploitation consists in 9 phases of open pit, from which the first three have been already developed (Picture 5).
The rock processing begins with the grinding and gathering of the debris in dynamic piles (Picture 6), where sea water with sulphuric acid (8 grams per liter) are used in the leaching process through aspersion and dripping, completing a 77 days cycle (8 days of humidification, 65 of aspersion/dripping and 4 of resting). The obtained solution by the leaching process is treated in an extraction plant through organic thinners and electrowinning in order to obtain the final product: high purity (99.99%) copper cathodes.
**EL PEÑÓN**

El Peñón district of northern Chile is located near the eastern margin of the Central Depression, about 165 km southeast of Antofagasta (Picture 7). The deposit is considered to be a typical low sulphidation epithermal Au-Ag deposit.

![Picture 7. Location of El Peñón Mine.](image)

The deposit is located within a north-south trending belt of epithermal deposits of Paleocene age, within the Central Depression of the Atacama Desert. The deposit is hosted by late Upper Paleocene to Lower Eocene rhyolitic, overlying Upper Cretaceous and Paleocene andesite and dacite, as we could see in the drill cores (Picture 8).

The distribution of Cretaceous and Eocene volcanic rocks is controlled by graben structures bounded by north-northeast trending faults, Dominador fault and La Mula fault. These are steeply dipping regional-scale structures with displacements of hundreds of metres. The principal direction of late dikes and main faults are parallel to the bounding faults. The faults dip steeply eastward on the east side of the property and westward on the west side, implying a horst/graben extensional structure.
The gold-silver mineralization is restricted to banded quartz-adularia veins, hydrothermal breccias and minor quartz stockwork. It comprises disseminations of electrum, native gold and silver, acanthite, silver sulphosalts and halides, plus accessory pyrite occurring with quartz, adularia, carbonates, and clays. Geochronology on supergene alunite and Mn-oxide indicates that oxidation of the El Peñón deposit occurred between 27 and 14 Ma. The deposits were also estimated to contain approximately 17.5 million tonnes of inferred resources at an average grade of approximately 1.7 g/t Au and 60 g/t Ag, which is approximately 960,000 ounces of gold, and 33.5 million ounces of silver.
The major grades are located in Bonanza, with 20 g/Tn of Au and 100 g/Tn of Ag. The underground mining (Picture 9) method used at El Peñón is the Bench and Fill Method.

![Picture 9. Photograph in the underground mine.](image)

The following steps are the ones used to process the material.

1. Crushing
2. Grinding and pre-leaching thickening
3. Leaching
4. Counter-current decantation concentrate solution recovery
5. Clarification, zinc precipitation and precipitate filtering
6. Refining
7. Tailings filtering
8. Tailings disposal

**Guanaco**
Guanaco is located approximately 220km SE of Antofagasta in Northern Chile at 2,700masl, 45km east of the Pan American Highway and 70km south of El Peñón (Picture 10). The trip from Antofagasta takes about three hours by car.
Guanaco is a high sulphidation epithermal system with E-W orientation (it is different to the majority of the structures in northern Chile, where the main trends are N-S). The mineralization is about 45Ma and it is located in an important paleocene volcanic belt (which include El Peñón and Amancaya deposits) (Picture 10).

El Guanaco district geology corresponds to 3 volcanic events limited by regional discordances:

1) Augusta Victoria Formation (upper Cretaceous)  
2) Chile-Alemania Formation (lower Paleocene – lower Eocene), and  
3) Catalina Basalts (upper Eocene). These events conform N-S ranges which are younger to the west.

Chile-Alemania Formation (Chong, 1973) is the main host rock of the mineralization in the district. This unit corresponds to a succession of volcanic and pyroclastic layers which hosts high sulphidation epithermal vein system rich in gold (Guanaco and Sierra Inesperada mines). It is maybe associated with a low sulphidation fluids in Cerro Campana sector too (Picture 11).
The minerals represent a vertical zonation (Picture 12). Shallow to deep we can see:

- **Leaching zone**: With Quartz, Barite and Jarosite and boxwork texture.
- **Oxidation zone**: With Olivianite, Vendulana, Chrysocolla, Chenevixita, cooper oxides and arsenides
- **Primary zone**: With cooper primary sulphides, like Enargite.
In the initial phases the exploitation was done by open pit (Picture 13), at present it continues by underground mining. After crushing material, it is leached by agitation tanks to obtain the pulp which is treated by the Merrill-Crowe method. The final result is the doré. The mining plant of Guanaco receives material of Amancaya (LS Epithermal deposit) too.
Mantos de la Luna
Mantos de la Luna copper deposit has been catalogued has a stratabound type deposit that belongs to the Northern Chile’s Coastal Range Metallogenic Belt (Boric et al., 1990), which presents 40,5 Mtons of Cu@1,39% measured reserves plus 6 Mtons of Cu@1,4 (Maksaev et al,. 2007). The host rock belongs to La Negra Formation, consisting totally of dark red to brown andesitic lavas presenting a wide textural variety, with a N-S bearing and 25º to 30º dip to the east (Leiva, 2010).

Taking into consideration the mineralized bodies’ geometries, Mantos de la Luna is considered as a vein, mantle and copper ore shoots deposit (Leiva, 2010), which most accepted origin theory fits an epigenetic hydrothermal génesis (Definis and Bello, 2000).

Among the mineralized bodies within the deposit, 4 subparallel and tabular veins are found bearing N35ºW to N-S (depending on the vein’s position) with thicknesses ranging 10 to 25 meters and vertical longitudes up to 190 meters long, which belong to the high assay zones of the deposit, presenting Chrysocolla, Atacamite and Chalcosine in lesser amounts. The mantles correspond to concordant tabular bodies according to the strata dispositions (N10ºE/30ºE), being Chrysocolla and Atacamite the minerals present. The copper ore shoots are emplaced in highly permeable zones such as the porphyryc andesites’ tonsils (Picture 14), or intense fracturing zones (Leiva, 2010).
The ore mineralogy present in this deposit is mainly conformed by supergenic origin minerals such as Chrysocolla, Atacamite, Chalcocite, and hipogen origin ones such Bornite, Chalcopyrite, Pyrite, Hematite, Specularite and traces of Magnetite. These minerals’ presence is mainly constricted to small veins, tonsils and local disseminations.

Based on the abundance and the characteristics of the mineral species present, Mantos de la Luna is considered as a copper oxides deposit with heavy development of supergenic mineralization, and little growth of hipogenic mineralization, being this last one restricted only to deep levels of the deposit (Leiva, 2010).
Bibliography
LEIVA, E. 2010. Caracterización y distribución de minerales oxidados de cobre y alteración en el yacimiento cuprífero Mantos de la Luna, II Región de Antofagasta, Chile. Bachelor memory. Santiago, Chile. Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas.