JCU SEG Student Chapter

# Patagonia Low-Sulfidation Systems Field Trip 2016

## Field Trip Report

JCU SEG Student Chapter group standing on the 1.3 Moz Au Eureka vein Cerro Negro gold deposi. Photo by Gautier Lavigne.

# Contents

# Introduction by the JCU SEG Student Chapter Committee

The James Cook University (JCU) SEG Student Chapter recently organized a geological fieldtrip to the Argentinian and Chilean Patagonia from 22 November to 5 December, 2016. Eighteen people attended this trip including three PhD students from JCU and one from the University of China, two undergraduate students from JCU, ten participants from industry and our Student Chapter Academic Advisor A/Prof. Dr. Zhaoshan Chang. Participants represented nine countries: Argentina, Australia, Brazil, Chile, China, France, Peru, Portugal, and United States. The aim of this trip was to see and appreciate different geological features across Patagonia which included Au-Ag low-sulphidation epithermal and Zn-Au skarn mines and advanced projects, paleo-geothermal fields and archaeological sites.

The trip started in Esquel on November 22$^{nd}$ with a group dinner and the following day a 25 km day hike of the Esquel Au deposit was completed. The following day, the group headed to Chile to visit the El Toqui Zn-Au skarn mine (Laguna Gold) on Friday November 25$^{th}$. On Sunday November 27$^{th}$ the group visited the Cerro Bayo silver mine (Mandalay Resources) located 25 km to the west of the town of Chile Chico in Chile. The same day the group crossed the border back to Argentina to visit the Cerro Negro (Goldcorp, November 28$^{th}$), the Cerro Moro (Yamana Gold, November 29$^{th}$) and the Cerro Vanguardia (AngloGold Ashanti and Formicruz, November 30$^{th}$) gold mines and advanced projects. In all of the mines we were happily received by the geologists in charge, they gave us geological presentations, we visited key outcrops and in the El Toqui mine we were able to visit the underground workings.

During this continental wide scale traverse, the group was able to visualize large scale geological features like the Jurassic Chon Aike volcanic large igneous province (LIP) outcrops, glacial moraine deposits along the Patagonian Cordillera from the Quaternary, regional scale fault systems (e.g. the Liquine-Ofqui fault zone), among others. The Chon Aike LIP has been recognized to be associated with the early stages of the Gondwana break-up as well to be the precursor of this Au-Ag-rich metallogenetic province of southern South America. In addition after November 30$^{th}$ the group was able to enjoy roadside geology along the famous Ruta 40 with the possibility to contemplate the Perito Moreno Glacier (El Calafate), the only advancing glacier in the area, and the Cerro Fitz Roy (El Chalten).

Finally, the JCU SEG Student Chapter would like thank the generosity of all our sponsors that contributed to make this fantastic fieldtrip happen. Thank you very much to the Australian Institute of Geoscientists (AIG), James Cook University (JCU), the Economic Geology Research Centre (EGRU), the Society of Economic Geologists (SEG), Bunnings Warehouse, Coles and Woolworths.

The JCU SEG Student Chapter Executive Committee

# Itinerary

JCU SEG
**Student**
**Chapter**
Field Trip

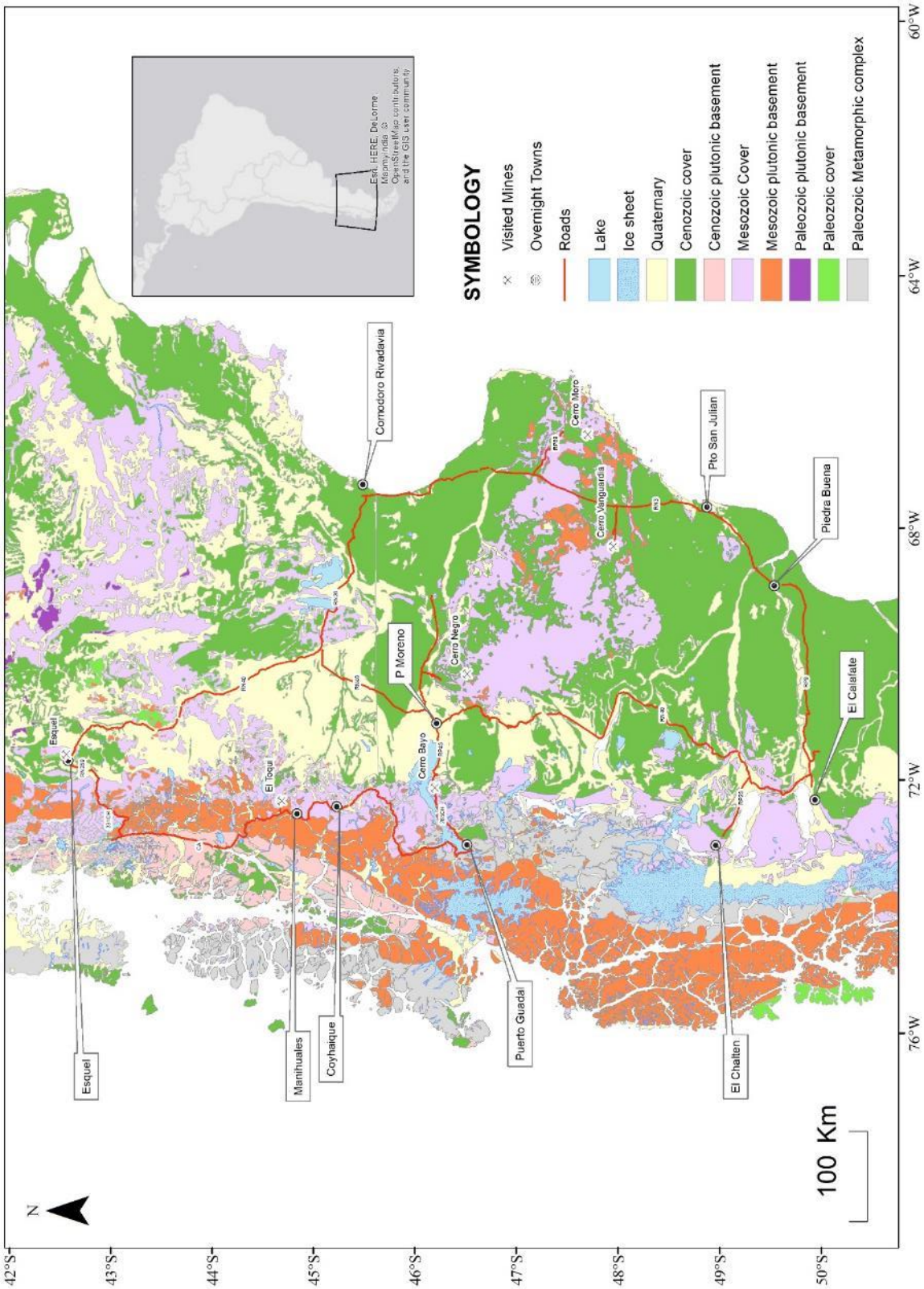
JAMES COOK UNIVERSITY
AUSTRALIA

## Low-Sulfidation Systems of Patagonia

22 November - 5 December 2016

| | Itinerary | Overnight |
|---|---|---|
| 22 Nov | Arrive in Esquel, Argentina. Pre-trip meeting | Esquel, Argentina |
| 23 Nov | Esquel geology trip (all day) | Esquel, Argentina |
| 24 Nov | Travel south along the Carretera Austral | Villa Mañihuales, Chile |
| 25 Nov | Visit El Toqui deposit | Coyhaique, Chile |
| 26 Nov | Continue traveling south along the Carretera Austral | Puerto Guadal, Chile |
| 27 Nov | Visit Cerro Bayo deposit | Perito Moreno, Argentina |
| 28 Nov | Visit Cerro Negro deposit and nearby prospects | Comodoro Rivadavia, Argentina |
| 29 Nov | Visit Cerro Moro deposit and Jaramillo petrified forest | Tres Cerros, Argentina |
| 30 Nov | Visit Cerro Vanguardia deposit | Piedrabuena, Argentina |
| 01 Dec | Roadside geology of southern Patagonia | El Calafate, Argentina |
| 02 Dec | Roadside geology of southern Patagonia | El Chaltén, Argentina |
| 03 Dec | Day hike in El Chaltén area, local geology | El Chaltén, Argentina |
| 04 Dec | Roadside geology and Cueva de las Manos | Perito Moreno, Argentina |
| 05 Dec | Travel north along Ruta 40, including geology stops | Esquel, Argentina |

# Regional Geologic Map



Wednesday, November 23rd

# Hiking to the Esquel Au Deposit

Sida Niu

*Introduction*

Esquel, a town in the northwest of Chubut Province in Argentinian Patagonia, is the place where we started our adventure. Here we met our excellent trip leader Walter Soechting, his wife Nichole, and of course all the other members of our group. The Esquel gold-silver deposit is located 12 km northeast of the town of Esquel. On the 22nd of November we had pre-trip meeting and on 23rd of November we hiked to the deposit.

*Pre-trip*

The greetings from the Andes should be the first impression of this beautiful town. After settling we had a pre-trip meeting in the hotel, we met each other and had more information about this trip. Then we travelled together to Walter's home for a typical Argentine lamb asado group dinner. There we spent a relaxing and enjoyable evening, checking rock samples from Esquel and discussing further details of the geology of the Esquel deposit and this trip via powerpoint presentation.

Figure 1. Our first group meeting at Walter Soechting's home (Photo by Nichole, Walter's wife)

Figure 2. Field trip participants checking rock samples from the Esquel Deposit before the group dinner

*Hiking and outcrops*

On 23 November we spent the whole day hiking to the Esquel deposit. Total round trip distance is approximately 25 km with about 1,000 m of elevation gain.

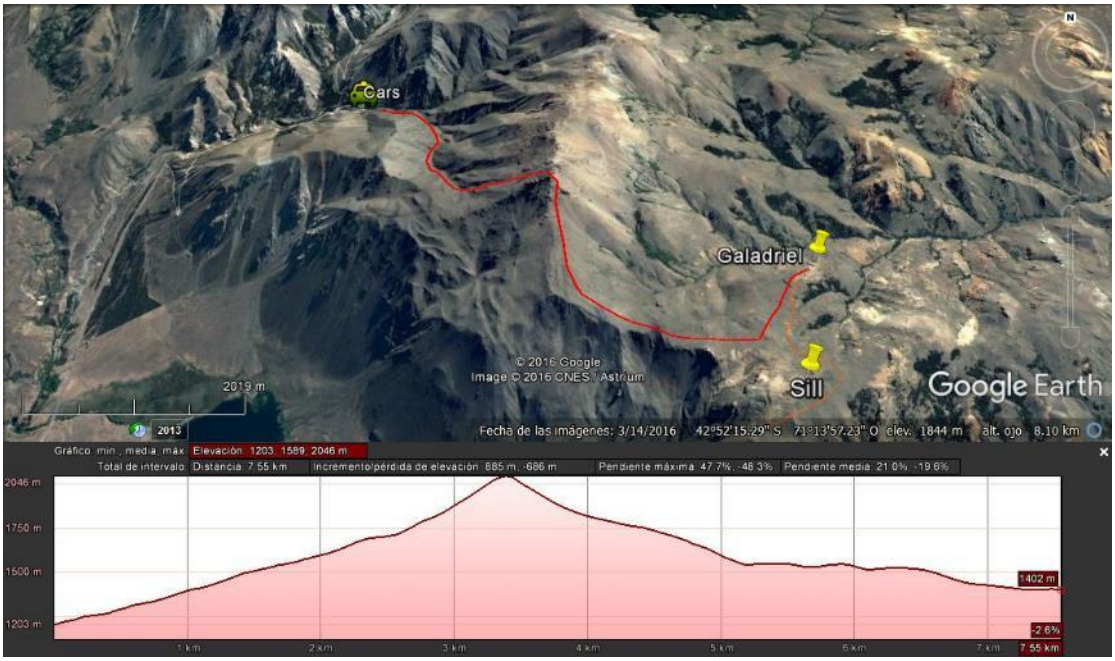



Figure 3. Hiking route at Esquel

Figure 4. Some picture shots during the hiking to the Esquel deposit

Andesitic and felsic volcanic rocks and sedimentary rocks including shale, sandstone and conglomerate can be seen along the way, which mainly belong to Lago La Plata Formation and Piltriquitron Formation. Oxidation of the mineralization of the deposit can be observed far away. It is a pity that I didn't reach the epithermal vein outcrop. Here some photos from others and the text from Walter's paper are used to make our report include such an important point.

The Galadriel-Julia ore shoots and the much more restricted ore shoots defined in the north-striking veins comprise mainly chalcedony and minor quartz. The chalcedony is either dark grey (and, locally, black) or white and displays evidence for multiple stages of vein filling and brecciation, which have defied rigorous paragenetic analysis. Nevertheless, it appears that much of the dark-grey chalcedony predates the white variety. In the Galadriel-Julia vein, the dark-grey chalcedony in the Galadriel ore shoot is more abundant along the footwall side, whereas in the Galadriel Sur and Julia ore shoots it preferentially occurs in the upper and hanging-wall parts.

Figure 5. Group photo during hiking. Behind the group Esquel town can be observed

Figure 6. Oxidation of pyrite to the south of the Esquel deposit


Figure 7. Epithermal vein in Galadriel, the Esquel deposit

*Summary*

As the first stop of our trip, it was really a good start. Members in our group became familiar with each other and we observed a typical low-sulfidation deposit on the ground systematically. Although the long distance hiking was very challenging, I am glad that finally we all made it. I am so happy to be a member in this group and thank everyone especially Walter for all they have done to make this hiking and our time in Esquel so fruitful and unforgettable.

Friday, November 25th

# El Toqui Au-Zn Skarn Deposit

Stephanie Mrozek

On Friday 25 November we departed Villa Mañihuales, Chile, and drove approximately 40 km northeast to the Toqui skarn deposit and mine. We were greeted by Glen van Kerkvoort, Executive Director and Head of Exploration for Laguna Gold, who presented an introduction to the regional and local geology. After the presentation, the group was split in half for alternating underground and surface tours with a lunch break intermission.

*Quick Facts (supplemented from Bussey et al., 2010)*

- Total resource (as of 2010) = 20 Mt at 8.2% Zn and 1.5 g/t Au.
- 40 km$^2$, zoned skarn district with at least 10 orebodies (Figure 1).
- Zoned mineralization: SE: Fe, As, Au, Bi, Co; NW: Pb, Ag.
- Skarn minerals: SE: garnet ± clinopyroxene ± amphibole; NW: epidote ± chlorite ± sericite.
- Two hydrothermal pulses overlap with igneous zircon U-Pb ages: 120-118 Ma, 113-108 Ma.

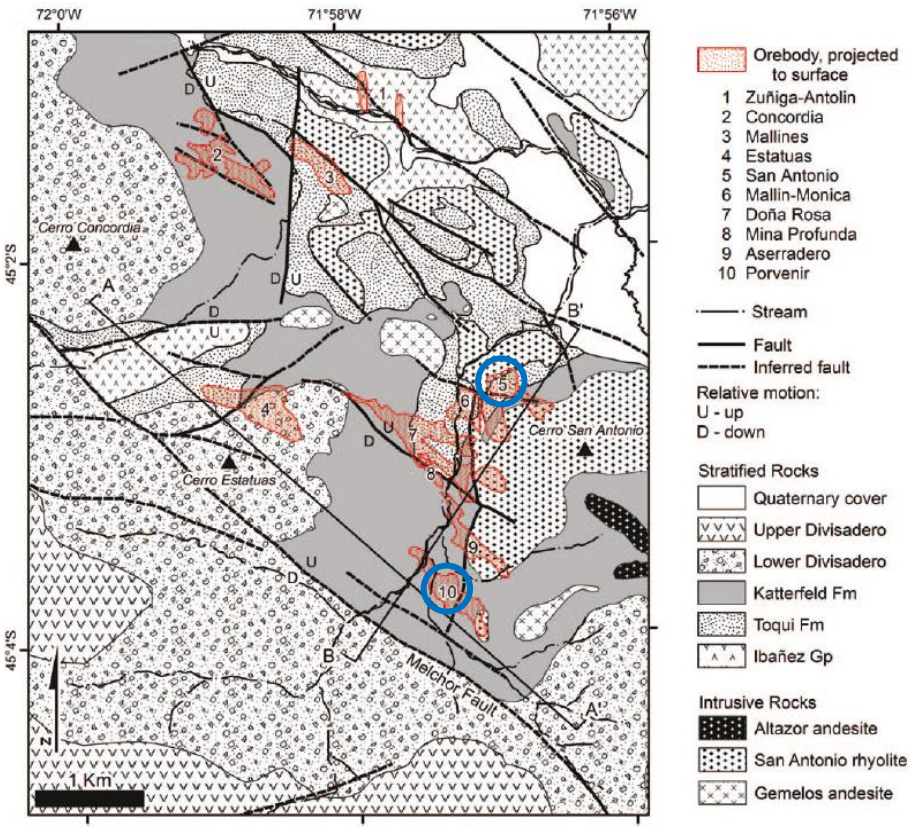



Figure 1. Geology of the El Toqui district, showing major rock types, structures, and orebodies projected to the surface (Bussey et al., 2010). Blue circles indicate areas visited on the mine tour: San Antonio (surface) and Porvenir (underground).

*Surface Tour*

Mine geologists led us to the San Antonio area (area 5, Figure 1) to view outcrops of the host rocks, skarns, and post-mineral units (Figure 2). As explained by the geologists, the El Toqui deposit is a stratabound skarn consisting of two mineralized beds of the Toqui Formation: the Upper Manto and Main Manto. At San Antonio, we viewed a remarkable exposure of the Main Manto and the overlying banded tuff (Figure 2A).

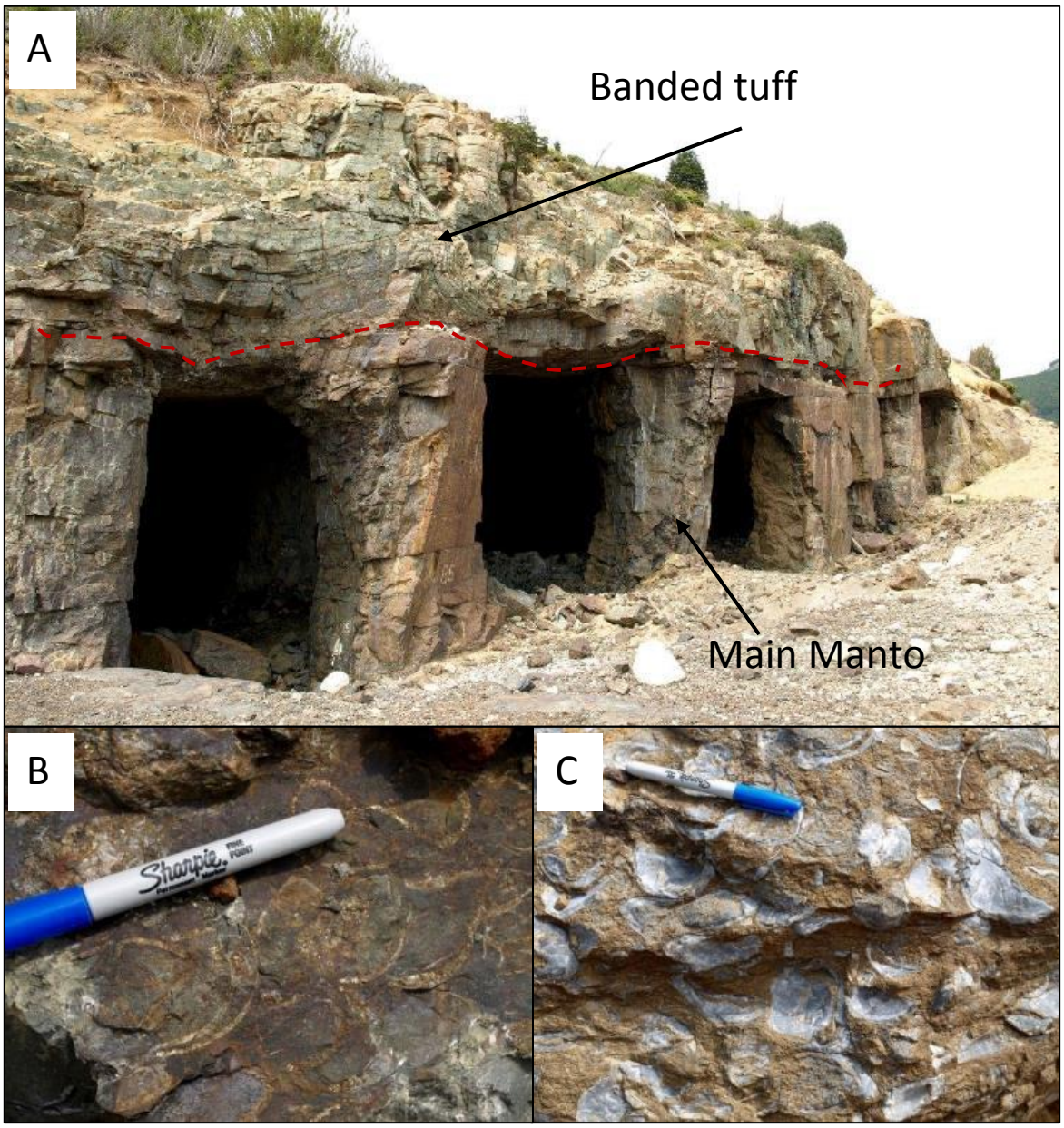



Figure 2. Field observations in the San Antonio area. A. Main Manto skarn (after limestone) with overlying banded tuff (contact approximated by red dashed line), also showing the room and pillar mining layout. B. *Gryphea* oyster fossils replaced by pyrite and sphalerite in skarn. C. *Gryphea* oyster bed in Toqui Formation limestone (host rock for the Toqui skarn).

Nearby, we observed the fossiliferous limestone host rocks and the metasomatic effects of selective replacement where *Gryphea* oyster fossils (Jurassic) are replaced by pyrite, sphalerite, and chalcopyrite in a matrix replaced by garnet and clinopyroxene (Figure 2B, 2C). This was a prime location to collect some run-of-mine samples, observe the layout of the 'room and pillar' mining method and observe its suitability for the flat-lying stratabound El Toqui deposit. Following our visit to San Antonio, we went to the core shack to examine several exoskarn intercepts with cross-cutting intrusions. Interestingly, the intrusions were relatively fresh compared to the adjacent exoskarns, and no endoskarn was observed. Despite the overlapping ages of intrusions and skarns, it is not confidently known which intrusion(s) are related to skarn formation, although it is generally assumed to be the Porvenir dacite.

*Underground Tour*

We visited two levels of the underground mine and several exposures of Zn- and Au-rich skarns in the Porvenir area (Figure 1). Geologists explained that the Porvenir orebody is fault-bounded to the NE and SW, and that the Au:Zn ratio changes from high (> 1) to low (< 1) from approximately north to south (Figure 3). A variety of interesting ore textures were observed, including replacement of fossiliferous horizons, disseminations, bands and lenses, and cross-cutting ore veins (Figure 4). At the final stop, we visited a very interesting rib exposure of Porvenir dacite surrounded by garnet exoskarn; however, no endoskarn alteration was observed in the dacite body, so it is more likely to be a post-skarn intrusion.

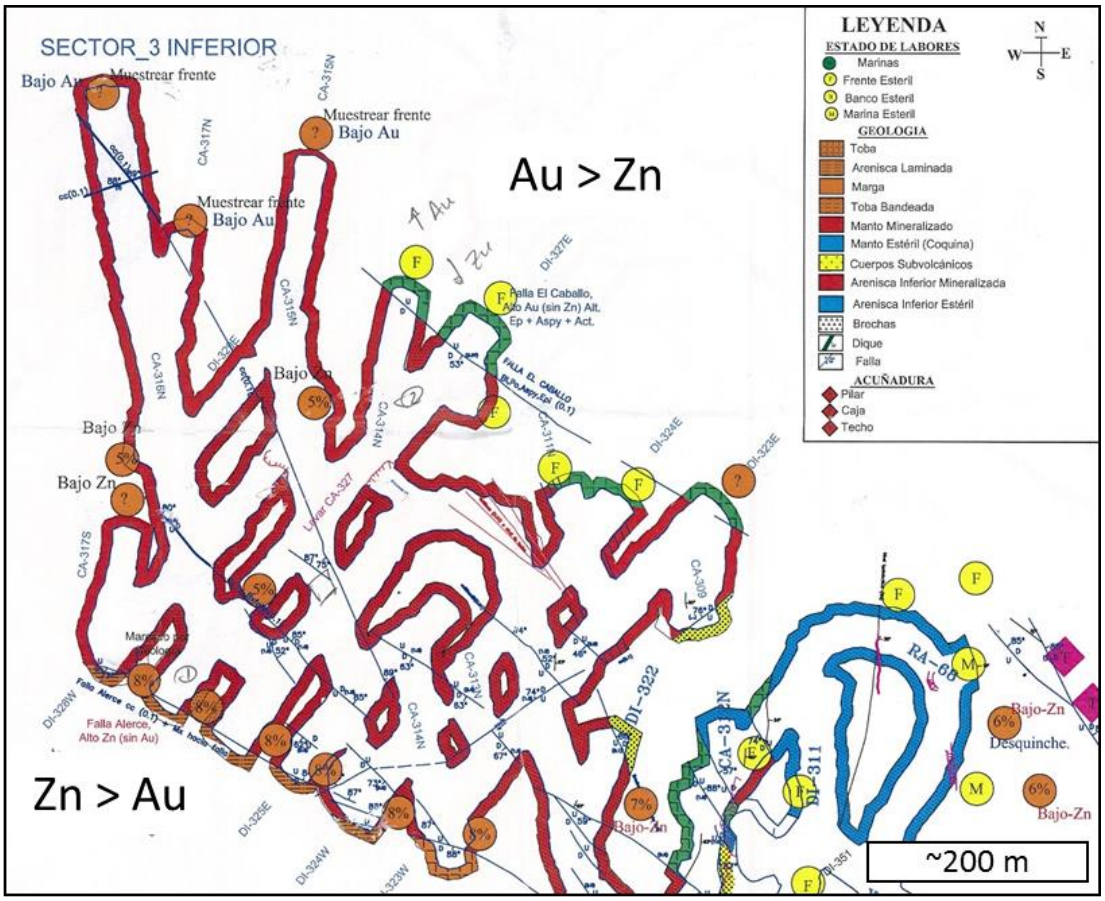


Figure 3. Plan map of underground working at the Porvenir orebody, El Toqui deposit, showing general geology (rock types and structures), approximate metal zoning, and room and pillar mine layout.

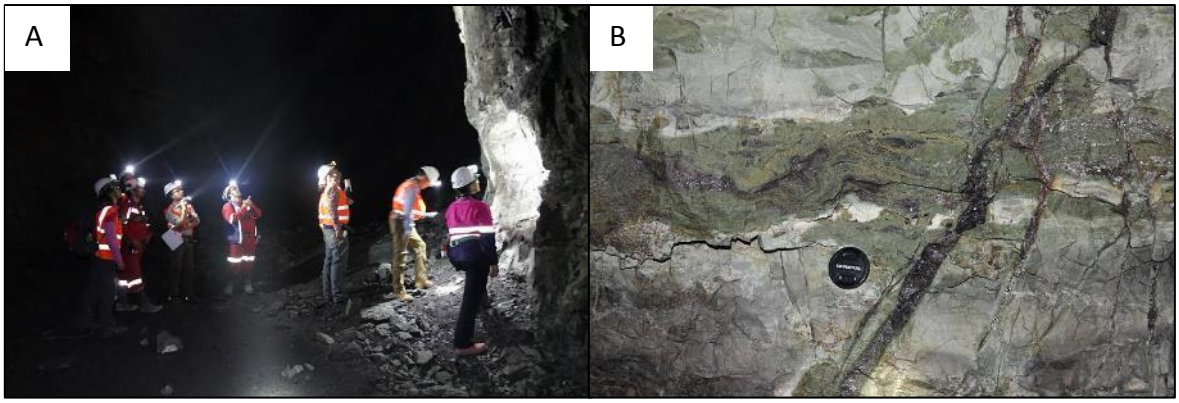



Figure 4. Underground tour. A. Half of the group observes skarn and replacement textures in the rib of a production stope. B. Close up of wavy-banded sphalerite + clinopyroxene + epidote skarn texture cross-cut by a ~5 cm wide sphalerite vein. Photos by Gautier Lavigne.

*References*

Bussey, S., Kakarieka, A., and Meinert, L., 2010, Geology of the El Toqui Zn-Au skarn district, Aysen Region, Chile: Geological Society of Nevada Symposium, Reno, NV, May 14-22, pp. 179-199.

Sunday, November 27th

# Cerro Bayo Ag-Au Deposit

Jaime Poblete

During the morning the group arrived to the Administration Office of Mandalay Resources located in the Laguna Verde area 15 km west from the town of Chile Chico, Chile. After a brief Health and Safety induction, the Cerro Bayo geologists gave an interesting talk about the geology, current production and exploration methods around Cerro Bayo.

The main mineralized areas are from west to east: Horquetas, Taitao-Cristal, Laguna Verde, Guanaco, Brillantes, Cerro Bayo, Mallines, Cascada and Meseta; which are connected by in an arrange of N-S, NE-SW and NW-SE trending fault systems (Figure 1). Distrital ASTER hydrothermal alteration analysis shows predominantly illite-silicification-kaolinite alteration towards the southeast (Cascada, Mallines, Meseta) and predominantly silicification-illite alteration to the northwest (Laguna Verde, Taitao-Cristal) of the district.

Currently Mandalay is mining the Laguna Verde area, particularly Delia, Dagny and Coyita veins. Delia vein has intercepts of up to 10 kg/t Ag with an average of 200 g/t. Mandalay is also in the late stages of analysing to mine under the Laguna Verde proper. The veins to mine in this area are Dagny, Irene, Yasna, Kasia and Coyita. Engineering studies suggested to leave around 50 m of rock on top for stability purposes.

Cerro Bayo geologists also exposed that Cecilia Rodriguez (2015) have worked in the paragenesis of the Delia vein. She described that vein emplacement occurred in six main stages. The first stage corresponds to a tectonic breccia with organic material, which was not been described before in any of the mined areas (Figure 2). The second stage corresponds to barren and low mineralized quartz and; colloform and drusyform textures. The third and fourth stages are barren/low-mineralized amethyst and green quartz. The main mineralising event is stage 5 corresponding to banded-breccia-ginguros bands with pyrite + proustite + achantite + polybasite mineralization (Figure 3). The last stage 6 corresponds to late carbonates (calcite + barite).

Historically the Laguna Verde, Taitao, Cristal, Condor-Temer, Guanaco, Raul-Marcela, Cerro Bayo and Cascada areas have been mined. An historical production totalling 41 Moz Ag and 0.62 Moz Au have been mined at Cerro Bayo from 1995 to 2016 by Coeur d'Alene Mines and Mandalay Resources. The 2016 measured plus indicated (M+I) resources are 18.3 Moz Ag and 0.18 Moz Ag, with a Ag:Au rations of 200 in well mineralized ore shoots and lower levels of 20.

During the Cerro Bayo presentations a quick overview of mining methods was presented by Sebastian Andrada. We were presented with the Dagny vein workings as an example. The ramp access dimensions to this underground workings are 4 x 4.5 m, with an average 3 x 3 m for any other underground road. The main mineral extraction method correspond to stoping (hole retreat) by sublevels, connecting different ore galleries with typical 15 m intervals between sublevels. Crown and rib pillars are important for mine stability. The current average production for Dagny is 800 ton/day with 80% of production coming from stopes with average grades of 1.4 g/t Au and 200 g/t Ag.

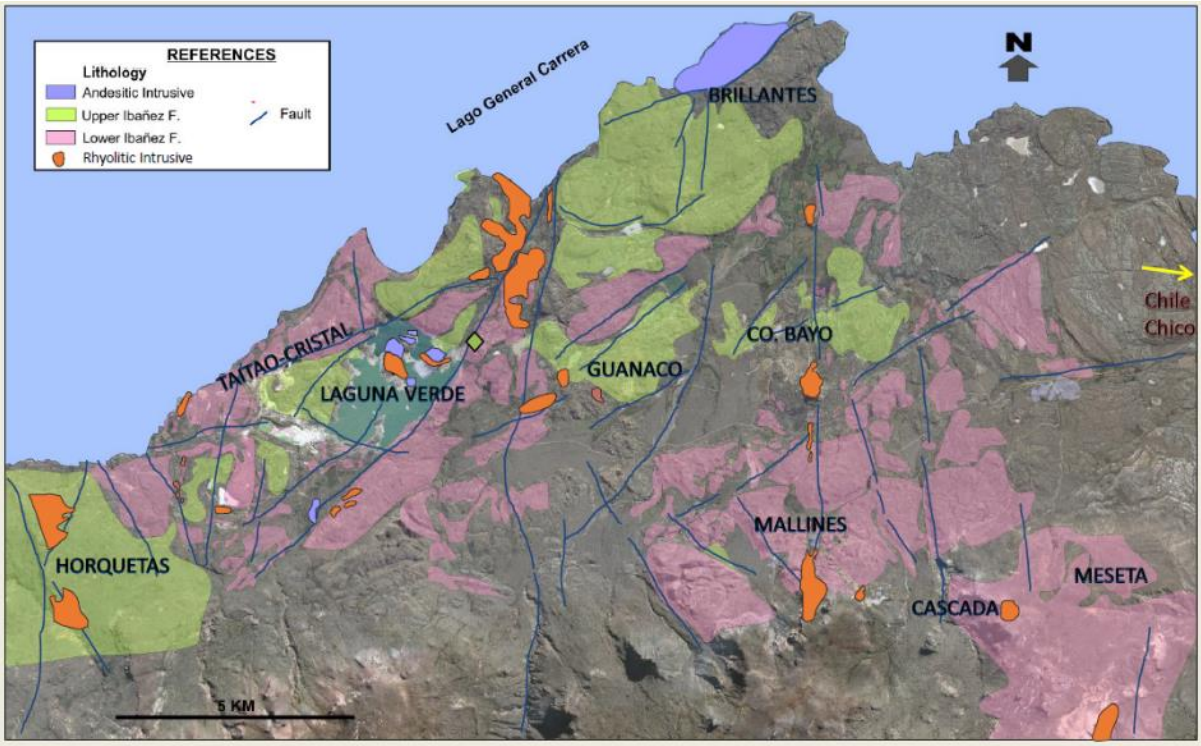



Figure 1. Geology of the Cerro Bayo area where the main mineralized areas are shown in black font. Mandalay Resources.

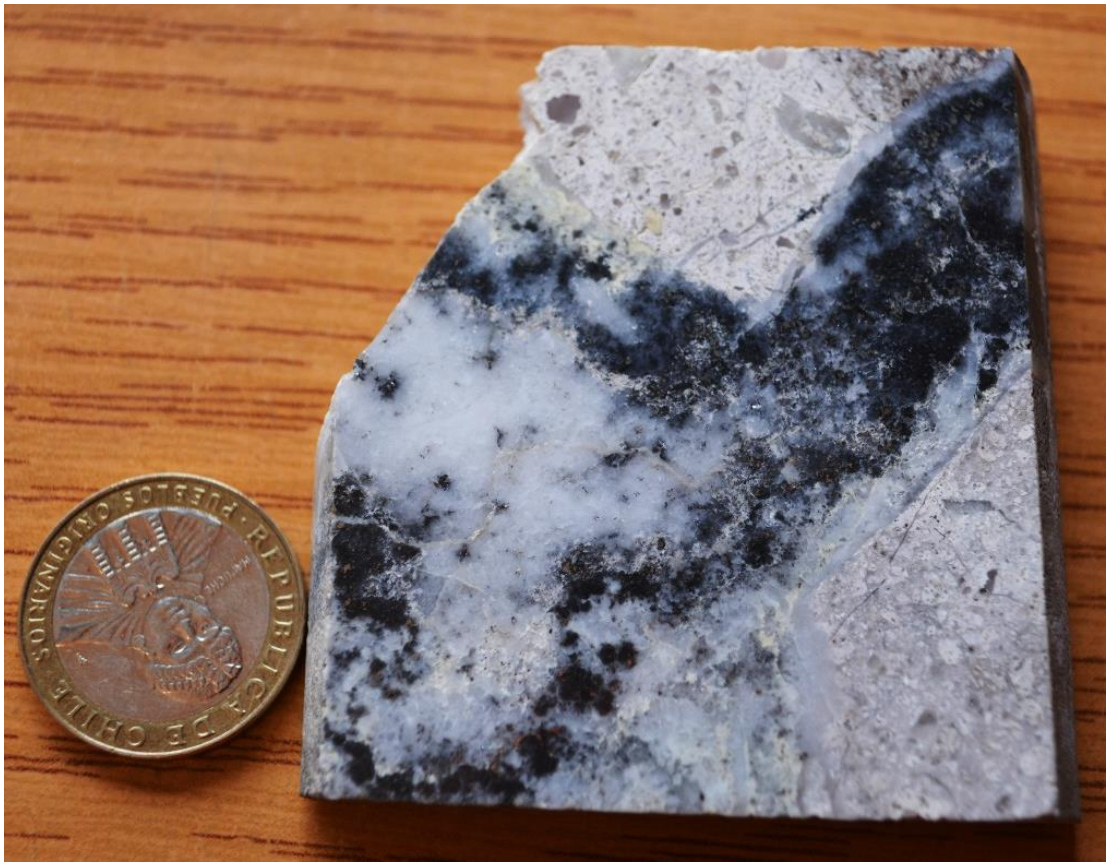


Figure 2. Close up to a specimen from Delia Vein (DLV16-046) showing organic material (black) in Stage 1. Photo by Jaime Poblete

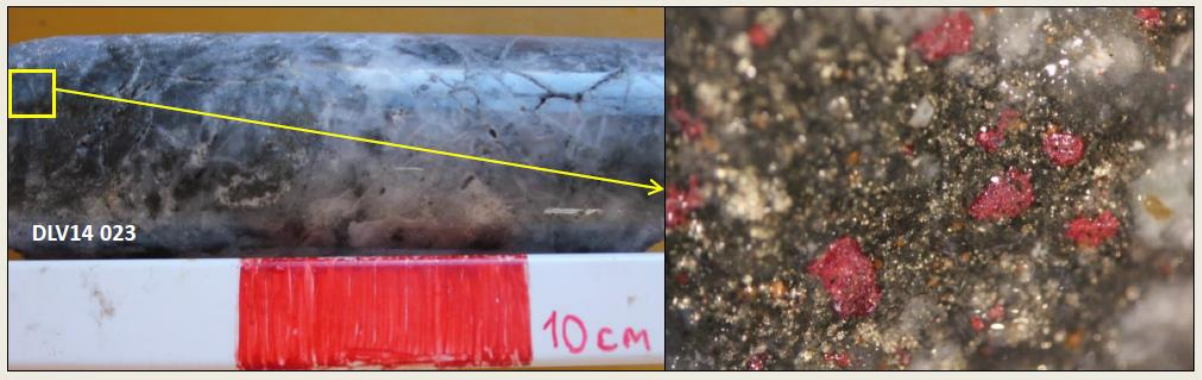



Figure 3. Images showing the Stage 5 mineralization event with reddish proustite in breccia texture vein. Photos by Mandalay Resources.

Monday, November 28th

# Cerro Negro Au Deposit

Luke Harriss

On 28th of November 2016, fifteen industry and student geologists during the JCU SEG International Fieldtrip ventured to the Cerro Negro mine located in the Santa Cruz province of Argentina, South America. The purpose of this visit was to perform field observations of what economic deposits looked like to exploration geologists and further understand how mining operations worked. Cerro Negro (Figure 1) is located on the low level Patagonian plains, elevated approximately 600 metres above sea level. It is a low-sulphidation epithermal system that hosts Au and Ag mineralization.

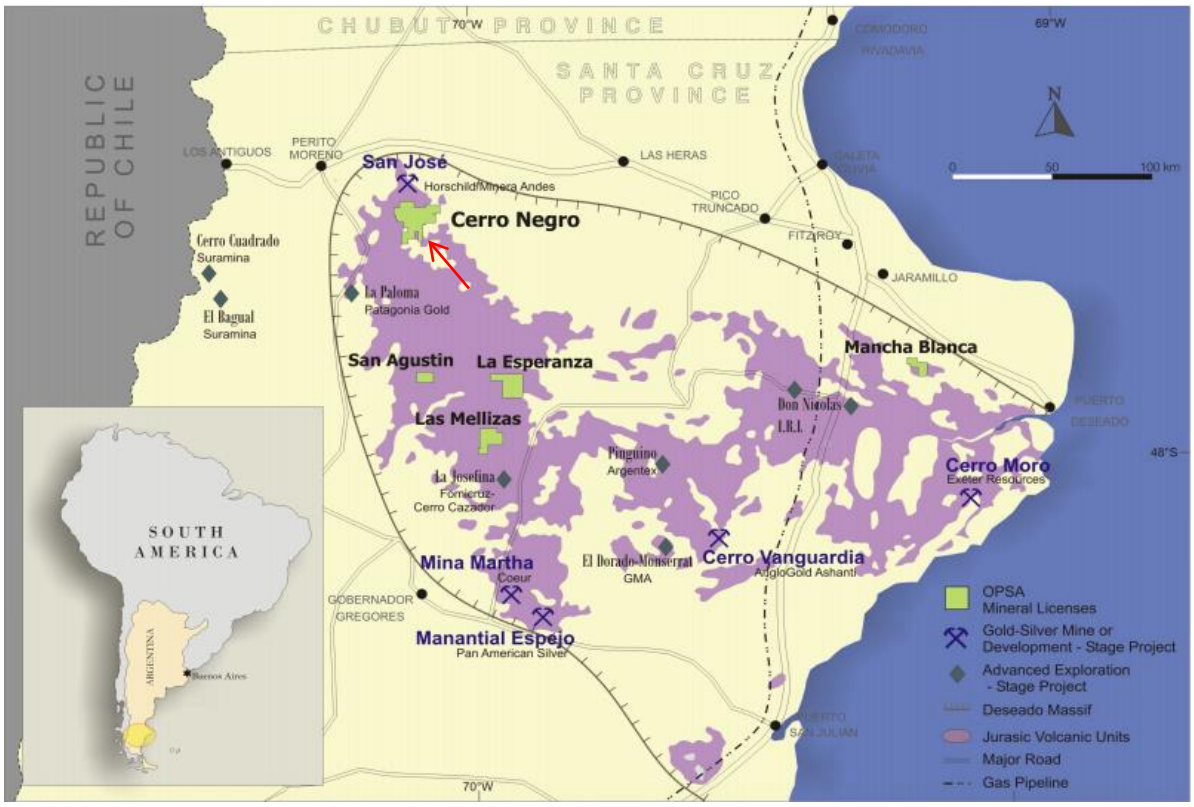



Figure 1. Regional setting of the Cerro Negro mine located in Jurassic volcanic units along the Deaseado Massif province of Argentina.

Upon arrival we viewed a presentation that discussed the current operations at the mine. We visited two main veins systems which was Mariana Norte-Central and then the Mariana-San Marcos vein system. The Mariana Norte-Central zone (Figure 2) is as follows:

- There is currently 26,800 Ha of mining tenement.
- There are six major economic veins, which are low sulphidation dated at 155 Ma.
- 840 km of drill core has been dug up since 1994. Current recovery has been 7.1 Moz of Au.

- The alteration consists of propylitic alteration with a silica cap.
- Gold is found in the hematite matrix in high grades. The Mariana Zone got assays of up to 80 g/t Au with an average of 16 g/t Au.
- RC holes were drilled every 300m @ 50m depth per hole.
- The Mariana system is hosted by andesitic lavas with phreatic breccia in which there has been 14.9 tonnes of Au currently recovered.
- There are fossil geyser with sinter preserved in this area.

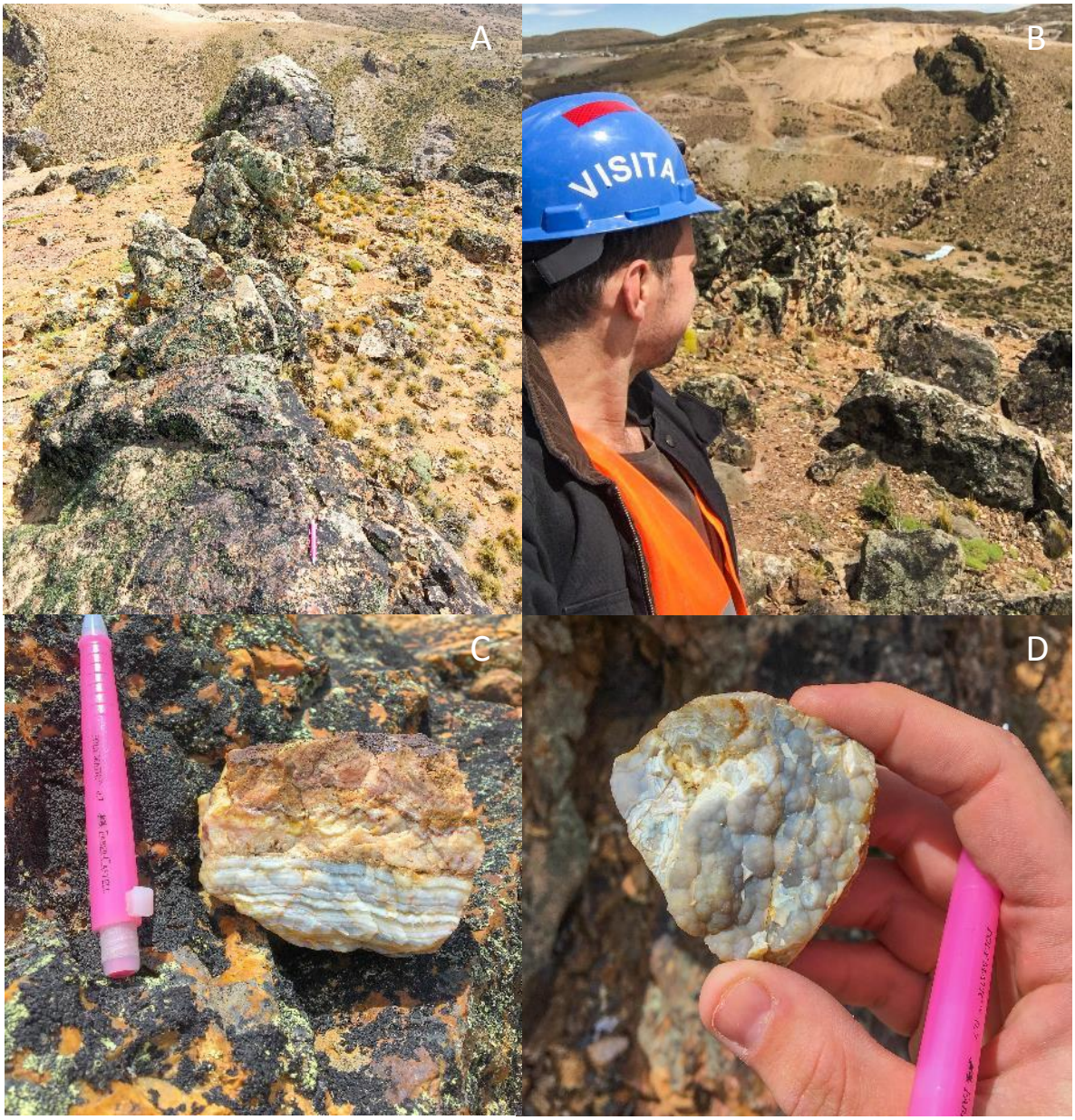



Figure 2. A and B. Close-up view of the Mariana Norte veins showing the dominant NW trend. C and D shows boiling textures that have occurred during ore deposition.

The Mariana-San Marcos zone (Figure#3) is shown in which the ore was mainly collapsed phreatic breccia. The most distinctive alteration associated with the orebody is the strong local silicification of the upper siltstone unit, although volumetrically this is a minor phenomenon. It consists of cryptocrystalline quartz and minor clays with cross-cutting calcite veinlets. Weak pervasive silicification

is also present in the Breccia Diablo of the ore zone.

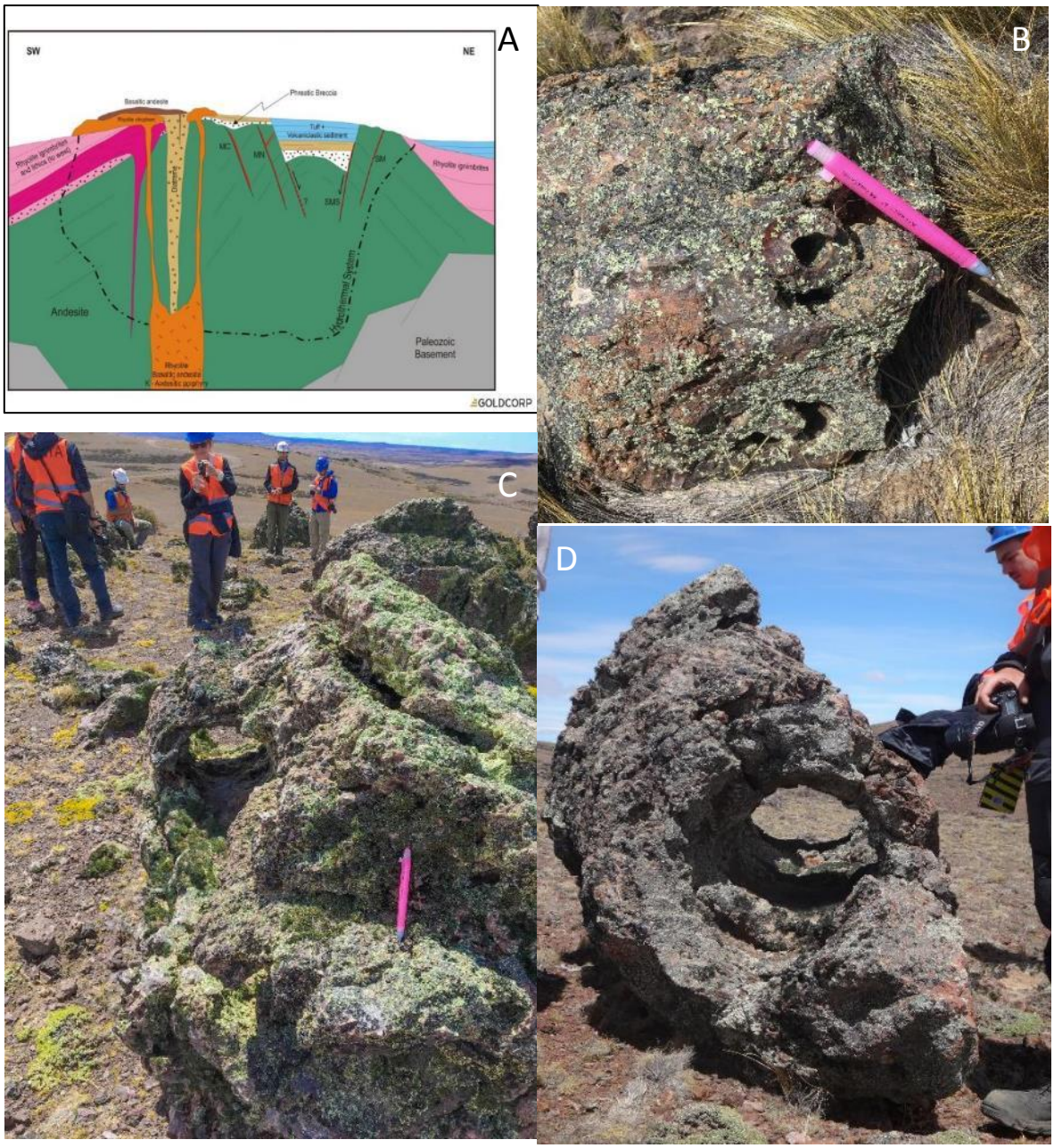



Figure 3. A. General geological cross section of the Mariana San Marcos zone presented to the group by the exploration team upon arrival. B and C. The phreatic collapse breccia. D. Fossilized Jurassic geyser conduit found on surface.

After observing the vein outcrops we were led to the core shed where we checked classic low sulfidation ore textures. The core in Figure 4 assayed 2682.8 g/t Au and 1529 g/t Ag, the highest concentration of gold out of the entire core shed we viewed. In comparison, the cut-off grade was around 40 g/t Au, so having core 67 times above the cut-off grade was very interesting to see. Notable features were that the textures of this high-grade section did not look different to core in the same box that assayed with a lot less gold in them. So visually you would not be able to realize that the gold is locked up in the hematite matrix and you need to assay them to get the concentrations.


Figure 4. Low sulphidation epithermal gold core that held the highest gold concentration that personally I have ever encountered.

Tuesday, November 29th

# Cerro Moro Au-Ag Deposit

Kairan Liu

After a week of travel in Patagonia, we arrived around lunch time to Cerro Moro Au-Ag deposit located in southern Argentina, around 60 km south-west from the city of Puerto Deseado.

The Cerro Moro Deposit was firstly discovered by MinCorp in 1993 and nowadays it has 2 Moz of AuEq indicated resources (2013). Currently, the mining plant is under construction and the underground ramps is still in progress.

Cerro Moro is an epithermal deposit in the Patagonia low sulphidation epithermal province hosted within the Chon Aike volcanic province, and the major ore mineral occurs in the hydrothermal quartz veins.

Yamana Gold Inc. is currently running the deposit, and the company has a good protection of the ecological environment around and in the deposit. Close to the gate of the mining lot, a group of flamingos gathered in a salty lake. We also found wild guanacos and lizards perching in the deposits (Figure 1).

Figure 1. Wild guanacos in the mining lot.

After having lunch, we visited the core shed. Drussy quartz and adularia are common in the quartz veins (Figure 2); however, we didn't found any native gold in the quartz. The ore is mainly hosted by the quartz veins filling rift structures or reactivation of the basement structures generally striking NW. By observing the cores, three pulses of mineralization were identified. The first is composed of crystalline quartz, fluorite, adularia and minor disseminated fine pyrite. The second event of breccias is characterized by high grade gold and silver, with black silica. Abundant coarse pyrite, galena, sphalerite, chalcopyrite, in addition to acanthite and electrum, where the most economic minerals found in this event. Some quartz fragments formed in the first pulse is hosted by the black silica (Figure 3). The third pulse, which does not carry significant mineralization, is characterized by chalcedony and fluorite colloform bands that usually dilutes the high-grade zones.

After checking the drill core, we went to examine few trenches and had a close observation of quartz vein subcrops containing sulphides and adularia (figures 4 and 5). We also found pyritic alteration in the host rock around the quartz veins, where pyrite cubes are visible (Figure 6). The pyrite is likely to have formed during the first mineralization pulse.

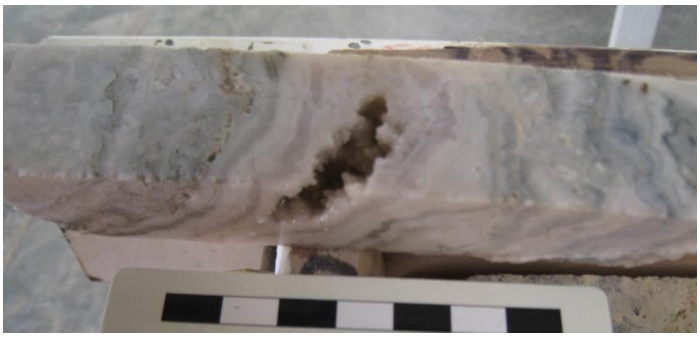


Figure 2. Quartz vein in the drill core.

Figure 3. Breccia with black silica in the drill core

Figure 4. Quartz vein subcrop in the field


Figure 5. Black silica in vein

Figure 6. Pyritic alteration in the wall rock

Wednesday, November 30th

# Cerro Vanguardia Au Deposit

Joshua Spence

The Cerro Vanguardia deposit is located approximately 360 km south of Comodoro Rivadavia, Argentina (figures 1, 2A and 2C). Upon arriving we were greeted by exploration manager Juan Perez and assistant director Mariana Gonzalez and invited to watch:

1) An introduction to Cerro Vanguardia video [15-18 min] which in particular emphasised the positive impact of Cerro Vanguardia on the city of Puerto San Julian, where most of its employees live.

2) Short safety video [5min], which among other things explained how to use their excellent safety code system (Figure 2B).

3) Geology of Cerro Vanguardia presentation [20-30 min] detailing location, history, shareholders, regional geology, stratigraphy, mineralisation, vein texture, abstract, local structures, geological profile, ore type, exploration – process structure, exploration works carried out, and longitudinal sections.

Following the presentations the party was split into two groups whereby each group would spend 1.5 hours observing either a) core log or b) vein outcrop with members of Cerro Vanguardia staff. This included a lunch break intermission.

Upon departure Cerro Vanguardia generously presented a gift brochure and cap to each member of the party.

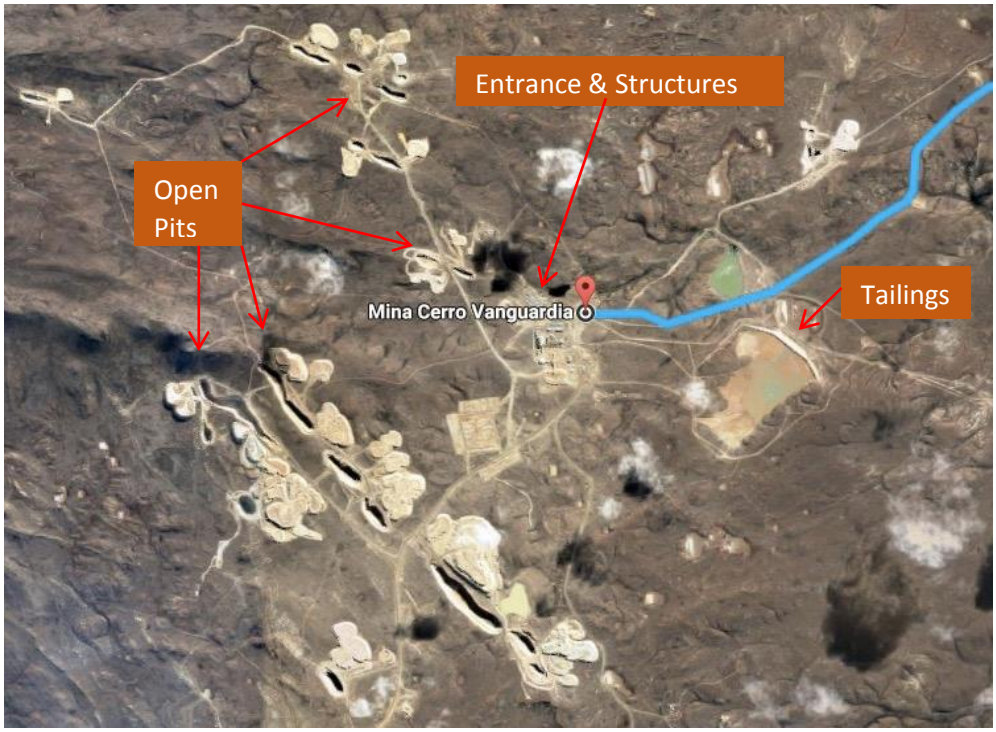



Figure 1: Satellite image of Cerro Vanguardia and its multiple open pits, tailings pond and entrance & structures related to Cerro Vanguardia's mining operations.


Figure 2. A. Cerro Vanguardia entrance. B. Safety Sign. C. Location of Cerro Vanguardia relative to Comodoro Rivadavia and Puerto San Julian

*Vein Outcrop*

Accompanied by mine geologists, we were led to several sites where observation of vein outcrops and its relationship to host rocks could occurred. The Granosa ignimbrite is the primary host rock for mineralisation due to its favourable rheology. This rhyolitic unit is approximately 250 m thick. Geologists allowed us to observe the uneconomic Trinidad vein, hosted in the Estratificada Superior [~25m thick] (above the Granosa ignimbrite, see Figure 3A) containing only minor Ag grades. Within the Estratificada Superior Unit, limited metal zonation patterns are identified, aside from depletion in alkali elements. Geologists explained that within the Trinidad vein there is a high abundance of late-stage chalcedony and opal, absence of lattice textures, low illite crystallinity, and weak elevation in Ag grades, which may reflect a late-mineralising vein stage from cooler temperatures above the boiling zone. There are a total of 119 veins so far with an extension of >242 km. Geophysical exploration has been challenging due to the high silica content of the host rocks (>75%). Induced Polarization geophysics has proved to be more effective (especially in the presence of metabasalt).

The Cerro Vanguardia deposit consists of 2 'blocks' (Figure 3B), blocks 1 and 2, representing low and intermediate sulfidation respectively, in a 9:1 ratio in terms of area. Block 2 is not currently mined as the processing plant accommodates only low-sulfidation ore but may be a viable future resource. Thus, only Block 1 accommodates the multiple open pits observed (Figure 1).

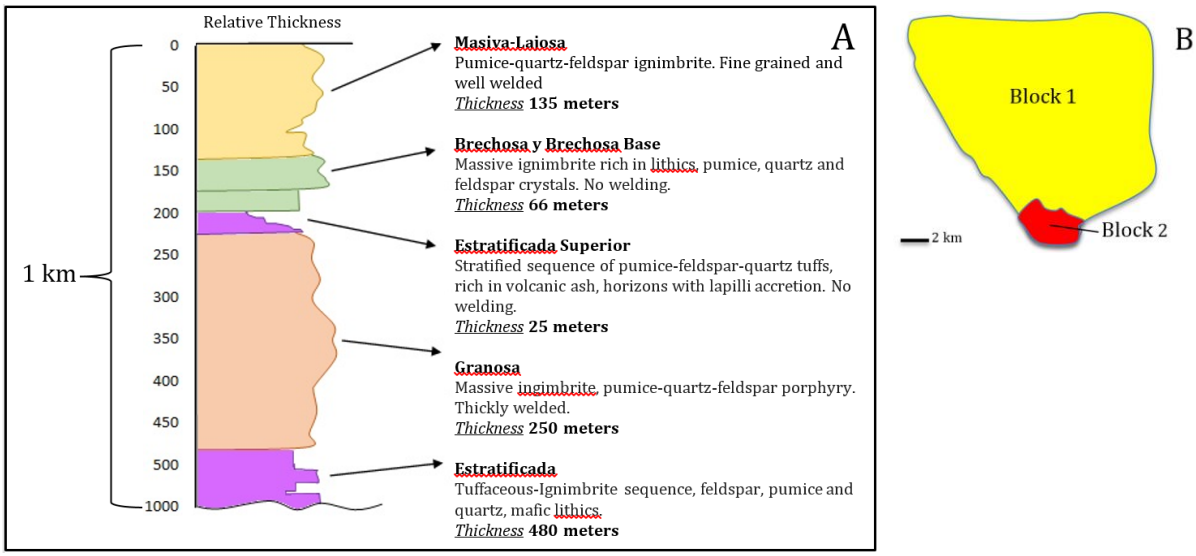



Figure 3: A. Units of the Chon Aike Formation and their relative thickness B. Illustration of 2 blocks hosting low sulfidation (90%) and intermediate sulfidation (10%) epithermal deposits respectively.

*Core Log*

Again accompanied by mine geologists, we were transported to the core shed. There we observed the various host units of the Chon Aike Formation, including the Masiva Lajosa, Granosa, and Estratificada Superior in addition to mineralisation, textures and alteration. Ore mineralogy consists predominantly of native gold and silver, electrum, argentite, chalcopyrite and sphalerite. Textures observed include filling and replacement, and alteration minerals include adularia, sericite-illite, smectite and kaolinite.

*Cerro Vanguardia & Cueva de las Manos*

A testament to the lateral coverage of the Chon Aike Formation is its presence at Cueva de las Manos, 226 km WNW of Cerro Vanguardia. Cueva de las Manos is an archaeological site which records the history of the pre-Tehuelche and pre-Mapuche people, including their handprints (Figure 4A), from 9300-1300 BCE. Figure 4B illustrates the difference in rheology between the Granosa and Estratificada units. At Cerro Vanguardia, the Granosa Unit is the preferred host for mineralization.

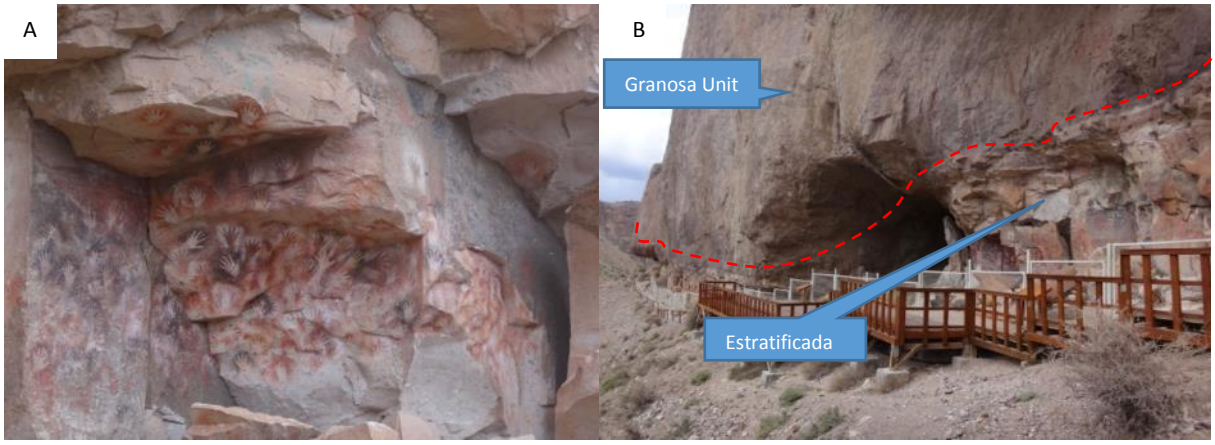



Figure 4: Chon Aike units at Cueva de las Manos, 226 km WNW of Cerro Vanguardia. A. Handprints of the pre-Tehuelche and pre-Mapuche culture (9300-1300 BCE) in the Estratificada unit. B. Red dashed line marks the contact between the upper Granosa and lower Estratificada units.