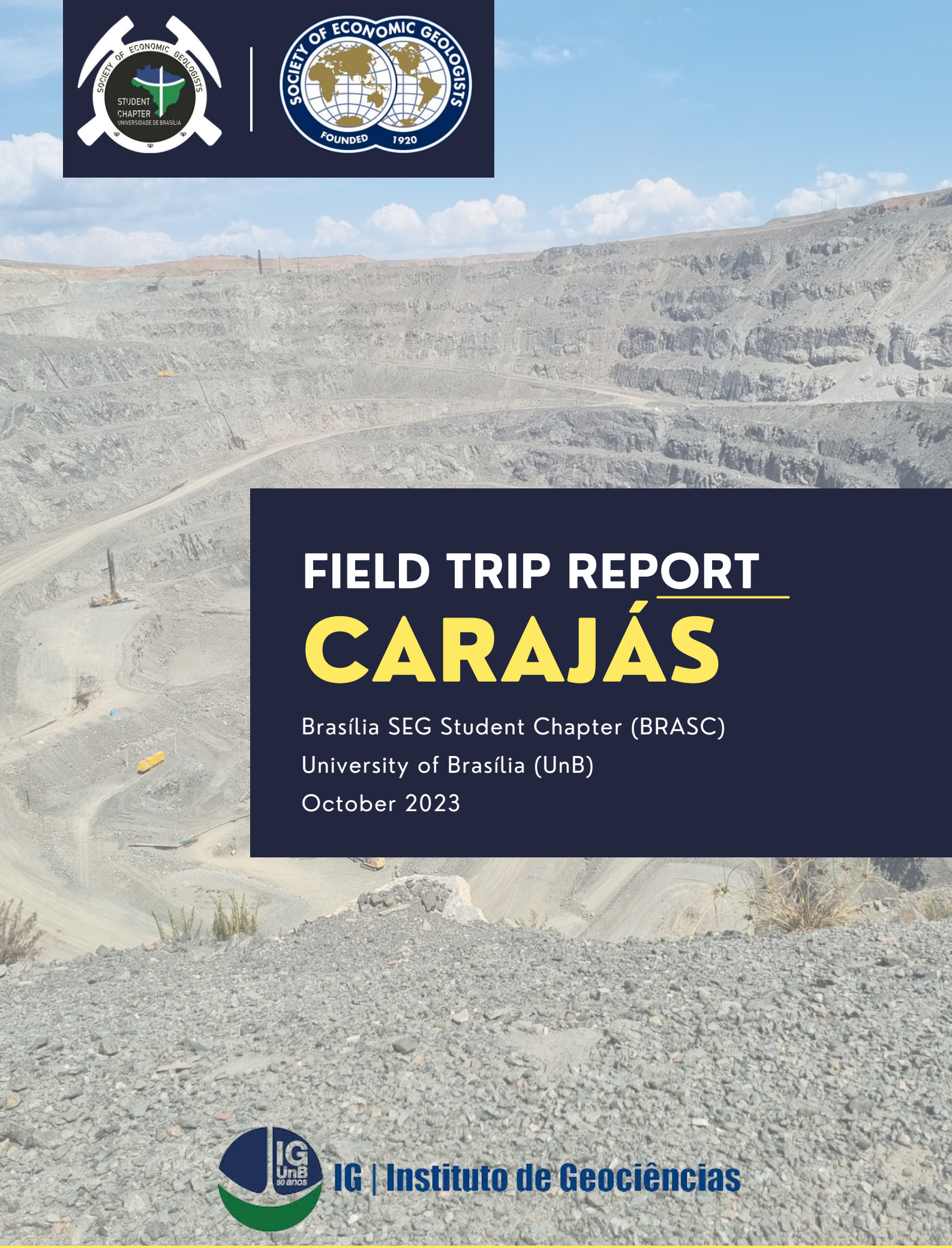

FIELD TRIP REPORT

CARAJÁS

Brasília SEG Student Chapter (BRASC)

University of Brasília (UnB)

October 2023

IG | Instituto de Geociências

Field Trip Participants

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04 Introduction

The present report aims to detail the activities carried out during the field excursion within the scope of the Carajás Project of BRASC-SEG (Student Chapter of Brasília - Society of Economic Geologists), affiliated with the University of Brasília (UnB). The fieldwork was conducted from August 12 to 20, 2023, in the context of the Carajás Mineral Province (CMP) - Pará (Brazil), one of the most important mining regions in Brazil and the world, involved in topics of extreme relevance both in terms of metallogeny and evolutionary geology for Brazil and South America. In this scenario, the main objectives of the excursion include introducing the province to the participating members, direct contact with the geology of the area, and fostering scientific discussions related to the CMP. The activities carried out on-site included visits to small-scale ventures to world-class deposits, as detailed below.

The Carajás Mineral Province, located in the southeast portion of the Amazon Craton, is bounded to the north by the Transamazonas Province and the Amazon Basin, to the east by the Araguaia Orogeny, to the south by the Parecis Basin, and to the west by the Central Amazon Province. This province can be subdivided into two tectonic domains: the Carajás Domain to the north and the Rio Maria Domain to the south. The Rio Maria Domain consists of rocks of mesoarchean age (3.0 to 2.86 Ga), while the Carajás Domain comprises basement rocks of mesoarchean age (3.0 to 2.83 Ga) intruded by neoarchean (2.75 to 2.57 Ga) and paleoproterozoic plutonic rocks, as well as covered by neoarchean metavolcano-sedimentary sequences (2.77 to 2.70 Ga).

The study region is globally recognized for its economic significance, resulting from the diversity and volume of mineral deposits. The CMP hosts significant deposits of iron, copper, gold, zinc, manganese, nickel, platinum group elements, rare earth elements, chromium, aluminum, among others. Over the past decades, the region has been investigated both academically and prospectively by mineral industry companies, especially in the context of the Carajás Domain, where most of the known large mineral occurrences are located. Based on the presented scenario, the excursion focused on Fe, Ni, PGE, Cu, and Au deposits associated with the Carajás Domain of the CMP.

05 Preparatory Activities

The excursion that marked the highlight of our academic year had its planning journey initiated in April 2023. Initially, the meetings were exclusive to the members of the board and our academic advisor, Prof. Cesar, and were later opened to other members. To ensure that our excursion was educational and enriching, we took additional preparation measures. We organized a series of presentations and discussions of scientific articles, each directly related to the mineral deposits we would visit. The class was divided into pairs and trios, covering a variety of related topics. This approach allowed us to delve deeply into specific areas of geological knowledge.

One of the most memorable moments of this preparation journey was a special lecture on the "History of Knowledge of the Carajás Mineral Province." The renowned geologist Noevaldo Teixeira, current head of the Center for Applied Geosciences at the Geological Survey of Brazil, was the keynote speaker. His presentation attracted the attention not only of the excursion participants but also of geoscientists throughout the university. The engagement generated by his lecture demonstrated how significant our endeavor was. Before embarking on the Carajás adventure, we gathered the group to discuss the itinerary and essential procedures that everyone should follow when visiting companies and mineral deposits. This final preparation step ensured that everyone was aware of the expectations and best practices to be followed during the excursion.

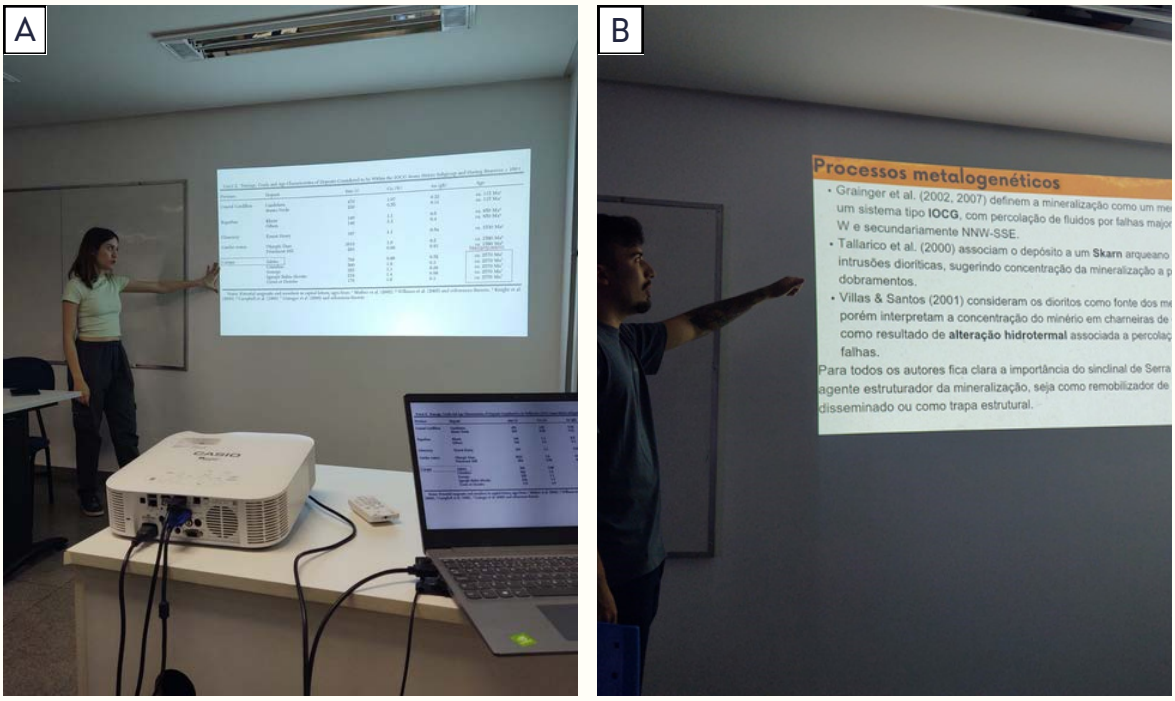

Figure 1: Discussions of articles related to the Carajás deposits carried out by BRASC members.

06 Itinerary

Our field itinerary was meticulously planned, considering all aspects of the journey. We began our exciting excursion from Brasília, with the final destination being Marabá in the state of Pará. To make the trip more comfortable, we decided to make a strategic stop in Palmas, Tocantins, where we would spend the night. The plan was to continue the journey and visit the Lunga Deposit, located near the city of Curionópolis. However, an unexpected setback forced us to rethink our plans. Our vehicle had mechanical issues in Teresina de Goiás on the first day of the trip. This unforeseen event required us to deal with the situation and caused us to miss the first day of scheduled visits. Fortunately, the rest of our itinerary proceeded as planned, allowing us to make the most of the visits to mineral deposits and the learning experiences that lay ahead. Thus, the excursion schedule can be summarized in Table 1.

Table 1: BRASC Excursion to Carajás Activity Schedule.

Day	Atividade/Local de Visita	Overnight Stay
1	Brasília - Teresina de Goiás	Teresina de Goiás/GO
2	Teresina de Goiás - Parauapebas/PA	-
3	Teresina de Goiás - Parauapebas/PA	Parauapebas/PA
4	Serra Norte (Fe) - Vale	Parauapebas/PA
5	Salobo (Cu-Au-Ag) - Vale	Canaã dos Carajás/PA
6	DBENS Mineração (Cu-Au)	Tucumã/PA
7	Jaguar (Ni) - Centaurus	Tucumã/PA
8	Tucumã/PA - Natividade/TO	Natividade/TO
9	Arrival in Brasília	

07 Day 1 - Serra Norte Deposit

On our first day of exploration, we visited the world's largest open-pit iron mine, Serra Norte. This mine is located near the city of Parauapebas, within the Carajás National Forest, and occupies less than 5% of the total area. Vale is responsible for preserving and controlling the wildlife and flora in the environmental area.

The visit began at 9:00 AM in the Geology, Topography, and Chemistry Laboratory of the Serra Norte Mine. Initially, safety work parameters were presented, along with the itinerary for the planned day.

The geology of the mine is characterized from bottom to top by Archean to Paleoproterozoic rocks, including the Basalts of the Parauapebas Formation, the Banded Iron Formations (BIFs) of the Carajás Formation, and the basalts of the Igarapé Cigarra Formation. The protomineral consists of BIF composed of bands of Hematite and Jasper (silica with a reddish Fe color), along with subordinate magnetite, and the enclosing rocks are basalts that are sometimes filled with carbonate veins. Structural geology can be predominantly described by a ruptile control with NW-SE faults, in addition to the presence of later diabase-filled dikes.

The deposit formation process can be described by two processes: predominantly supergene at the top and hypogene at the base in contact with the host rock. The ore is described as a compact mass of massive BIF composed of hematite (hard ore) and a friable ore with iron content exceeding 60%.

The Serra Norte complex consists of approximately 14 pits with depths of up to 300 meters, divided into N4 and N5. The beneficiation process primarily involves crushing, as the waste ore ratio is low. Quality control focuses on elements such as silicon, manganese, phosphorus, and aluminum, considered contaminants in the ore. The Serra Norte mine is the world's largest open-pit iron mine, with approximately 90% of its product being exported.

Figure 2: BRASC members in a pit at the Serra Norte deposit.

Day 1 - Serra Norte Deposit

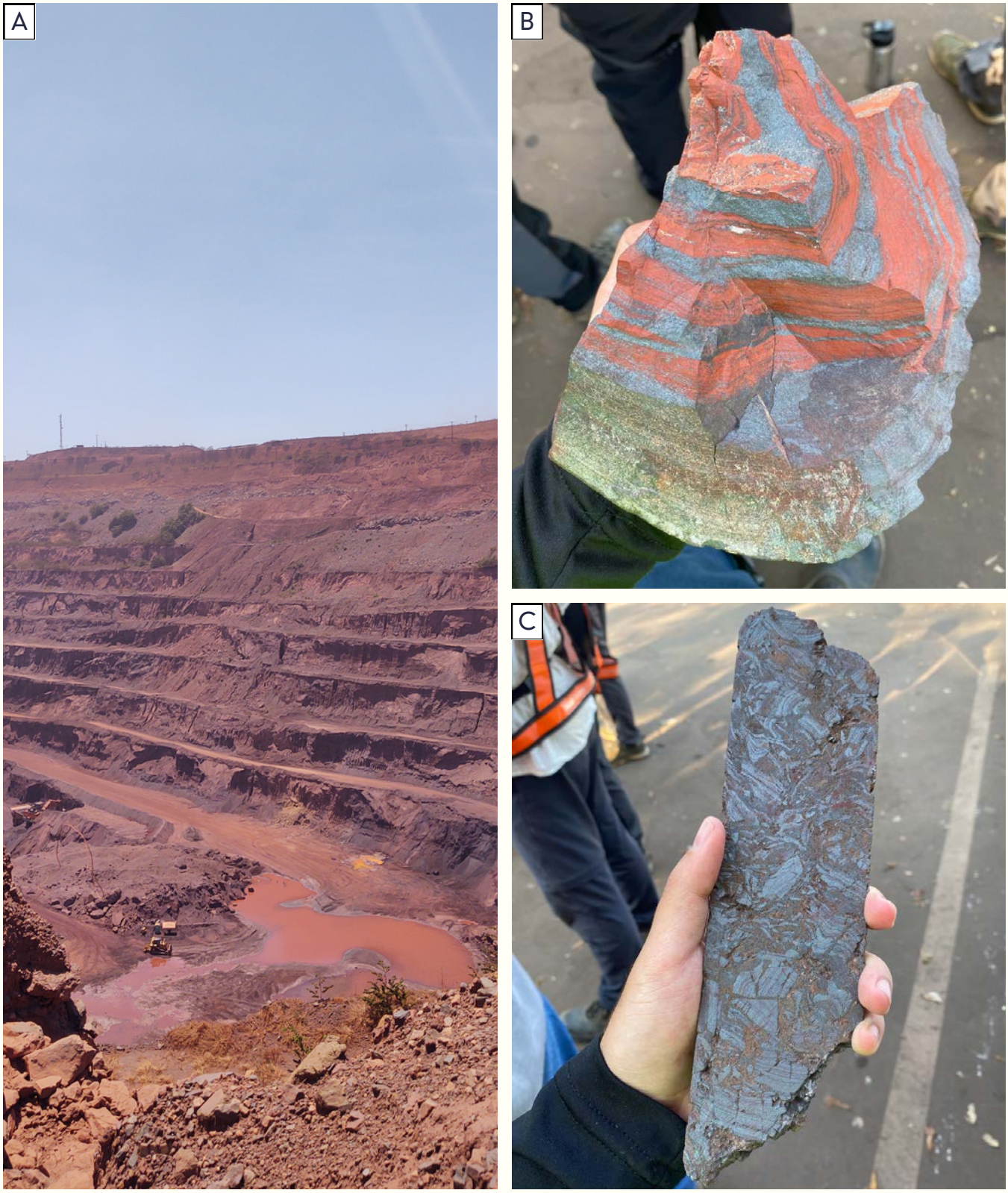

Figure 3: A - One of several pits at the Serra Norte deposit. B - Sample of jaspelites. C - Core sample of iron ore extracted from the deposit.

Day 2 - Salobo Deposit

On August 16, 2023, the members of SEG UnB visited the Salobo deposit of Vale, the largest iron-copper-gold oxide (IOCG) deposit in the Carajás Mineral Province. First, at the Vale Metais facilities, the students attended a lecture on the geology of the deposit and the mining and production of the mine. They then went to the viewpoint at the Phase 4 Pit (NW sector) of the Salobo Project, an open pit with a depth of over 700 meters. Finally, they visited the TopGeo core shed in the city of Parauapebas to observe the drill core samples from the Salobo deposit. TopGeo is a company contracted by Vale to perform petrographic, structural, and petrophysical descriptions of their drill core samples.

Among the key geological features of the deposit, it is worth noting that the mineralization is structurally controlled by the Gray Shear Zone, the ore body is sub-vertical and deep, and the ore is in the form of copper sulfides (chalcopyrite, chalcocite, and bornite) primarily associated with biotite schists (BDX), magnetite schists (XMT), and garnet-grunerite schists (DGRX).

The mine is the largest copper producer in Brazil and the second-largest gold producer (1.1 billion tons with 0.65% Cu and 0.33 g/t Au). Currently, the monthly production of the mine is 18,000 tons of copper. The copper ore recovery rate is 91%, and the Waste-Ore Ratio (WOR) of the mine is 1.4.

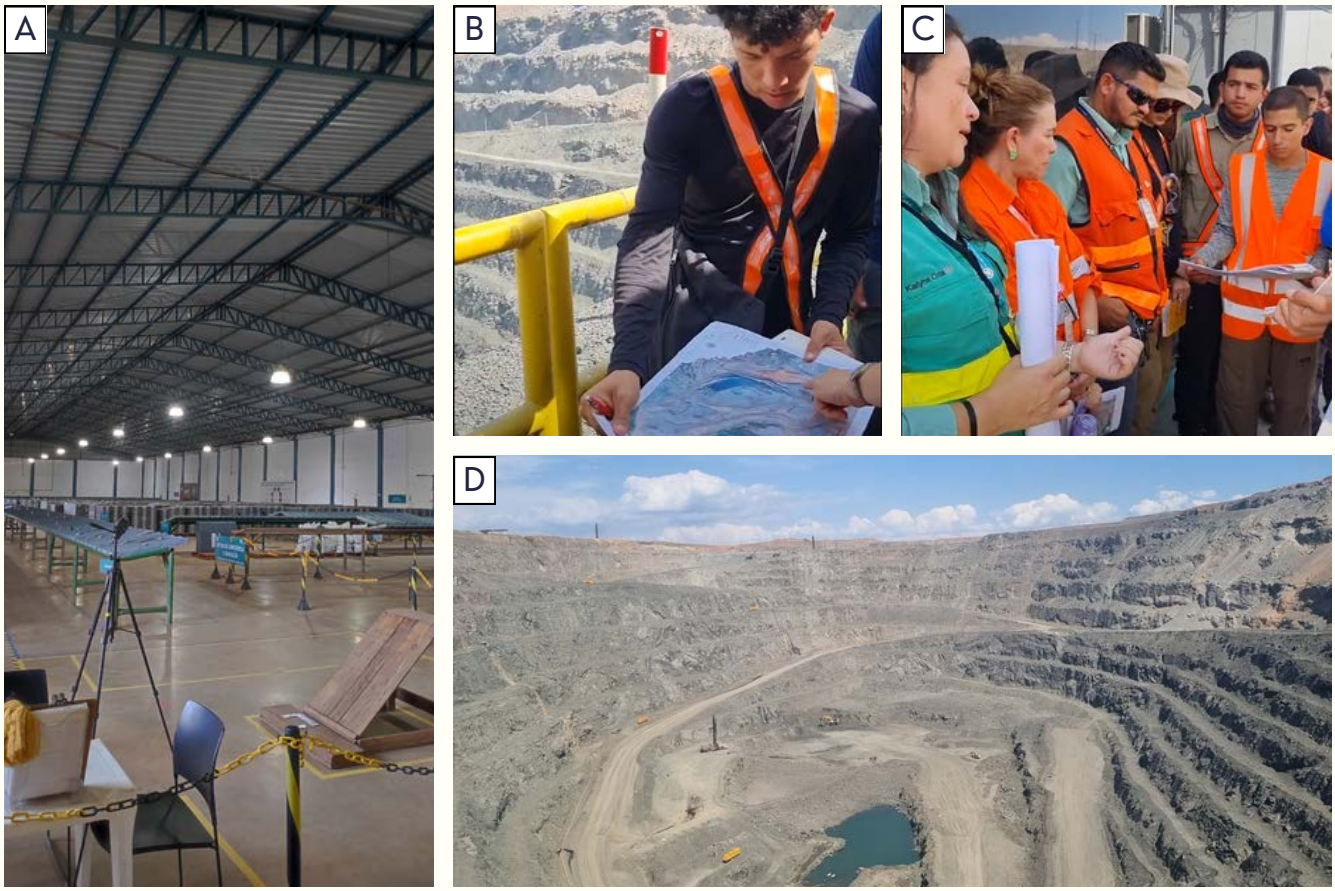

Figure 4: A - Warehouse for drilljoles of various Vale targets, including the Salobo deposit. B & C- Vale geologists explaining the characteristics of the deposit to the group. D - View of the Salobo deposit.

Day 3 - DBens Deposit

Within the geological context of the Xingu Complex, we visited the Maranhense pit, where we observed a basic dike from the Sequeirinho Group intruding into the Serra Dourada granite. This basic dike consists of a metabasalt with mineralized lenses resulting from the potassic alteration process associated with chalcopyrite, primarily.

Characterizing an IOCG-type deposit, the copper mineralization is located in narrow, underdeveloped potassic alteration zones, present in sub-vertical bodies, with copper content ranging from 1 to 2%. In the transition zone, approximately 15 meters wide, the occurrence of malachite and chrysocolla is marked, secondary minerals generated by the alteration of ore minerals.

After visiting the pit, the responsible geologist presented some drill core samples, allowing us to closely observe the mineralogical characteristics of the mineralized zone. Sulfides were quite common, and at times, their differentiation with the naked eye was hindered by oxidation. In such cases, concentrated hydrochloric acid was used to "clean" the chalcopyrite and distinguish it from bornite.

We concluded our visit by exploring the copper ore beneficiation plant, where high-grade concentrate is produced for export by the company. The engineer in charge of operations guided our visit, explaining the beneficiation stages and the machinery used.

The beneficiation process primarily involves four main stages: crushing, grinding, flotation, and drying. In the crushing stage, a primary jaw crusher and a cone crusher are used to break down the particles to 12.5 mm. In the grinding stage, the material goes through a steel-lined ball mill, where the ore is fragmented into a fine powder.

In the flotation stage, four Denver-type flotation cells are used to separate the concentrate, while the residue is directed to two lines of four flotation tanks each. These tanks are interconnected and separate a new fraction of concentrate. The residue is then sent to the tailings dam. The concentrate is transported to a distribution box, which directs the ore to bays for the drying stage.

As a result, DBens produces the final product, a high-grade copper concentrate (around 60%). The production is transported by trucks to Peru, where it is exported to other countries.

Day 3 - DBens Deposit

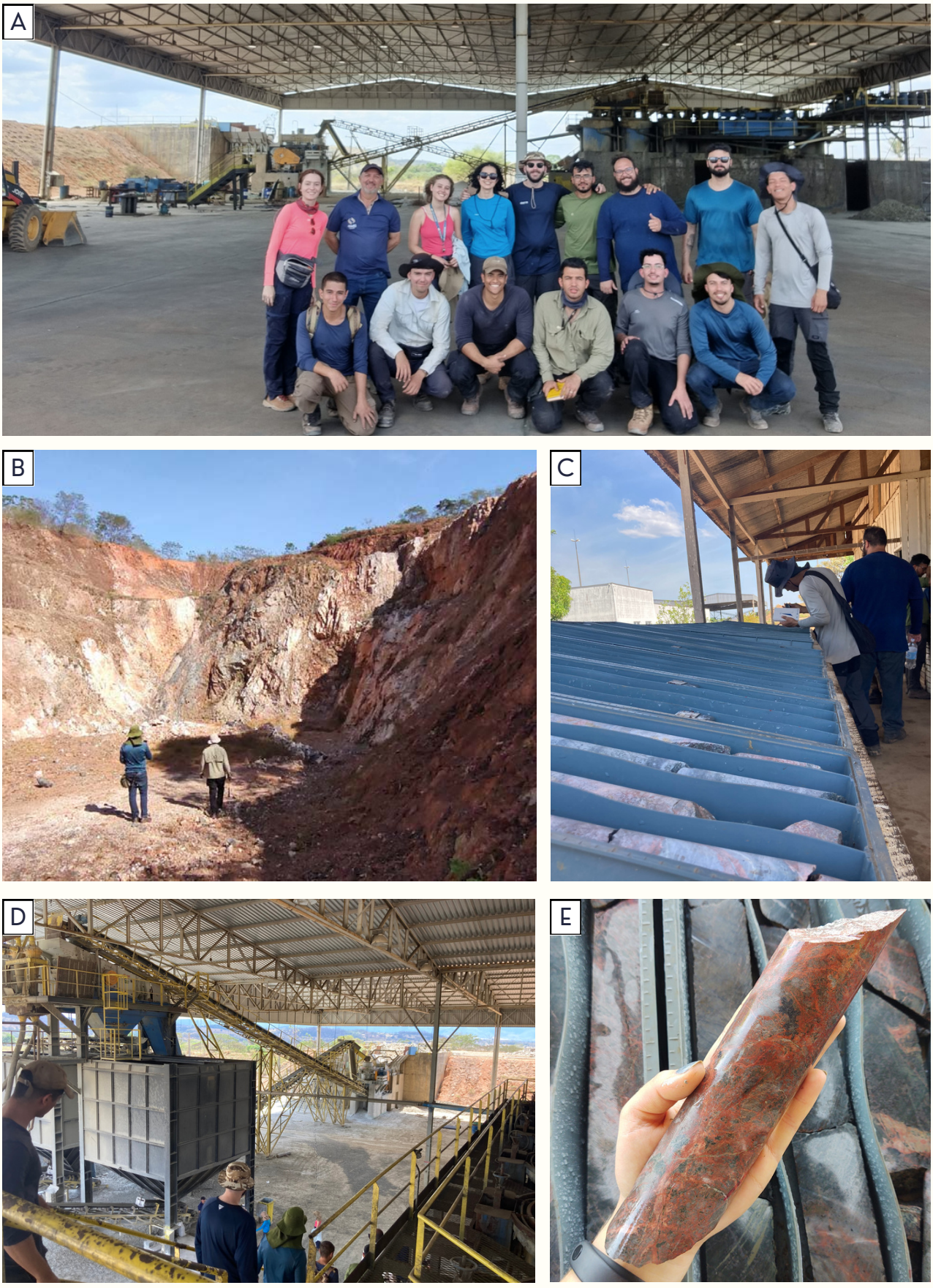

Figure 5: A - Photo of the group at the beneficiation plant of DBENS Mining. B - View of a mining operation. C & E - Core samples. D - Beneficiation plant of DBENS Mining.

Day 4 - Jaguar Deposit

On the last day of the field trip, we had the opportunity to visit the Jaguar project of Centaurus Metals, located in the center of the municipality of Tucumã, Pará, even though the deposit is approximately 30 km to the north. The group arrived at the company's facilities at 9:00 AM and stayed until 4:00 PM. In the morning, the company's geologists provided a detailed presentation about Centaurus Metals and the targets of the Jaguar deposit. After lunch, we headed to the core shed, where we observed drill core samples from three targets of the project.

The Jaguar nickel deposit is situated 2 km to the north of the Serra Arqueada iron deposit and 10 km to the southwest of the lateritic nickel deposit of the Serra do Puma Complex, in the western part of the Carajás Mineral Province, southeast of the Amazon Craton. Jaguar is interpreted as an unusual hydrothermal nickel deposit with characteristics in common with the IOCG system of the Carajás Province.

Based on data obtained from magnetic and radiometric airborne surveys in the late 1990s, which revealed small anomalies between Serra do Puma and Serra Arqueada, the Jaguar deposit was discovered in the early 2000s by VALE through high-resolution GEOTEM surveys. This survey indicated a trend of high-conductivity anomalies coinciding with magnetic anomalies. After an extensive soil geochemistry campaign in 2005, nickel and copper anomalies were identified. The initial drilling results in 2007 intercepted 79 meters of sulfide mineralization with 0.87% nickel. Following an extensive drilling campaign between 2008 and 2010, a preliminary resource of 92 million tonnes at 0.65% Ni was defined. In 2020, Centaurus Mining Ltda acquired the Jaguar deposit from VALE.

The sulfide deposit at Jaguar occurs at the intersection of the NE-SW Canaã and McCandless shear zones. The geological context of the Jaguar deposit includes gneisses and migmatites from the Xingu Complex, granitic and mafic-ultramafic intrusions, metavolcano-sedimentary sequences of the Itacaiúnas Supergroup, and younger diabase dikes. The mafic-ultramafic rocks of Serra da Onça and Serra do Puma and the iron formations of Serra Arqueada corroborate the magnetic anomalies.

The mineralizations are associated with hydrothermal alteration zones, structurally controlled by regional W-NW-trending faults, particularly at the contact between the granite-gneiss basement rocks and the felsic subvolcanic rocks, forming lenticular bodies. The ore consists of subvertical brecciated bodies in a W-NW direction, overlying or cutting through the hydrothermal alteration zones. The primary sulfide is pyrite, followed by millerite, pentlandite, chalcopyrite, pyrrhotite, and sphalerite. The most abundant mineralization occurs in the form of veins or disseminated with lower grades.

Day 4 - Jaguar Deposit

Breccias and massive sulfides occur subordinately and host higher-grade ore. The hydrothermal alteration zones are enriched in REE, Fe, U, P, Pb, Ni, and Co, a common characteristic of IOCG deposits in the Carajás Mineral Province.

Figure 6: A,B,C - Photos of the group observing samples from the drill holes of the Jaguar project. D - BRASC and the Centauros team after a brief lecture on the deposit.

ACKNOWLEDGMENT

We would like to thank everyone who made this excursion possible. Starting with the SEG Stewart R. Wallace Fund, which contributed $750.00 to our Field Trip. We are thankful to SBG Núcleo Brasília, which contributed $250.00 to our fund, and the management of the Institute of Geosciences, Professors Elói Campos and Welitom Borges, who kindly provided the drivers and transportation. We also thank our drivers Jean and Mendes, who carefully and attentively drove us to Pará.

We are very grateful to the geologists from Vale, Samuel and Kalyne, to DBens Mineração, and to the geologists Daniel and Renato from Centaurus Nickel. We would also like to thank Bravo Mining for the dedication and care with which they responded to us and planned our visit. Unfortunately we were unable to visit the Luanga deposit, but we would like to thank Bravo Mining for the dedication and care with which they responded to us and planned our visit.