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The Trouble with Glaciers: A Case Study in the Region of San Juan, Argentina

ESS 511 Master's Thesis

Author
Sandra Werthmüller
09-925-579

Supervised by
Dr. Frank Paul
Dr. Muriel Côte

Faculty representative
Prof. Dr. Andreas Vieli

25.09.2020
Department of Geography, University of Zurich

Department of Geography

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Abstract

In 2010 Argentina passed the first glacier law in the world. This law regulates the protection of glaciers and the periglacial environment against external influences. Within the framework of this law, the Argentine glacier inventory was developed. This inventory includes glaciers, snow patches and rock glaciers. The National Institute of Snow, Ice and Environmental Research (IANIGLA), headed by Ricardo Villalba, was responsible for compiling the Argentinean glacier inventory. Between 2015 and 2017 there were three accidents with cyanide at the Veladero Mine in the Province of San Juan. In one case the cyanide reached the watershed. Following these accidents, the environmental group Jáchal No Se Toca filed lawsuits against both the mine operators (Barrick Gold) and IANIGLA. Ricardo Villalba and IANIGLA were accused of not implementing the law correctly because they used the standard threshold for glaciers of one hectare. The Critical Physical Geography Approach is used to illuminate and analyze the conflict between the different parties. This approach is used because the approach assumes that physical landscape changes do not take place in a social vacuum, but are influenced by social aspects. To analyze the social aspects of the conflict, a content analysis of the definitions, values and boundaries of a glacier is made. This analysis is carried out with different stakeholders involved. Furthermore, it is analyzed how the different stakeholders understand and interpret the term "glacier". In order to understand the physical aspects of this conflict, two inventories of satellite images from ASTER and Sentinel-2 have been created for comparison it with the Argentine glacier inventory. The organization Center for Human Right and Environment (CEDHA) is very critical of the Argentine glacier inventory, so the inventory of this organization is also used for further analysis. To fully understand the conflict, it is important to understand the amount of water stored in these different features, as the Veladero Mine is located in an arid area. The results show that Ricardo Villalba and the institution IANIGLA did not make any obvious mistake during the mapping of glaciers, snow patches and rock glaciers. However, it is clear that the Argentinean glacier inventory tried to find a balance between what is on the one hand legally and on the other hand scientifically justifiable. In addition, the water content of the features shows that glaciers and the periglacial environment in this region play an important role as a water resource, since the conflict takes place in a rather arid area.

Acknowledgements

The realization of this master thesis was possible thanks to the support of my supervisors Dr. Frank Paul and Dr. Muriel Côte. They have accompanied me through my thesis and were at my side when I had questions. Their professional support made this thesis possible. I would also like to thank Giulia Wienhues and Kathrin Tschanen, who proofread my thesis. Also thanks to my work place and friends who have accompanied and supported me through my journey with this thesis.

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1. Introduction

1.1 Background on glaciers and glacier inventory

Glaciers consist of ice, firn and snow. To define a glacier as a glacier, the ice must be perennial and flowing (Haeberli, 2017). The flow of ice creates characteristic features such as crevasses and stratifications (Hambrey and Alean, 2004). Another important feature is the equilibrium line altitude (ELA), which defines the glacier into an accumulation and ablation zone (Haeberli, 2017). The ELA depends on the latitudinal location of a glacier. In the tropics, glaciers occur at an altitude of 5,000 to 6,000 meters above sea level (Clapperton, 1983).
In the study region (Figure 1), small isolated glaciers are most common. The snowline in this area is at 4,600 to 4,700 meters above sea level (Rabassa and Clapperton, 1990). In light of climate change, Andean glaciers are rapidly retreating. Especially in the arid regions of the Andes, the strong glacier mass loss is a large problem, as these regions depend on the glacial meltwater. In these regions, glacier runoff serves as an important water resource (Rabatel et al, 2013). Glaciers can contribute large amounts of water to the runoff in a catchment area, even if less than 1% is glacierized (Huss and Hock, 2018).
Consequently, it is important to monitor where the glaciers are located and how much water they might store. The UNESCO document of 1970 was the first document that provided guidelines for the systematic recording of glaciers (International Commission of Snow and Ice, 1970). In Argentina, however, the first regional glacier inventory was made between 1907 and 1912. For different catchment areas in the San Juan and Mendoza regions, different glacier inventories were compiled between 1978 and 1987 (Casassa et al., 1998). Zalazar et al. (2017) compiled the first preliminary glacier inventory for Argentina. This inventory was collected on the basis of the Glacier Protection Act and includes glacial and periglacial forms with a total area of 5,743 km^2 (Zalazar et al., 2017).

1.2 The Law Case of Ricardo Villalba

Since the mid-20th century, glaciers have been shrinking in both the tropical and extratropical Andes (Rabatel et al, 2013; Clapperton, 1983). Through this retreat of regional glaciers, exploration sites that were covered by glaciers become accessible for mining activities (Kronenberg, 2013). Due to this emerging exploration, glaciers have even been damaged through mining activities in several countries (e.g. Chile and Kygyzstan) (Jamieson, Ewertowski and Evans, 2015; Kronenberg, 2013). In several countries, such as Argentina and Chile, this led to the design of a Glacier Protection Law (GPL). In September 2010, Argentina was the first country to enact a law to protect their glaciers from such harmful activities and implemented the creation of a glacier inventory in the law (Anacona et al., 2018). In 2012, Ricardo Villalba launched the work on the new glacier inventory for Argentina. At this time he was head of the National Institute of Snow, Ice and Environmental Research (IANIGLA) (Fraser, 2017).
In the years 2015 and 2017 the Veladero mine close to San José de Jàchal (northwestern Argentina) spilled highly toxic cyanide into the adjoined watershed (Fraser, 2017) and environmental activists in Argentina launched a law suit against Villalba and his institution (Tollefson and Rodríguez Mega, 2017). They argued that Villalba did not do his job and manipulated the results of the glacier inventory for the interest of the mining company. The activists claimed that smaller glaciers (<1 ha) should also be included in the inventory (Tollefson and Rodríguez Mega, 2017). However, until

today it is common practice to only map glaciers that are larger than 0.01 km^2 as Leigh et al. (2019) show in their work.

1.3 Hypothesis and research Question

The aim of this thesis is to investigate the issues surrounding the lawsuit against Ricardo Villalba and to analyze why the case was so contentious in regard to the Glacier Protection Law and its inventory. A main focus lies on the physical features that define the glacier inventory of Argentina by using the approach of Critical Physical Geography. This approach assumes that changes of the physical landscape do not take place in a social vacuum but rather are also influenced by the social aspects. Therefore, a broad range of methods are applicable following this approach (Lave, Biermann and Lane, 2018a). In order to achieve the goal of this study, the following questions and hypothesis will be discussed.

Question
What are the physical features of glaciers and the periglacial environment that made the case of the glacier inventory work of Argentina so contentious?

Sub-questions
Why are features of glaciers and the periglacial environment missing in Argentina's glacier inventory that various stakeholders believe should be included?

What features of glaciers and the periglacial environment have been missed in the mapping of the glacier inventory in Argentina?

Hypothesis
There are features of glaciers and the periglacial environment that explain why the case of Argentina is so contentious.

The thesis is divided into seven chapters. Chapter 2 presents a general overview of the study region and the case study site were the Veladero mine is located. Chapter 3 provides background information on glaciers and mining as well as on the influencing laws in the case of Ricardo Villalba. Applied methods and used datasets in this thesis are explained in Chapter 4. The results are presented in Chapter 5, followed by their discussion and interpretation in Chapter 6. Major results are summarized with regard to the research questions and the hypothesis in Chapter 7. Chapter 7 also includes a brief outlook on potential further research on this topic.

2. Study region

The first section focuses on the conditions in the province of San Juan. The climatic conditions as well as the economic situation of the province are pointed out. In a second section the climatic and geological conditions at the Veladero Mine are presented. Finally, the history of the mine is discussed.

2.1 General characteristics

The Province of San Juan is located in the west-central part of Argentina (Encyclopaedia Britannica, 2020) and has an area of 89,651 km^2 (Uñac et al., 2017) (Figure 1). In total 681,000 people lived in the San Juan province in 2010 (Dirección Nacional de Asuntos Provinciales, 2018). The Province of San Juan has borders with the Provinces of Argentina La Rioja, San Luis and Mendoza and shares a boarder with Chile (San Juan, 2020). The Province of San Juan is divided into nineteen departments: Albardón, Angaco, Calingasta, Capital, Caucete, Chimbas, Iglesia, Jáchal, 9 de Julio, Pocito, Rawson, Rivadavia, San Martín, Santa Lucía, Sarmiento, Ullum, Valle Fértil, 25 de Mayo and Zonda (Uñac et al., 2017). The north-south oriented Cordilleras of the Andes and their Pre-Mountain Range characterize the western part of the Province of San Juan (San Juan 2020). The Andean mountain range is on average between 4,500 and 5,000 meters in elevation (Encyclopaedia Britannica, 2020). The highest peak in the province is the Mount Cerro Mercedario with an elevation of 6,770 meters above sea level. In front of the Andes is the Pre-Mountain Range, which, like the Andes, stretches from north to south across the Province of San Juan (San Juan, 2020).

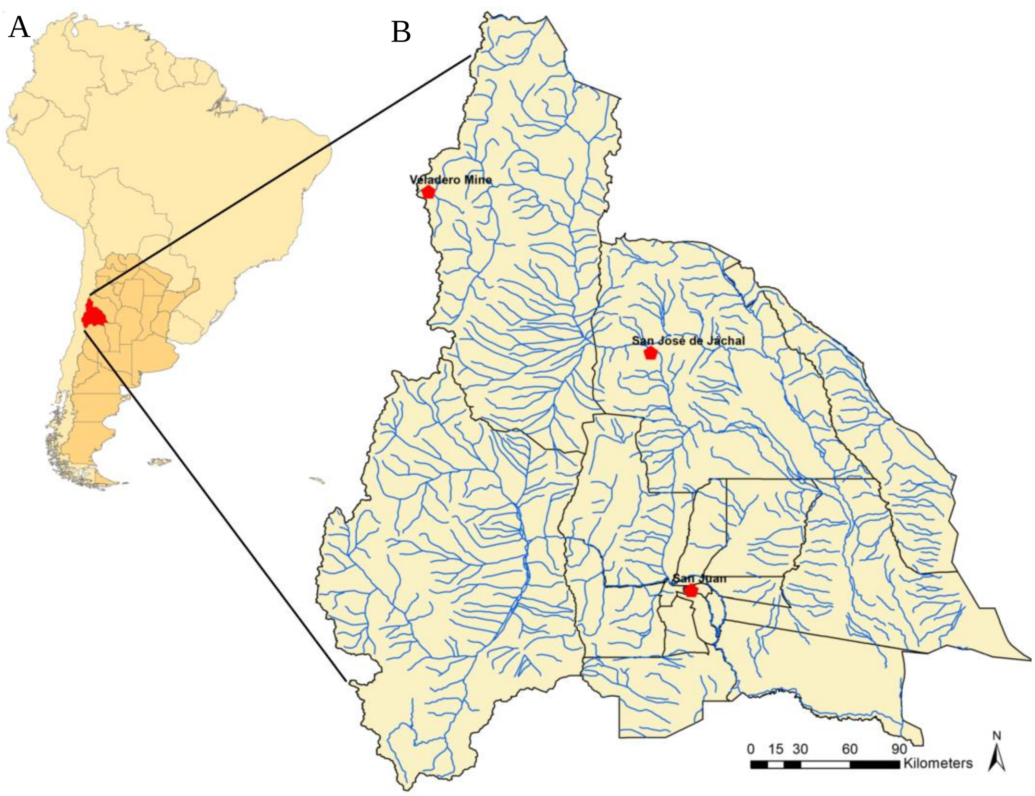

Figure 1: (A) South America with Argentina and the Argentinean provinces. The province San Juan is colored red. (B) Close-up of Province San Juan with its 19 departments. The blue lines indicate the rivers. In addition, the cities of San José de Jáchal and San Juan as well as the Veladero Mine are displayed in red dots (created using the data sources DIVA-GIS, 1999; HDX, 2020; Porto Tapiquén, 2020; The World Bank Group, 2020).

2. Study region

Numerous rivers originate in the Andes, including the Rivers of Jáchal, Bermejo and Valle. However, the most important river of the province is the San Juan River, which has three tributaries that have their source in the Andes (San Juan, 2020). The rivers of Jáchal, Bermejo and San Juan are fed by the melting snow and ice from the Andes. The water of the three rivers is used to irrigate fields and ends up in the semi-arid southeastern part of the province (Encyclopaedia Britannica, 2020). In addition, the San Juan River is also used for hydroelectric power. For this purpose, two dams have been built in the province (San Juan, 2020).

The province of San Juan has a mild and dry climate. The Andean region is characterized by a semi-arid mountain climate with a large thermal amplitude. The western Andean peaks prevent that humid and cold air from the Pacific can flow into the province, whereas the Atlantic winds are shaded by the Pampa Mountains in the east, preventing a humid air flow into the area. The average temperature in the mountains is 5 °C but can reach up to minus 30 °C (in the winter). In the mountain valleys, the climate is slightly warmer and temperatures vary according to the elevation. Here, summer temperature maxima reach up to 45 °C (San Juan, 2020).
Figure 2 shows the average monthly precipitation values over the years 1981-2010 for the cities of San Juan and San José de Jáchal. Both cities get the highest amount of rainfall in the months of December, January and February and the lowest amount of precipitation in June, July and August. The annual average precipitation (1981 to 2010) is for the cities San Juan and San José de Jáchal is 90.9 mm and 130.3 mm (Servicio Meteorológico Nacional, 2019).

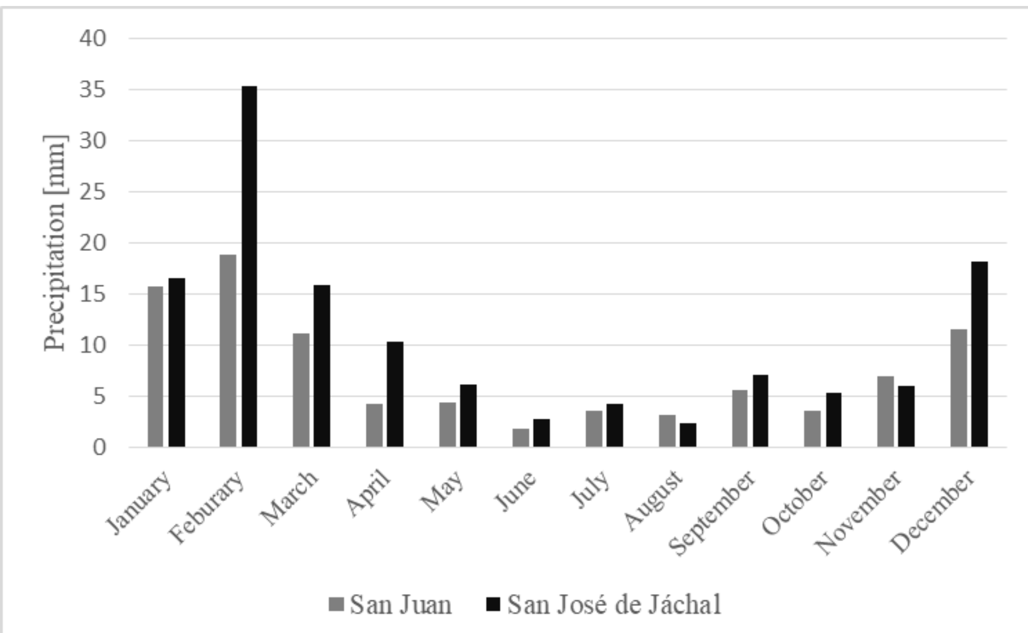

Figure 2: Average precipitation values over the years 1981-2010 for the cities of San Juan and San José de Jáchal (created using the data source Servicio Meteorológico Nacional, 2019).

The economy is an important factor for the development of a region. Between 1993 and 2002, economic activity in the Province of San Juan is characterized by fluctuations between periods of growth and decline. Between 2003 and 2012, economic activity in the province of San Juan grew at a rate of 11.3%. Approximately 50% of this growth was generated in the goods producing sectors. The "manufacturing industry" accounts for about 21.5%, which includes the extraction and

processing of gold and silver. For the economy of the province of San Juan, mining and agriculture are the two most important sectors. In agriculture, viticulture plays an important role, as well as the cultivation of olives, vegetables and fruit trees.
From 2005 onwards, mining production became a driving force in the economic growth of the province. The gold production plays a central role in the mining activities, with the result that the province of San Juan is currently the largest gold producer in Argentina. In 2012, the province produced 30,829 kg of gold, which represents 56% of the country's total gold production. Another important metal produced in the province is silver. In 2012, the province contributed 14% of the national silver production (Dirección Nacional de Asuntos Provinciales, 2018). Metal-bearing mining accounts for about 6% of the gross national product (GNP) in 2015 in the Province of San Juan. Social, communal and personal services accounted for 38% of the province's GNP. Agriculture contributed about as much to the GNP of the Province of San Juan as metal-bearing mining (Uñac et al., 2017).
The mining activity of metalliferous minerals takes place in the north and northwest of the province. Gold and silver are mined in the mines of Veladero and Gualcamayo. The main export product is gold, which is mainly exported to Canada and accounts for 74% of the total value of the province's exports. Indeed, in the year 2012 Canada was the only buyer of gold from the province of San Juan.
In 2017 the employment rate in the Province of San Juan stood at 41.5% and unemployment at 4.5%. The number of people employed in the formal private sector is 79,000. The share of the population living below the poverty line was 26.4% in 2017 (Dirección Nacional de Asuntos Provinciales, 2018).

2.2 Case study site

2.2.1 Location

The Veladero mine is located in the province of San Juan in Argentina at the western flank of the Andes Cordilliera. The mine is also situated around six kilometers from the Chilean border (Evans, Ehasoo and Krutzelmann, 2018) (Figure 3). The Veladero mine is located about 8 km southeast of the Pascua-Lama Projcet in Chile (Bissig et al., 2015) at an altitude of 3,800 to 4,800 meters above sea level (Evans, Ehasoo and Krutzelmann, 2018). The mine is located south of the arid diagonal. This area has a arid climate with severe winters and prevailing strong winds (Perucca and Angillieri, 2011). In the summer (December to February) the daytime temperatures are between 10°C and 20°C degrees. The lowest temperature in summer during daytime is between -5 °C and 5 °C. Between June and August (austral winter) the daytime temperature is between -10 °C and 10 °C. The nighttime temperatures in the winter months are between -10 °C and -30 °C. The mean annual precipitation at 4,400 meters above sea level is about 200 mm. This precipitation falls mostly as snow (Evans, Ehasoo and Krutzelmann, 2018). The mine is located in the catchment area of the Rio de las Taguas. The other perennial rivers in the area are Despoblados, Potretillos, Guanaco Zonzo and Canito creeks. The water required for the operation of the mine comes partly from surface water and partly from groundwater (Evans, Ehasoo and Krutzelmann, 2018).

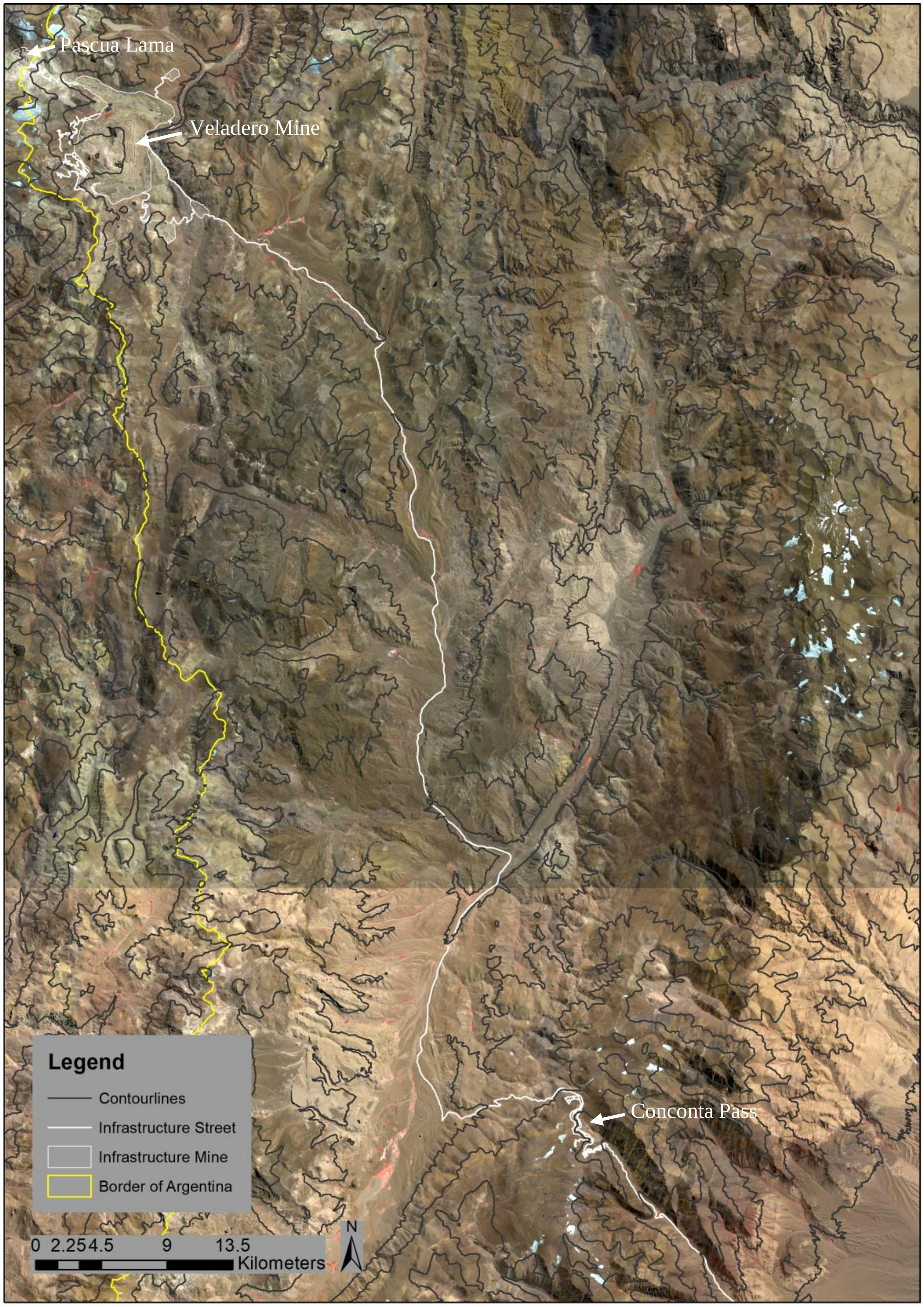

Figure 3: The map shows the road and the mine. The infrastructure of the mine and the road are shown in white and the Argentine border in yellow (created using the data sources HDX, 2020; infrastructure data set (chapter 4.3.1)). The contour lines are shown in grey ((created using the data source USGS, 2020a). The Pascua Lama project, the Veladero mine, and the Conconta Pass are also displayed. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

2. Study region

The deposit of the Veladero Mine is characteristic for the Andes. In the Andes there are some high-sulfidation epithermal gold-silver (Au-Ag) deposits, including the El Indio Belt (Bissig et al., 2015). These high-sulfidation epithermal deposits are often located between 3,500 and 5,200 meters above sea level and are between 200 and 500 meters below the surface. The El Indio Belt is a 120 km long and 25 km wide belt of volcanic and intrusive rocks formed during Permian to late Miocene (Evans, Ehasoo and Krutzelmann, 2018). This belt extends along the Chilean and Argentinean borders and includes the Tombo, Veladero, Pascua-Lama and El Indio deposits (Figure 4). The mines in the El Indio Belt contain a gold reserve of about 40 Mega ounces (Moz) (Bissig et al., 2015).

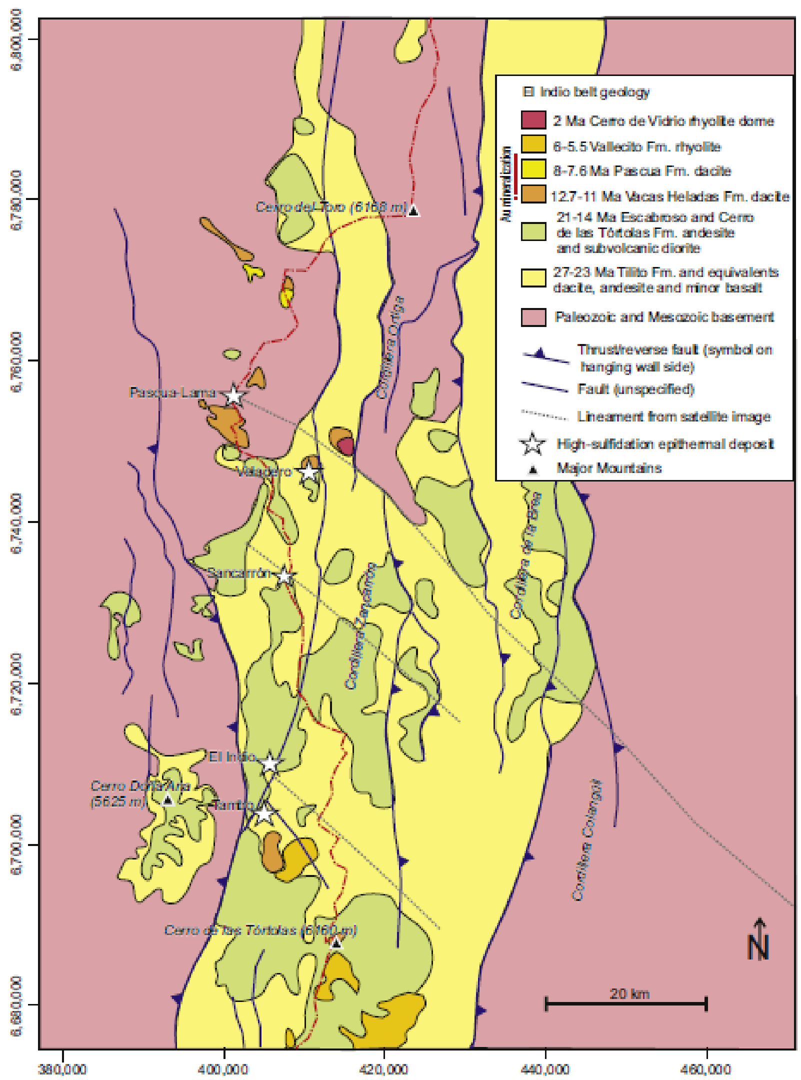

Figure 4: The geological map of the El Indio belt with the main epithermal deposits (Bissig et al., 2015: 336).

The gold and silver deposits in the Veladro Mine occur in two main breccia bodies. These are Amable and Filo Federico (Figure 5). The mineralization of the Amable ore zone took place in the Miocene. The geological age of this body is estimated between 12.14 mega annum (Ma) and 12.7 Ma depending on the dating approach. The Amable ore zone consists of coarsely stratified volcaniclastic breccias that belong to the Cerro de las Tórtolas formation. Above the Cerro de las

Tórtolas formation is the Tilito Formation, which consists of andesites and dacites as well as Permian felsic tuffs. The Filo Federico ore zone was also mineralized during the Miocene. The age of this ore zone is estimated between 10.3 and 11.1 Ma. The Filo Federico ore zone is located in volcanic deposits belonging to the Vacas Heladas Formation. The deposit is related to hydrothermal breccias that have intruded into the volcaniclastic deposits. Both ore zones of the Veladero mine are the result of hydrothermal alteration (Bissig et al., 2015).

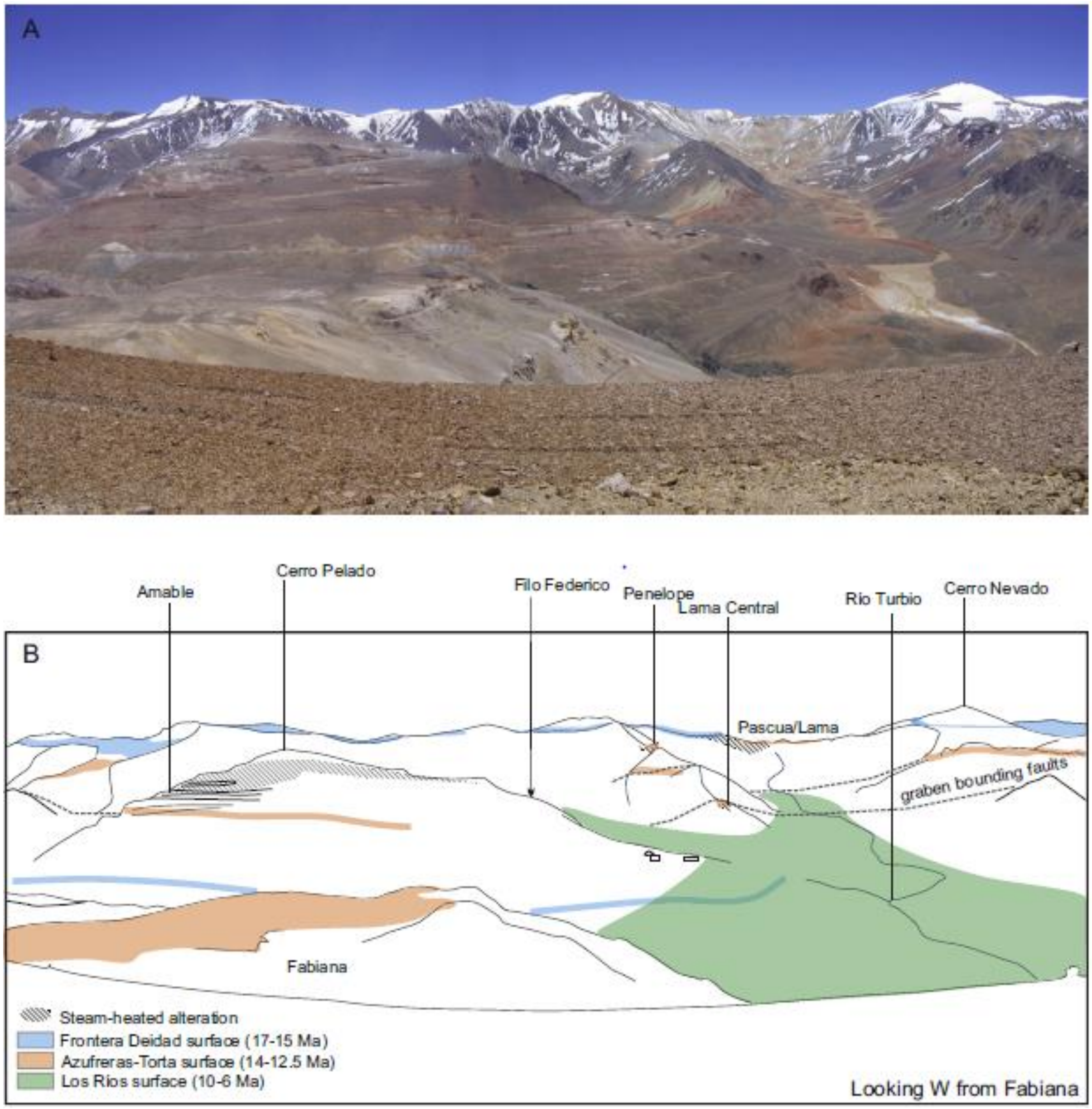

Figure 5: The landscape around the Veladero Mine and the Pascua Lama Project. (A) A panoramic view taken from the Fabiana viewpoint facing to the west. (B) Stylistic view on the major landscape elements and the alteration zones (Bissig et al., 2015: 340).

2.2.2 History of the mine and mining activity

The exploration at the Veladero mine site started in the late 1980s when Argentine government geologists identified gold anomalies. During this time the administration of the mineral rights transferred from federal to provincial government. In 1994 the Canadian Company Argentina Gold Corporation (AGC) acquired the rights for the Veladero mine. The AGC entered into a joint venture agreement with Barrick Gold. The mine was owned 60% by AGC and 40% by Barrick Gold. In 1999 Homestake Mining acquired AGC. Barrick Gold and Homestake Mining merged in late 2001. As a result of this merger Barrick Gold gained 100 % control of the Veladero Mine (Evans, Ehasoo and Krutzelmann, 2018). In June 2017, Barrick Gold and Shandong Gold entered into a joint venture. Shandong Gold acquired 50% of Barrick Gold's interest in the Veladero mine (Barrick Gold, 2017). Table 1 shows the ounces of gold (Au) produced at the Veladero mine since 2005.

Table 1: The production of Gold (Au) in ounces (oz) at the Veladero mine during 2005-2019. The values of the ounces are form the annual reports of Barrick Gold.

Year	Oz of Au
2005	56,000
2006	511,000
2007	-
2008	> 500,000
2009	-
2010	> 1,100,000
2011	957,000
2012	766,000
2013	641,000
2014	722,000
2015	602,000
2016	544,000
2017	432,000
2018	278,000
2019	274,000

In May 1997 the deposit Filo Federico was discovered. The first resources were declared to be about 2.5 million ounces (Evans, Ehasoo and Krutzelmann, 2018). Between 2001 and 2003 the exploration at the Veladero mine continued. The mine has two deposit, Amable and Filo Federico. Therefore, the feasibility study includes two open pits, a two stage crushing circuit and a valley fill heap leach pad (Figure 6) (Barrick Gold, 2002). At the beginning of 2003 the company submitted its Environment Impact Statement (EIS) (Barrick Gold, 2002) which was approved in October by the government (Barrick Gold, 2003). The construction of the Veladero mine started in November of 2003 (Barrick Gold, 2003) and the access road and the camp was constructed in October 2004 (Barrick Gold, 2004). Furthermore, the pre-stripping of the mine started in 2004 (Barrick Gold, 2004). In the last quarter of 2005 the Veladero mine started to operate (Barrick Gold, 2005). In the first year of full operation (2006) the Veladero mine produced 511,000 ounces of gold (Barrick Gold, 2006). In 2008 Barrick Gold expanded the crusher at the site to increase the process capacity

(Barrick Gold, 2008). The area of the Veladero mine that includes all mining concession is approximately 14,447 ha (Evans, Ehasoo and Krutzelmann, 2018).

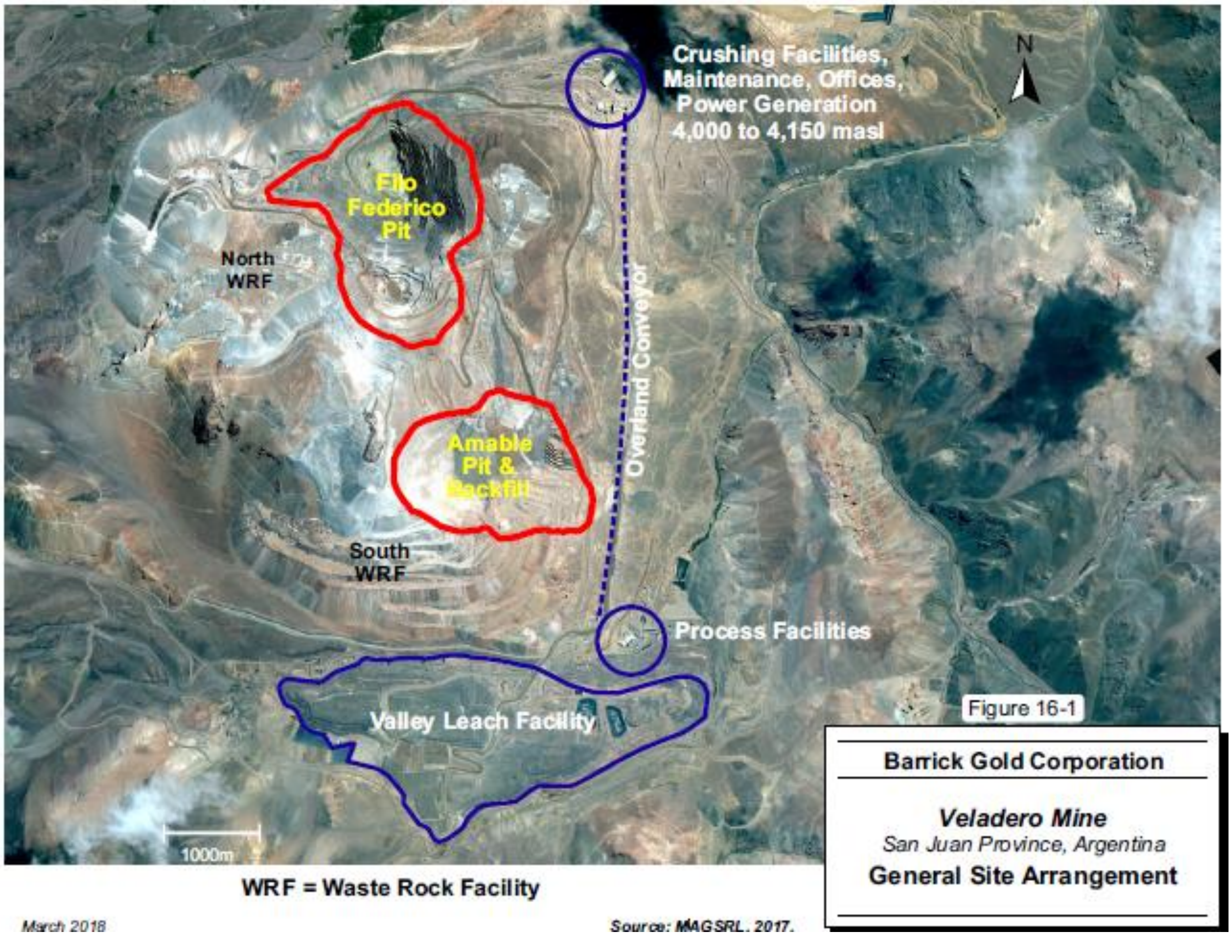

Figure 6: The image shows the Filo Federico and the Amable pit as well as the heap leach facility and the crushing facility (Evans, Ehasoo and Krutzelmann, 2018: 16-3).

The Glacier Protection Law required the province of San Juan to do an environmental audit at the Veladero mine and the Pasuca-Lama Project. In January 2013, the province announced that neither the Veladero mine nor the Pascua Lama project will have any impact on glaciers or the periglacial environment (Barrick Gold, 2012). In September 2015, a valve on a leach pad pipeline failed at the Veladero mine which led to the release of cyanide-bearing solution into the nearby watershed. The solution reached the watershed because a diversion of a channel gate was open during the time of the incident. The temporary restriction to add new cyanide to the processing circuit was lifted at the End of September and the operation returned to the normal process (Barrick Gold, 2015). A second incident happened at the Veladero mine in September 2016. An avalanche at the leach pad slope damaged a pipe that carried process solution. The material was returned to the leach pad (Barrick Gold, 2016). According to Barrick Gold (2016) the incident did not impact the environment and the watershed. Another rupture of a pipe that carried gold-bearing process solution on the leach pad happened at the Veladoro mine in March 2017. The solution did not reach the watercourses. However, that was the third incident in relation with cyanide-related solution that happened at the Veladero site in three years. In order to reduce the risk of further cyanide-related incidences, modifications on the leach pad were made by the company (Barrick Gold, 2017). But these accidents were the trigger for the local activist group "Jáchal No Se Toca" to file criminal charges against Barrick Gold for environmental damage and against the state for inaction (Healey and Martin, 2017).

3. Background

In order to gain a better understanding of the law case against Ricardo Villalba in connection with the Veladero mine, interdisciplinary background knowledge is needed. On the one hand, it is necessary to understand how a glacier is characterized and how its boundaries or size are determined from a physical point of view. It is also important to understand how the term "glacier" differs from the terms debris-covered glacier, rock glacier and perennial snow patches. Furthermore, since the Veladero Mine is located in a arid area, it is important to understand where the glaciers and rock glaciers are located in the Andes and Argentina respectively. For this purpose, the existing glacier inventories in Argentina are taken into consideration.

On the other hand, it is necessary to review the different concepts of mining. It is important to understand how a mine works, what value it adds to a region or country, and what impact the mine has on the environment. Due to the cyanide accidents at the Veladero mine, the water resources are an important element. Also, not only the definition of a deposit has to be taken into account, but also the laws that regulate the mining of minerals. Only by taking everything into account, a better understanding of the Argentine glacier law and therefore the law case of Ricardo Villalba can achieved.

3.1 Glaciers

3.1.1 Definition of a glacier

In general, glaciers develop on land and are masses of compressed perennial snow. On top of a glacier layers of snow and firn can be found (Haeberli, 2017). A transformation from snow to ice is necessary for a glacier formation. This metamorphosis continues over several years up to decades. After a snowfall, the snow crystals are compressed and pressed together by the superimposed weight of new snow. Over time, the snow crystals become rounder and harder and therefore denser (Hambrey and Alean, 2004). If the snow remains for more than one year, it is called firn. The firn is further compressed by the deposition of new snow on top of it (Haeberli, 2017). In a next step the firn grains start to recrystallize and build ice crystals (Hambrey and Alean, 2004). During this densification from firn to ice the air is being trapped in bubbles so that it cannot be exhausted anymore. Usually, the firn layer of mountain glaciers is several tens of meter thick. The snow-firn-ice metamorphosis for a glacier takes several decades to be completed, and depends to some degree on the temperature regime (Haeberli, 2017). Therefore the snowfall in winter must be higher than the melting during the summer months (Hambrey and Alean, 2004).

A schematic illustration of glacier mass gain, loss and flow is shown in Figure 7. The accumulation zone of a glacier is normally at a higher and thus colder elevation than the ablation zone. In the accumulation zone the mass is added to the glacier through snowfall. In the ablation zone the mass is removed from the glacier through melting. The ablation zone is the zone that mostly produces the meltwater from the glacier. The zone of a glacier where accumulation and ablation balances each other are defined as the equilibrium line. A glacier reaches a stable extent when the accumulation of snow and the melting of ice and snow are similar over several years, i.e. its mass balance is close to zero. This stable state can be affected through changes in the climate either through increase in air temperature or a decrease in precipitation. If these environmental changes are high and persistent over several years the glacier either grows or shrinks until the extent is again in balance with the governing climatic conditions (Haeberli, 2017). For this reason glaciers are highly climate sensitive and can be considered as indicators of climate changes (Mark and Fernandez, 2017).

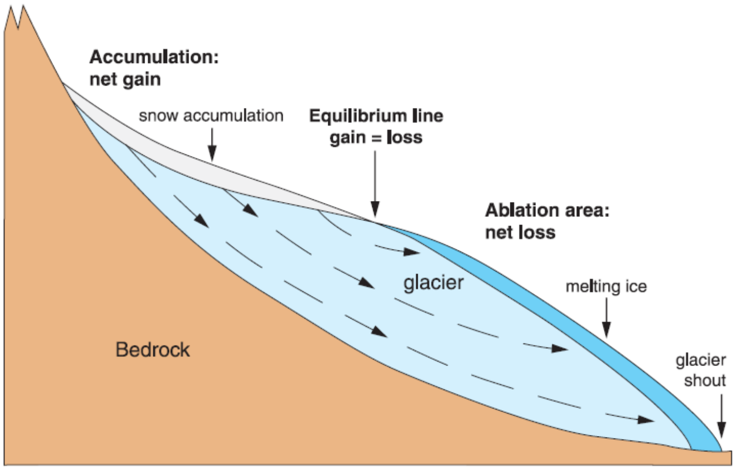

Figure 7: Schematic illustration of the accumulation and ablation zone of a glacier with the equilibrium line. Furthermore, the transport of mass from the accumulation to the ablation zone by flow is shown (Hambrey and Alean, 2004: 30).

The mass balance of glaciers in the subtropical Andes (Rabatel et al., 2011), where the Veladero mine is located, is not influenced by the short-wave solar radiation as is the case in other regions (Haeberli, 2017). Temperature changes in the area of the subtropical Andes have a secondary influence on the mass balance of the glaciers. In this region the mass balance of glaciers and glacierets is influenced by precipitation. A decrease in precipitation in this region results in a negative mass balance (Rabatel et al., 2011).

A typical feature of glaciers is that they flow downslope. This feature also helps to distinguish a glacier from other ice masses as well as perennial ice and snow. The flow of glaciers involves ice deformation and basal sliding, the sliding of the glacier over the hard bedrock (Haeberli, 2017). The flow velocity is greatest in the middle of a glacier and decreases with depth towards the bedrock (Figure 8). The glacier flow has an influence on the composition of the glacier ice. In the uppermost 30 meters, the ice is brittle due to tension. When the glacier moves downwards, the ice breaks up and crevasses are formed. Basal sliding is influenced by the meltwater between the glacier and the bedrock. The more meltwater between the glacier and the bedrock, the less friction is created. The lower the friction, the faster the glacier flows (Hambrey and Alean, 2004).

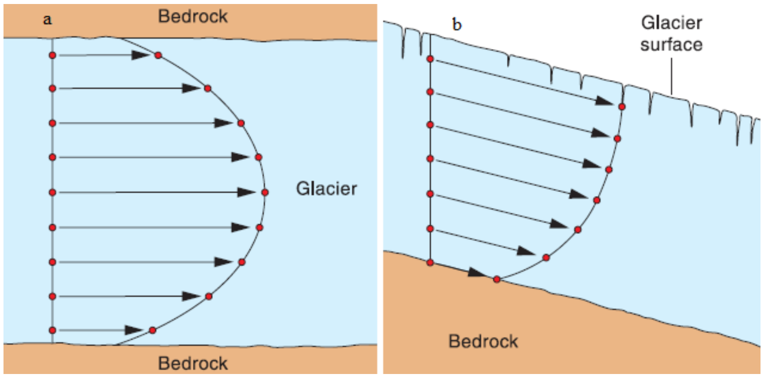

Figure 8: Flow direction and velocity of a glacier. (a) shows the plain view and (b) the longitudinal cross-section (Hambrey and Alean, 2004: 70).

3. Background

The sizes of glaciers can vary greatly depending on the location of the glacier. The largest ice caps have a size of several thousand km^2 (Nesje and Dahl, 2016). The smallest threshold used for mapping glacier is 0.01 km^2. Such small features occur in all mountains region of the world. In inventories features smaller than 0.01 km2 are often ignored or removed since there is a large uncertainty if these features are glaciers. The minimum size-threshold is used to define the smallest extents necessary for a feature to be considered a glacier and therefore defines a boundary for a glacier (Leigh et al., 2019). Table 2 was adopted from Leigh et al. (2019) and serves as an illustration of the threshold values used in glacier studies.

Table 2: Examples of different thresholds used for glacier mapping (adopted from Leigh et al., 2019).

Authors	Study area	Minimum glacier size km^2
Barcaza and others (2017)	Southern Andes	0.01
Ganyushkin and others (2017)	Altai Mountains	0.01
Earl and Gardner (2016)	North Asia	0.02
Lynch and others (2016)	Kamchatka Peninsula	0.02
Racoviteanu and others (2015)	Eastern Himalaya	0.02
Burns and Nolin (2014)	Cordillera Blanca	0.01
Paul and Mölg (2014)	Northern Andes	0.05
Pfeffer and others (2014)	Global	0.01
Xiang and others (2014)	Poiqu River basin	0.01
Bliss and others (2013)	Antarctic periphery	0.01
Jiskoot and others (2012)	East Greenland	2
Andreassen and others (2012)	Norway	0.0081
Frey and others (2012)	Western Himalaya	0.02
Rastner and others (2012)	Greenland	0.05
Bajracharya and others (2011)	Hindu Kush-Himalayan region	0.02
Bhambri and others (2011)	Garhwal Himalaya	0.25
Kamp and others (2011)	Himalaya Range of Zanskar	0.05
Paul and others (2011)	European Alps	0.01
Bolch and others (2010)	Canadian Cordillera	0.05
Narama and others (2010)	Tien Shan Mountains	0.01
DeBeer and Sharp (2009)	Monashee Mountains	0.01

3.1.2 Distinction between Glacier, debris covered glacier, rock glacier and snow patches

Glaciers are perennial masses of ice. However, they also have snow and firn on them (Cogley et al., 2011). Where their surface is smooth glaciers are of blue to white color. Through, solar radiation and weathering the surface of a glacier becomes furrowed. One of the most distinguishing feature of a glacier are its crevasses. Crevasses are classified into longitudinal, marginal, traverse and splaying (Hambrey and Alean, 2004). Another feature to differentiate glaciers from snow patches is deformed stratification that indicate the presence of foliation or deform the glacier banding. Furthermore, small glaciers can have multiple debris bands. These bands have parallel strips of darker and lighter ice resulting from stratification of supraglacial debris (Leigh et al. 2019). Besides this, the so called bergschrund can also be a feature found of a glacier. The bergschrund is a crevasse that occurs at the head of a glacier (Hambrey and Alean, 2004; Leigh et al., 2019). Moraines are also distinguishing characteristics of a glacier. They can be separated into middle and lateral moraines (Hambrey and Alean, 2004). The differences between a glacier and a snow patch are also displayed in Table 3.

Table 3: The different features between glaciers and snow patches (created using the sources Hambrey and Alean, 2004; Cogley et al., 2011; Leigh et al., 2019).

Glacier	Snow patch
Perennial masses of ice	Masses of snow and firn
Minimum size 0.01 km^2	Restricted extent
Flow features	No flow pattern
Crevasses	Persistent through ablation season
Deformed stratification	
Debris	
Bergschrund	
Moraine	

As soon as there is an accumulation of debris in the ablation zone with a layer thickness of less than 50 cm, a glacier is classified as a **semicovered glacier**. At the accumulation zone of the partially debris-covered glacier there is still enough snow that ice continues to form. In a **debris-covered glacier** the debris coverage is between 95% and 100% and the ice content between 45% and 85%. Depending on the thickness of the debris cover, a debris-covered glacier takes on different forms. With a debris thickness of less than three meters, the ice under the debris cover is not insulated and thus melts. This results in a sorting of the sediment. The fine sediment is transported away with the meltwater. These debris-covered glaciers have a chaotic morphology. They show no signs of flowing or arched ridges. It is not possible to distinguish clearly between the accumulation and ablation zone. When the debris is more than three meters thick, the ice is isolated by the debris and the ice of the debris-covered glacier is partially visible in crevasses. This debris-covered glacier shows weak arched rolls, which indicate that the glacier is flowing. In addition, thermocast depressions are able to develop on this type of glacier. These depressions appear through the collapse of thermokast features (Janke, Bellisario and Ferrando, 2015) (Table 4).

Rock glaciers are typical for the periglacial zones. They develop from ice and angular clasts and there is no ice visible on the surface. (Perucca and Angillieri, 2011). Depending on the rock glacier, the ice content is between 25% to 45% (Janke, Bellisario and Ferrando, 2015). However, the proportion of ice is often defined differently between authors and studies and can be between 40% and 60% (Perucca and Angillieri, 2011; Rangecroft, Harrison and Anderson, 2015). When the ice content in a rock glacier is high, the flow creates transverse ridges and furrows. These are very pronounced at this stage of rock glaciers and are formed perpendicular to the direction of flow. Longitudinal ridges, which are aligned parallel to the direction of flow of a rock glacier, can also be formed. The front slope is rather steep when there is a high proportion of ice (Janke, Bellisario and Ferrando, 2015). The form of a rock glacier is either lobate or spatulate and they move slowly down the slope (Perucca and Angillieri, 2011) (Table 4). As the ice content decreases, the front slope becomes flatter until the transition between surface and front slope is no longer clearly visible. With decreasing ice content in a rock glacier, the surface appears more rounded than with a high ice content. If the proportion of ice is less than 10%, the surface of a rock glacier appears more erratic and chaotic with small hills and blocks that stand out. In these rock glaciers no flow is visible (Janke, Bellisario and Ferrando, 2015). Rock glaciers can be classified into the following subdivisions: active, inactive and fossil (Perucca and Angillieri, 2011).

Table 4: The difference between debris-covered glaciers and rock glaciers (created using the sources Perucca and Angillieri, 2011; Janke, Bellisario and Ferrando, 2015).

Debris-covered glacier	Rock glacier
Ice content of 45-85%	Ice content of 25-60%
Ice visible in crevasses	No ice visible on surface
Debris coverage between 95-100%	traverse ridges and furrows
sorting of sediment and chaotic morphology	longitudinal ridges
thermokarst depression	steep front with high ice content
flow down slope	flow down slope
	lobate or spatulate form

Snow patches have a restricted extent. Furthermore, snow patches can be perennial. If they remain throughout the ablation season, snow patches are difficult to be distinguished from glacierets since both of them have no flow pattern. Snow patches are difficult to be distinguished from glacierets since they do not exceed a size more than 0.25 km^2 (Cogley et al., 2011).

3.1.3 The distribution of glaciers in the Andes

The Andes range from the tropical to the cold and temperate zone. The distribution of the glaciers is influenced by the elevation, the topographic barrier of the Andes and the general climatic system in the region. The climate in Andes is influenced by the seasonal interactions between the monsoon-like air masses in the north, the Atlantic trade winds, the Pacific anticyclonic circulation in the central part of the Andes and the Pacific westerly winds in the south. Thus, permanent snow and glaciers can be found in a wide range of elevation (Clapperton, 1983). Figure 9 shows that glaciers occur from 10°N latitude to 55°S latitude. In the Tropics the area of permanent snow and glacier ice are located in the high elevation region, commonly at 5,000-6,000 m above sea level (Clapperton, 1983). Furthermore, the size and extent of the glacier system depends on the regional and local equilibrium line altitude (ELA). The ELA in turn depends on the climate and topography of the region. In southern Patagonia, the ELA is below 1,500 m. The ELA keeps rising towards the north until it reaches a height of about 6,000 m above sea level near the 20°S latitude. After the 20°S latitude, the ELA descends to about 4,600 m above sea level (Clapperton, 1983). The Veladero mine is located in the Desert Andes, which extend between 21° and 31° S. In this region, ice and snow can only form on the highest peaks, since the Desert Andes are characterized by their very arid climate (Zalazar et al., 2017). Due to this climate the glaciers are sparsely distributed and the low precipitation is often not sufficient to feed glaciers, even at an altitude of over 6,000 meters above sea level (Masiokas et al., 2009). Therefore, only small isolated glaciers and snow patches occur in this region. In the area of San Juan and Mendoza the first valley and kar glaciers are beginning to form. The glaciers in this area are often covered by debris. The snowline is between 4,600 and 4,700 meters above sea level. In addition, the general height of the Andes is decreasing, so that the mountain glaciers are disappearing and being replaced by small isolated ice masses (Rabassa and Clapperton, 1990). The ELA north of 30° S is slightly above 5,000 meters above sea level and drops to 4,300 to 4,400 meters above sea level between 32.5° and 33° S (Brenning, 2005). In the Huasco Valley (28° - 29° S), most of the ice areas are located at an altitude between 5,000 and 5,200 meters above sea level (Nicholson et al., 2009). All ice areas in this region are located on the southern slopes of the highest peaks and extend over a range of 4,780 to 5,485 meres above sea level (Rabatel et al., 2011).

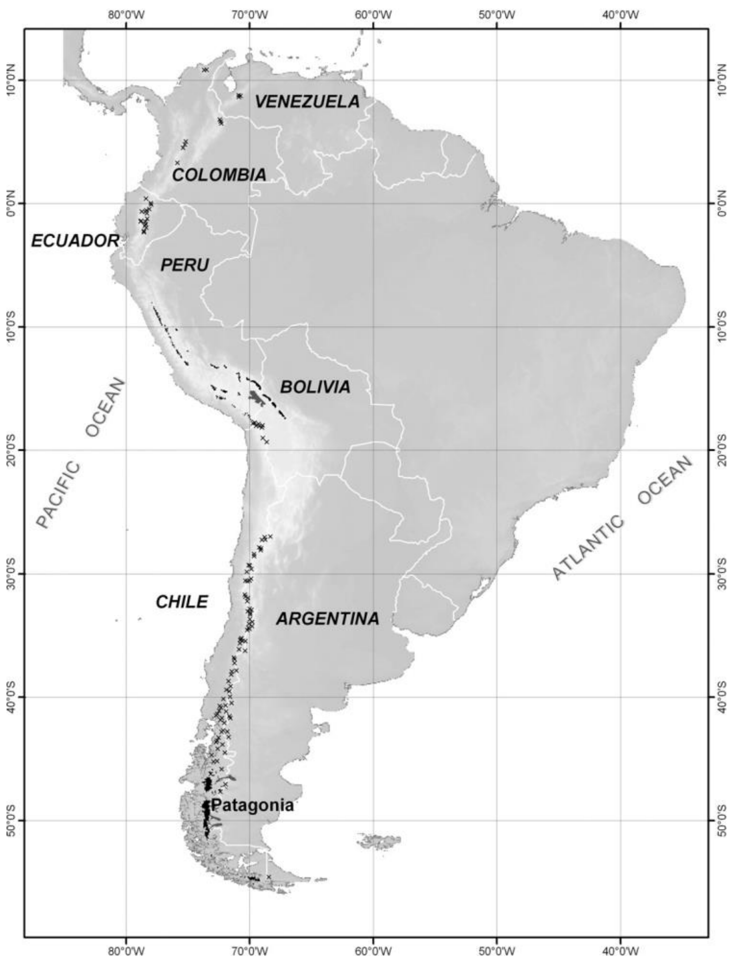

Figure 9: The distribution of glaciers in South America. Glaciers are displayed in dark gray(Casassa et al., 2007: 4).

As in the rest of the world, the glaciers in the Andes are shrinking. In the tropical Andes, glaciers have been declining rapidly since the 1970s and their loss is directly related to the size and elevation of the glacier. The decline in the glaciers of the tropical Andes is due to atmospheric warming, as precipitation has not changed significantly since the mid-20th century (Rabatel et al., 2013).This shrinking of the glaciers is much more pronounced on small glaciers than on bigger ones. The possible reason is that the small glaciers might not have a permanent accumulation zone. The dry and central Andes belong to the extratropical Andes, where glacial mass losses have also been recorded since the mid 20th century although there is not a lot of data on this area (Masiokas et al., 2009).

In general, the decrease of glaciers in the Andes is not only due to global warming but also to the El Niño-Southern Oscillation (ENSO) effect (Rabatel et al., 2013). The ENSO usually brings a lot of snow to this region. However, this also applies to the subtropical Andes. In the subtropical Andes the reduction of precipitation is more important for the skrinking of glaciers than air temperature. The shrinkage of the glaciers in the subtropical Andes varies with the years, depending on how the precipitation is. If the precipitation is higher than usual due to El Niño conditions, the shrinking of the glaciers is reduced (Rabatel et al., 2011).

Glaciers are the largest reservoir of fresh water on Earth (WGMS, 1998) and contributing large amounts of melt water to local and regional run-off even in catchments that have less than 1% glacierization (Huss and Hock, 2018). This is a very critical issue in the tropical Andes especially in the dry season when glaciers provide an important reservoir for the precipitation deficit (Drenkhan et al., 2015; Mark and Fernández, 2017).

Apart from glaciers, the surrounding periglacial environment is also able to store water. Rock glaciers as well as heavily debris-covered glaciers are important for water storage in semiarid regions (Janke, Bellisario and Ferrando, 2015). Schrott (1996) investigated the influence of the periglacial environment on river discharge in the Andes and showed that frozen ground and rock glaciers have an important share from January to March (summer months). They can contribute approximately 30% to the summer discharge of rivers (Schrott, 1996). Rock glaciers, like glaciers, can store frozen water long-term and can release it gradually (Azócar and Brenning 2010). According to Azócar and Brenning (2010) rock glacier store a significant amount of water between 29° S and 32° S. The water equivalents for the longitudinal classes of 29°-30° S, 30°-31° S and 31°-32° S are 0.85 km^3, 0.32 km^3 and 0.06 km^3 respectively (Azócar and Brenning 2010). Rock glaciers are already important water reservoirs in this region of the Andes and could gain even more influence and significance on the hydrological cycle due to the warming climate (Nicholson et al., 2009). They already influence the water supply of the cities of Santiago (Chile) and Mendoza (Argentina) and irrigate the surrounding land (Brenning, 2008).

3.1.4 History of Glacier inventories for Argentina

The first glacier inventory in Argentina was made between 1907 and 1912 and covered the area between Mount Aconcagua and Mount Tupungato. The Instituto Argentino de Nivologia y Glaciologia compiled glacier inventories for various catchments in the provinces of Mendoza and San Juan between 1978 and 1987. The glacier inventories covered the following catchment areas: Rio Mendoza, Rio Tunuyán, Rio Atuel, Rio Malargüe and Rio San Juan. Together these catchments have a glacierized area of 1,402 km^2. This inventory includes both clean and debris-covered ice. At the same time, Rabassa et al. compiled the glacier inventory for Argentine Patagonia (Casassa et al., 1998). In 2002 Bottero published a glacier inventory for the provinces of Mendoza and San Juan. The glacierized area here is 1,564.10 km^2 and contains 48% of clean ice and 52% of debris-covered ice (Bottero, 2002). Villarroel (2013) calculated a glacierized area of 21.57 km^2 for the catchment of the Río Mercedario in the province of San Juan. Falaschi et al. (2013) established an inventory for Monte San Lorenzo region in Southern Patagonia. The inventory includes 213 glaciers which cover a total area of about 207 km^2. ASTER and Landsat ETM scenes from 2005 to 2008 were used for the evaluation (Falaschi et al. 2013). Masiokas et al. (2015) used ASTER scene from February 2005 to detect 187.2 ± 7.4 km^2 of glacier area on the northeast margin of the Southern Patagonia Icefield in Argentina. Falaschi et al (2016) calculated the glaciated areas for the region Volcán Domuyo southernmost, Central Andes using ALOS AVNIR-2 and PRISM satellite images. Falaschi et al. (2016) detected 106 glaciers in the Volcán Domuyo region, covering an area of about 25.4 km^2. Zalazar et al. (2017) published a preliminary glacier inventory, which is based on the Glacier Protection Law (GPL). This inventory contains 15,482 geoforms with a total area of 5,743 km^2. The geoforms include glaciers, debris-covered glaciers, snowfields and rock glaciers (Zalazar et al., 2017).

However, there are not only inventories of glaciers but also of rock glaciers. These inventories are of special importance since rock glacier contribute a significant amount of water to river discharges. An interesting study was done by Nicholson et al. (2009) in the Upper Huasco Vally in Chile where they generated an inventory for glaciers and rock glaciers. The study area is located in the semi-arid Norte Chico region (27-33°S). For the glaciers, they calculated an area of 16.86 km^2 and for the Rock glaciers an area of 6.30 km^2 (Nicholson et al., 2009). Perucca and Angillieri (2011) made an inventory of rock glaciers and glaciers in the Cerro El Potro region. They put the number of glaciers at 6 and rock glaciers at 38, with an area of 15.98 km^2 and 5.86 km^2 respectively (Perucca and Angillieri, 2011). Ahumada, Páez and Palacios (2013) prepared an inventory for the Aconquija range region in Argentina. They counted 246 rock glaciers and 16 debris-covered glaciers with an area of 16.46 km^2 and 1.17 km^2 respectively (Ahumada, Páez and Palacios, 2013). In the sub-basin of Pachon River 136 active and inactive block glaciers were counted, with an area of about 15.51 km^2. Around 63 active and inactive block glaciers have been counted in the catchment area of the Mercedario River. This corresponds to an area of 7.63 km^2 (Villarroel, 2013). Falaschi et al (2014) compiled an inventory of rock glaciers for the Valles Calchaquíes region in the province of Salta. They counted 488 rock glaciers, where 66 are fossil rock glaciers. The total area of all rock glaciers is 58.5 km^2, of which 19.9 km^2 are fossil rock glaciers. (Falaschi et al., 2014).

3.2 Mining in the Andes

3.2.1 Definition of ore deposit

Deposits are natural concentrations of useful metals, minerals or rocks. These concentrations can be economically exploited (Pohl, 2011). Therefore, the definition of an ore deposit is often based more on an economics note rather than on a geological one (Ridley, 2013). The deposit has a certain shape and size, which is determined on the basis of economic criteria. The criteria are the quantity (tonnes) and the average quality (% grade) of the deposit (Haldar, 2018). Normally, ore deposits can contain one or more ore bodies within a host rock (Ridley, 2013). The principal ore mineral that is recovered from the mine is referred to as prime commodity. Associated minerals are defined as associated commodities and are mined as by-products together with the main minerals (Haldar, 2018). The extracted ore has some economic value. However, not all ore in the ore bodies is going to be extracted (Ridley, 2013). Occurrences or mineralizations are concentrations that are too small or too low-graded for mining and therefore have no economic values.
Mineral deposits can be seen basically as valuable rocks. These deposits are geochemical enrichments of elements or compounds in the curst of the Earth. From this information the “concentration factor” can be determined. The “concentration factor” is the ratio between the content of a valued element in a deposit and its crustal average. The gold ore that has 10 grams (g)/ton (t) Au compared to the crustal average of 0.002 g/t Au has an enrichment of 5000-fold of concentration (Pohl, 2011). From this information the cut-off grade can be calculated by assessing the feasibility of extraction and profit gain. The cut-off grade helps to decide if gold can still be

mined profitably-and whether the material is ore or waste within the mineral deposit. The material in the deposit is classified as ore, when the material grade is equal or more than the cut-off grade. Furthermore, the cut-off grade tells the mining operation about the quantity of ore and waste that an operation has to handle in a certain time period (Biswas, 2020).

3.2.2 Location and types of mines

The highest mines in the Andes are located at an altitude of 4,800 to 5,000 meters above sea level (Figure 10). Among the highest mines is the Pascua-Lama Project in Chile and Argentina. The high altitude mines are located in Peru, Bolivia and Chile and include both open pit and underground mining. Copper, lead, zinc, silver, gold and molybdenum are mined there (Ashkar, 2016).

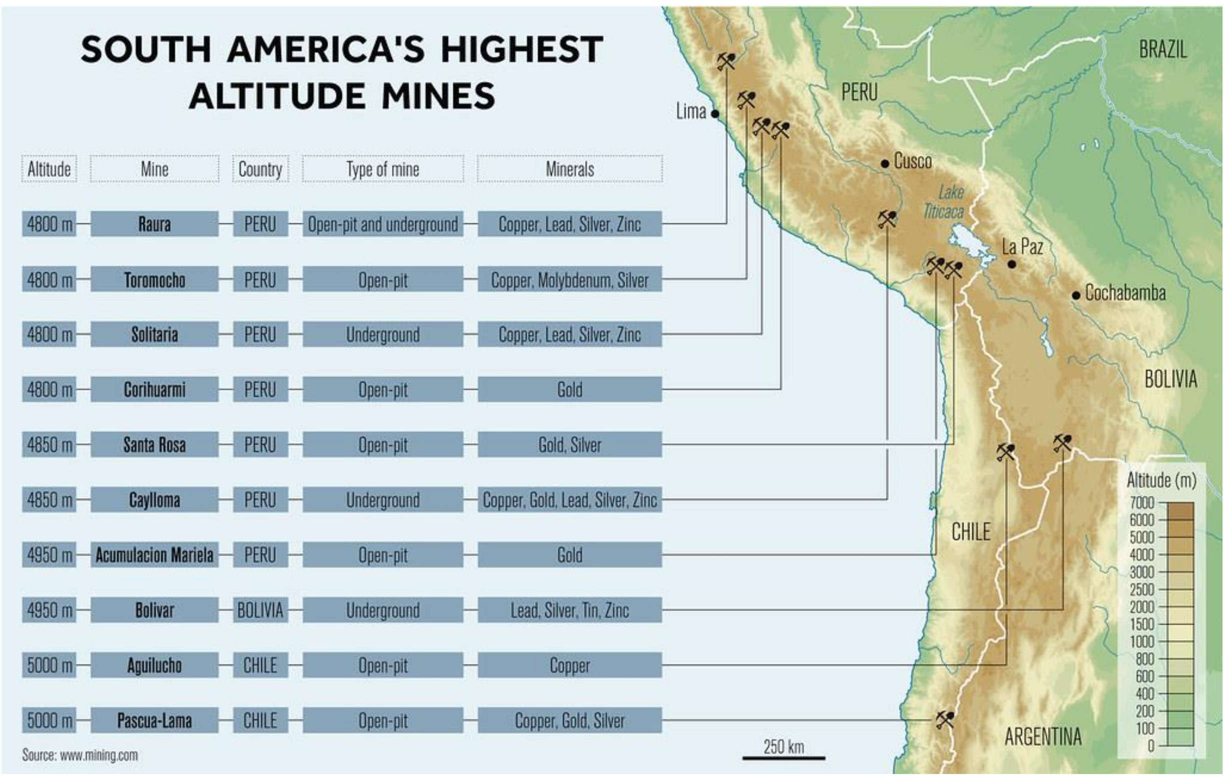

Figure 10: Location of the highest mines in South America (Ashkar, 2016).

The location of gold and other major metals found in Latin America is shown in Figure 11. Most of the sites are located in the western part of South America near or in the Andes. There are also gold occurrences in the continent itself and not just on the edge of the plate. The gold deposits are mainly in Brazil. The most important metals are copper, gold, lead and zinc, nickel and silver. The deposits follow the path of the Andes (Walter, 2016).

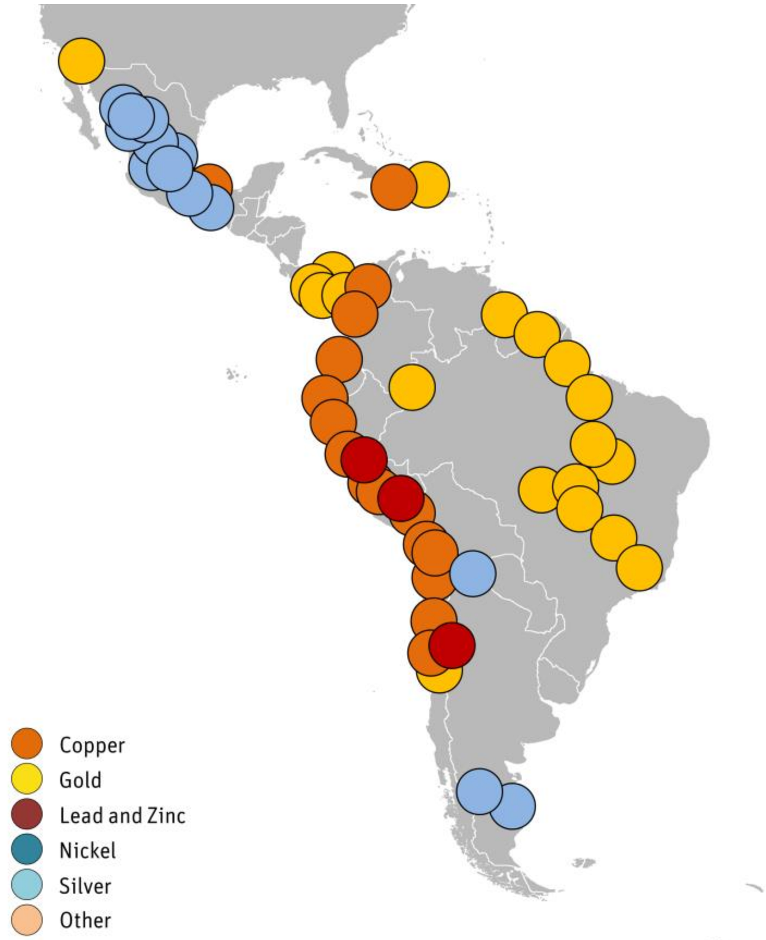

Figure 11: Location of significant gold, base metals or other drill results (Walter, 2016: 7).

Before ore mineral deposits are mined, it has to be decided whether the ore is mined by open pit or underground mining. Open pit mining is mainly used when the ore body is close to the surface level. The underground mining technique is mainly used when open-cast mining is uneconomical and not profitable due to the high ore-to-overburden ratio. Deep-lying ore deposits are mainly mined using underground mining methods. It is also possible that, over time, an open pit mining operation is converted to an underground operation because the ore body is too deep in the earth's crust and open pit mining is no longer economically profitable. Open pit mines are in general much cheaper than underground mining and comprise about 70% of the global mineral production. In open pit mining the ore body is mined from the surface. The ore and the associated waste rock are mined separately as far as possible. As mentioned above, open pit mining is the most economical option for mining ore until the ratio of ore to waste can no longer be maintained. Once this point is reached, a decision must be made whether to continue mining with underground mining or to close the mine. There are some advantages to open pit mining like full visualization of the orebody, better grade control, easy draining of surface water and lower capital and operating cost. However, there are also some disadvantages like needing a large surface area, generates large amount of waste rocks that needs to be stacked (Haldar, 2018). Once the ore has been mined, it is transported to a downstream processing site. The waste produced during mining is transported to a disposal site and stored there (National Research Council, 2002). In a first step, the topsoil, subsoil and the overlying rock are removed in open pit mining. In a next step, the mineralized ground is opened up (Haldar, 2018). The open pit mine comprises a sequence of benches. These benches go from the surface to the deposit, as shown in Figure 12. The mine is mined from the top, so the open pit is penetrating deeper and deeper into the ground. The already existing benches must therefore be extended outwards each time the mine is lowered. From above the open pit also resembles an inverted pyramid. In open pit mining, very large equipment such as trucks, bulldozers, front loaders, cranes or bucket excavators are used as well as other modern technologies (National Research Council, 2002).

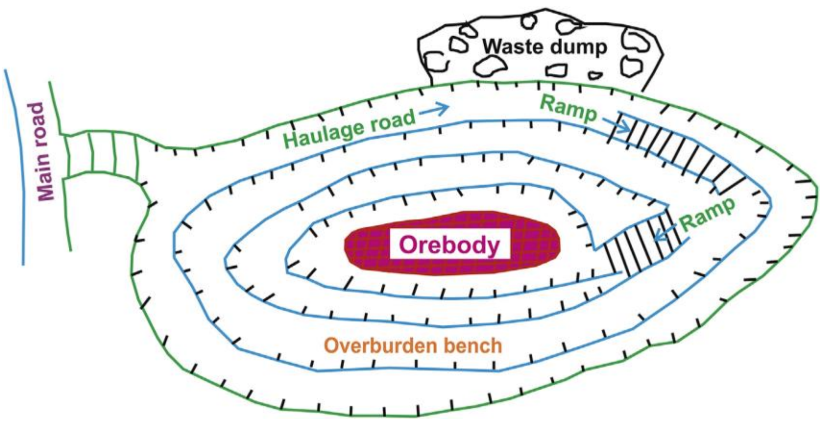

Figure 12: Schematic sketch of an open pit mine (Haldar, 2018: 234).

As already mentioned, underground mining is mainly used if the deposit is too deep for open pit mining or if there are restrictions on the use of the surface land. The mine is developed from the surface and the deposit accessed by vertical shafts, horizontal galleries or inclines. The deposit is developed in the ore body by crisscrossing openings. These openings are used not only to create ore blocks that are mined according to a certain sequence, but also to provide access for people and to transport the ore and waste away. In addition, these openings serve to provide adequate ventilation underground (National Research Council, 2002).

After the minerals have been extracted, mineral processing takes place. In mineral processing, the ore minerals are separated from the unusable waste (tailings). The procedures applied should not change the physical and chemical identity of the original mineral. The metal-containing concentrate is treated by extraction metallurgy and electrometallurgy to recover the metals in their purest form. Mineral processing can be divided into four main activities: comminution, sizing, concentration and dewatering. Most minerals do not occur individually but in a mixture of ores and gangue minerals. In most cases, the minerals are composed in different proportions with different shapes and range from very fine to extremely coarse grain size. The size of an ore is continuously crushed until it has the optimal fraction size for the separation of ore minerals and waste. The physical-chemical properties of a mineral play an important role in determining the optimum fraction size. The physical-chemical property of a mineral in turn influences the method used for the separation of ore minerals and unusable waste. During crushing, the ore follows the following sequence. First the ore is crushed, then ground and finally pulverized. As soon as the mineral grains are small enough to be further processed, they are processed with the appropriate processing technology. The second important main activity is sizing. In mineral processing, particle size plays an important role. Screening and classification are techniques for particle separation based on size. The coarse-grained particles are separated by screening. Screens are installed at all crushing plants and sort the material. The particles that are too small for screening are separated by classifier, whichare installed at the grinding units for processing over- and undersized particles. The next step in the processing of ores and minerals is the process upgradation. The upgradation process is also called concentration. There are various methods available for concentrating the ores and minerals. Depending on the physical and chemical behavior of the starting material, a different method is used. Among the used methods are: leaching, sorting, gravity, magnetic, electrical and flotation. Leaching is the process of extracting metals directly from the low-grade ore using leaching reagents such as diluted hydrochloric, sulphuric and nitric acid. Leaching is a slow process and may take several months to complete the metal recovery process. During leaching, the ore is spread onto leaching pads and the diluted acid solution is applied to the ore through pipes and hoses distributed over the leaching pad. The solution containing the dissolved metal is brought into the solvent extraction circuit for further processing. Here, the metal is bound by the addition of chemical reagents and can be easily separated from the reagent. The next step in the process of gaining ore is the dewatering. The dewatering is the fourth main activity. For the production of ore a large amount of water is needed for the separation of ore and gangue minerals. As a result there is a high moisture content in the final concentrates. To reduce the transport costs the concentrate is dewatered to obtain a dry concentrate. The dewatering of the concentrate is done in the following order: sedimentation or thickening, filtration and thermal drying. However, the mines have to deal not only with the valuable ore but also with the waste they produce. During the production of ores, fine residues or tailings occur. The production of one ton of concentrate produces between 5 and 15 tons of fine residues which then have to be disposed. For the disposal of the tailings, the tailings have to be thickened. Afterwards, the tailings is pumped into tailing pond where the tailings are deposited. The tailing pond is dammed by a tailing dam (Haldar, 2018).

3.2.3 What is extracted and its value

The Latin America and Caribbean region is one of the most important global player in the international minerals sector. The continent has many minerals that are important for global trade. The tectonic position of the continent is responsible for the wealth of mineral reserves (Walter, 2016). A steady increase in natural resource extraction has been ongoing since 1970s in Latin America. The increase in mineral ores is around 5.5% per year (Smart, 2020). The most important minerals that are mined in the region are: niobium, silver, copper, lithium, molybdenum, boron, tin, zinc, bauxites, gold and iron ore. The region produces approximately 45% of the world's silver demand and 15% of the world's gold demand. The region also accounts for about 40% of copper production. Chile is an important player in the world market for copper production. Furthermore, the Latin America and Caribbean region has large mineral reserves. Brazil has about 95% of the niobium reserves. Chile and Argentina own 65% of the world's lithium reserves. 49% of the world's silver reserves are located in Peru, Chile, Mexico and Bolivia. In addition, the countries Peru, Chile and Mexico own about 44% of all copper reserves (Walter, 2016). The added value of the mined minerals is very strongly linked to the world market and thus to the global demand for raw materials. The price of a mineral therefore always depends on the global market. This can be seen in the example of copper. In the last century the price of a ton of copper was around 7,000 US dollars. In 2002 the price of a ton of copper fell to 1,800 US dollars and in 2010 the price was 9,000 US dollars. Most minerals show a similar trend to copper. The volume and intensity of extraction and consummation of natural resources have increased over the last several decades all over the world (Arndt and Ganino, 2010). Most importing states have increased their demand for natural resources. To meet the demand on the market new technologies had to be introduced so that also lower-quality resources can be mined (Smart, 2020). As a result of the new technologies, exploration and expansion of mining is done in more remote places of the Earth (Kronenberg, 2013). This expansion of mining in such regions that are not accustomed to this kind of work leads to conflict at local level (Smart, 2020). In addition, the immense demand for metals has driven up the price of these metals (Arndt and Ganino, 2010).

3.2.4 Economic value

For the growth of the human society, minerals and metals are an important and central component. With population growth and rising living standards, the demand for minerals and metals is increasing. A social and economic growth would not be possible without metals and minerals (Haldar, 2018). The need for social and economic growth also leads to an increased investment in Latin America. Therefore, in the early 1990s Latin America promotes the idea of foreign direct investments (FDI) so that their natural resources can be exploited. Especially, during 1980s and 1990s the FDI has increased drastically in Latin America. Therefore, Latin America is after the Asia Pacific region the most open region for FDIs in the world. The extractivism in Latin America depends highly on the international market and the globalization of the world. The demand on the extracted material is global demand and not a local demand. Therefore, the role of Asian players is increasing in international trade and thus also in investment in mineral extraction. Between 2005 and 2014 China increased its FDI in Latin America and the Caribbean from 3.8 billion to 109.5 billion US dollars. India's FDI was growing to 16 billion US dollars by 2014. Global investment in the mining industry increased from 86 billion to 735 billion US dollars between 2000 and 2013. One of the main reasons for the high level of investment is the currently prevailing commodity prices. Mining investments are mainly related to the copper, iron ore and gold deposits in the region. The majority of the exploration investments are made in the following countries: Mexico, Peru, Chile, Brazil, Argentina and Colombia (Walter, 2016). The foreign investment provides the necessary capital to increase the local economy, create employment and reducing poverty. However, on the national scale to overcome the poverty of the state is difficult since very little of the revenue flows into the national budget. One reason for this is that a depoliticization of extractivism took place in the 1980s. This depoliticization ensures that natural resources continue to flow into the global market. With this decision, the international commodity market and its regulation was handed over to private actors. With this adjustment, foreign investors are attracted to extract raw materials. However, governments receive only a small part of the taxation, as tax laws are often adjusted to attract foreign investors (Smart, 2020).

In addition, since 2011, tax revenues and investment flows to the region have fallen as a result of the fall in commodity prices on the world market. The lower commodity prices have also reduced the contribution of mining to gross domestic product (GDP). In 2015 the GDP of the mining industry added about 10% to the total GDP of Chile. In the previous years, mining industry contributed between 15% and 18% to the total GDP of Chile (Walter, 2016). In the countries Peru, Brazil, Colombia and Bolivia, the GDP of the mining industry was 15.9%, 4.4%, 12.5% and 19.8% in 2011, respectively. Until 2019, the GDP of the mining industry in the above-mentioned countries decreased to 10.1%, 3.0%, 6.1% and 11% of the total GDP for each country respectively. In Argentina, the contribution of the mining industry to GDP increases continuously from 2000 to 2019. In 2000, mining contributed 2.7% to GDP and in 2019 4.7% (CEPALSTAT, 2020). The number of people employed in Argentina in mining production was 12,000 in 2000. By 2015, the number doubled to 26,000 (García et al., 2016).

3.2.5 Environmental impact of mining

Like other industrial operations, large mining companies also influence their environment (Pohl, 2011). Among the most important environmental issues affected by mines are air quality, water quality and quantity, acid mine drainage, impact of land and environmental impact (Jain, Cui and Domen, 2016).

Air emissions will not only affect the air in the surrounding areas around mining operations but also reduce regional and global air quality. In general, air quality is defined as the mass of air pollution in the environment in relation to the potential for environmental damage or impairment of human health. Unlike water, air cannot be recycled, making it much more vulnerable to contamination. Therefore, air pollution and fine dust emissions from a mining operation should be minimized in order to reduce the negative impact on the local and global environment. Air pollutants can be divided into gaseous and particulate. Sulphur oxides, nitrogen oxides, carbon oxides, photochemical oxidants, VOCs, hydrocarbons and methane are among the most worrying gaseous emissions in mining and mineral processing. These emissions usually come from mining equipment and processes, including diesel engines and blasting. However, air quality is most affected by particulate emissions. This particulate matter originates mainly from the clearing and removal of soil, excavation, ore crushing, loading and vehicle transport. A distinction is made between mobile, stationary and fugitive emission sources. In the case of the former two, emission reduction is often already integrated in the equipment. This is not the case for fugitive emissions. Fugitive emissions are generated during material handling and storage, fugitive dust and explosions. With these emission sources, the emission of particles cannot be reduced (Jain, Cui and Domen, 2016).

Water is essential for life and therefore it is important that water is available in good quality. Good water quality is necessary for agricultural, industrial, recreational and household use. Mining has negative effect on water quality and quantity. These negative impacts also have a major impact on the population living in the vicinity of a mine, as they can affect the water supply and contaminate water resources. The mining industry needs water at all production stages, from exploration to rehabilitation. In the mining industry, water is used for mineral processing, metal recovery, cleaning, pumping and transport, cooling, dust control and for the needs of workers. In addition, mining operations result in various types of mine water that is produced. In the United States, according to the U.S. Geological Survey, approximately 20.1 million m^3 of water per day is abstracted for mining operations, of which 5.3 million m^3 is from surface runoff and 14.8 million m^3 from groundwater. Between 2005 and 2010, total water withdrawal increased by 39%. The water consumption of the mining industry is about 2-4.5% of the average national water consumption, even in countries such as Chile and Australia with a great mining industry. Global annual water consumption in the mining industry is estimated at 7-9 billion m^3 of water. Water consumption can vary depending on the size of the mine, the raw materials mined, the mining method, the method of ore processing and water recycling practices (Jain, Cui and Domen, 2016). In general, leaching and dust suppression require the most water for a gold mine. In a typical operation with a leach pad surface area of 10,000 m^2 with constant leaching, a 60-day leaching cycle and uplifts of 10 meters per million tons, the leach application rate is between 8 and 12L/m^2/h. At this application rate, the average annual leachate requirement is estimated at 82,000 to 120,000 L/m^2/year. For evaporation an additional 5-10% of this amount must be added. For a mine treating 5 mega tons (Mt) of gold ore, this means a leachate requirement of 3.6 to 5.4 billion liters of water for one year of operation. Depending on the additional water, 0.18-0.54 billion liters of water are added to the leachate requirement (Bleiwas, 2012). However, the impact on water quantity does not always have to be negative, but there can also be positive effects if this results in a new water source for a community. The quality of ground and surface water can also be negatively affected by the mining industry. Depending on the monitoring program and the environmental commitment of the mine operator, the negative impacts vary. In addition, the effects still depend on the minerals mined, the mining technology and processes used, and the sensitivity of water habitats and water resources. The pollutants can be both organic and inorganic. Water pollution from a mine can have various consequences, such as fish mortality, pollution of drinking water and deterioration of habitats for wildlife. When surface water is discharged from the mine into a river, it must be carefully regulated, otherwise these discharges will have a direct impact on the pH-value, dissolved oxygen content and temperature of the river. Waters with a low pH-value contain most likely a higher concentrations of soluble heavy metals and other toxic components. The increase in temperature caused by mine effluents leads to a decrease in oxygen solubility, thus reducing dissolved oxygen. The amount of groundwater may be affected as well by the drainage from the mines under certain circumstances. In addition, mine drainage can have a negative impact on the salinity of water bodies (Jain, Cui and Domen, 2016).

Acid mine drainage (AMD) is the term used to describe the discharge of acidic water from mining operations. The oxidation of sulfide-rich minerals with water and oxygen leads to these acid mine drains. This runoff can contaminate surface and ground water. Furthermore, there is the possibility that metals from the sulfide-rich rock may dissolve with the help of these acid mine drains, and increase the concentration of toxic metals in the water. Acid mine drainage occurs throughout the lifetime of a mine and keeps affecting the environment long after it has been closed down (Jain, Cui and Domen, 2016).

Not only mining has an influence and impact on the water and air but also on the physical characteristics of a its catchment. Those combined environmental impacts of mining affect as well the local land use patterns, and thjs in turn have again influence on land management properties such as soil contamination, topsoil disturbance, erosion, subsidence and land use patterns (Jain, Cui and Domen, 2016).

Mining operations also have a general impact on the natural ecosystem including deforestation, destruction of vegetation and habitats and their fragmentation and deterioration of air, water and soil quality. This deterioration of the local and regional ecological systems causes losses in biodiversity of flora and fauna(Jain, Cui and Domen, 2016).

3.3 Mining and glacier protection laws in Argentina

3.3.1 Mining Laws

In Argentina, laws are civil in nature. The law is approved by the legislature at national, provincial and local level. In addition, the law also results from international treaties. The regulations affecting the mining industry cover areas such as taxation, labour, safety, environment, and others. However, for mining only two main regulations exist that control the mining activities in Argentina. The first one is the National Code of Mining (NCOM) , which is approved by the National Congress of Argentina. The second regulation is the Provincial Code of Procedures (PCPs), which is under responsibility of the Provinces. The NOCM regulates how minerals exploration and mining rights are acquired. Thus, the NOCM includes - exploration rights (“exploration permit”) and mining rights (“mining concession”). Furthermore, environmental obligations and procedures are regulated in the NOCM. These obligations and procedures apply for all the stages of minerals exploration and mining. If the environmental obligations are violated, sanctions will be imposed. The PCPs are responsible to regulate the procedures that have to be followed by the companies before the provincial mining authorities (Lucero, 2019).

In general, the mineral resources belong to the provincial states and they manage them in accordance with the NOCM. Therefore, the provinces have the right to administer the mining industry in their territory, to grant rights and to regulate it. The mining industry is obliged to follow and comply with the regulations of the national and provincial governments. The rights are given by the provinces according to NCOM regulations and provincial procedural rules. Permission to built and operate a mine is granted by both national and provincial authorities (Lucero, 2019).

The exploration permits (EPs) are issued by the provincial mining authority. The applicant is granted to carry out exploration in a specific, previously defined area. EPs are only given for a certain period of time, which is determined by NCOM and depends on the number of units. A unit is made up of 500 hectare and the maximal units per EP are 20 (=10,000 hectare). In one Province a person or company can hold maximum 20 EPs. The first unit is valid for 150 days and each additional unit adds 50 days to the first one. Therefore, 20 units have a grant approval of 1,100 days. But in order for a company to obtain a mining concession (MC), it is not absolutely necessary to have an EP first. According to the NCOM, a MC can also be granted, although it is not clear whether a feasible mining deposit exists. Therefore, the mining rights are attributed to one person or company only. They are granted on a "first come, first served" basis (Lucero, 2019).

The NCOM defines minerals into three categories. The first category of minerals can only be extracted with a mining concessions. These minerals are owned by the government on which territory they are located. The second category of minerals are owned by the landowner because these minerals are less important than the first category of minerals. The last respectively the third category of minerals solely belongs to the landowner. Therefore, these minerals can only be mined with the permission of the landowner or they are of public use. The holder is entitled by exploration permits and mining concessions to explore and mine the minerals for a certain category. However, the holder of an EP or MC does not have to be the owner of the land. The EP authorizes the person or company to carry out appropriate exploration work. Additionally, the MC provides for granting easements and rights of way that are necessary for the construction of the operational infrastructure. The easements of a MC are also used to ensure the access to water for the operation of the mine. However, the holder of EP and MC has to compensate the land owner. This decision is not subject to any further conditions except that the mine owner decides to continue with the purchase of the land. An extension of the area can be made legal at the mining authority. However, this requires sufficient proof that this is necessary. The mining authority decides, then in each case individually (Lucero, 2019).

3. Background

The environmental aspect of a reconnaissance, exploration and mining operation is regulated in the Argentinean constitution. The most important aspects are the following: Environmental Impact Declaration, Environmental insurance, public hearing , different environmental regulations and the Glacier Protection Act. Furthermore, the environmental aspects also include the closure of a mine. The main objective for the closure of the mine is to ensure the safety of the population and to minimize potential environmental damage. Anyway, these environmental aspects of mine closure are not regulated by NOCM or provincial laws. The closure of the mine is subject to the rules for environmental projects and is therefore part of environmental permitting and assessment procedures. To summarize the discussed legal conditions, all land in Argentina is in principle available for exploration and exploitation. and only some exceptions exists where mining is forbidden, for instance the Law No 26639 on Minimum Standards for Protection of Glaciers (Lucero, 2019).

3.3.2 Evolution of the Glacier Protection Law in Argentina

In the year 2008, the first bill of the Glacier Protection Law (GPL) passed the Congress in Argentina. However, Cristina Fernández de Kirchner, at that time President of Argentina, voted against the law (Anacona et al., 2018; Wilmarth, 2011; Khadim, 2016). The law was vetoed because of economic interests, in particular from the mining industry, which did not want the law to become in force (Wilmarth, 2011; Khadim, 2016). On September 30, 2010 the second Glacier Protection Law of Argentina was enacted (Barrick Gold, 2011; Anacona et al., 2018) and came in force shortly afterwards. In November 2010, the federal court in the province of San Juan issued interim injunctions on the basis of the unconstitutionality of the federal law. Therefore, the court suspended the application of the law in the province and in particular on the mines of Veladero and Pascua-Lama. Previous to the court order, a lawsuits against the law and the nation state were filed by local unions and the San Juan based mining and construction chambers, including Barrick Gold's subsidiaries. The province of San Juan joined the lawsuit in December 2010. Due to this affiliation of the province of San Juan, the case was referred to the National Supreme Court of Justice of Argentina to clarify whether the law is constitutional (Barrick Gold, 2010). The National Supreme Court of Argentina found that this decision falls within its jurisdiction. The Nation State made a request that the order issued by the Federal Court in the province of San Juan has to be revoked (Barrick Gold, 2011). In July 2012, the Supreme Court overturned the interim injunctions issued by the San Juan Provincial Court (Barrick Gold, 2012). The federal authorities published a partial inventory of the national glacier inventory in October 2016. This partial inventory also includes the area of the Veladero Mine and the Pascua-Lama Project (Barrick Gold, 2016). The complete national glacier inventory of Argentina was published by the federal authorities in June 2018. In the area of the Verladero Mine and the Pascua-Lama Project, the complete glacier inventory was consistent with the partial inventory published in 2016 (Barrick Gold, 2018). In June 2019, Argentina's Supreme Court confirmed the GPL of Argentina. The court thus rejected the attempt by Barrick Gold Corp to have the law declared unconstitutional (Associated Press, 2019).

3.3.3 Law Case of Villalba

The law case of Ricardo Villalba started shortly after the first incident in September 2015 at the Veladero mine (Fraser, 2017). During this time Villalba was the head of the Instituto Argentino de

Nivologia, Glaciologia y Cencias Ambienales (IANIGLA). The IANIGLA is responsible for generating the glacier inventory of Argentina. After the incident at the Veladero mine, an environmentalist group named “Jáchal No Se Toca” lodged a criminal complaint against Barrick Gold for environmental damage and against the state for failing to act on the GPL. The criminal case against Barrick Gold was dealt with by a provincial court. In this trial, Barrick Gold got away with a small fine. However, the accusations against the state resulted in a federal lawsuit. According to the judge's federal indictment, the defendants acted intentionally and negligent by carrying out the inventory and in implementing the GPL. The judge argued that if the glacier inventory had been carried out properly, the mine should have been closed by the time the spilling of the cyanide solution happened. In addition, the indictment accused Villalba and the three environmental officials responsible of having violated the law. The reason given for the infringement was that the four defendants were too slow in generating the glacier inventory and that the Veladero mine was not given priority in the mapping process. However, the most serious accusation concerned the technical standards used for mapping glaciers. Only areas larger than one hectare were included in the glacier inventory. With this threshold value, Villalba had chosen the international standard used for mapping glaciers. The judge contradicted this international standard and argued that according to the law, all glaciers and periglacial areas must be mapped. The periglacial environment at the Veladero mine was not mapped correctly according to the judge and the judgement (Healey and Martin, 2017). In addition, the indictment argued that the threshold value of one hectare and the lack of field inspection on site led to the fact that many small ice areas in the vicinity of the Veladero mine were not included in the inventory (Fraser, 2017).

A lawyer for the environmental group “Jáchal No Se Toca” noted that the group did not mention Villalba or the other three officials by name in their complaint. The indictment against Villalba and the other officials come about, because in the Argentine law, the criminal charges are directed against individuals and not against public authorities, so that Villalba and the other officials were charged (Fraser, 2017). Additionally, the activists argue that the law obliges scientists to audit the impact of the mine on glacier resources. Villalba, however, contradicts this argument. Villalba believes that IANIGLA is not responsible for enforcing environmental legislation, but rather the Argentine environmental regulatory authority and Barrick Gold are responsible for that (Tollefson and Rodríguez Mega, 2017).

Furthermore, the provinces play a key role in environmental regulation. The province of San Juan has done a lot to ensure that Barrick Gold's mines are not closed by the GPL. As mentioned above, the province of San Juan claimed that the law violated the province's autonomy and obtained an injunction against the law. In 2012, the province passed its own glacier law. The inventory that was created by the province’s glacier law only incluced glaciers but not periglacial environments. All these measures taken by the province of San Juan were not taken into account in the charges against the four defendants. The blame was placed solely on Villalba, and therefore on IANIGLA, and on the national officials (Healey and Martin, 2017). Yet, various scientists around the world rushed to Ricardo Villalba's aid with a letter. In this letter the scientists supported the method Villalba had applied for mapping the glaciers (Fraser, 2017), since the use of a minimum glacier size of one hectare avoids the mapping of snow fields and snow patches (Tollefson and Rodriguez Mega, 2017).

4. Methods

The discussion of the case of Ricardo Villalba has shown that the minimum size of one hectare is used in science to define the boundaries of a glacier. The different threshold values applied in glacier mapping are listed in Table 2. Those parameters are used to distinguish glaciers from snowfields and thus to detect changes in glaciers.
Based on these thresholds, the study of Côte, Wartmann and Purves (2018) is consulted for this thesis. In their study they explored the concepts of definition, values and boundary for the term "forest". According to Côte, Wartmann and Purves (2018), the link between definition and values is silent and often not explicitly stated. This connection only becomes visible through the boundaries. In the center is the value of a forest and not the definition or the boundary of a forest. To understand the difficulties related to the term “forest”, it is necessary to understand how and by whom a forest is valued. Through these values it can be understood how definitions and boundaries of forests are produced and used (Côte, Wartmann and Purves, 2018). In the case of Villalba the discussion is not about the value but about the boundaries of glaciers or the minimum threshold value respectively. This threshold implies a certain definition of glaciers and therefore the three concepts of definition, values and boundary, can be applied to the term "glacier". In order to better understand and analyze the conflict with environmental activists in the case of Ricardo Villalba, the approach of Critical Physical Geography (CGP) is used. This approach enables to capture and understand social as well as biophysical processes better during environmental changes. The CGP challenges science to think about how their analyses and practices influences the environment and society around them (Lave, Biermann and Lane, 2018b). This approach is suitable in case of the discussed conflict in Argentina, because both the social and the physical aspects can be taken into account. In the following section, the applied approach and methods are explained in detail.

4.1 Approach of Critical Physical Geography

The emerging field of "Critical Physical Geography" (CPG) will contribute to the orientation of research. This approach assumes that physical landscape changes do not take place in a social vacuum. It provides the resources to identify the link between research in physical geography and its social, economic and political context (Lave et al., 2014). Moreover, the CPG allows for the joint investigation of material landscapes, social dynamics and knowledge policies that construct each other.
Although, the CPG has a common, integrated and iterative research structure, there is no standard set of research methods. This is because the CPG research deals with a wide range of environmental issues and problems, so the most appropriate method must be adapted to the problem at hand (Lave, Biermann and Lane, 2018a). Methods range from historical material to more technical analyses (Lave et al., 2014). However, the CPG can be characterized as a mixed approach, which is also shown in Figure 13. It illustrates the contrast between the natural and social sciences on the one hand and the contrast between quantitative research versus qualitative research on the other. Therefore, CPG research has a wide range of methods that can be applied and most research studies cover three of the four fields. The different methods can be used to generate several data sets. The method of triangulation is used to analyze these data sets together. Triangulation has the potential to increase the explanatory power of the data sets (Lave, Biermann and Lane, 2018a). The approach of the CPG is reflected in the selected methods used for this study.

	Quantitative Methods	Qualitative Methods
Natural Science	frequency/magnitude curves geospatial analysis hydraulic modeling soil chemistry	descriptions of species and ecosystems soil classification aerial photograph analysis
Social Science	surveys social network analysis Q-method econometrics	ethnography/participant observation interviews document analysis archival

Figure 13: The four-squares of methods used in the approach of CPG. The methods used in this figure are only examples (Lave, Biermann and Lane, 2018a: 10).

In this thesis, methods from both the social and natural sciences are used (Figure 14). Some actors involved in the conflict have already been introduced in the background section. In order to be able to analyze the point of view of the different stakeholder involved regarding the concepts of definition, values and boundary for the term "glacier", the information has to be gathered. This data collection is based on a text-based approach. For each stakeholder, texts are analyzed and evaluated whether they are sufficient for data collection. The actual analysis is done with a content analysis. The content analysis determines how stakeholder interprets the definition, values and boundary of the term "glacier". This procedure covers the social science area of CPG. The natural scientific methods are covered by the qualitative analysis of different inventories and the calculation of the water equivalent. The inventories include the Argentine glacier inventory as well as two inventories that are mapped based on satellite images. The two mapped inventories help to identify if anything has been missed in the Argentine glacier inventory. The water equivalent is calculated based on the Argentine glacier inventory and one of the mapped inventories. This helps to identify how much water is stored in these features.

	Quantitative Methods	Qualitative Methods
Natural Science	Calculation of volumes and water equivalent	Analsyis of four different inventories by separating glaciers, debris-covered glaciers, rock glaciers and snow patches
Social Science		Textual approach with Content Analysis

Figure 14: The four-squares of methods used in the approach of CPG with the methods used in this thesis.

4.2 Textual approach with Content Analysis

The case of Ricardo Villalba in connection with the Glacier Protection Law (GPL) in Argentina affects many different interest groups. These interest groups are selected based on the conflict. From the actual conflict the following stakeholder interest groups have been identified:
First of all, the interest groups "Inventory", "Law" and "Environmentalists" are selected. The "Inventory" includes the Argentinean glacier inventory, which is compiled by Ricardo Villalba and IANIGLA, and the related documentation. The "Law" stakeholder includes the Argentine glacier law. The stakeholder "Environmentalists" stands for the environmental activists who have accused Ricardo Villalba. In addition, a major part of this legal conflict is related to the threshold value of one hectare. Accordingly, two more stakeholder groups, the “Science community” and the “Guidelines” have been defined. Furthermore, the “Mining Company” is added as another interest group, because the conflict originally arose from the water pollution of the Veladero Mine. As a last stakeholder the "Center for Human Right and Environment (CEDHA)" is selected, since this interest group is very critical about the Argentine glacier inventory.
Due to the sensitive nature of the topic, there is a possibility that not all stakeholders would participate in interviews which would leave data gaps, so a textual approach is chosen. As there are enough written material available online to conduct the data collection in a textual approach and to answer the questions on definitions, values and boundary of the glacier for each stakeholder, a text-based approach will give an adequate capture of the conflict.

The data analysis is carried out with the help of qualitative content analysis. The content analysis is based on Kuckartz (2016) and refers mainly to the chapter “Die inhaltlich strukturierende qualitative Inhaltsanalyse”. The procedure for the textual approach in combination with a content analysis is presented in more detail in the following sections.

Selection of text documents
Documents are not neutral, they always reflect back on the authors. Therefore, documents construct the reality of the authors or organization they work for. Organizations and institutions produce documents and reports on a daily bases. However, in the present time texts from other sources should also be included in the analysis (Atkinson and Coffrey, 2011). As Waitt (2010) mentioned in his paper “Doing Foucauldian Discourse Analysis – Revealing Social Realities” the first step is to choose the texts. In this thesis the text corpus is gathered from websites, scientific articles, law text, inventory documents, reports and guidelines that have either relate to the GPL in Argentina and/or have some information about the definition, value or boundaries of glaciers. The texts are arranged according to the defined stakeholders: “Inventory”, “Law”, “Environmentalist”, “Guidelines”, “Science Community”, “Mining Company” and “CEDHA”.

Inventory
For the “Inventory” one document (IANIGLA-CONICET, 2010) is used. The document is produced by the Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA) and the Centro Científico Tecnológico – CONICET Mendoza (CONICET). In the document the fundamentals and schedule of implementation of the national glacier inventory is described. For better understanding the document was translated form Spanish into English.

Law
The Argentine National Glacier Act (2010) is used for the stakeholder "Law". The Argentine National Glacier Act also known as GPL (Law 26.639) is translated from Spanish into English by CEDHA and edited for scientific purpose by A. Brenning.

Environmentalist
To analyze the information about the "Environmentalist", the homepage of the organization "Jáchal No Se Toca" (https://jachalnosetoca.com/) is investigated. From the 23 articles on the homepage, five are used to gather the information for this master thesis (Jáchal No Se Toca, 2017). These texts also have to be translated.

Guidelines
The information of the stakeholder "Guidelines" is based on three documents. The: "Perennial ice and snow masses from the International Commission of Snow and Ice" (1970) which will in the following be referred to as UNESCO document, the "GLIMS Analysis Tutorial" by Raup and Khalsa (2010) and the "Glossary of Glacier Mass Balance and Related Terms" by Cogley et al. (2011).

Science Community
For the stakeholder of the "Scientific Community" three documents are selected (Leigh et al., 2019; Mark and Fernandez, 2017; Carey, French and O'Brien, 2012).

Mining Company
Four documents are utilized to generate the material needed for the stakeholder "Mining Company" (Smith and McCormick, 2019; Li, 2018; Ross, 2005; Barrick Gold, 2001). However, not all documents are based on a scientific foundation.

CEDHA
For the Analysis of the Stakeholder "Center for Human Right and Environment" (CEDHA) the document "Barrick's Glaciers" by Taillant (2013) is used to gather the relevant information.

4.2.1 Content Analysis of the text documents

According to Kuckartz (2016), the category definition together with the category system is a central part of the qualitative content analysis. The category definitions are used to document the procedure in content analysis so that the analysis is reproducible. In a first step the main categories are defined. The definition of the main categories rely on the paper of Côte, Wartmann and Purves. (2018), which discussed the definition, values and boundaries of a forest. For this thesis, the definition, values and boundaries are adapted to glacier. Therefore, the chosen texts are scanned for definitions, values and boundaries.
For definition, the question: "What is a glacier?" is asked. This question is answered by analyzing the physical features of a glacier and its periglacial environment. These features help to identify the glacier in a satellite image or in the field. The category "Definition" is described in Table 5.

Côte, Wartmann and Purves (2018) mentioned that values are mostly "human-centered" values. Therefore, the question asked here is "How and by whom are the glaciers valued". This procedure helped to make selections about the main category "Value" (Table 6).
The Boundaries question is where a glacier starts and ends. The texts of the different stakeholders are scanned for a specific number or words that describe the size of a glacier. This is also described in Table 7.

Table 5: Description of the main category of Definition.

Name	Description
Content description	The category "Definition" describes the features of glaciers and the periglacial environment that is characteristic for them, incl. perennial snow masses.
Application of category	Category is coded when the following aspects or similar ones are mentioned in the text: snow mass, snow field, permanent ice body, recrystallization, flow features or movements, frozen debris, frozen ground, debris, rock glacier, glacier, periglacial environment.

Table 6: Description of the main category of Value.

Name	Description
Content description	The category "Value" describes the value of glaciers and the periglacial environment in the context of the human-centered view.
Application of category	Category is coded when the following aspects or similar one are mentioned in the text: freshwater, water supply, sacred or holy symbols, History / Archives, absorb and release pollutant, Economic and cultural significance, knowledge for human society, tourism, water.

Table 7: Description of the main category of Boundaries.

Name	Description
Content description	The category "Boundaries" describes the boundaries of a glacier respectively of periglacial environment on where they start and end.
Application of category	Category is coded when the following aspects or similar ones are mentioned: specific values like 0.01 km^2, dimension, size, form, visual in a data sheet, boundaries.

In order to get a better overview of the gathered information about the definitions, values and boundaries for each stakeholder, a theme matrix is generated (Appendix B). The theme matrix is used for the analysis of the information and especially for the theme summaries.

In a second categorizing step, for each main category sub-categories are defined. To define the sub-categories for the main category "Definition" the glossary of Cogley et al. (2011) is adopted except for the periglacial environment. The development of the sub-categories for "Values" and "Boundaries" is based on the data itself. Sub-categories for the main category "Definition" are displayed in Tables 8 to 12. Tables 13 to 17 show the sub-categories for the main category “Values” and Tables 18 to 19 the sub-categories for “Boundaries”.

Table 8: Description of the sub category of Glacier.

Name	Description
Content description	The category describes a Glacier.
Application of category	Category is coded when some of the following aspects are mentioned: perennial mass of ice, recrystallization of snow or other forms of solid precipitation, evidence of past or present flow.

Table 9: Description of the sub category of Glacieret.

Name	Description
Content description	The category describes a Glacieret.
Application of category	Category is coded when some of the following aspects are mentioned: very small glacier (< 0.25 km^2), no flow pattern visible on surface, perennial, no shape.

Table 10: Description of the sub category of Snow Patch.

Name	Description
Content description	The category describes a Snow Patch.
Application of category	Category is coded when some of the following aspects are mentioned: mass of snow, can be perennial, < 0.01 km^2.

Table 11: Description of the sub category of Rock Glacier.

Name	Description
Content description	The category describes a Rock Glacier.
Application of category	Category is coded when the following aspects are mentioned: mass of rock fragments and finer material (debris), matrix of ice, past or present flow, frozen debris and ice, detritic rock material, permafrost, creep flow.

Table 12: Description of the sub category of Periglacial Environment.

Name	Description
Content description	The category describes the Periglacial Environment.
Application of category	Category is coded when the other sub categories of the main category “Definition” cannot be applied.

Table 13: Description of the sub category of Water Resource

Name	Description
Content description	The category describes “Water Resource”.
Application of category	Category is coded when the following aspects are mentioned: freshwater, drinking water, water for irrigation, water storage, water supply, hydrology, water security, water reserves.

Table 14: Description of the sub category of Archive.

Name	Description
Content description	The category describes “Archive”.
Application of category	Category is coded when the following aspects are mentioned: history, archive, scientific knowledge/information, climate changes.

Table 15: Description of the sub category of Environmental.

Name	Description
Content description	The category describes “Environmental”.
Application of category	Category is coded when the following aspects are mentioned: pollution, ecosystem, biodiversity, nutrients.

Table 16: Description of the sub category of Society Goods.

Name	Description
Content description	The category describes “Society Goods”.
Application of category	Category is coded when the following aspects are mentioned: goods, tourism, local cultures, economic, cultural, human activity.

Table 17: Description of the sub category of Manageable Good.

Name	Description
Content description	The category describes “Manageable Good”.
Application of category	Category is coded when the following aspects are mentioned: remove, management, transported, glacier pieces or relocation.

Table 18: Description of the sub category of Number.

Name	Description
Content description	The category describes Number.
Application of category	Category is coded when the following aspects are mentioned: specific number, equal or bigger than 0.01 km^2.

Table 19: Description of the sub category of No Size.

Name	Description
Content description	The category describes No Size.
Application of category	Category is coded when the following aspects are mentioned: Form, dimension, state, size do not matter, irrespective to size.

According to Waitt (2010) silence is an integral part of the discourse analysis. This also applies in this qualitative content analysis, since not everything is explicitly mentioned or said in the text. By including what is not said, a holistic analysis of the conflict can be made. This is especially important when assigning sub-categories to the main category "Definitions". For example, in the main category "Definitions" the sub-category "Glaciers" is entered because of the applied criterion. However, in the main category "Boundaries" no minimum size for glaciers is given. This implies that glaciers also include glacieret and snow patches. Therefore the sub-categories “Glacieret” and

"Snow Patches" are also included but are displayed in a different color in the theme summaries to make clear that these sub-categories are implicit (Appendix B). .

In a next step, the sub-category "Glacier" of the individual stakeholders are compared to each other with regard to the different "Glacier" definitions of the stakeholders. This evaluation intends to show how the stakeholders understand this term and how a conflict can arise.
In a final step, the case-oriented perspective of the individual stakeholders has to be examined. All main categories as well as their sub-categories are considered. These also represent the categories that has to be considered in an inventory.

4.2.2 Positionality

Some basic knowledge about glaciers exists. However, this knowledge is not sufficient to enable the examiner to critically consider the questions. The most critical point of the analysis is the selection of documents. This was done consciously, and therefore there is a possibility that certain documents were not considered for the analysis. In order to perform a confidential analysis, all steps are documented so that each step can be reconstructed and the pathway of interpretation is clearly visible.

4.3 Glacier mapping and GIS Analysis

In addition to the Argentine glacier inventory, two inventories with satellite images are created for the analysis of the features. These mapped inventories are used to determine whether features have been missed in the Argentine glacier inventory. As mentioned above, the organization CEDHA is very critical towards the Argentinean glacier inventory. This organization has also produced a glacier inventory in this region. Therefore, this inventory is considered and analyzed. The procedure for the analysis is described in the next sections.

4.3.1 Separating glaciers, debris-covered glaciers, rock glaciers and snow patches

Datasets
The following data sets are explored for the investigation of glaciers, debris-covered glaciers, rock glaciers and snow patches: Glacier Inventory of Argentina, Inventory of CEDHA, ASTER and Sentinel-2 satellite data.

Glacier Inventory of Argentina
For the Glacier Inventory of Argentina the data is downloaded from the website of the "Inventario Nacional de Glaciares" for the sub-catchment area of the Rio de la Palca (Inventario Nacional de Glaciares, 2020b) and the area of the Rio Blanco (Inferior Inventario Nacional de Glaciares, 2020a). Both of these areas belong to the catchment of the Rio Jáchal. Besides the geometry the data also includes the meta-data that is used for the analyses. The most important metadata for this thesis is: Tipo_geoforma, Área, Largo_total, H_max_total, H_min_total, Img_ap_F and Img_ap_S. The Tipo_geoforma provides information about the features that are mapped as glaciers or snow patches. Largo_total is the length of each feature in meters. H_max_total and H_min_total include

the maximum and minimum altitude of a features measured in meters above sea level. Img_ap_F provides information about the date when the satellite image is taken and Img_ap_S is the satellite used.

CEDHA
The dataset of CEDHA is published on their website and is downloaded from there for the analyses. The following inventory is used for the analysis: Inventory of Glaciers for Barrick Gold's Pascua Lama and Veladero projects - Argentine Side. However, there are no metadata included in the dataset (CEDHA, 2017).

ASTER
The ASTER satellite image is downloaded from the website https://earthexplorer.usgs.gov/. The satellite image is from 04.02.2009. The ASTER sensor is chosen because some of the glacier inventories of Argentina are generated with it. Therefore, the date of the satellite image also concerted with the inventory of Argentina. The spectral bands that are downloaded are band 1 (green), band 2 (red) and band 3 (NIR) (USGS, 2020b).

Sentinel-2
The Sentinel-2 satellite image is downloaded from the website https://earthexplorer.usgs.gov/. The Sentinel-2 data is used to get a current overview of the glacier and snow patches in the study area. The Sentiel-2 are acquired on 19.03. and 24.03.2020 as two different tiles have to be used to cover the study area. The spectral bands that are downloaded are band 2 (blue), band 3 (green), band 4 (red), band 8 (NIR), band 11 (SWIR) and band 12(SWIR) (USGS, 2020c).

The so-called Permafrost Zonation Index (PZI) are downloaded from following website https://www.geo.uzh.ch/microsite/cryodata/pf_global/. This dataset is used to get a better understanding where in the study area permafrost is possible. The PZI is a color coded raster map (Gruber, 2012).

Furthermore, the ASTER Global Digital Elevation Model are downloaded from the same website as the ASTER and Sentinel-2 satellite images to use as a digital elevation model (DEM) (USGS, 2020a).

Glacier mapping
As a first step, the spectral bands of ASTER and Sentinel-2 are resampled to a resolution of 10 meters. For the ASTER satellite images, all spectral bands are resampled to a resolution of 10 meters. The resampling for Sentinel-2 is only applied to the SWIR spectral band. The remaining spectral bands already have a resolution of 10 meters. To map the glaciers and snow patches the band ratio of red/NIR is used for ASTER satellite image using a threshold value of 0.89 to create a binary glacier map. For the Sentinel-2 images, the red/SWIR band ratio is used to map glaciers and snow patches. A threshold in the blue band is used to better map ice in shadow. This band ratio is also used by Paul et al (2016) for automated mapping of glaciers. The threshold value of 2.2 for the band ratio and 1100 for the blue band are in the same range of values used by Paul et al. (2016). A noise filter is applied to both the ASTER and Sentinel-2 data sets to reduce noise. In order to perform further data analyses, raster-vector conversion is performed to create a shape-file, for which the "non-glaciers" value is set to no data first. In the ASTER data set, incorrectly classified

glaciers and snow patches are manually removed or reshaped.
The DEM is utilized to generate a surface slope raster data set. Both are used to derive the mean slope as well as the maximum and minimum elevation of the Sentinel-2 dataset. All three values are calculated in ArcGIS using the function, zonal statistics as table. The data is used to calculate volume of all glaciers from the extents derived by the Sentinel-2 data.

Rock glacier classification
In the Argentinean Glacier Inventory and the Inventory of CEDHA, rock glaciers are evaluated according to the criteria in Table 20. For classification and evaluation, the high-resolution satellite and aerial imagery provided by ESRI in ArcGIS is used. In case of uncertainties and for verification purposes, the very high-resolution images provided by Bing in https://www.bing.com/maps/aerial is also used. The classification is performed according to the criteria listed in Table 20 that is compiled according to Janke, Bellisario and Ferrando (2015).

Table 20: Quality criteria for the evaluation of rock glaciers in the inventories of Argentina and CEDHA. The criteria are based on information of the study of Janke, Bellisario and Ferrando (2015).

Code		Criteria
1	Certain	No ice is visible on the surface; ridges and furrows are clearly visible and are perpendicular to the direction of flow; at the edges there are longitudinal ridges that are parallel to the direction of flow; steep front and side; lobate or spatulate from;
2	Less certain	Ridges and furrows are not that clear anymore; front angle is less steep and appears elongated; large rocks are visible on the surface;
3	Uncertain	No ridges and furrows are visible; surface has an erratic, chaotic appearance; superficial debris characterized by irregular, small hills and boulders; front slope is not visible; snow accumulation in depression is possible;
4	Very uncertain	No ridges and furrows are visible; surface seems smooth and not chaotic; superficial debris is visible however not very clear; front slope is not visible; snow accumulation in depression is possible
5	None	No ridges and furrows are visible; surface is smooth; no superficial debris is visible; front slope is not visible; small snow accumulation

Preparation of infrastructure data set and assessment of affected glaciers
With the help of the high-resolution satellite and aerial imagery provided by ESRI in ArcGIS and the documents of Evans, Ehasoo and Krutzelmann (2018), vector data sets for building infrastructure, road infrastructure and the mine concession area are created. These infrastructure datasets are used against outlines from the Argentine glacier inventory, the inventory of CEDHA, ASTER and Sentinel-2 inventory to determine the direct influence of infrastructure on glaciers, debris-covered glaciers, rock glaciers and snow patches. The classification is done in two steps. In the first step, it is evaluated if the features are in direct contact with roads or buildings. These

features are given the number 1. At the Veladero Mine these features are also located in the mining concession area. In a second step, the features of the inventory datasets are analyzed against the mining concession area. These features are given the number 2.

Differentiation of water flow above and below the mine
To see how the water flow of the features for the different inventories interact with the mine, the features are divided into two watershed groups. These watershed groups are: by the mine and below the mine. For the Differentiation of the features the Figure 4-1 of Evans, Ehasoo and Krutzelmann (2018) is considered and the features are divided according the displayed watersheds.

In order to minimize the number of glaciers and periglacial features to be assessed, a buffer with a distance of 10 kilometers linear from the road dataset is created before the analysis by using the ArcGIS buffer function.

4.3.2 Calculation of volumes and water equivalent

Rock glaciers
Calculation of volume and water equivalents of rock glaciers is done after the equation of Azócar and Brenning (2010). The ice content in a rock glacier is assumed to be 50% with an ice density of 0.9 g/cm^3. These values are not only used by Azócar and Brenning (2010) but also by Perucca and Angillieri (2011). The latter calculated the thickness and the water equivalent of rock glaciers in the Ingesia Department which also contains the Veladero mine. Their study site is situated a bit further north at the latitude of 28°S. However, the area is still close enough to use the same approach to calculate the water stored in rock glaciers. To estimate the thickness of the ice-rich layer the following equation is used:

$$50 * [area(km^2)]^{0.2} = thickness\ of\ ice - rich\ layer\ [m]$$

The ice volume [km^3] of a rock glacier is calculated by multiplying its area [km^2] with the ice-rich layer, where the ice-rich layer has an average ice content of 50 % (Perucca and Angillieri, 2011).

Glaciers
The calculation of glacier volume is based on Haeberli and Hoelzle (1995). The parameters necessary for the calculation are: area (F), total length (L0), maximum and minimum altitude, vertical extent (ΔH), average surface slope (α), mean basal shear stress (τ_f), central flowline (h_f) and average thickness (h_F).
The area, maximum and minimum height and total length are either already present in the data or are calculated using a DEM. The vertical expansion (ΔH) is calculated from the maximum altitude minus the minimum altitude. The average surface slope (α) is calculated as follows: $\alpha = \arctan [\Delta H / L0]$. The formula in Figure 1 in Haberli and Hoelzle (1995) is used to calculate the mean basal shear stress. The formula is: $y = 0.005 + 1.598x - 0.435x^2$ with x representing the vertical extent in km. The thickness along central flow line (h_f) is calculated from $\tau_f = f \rho g h_f \sin\alpha$. The shape factor (f) is chosen as 1, the density ρ as 900 kg/m^3 and the acceleration due to gravity g as 9.80665 m/s^2.

The formula for the average thickness of a glacier is $h_F = (\pi/4)h_f$, assuming a semi-elliptic cross section. The volume of a glacier is then $V = Fh_F$. The ice density of 0.9 g/cm^3 is used to calculate the water equivalent of a glacier and a density of 0.5 g/cm^3 is used for snow patches.

The following programs are used for the evaluations: ArcGIS, R and Excel.

4.4 Triangulation

Triangulation is widely used in multi-method research designs. When different methods of data collection are used in a research project, several data sets will result from the data collection. The analysis of the results of the data sets is done independently, but these results have to be compared. In order to compare the results with each other the method of triangulation is used. Triangulation distinguishes between three types of triangulation: convergence, complementarity and divergence. Convergence is the most common type and assumes that the different data sets produce the same result. Complementary triangulation combines and uses information from different methods to obtain a complete picture of the research questions. Complementarity triangulation allows to link qualitative and quantitative data sets together. In this form, it is not expected that the results are the same, but that the results together make sense. Complementary triangulation thus helps to better understand a research problem, since the data sets provide similar information to the same topic. When using triangulating divergence, researchers do not assume convergence or complementarity, but expect both inconsistency and consistency in the data sets. Inconsistency does not signal a problem in data collection but rather indicates a problem in theoretical assumptions (Nightingale, 2009). Since qualitative as well as quantitative data sets are used in this thesis, complementary triangulation is applied to discuss and interpret the different data sets.

5. Results

In a first section, the results generated by the content analysis are presented. The definition of "glaciers" and how the different stakeholders define the content of an inventory are explained. In a second section, the results of the four inventories are presented and related to the infrastructure. Finally, the results of the water equivalent for the Argentine glacier inventory and the Sentinel-2 inventory are displayed.

5.1 Definition of „Glacier“ by different stakeholders

The results for the definition of glaciers by the different stakeholders are presented in Table 21. The Argentinean Glacier Inventory, or "Inventory" for short, uses the terms glacier and glacieret to describe and define glaciers. In its definition, the “Law” includes the terms glacier, glacieret and snow patches. Among “Environmentalists”, the terms glacier, glacieret and snow patches are included in the definition of glaciers. The “Guidelines” define glaciers with the term glacier. In the “Science community” the glacier definition consists of the term glacier. The definition of glacier for the “Mining company” consists of the term glacier. The “CEDHA” organization uses the terms glacier, glacieret and snow patches in the definition of glaciers.

Table 21: The different stakeholder’s definition of glaciers.

	Inventory	Law	Environ-mentalists	Guidelines	Science community	Mining company	CEDHA
Glacier	X	X	X	X	X	X	X
Glacieret	X	X	X				X
Snow Patches		X	X				X

Figure 15 illustrates how the various stakeholder’s definition of glaciers are related to the terms glacier, glacieret and snow patches. The “Guidelines”, “Science community” and “Mining company” assign the term glacier to the glacier definition. The “Inventory” understands the glacier definition to mean the terms glacier and glacieret. The “Law”, “Environmentalists” and the organization “CEDHA” use the terms glacier, glacieret and snow patches to define glaciers.

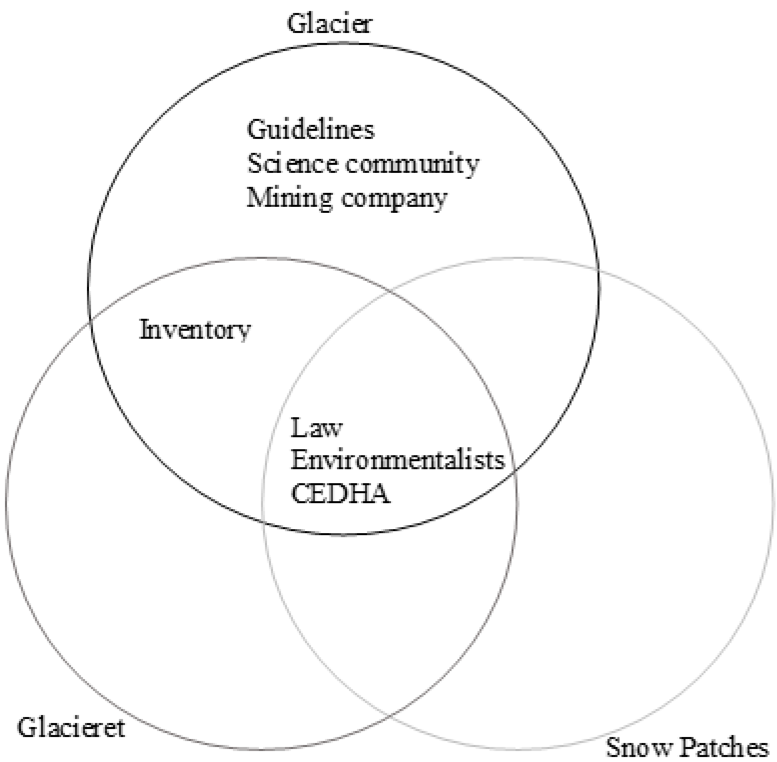

Figure 15: The graphic displays the different stakeholder's definition of glaciers in relation to the components glacier, glacieret and snow patches .

5.2 Various Features of an Inventory by different Stakeholders

Table 22 shows which terms and features are included in an inventory by the various stakeholders. According to the "Inventory", the terms glacier, glacieret and rock glacier should be included in an inventory. The "Law" includes the terms glacier, glacieret, snow patches, rock glacier and periglacial environment in an inventory. The terms that are included in the inventory for "Environmentalists" are glacier, glacieret, snow patches, rock glacier and periglacial environment. Most "Guidelines" include the terms glacier and glacieret in an inventory. However, the 1970 UNESCO report also includes snow patches, rock glaciers and periglacial environments in an inventory under certain aspects. The "Science community" describes an inventory using the terms glacier and glacieret. However, the term glacieret is only included under certain aspects in an inventory. Therefore, this term is displayed in brackets. The "Mining company" understands the term inventory as glacier. The organization "CEDHA" includes the terms glacier, glacieret, snow patches, rock glacier and periglacial environment in an inventory.

*Table 22: The table shows the features each stakeholder would include in an inventory. * is used to identify the suggestion of the UNESCO report from 1970.*

	Inventory	Law	Environ-mentalist	Guidelines	Science community	Mining company	CEDHA
Glacier	X	X	X	X	X	X	X
Glacieret	X	X	X	X	(X)		X
Snow Patches		X	X	X*			X
Rock Glacier	X	X	X	X*			X
Periglacial Environment		X	X	X*			X

The value and purpose of an inventory for the various stakeholder is described in Table 23. The "Inventory" describes the value of the inventory as a water resource. For the "Law" the inventory has the values water resource, archive, environmental and society goods. "Environmentalists" refer to the value of the inventory as water resource. For the "Guidelines", the value of the inventory is designated by the terms water resource, archive and society goods. For the "Science community" the terms water resource, archive, environmental and society goods describe the value of an inventory. The terms water resource and manageable goods are the values for an inventory defined by the "Mining company". The organization "CEDHA" describes the value of an inventory with the term water resource.

Table 23: The values that an inventory can have according to the different stakeholders.

	Inventory	Law	Environ-mentalists	Guidelines	Science community	Mining company	CEDHA
Water Resources	X	X	X	X	X	X	X
Archive		X		X	X		
Environmental		X			X		
Society Goods		X		X	X		
Manageable Good						X	

The boundaries or size of a glacier vary between the different stakeholders (Table 24). The stakeholders “Inventory”, “Guideline” and “Science community” set a number for the boundaries of glaciers. The “Law”, “Environmentalist”, “Mining companies” and the “CEDHA” organization, instead, define glaciers without giving a concrete number.

Table 24: The stakeholder and their glacier boundary definition.

	Inventory	Law	Environ-mentalists	Guidelines	Science community	Mining company	CEDHA
Number	X			X	X		
No Size		X	X			X	X

5.3 Glacier inventory analysis

In the next sections the results of the Argentine Glacier Inventory, the CEDHA Inventory, the ASTER Inventory and the Sentinel-2 Inventory are presented. The four inventories are shown in the areas of the Veladero mine and the Conconta Pass (Figure 3). The Conconta Pass has been chosen because the road leading to the mine also has an impact on the periglacial environment according to CEDHA (Taillant, 2013). For the comparison between the Argentine glacier inventory and the CEDHA inventory the results at the Veladero Mine are presented here. The results for the Conconta Pass can be found in Appendix C. The glaciers and rock glaciers of the two inventories are compared. In addition, the results of the ASTER inventory are compared with the Sentinel-2 inventory and all four inventories are compared with each other. In this evaluation of the four inventories, both the Veladero Mine area and the Conconta Pass are considered. Also, the four inventories are compared with the mine concession area and the infrastructure. To get an impression of the water content of these features, the water equivalent for the Argentine glacier inventory and the Sentinel-2 inventory has been calculated.

5.3.1 Argentine glacier inventory and CEDHA Inventory

The results for the comparison between the Argentine glacier inventory and the CEDHA inventory for glaciers are illustrated in Figure 16. The Argentinean glacier inventory includes only those features that have an area larger than 0.05 km^2. The Argentine glacier inventory has consecutive numbers for its features, which start with AGI and go from 1 to 164. In the CEDHA inventory, only those features are shown which correspond to the Argentine glacier inventory. At the Veladero mine the features AGI_06, AGI_25, AGI_31, AGI_32, AGI_33 and AGI_50 are shown. The Features AGI_06, AGI_25, AGI_31 and AGI_32 have both a green and a black border. This means that these features appear in both the Argentinean and the CEDHA inventory. The features AGI_33 and AGI_50 each have a green border. These features can only be found in the Argentinean inventory.

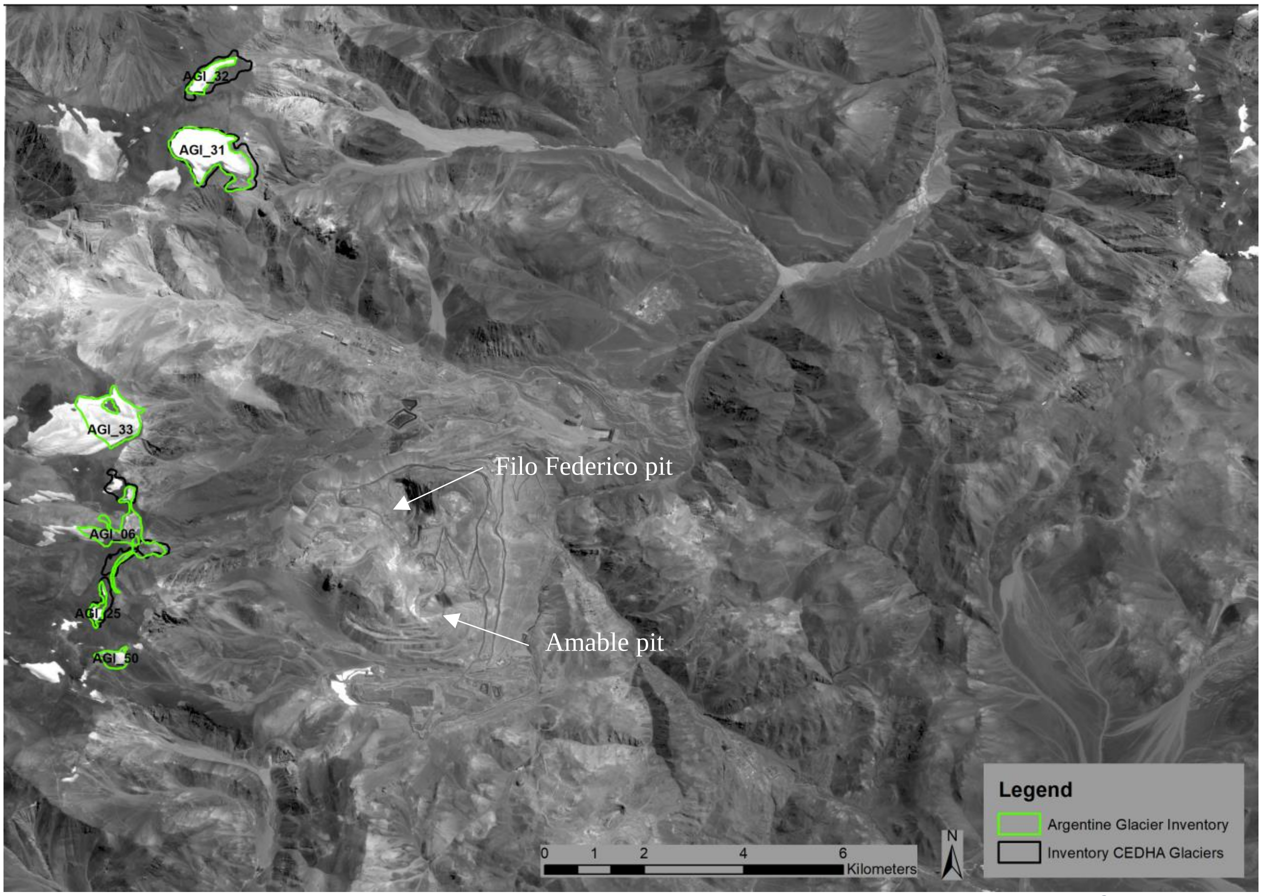

Figure 16: The features from the Argentinean glacier inventory that have an area greater than 0.05km^2 are displayed in green. The features of the inventory of the organization CEDHA are displayed in black. In this inventory, only those features are shown which correspond to the Argentine glacier inventory. The area is located at the Veladero mine. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

However, the Argentine glacier inventory not only mapped glacier and snow patches but mapped rock glaciers shown in Figure 17A as well. The rock glaciers are given a consecutive number together with the glaciers. Figure 17A shows 20 rock glaciers, five of which have the quality criteria "Certain". Six rock glaciers have the quality criteria "Less certain" and another five rock glaciers have the quality criteria "Uncertain". The last four rock glaciers have the quality criteria "Very uncertain". A total of eleven rock glaciers are included for the CEDHA Inventory in Figure 17B. Three of these rock glaciers have the quality criteria "Certain" and three rock glaciers have the quality criteria "Less Certain". The quality criteria "Uncertain" and "Very Uncertain" have two and three rock glaciers respectively.

When comparing the two inventories, it is noticeable that the CEDHA inventory has mapped fewer rock glaciers in all quality criteria. Especially the rock glaciers AGI_60 and AGI_87 are missing in the CEDHA inventory, even though they were declared as "Certain" in the Argentine glacier inventory. Furthermore it should be mentioned that the rock glaciers AGI_55, AGI_61 and AGI_86 are missing in the CEDHA inventory. These rock glaciers have the criterion "Less Certain" in the Argentine glacier inventory. The CEDHA Inventory has also mapped a rock glacier that does not appear in the Argentine glacier inventory. In addition, the shapes and sizes of the rock glaciers differ in the two inventories.

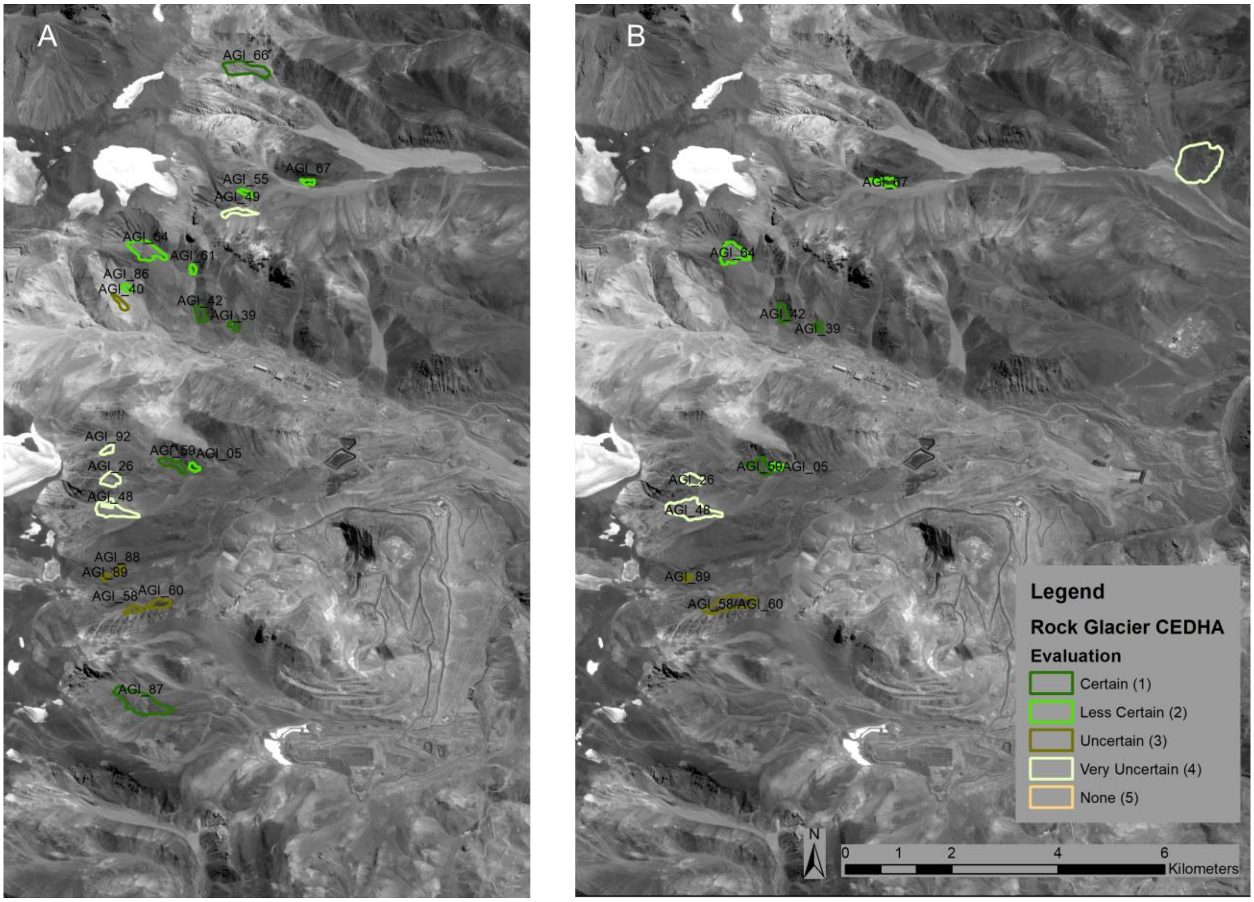

Figure 17:The classified rock glaciers at the Veladero mine site. The rock glaciers are classified after the quality criteria. (A) displays the rock glaciers for the Argentine Glacier Inventory and (B) shows the rock glaciers form the CEDHA inventory. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

The Distribution of the various quality criteria for the Argentine glacier inventory and the CEDHA inventory are shown in the histograms below (Figure 18). It is noticeable that the Argentine glacier inventory has considerably more rock glaciers with the quality criteria "Less Certain" than the CEDHA inventory. For the quality criteria "Certain" and "Uncertain" the Argentine glacier inventory has only a few more rock glaciers than the CEDHA inventory. For the quality criteria "Very Uncertain" the Argentine glacier inventory has defined a few more rock glaciers. Furthermore, the quality criteria "None" was only used in the CEDHA inventory. In the Argentine glacier inventory this criterion does not occur.

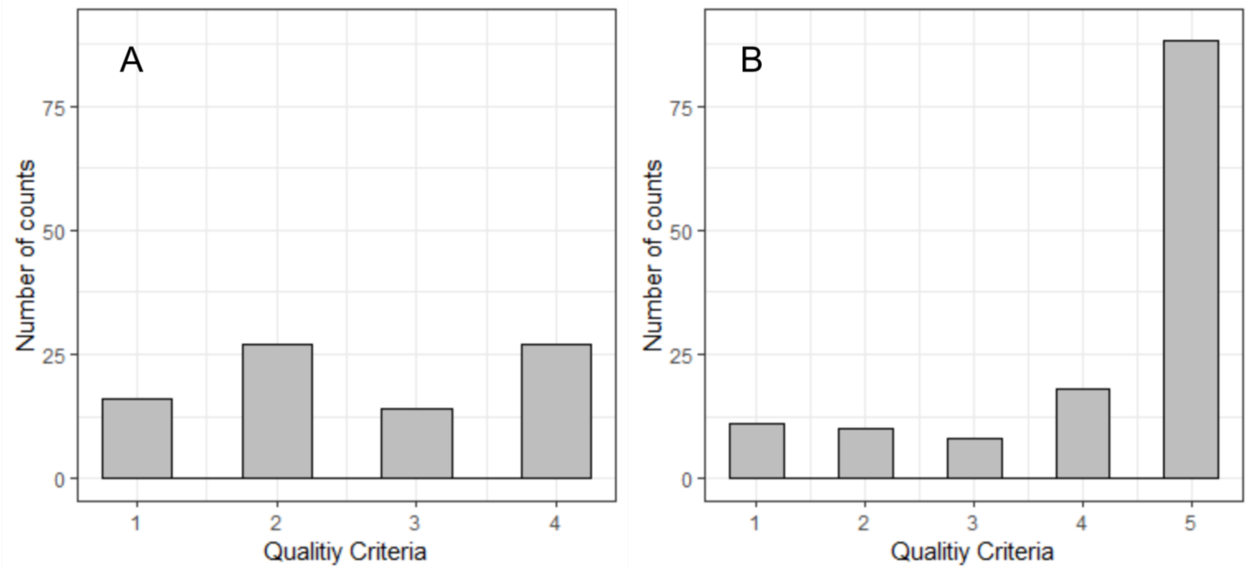

Figure 18: Histogram of the distribution of the rock glacier depending on the quality criteria.(A) show the distribution of the Argentine Glacier Inventory and (B) the distribution of the CEDHA Inventory. Number 1 corresponds to the quality criteria "Certain". The quality criteria "Less Certain" has the number 2. The numbers 3 and 4 correspond to "Uncertain" and "Very Uncertain" respectively. The quality criteria "None" has the number 5.

To better answer the controversial question about the Argentinean glacier inventory, a scatterplot was created for the features glacier, debris-covered glacier and snow patches of the Argentinean glacier inventory (Figure 19). The plot shows the area in km^2 versus difference between maximum elevation and minimum elevation. A total of 81 features are plotted. For the plot the complete glacier inventory of Argentina is used. The snow patches have a maximum area of less than 0.25 km^2 except for one snow patch. The Maximum difference in elevation height for the snow patches is less than 250 meters with the exception of one snow patch, which has a difference in elevation of around 400 meters. Hence, most snow patches are located in the lower left part of the plot. The debris-covered glaciers have a difference in elevation between 200 and 500 meters and the area of all three debris-covered glacier is less than 0.15 km^2. The glaciers range from less than 0.125 km^2 to more than 1.05 km^2 with the exception of one glacier that is smaller than 0.125 km^2. The difference in elevation varies between 150 and 900 meters. The glaciers are more scattered in the plot.

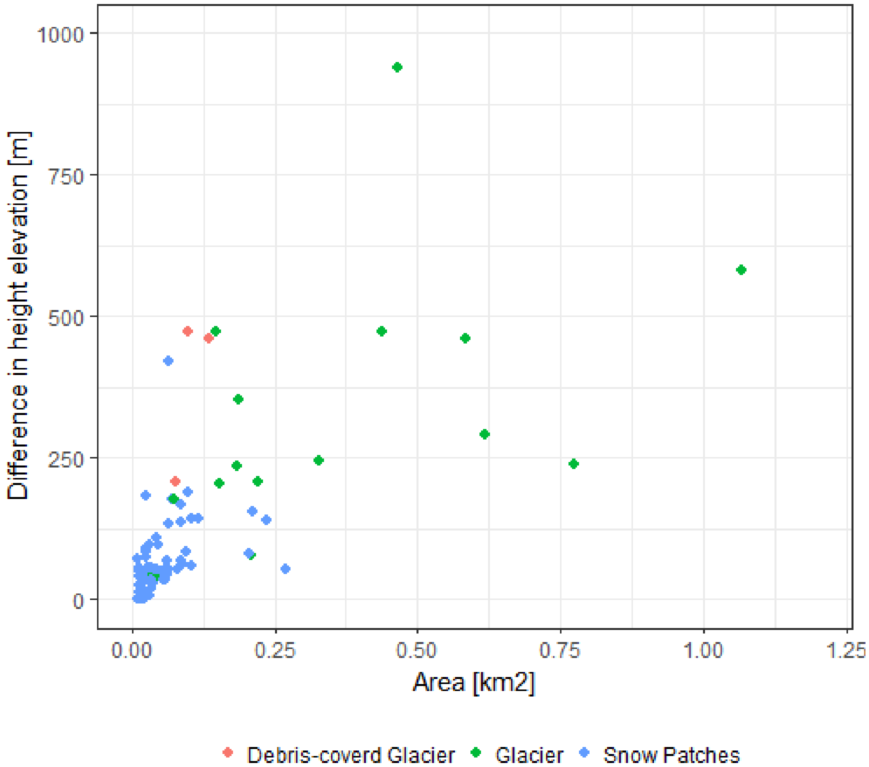

Figure 19: Scatterplot of Glacier, debris-covered Glacier and snow patches. The blue rhombohedra are the snow patches, the green rhombohedra are the glaciers and the red rhombohedra are the debris-covered glaciers in the study area based on the data set of the Argentine glacier inventory. X-axis shows the area in km^2 and the y-axis the difference in height elevation in meters [m].

5.3.2 Results of ASTER and Sentinel-2 inventories

The results of the comparison between the ASTER inventory and the Sentinel-2 inventor are displayed in Figure 20 for the Veladero mine (A) and Conconta Pass (B). The ASTER inventory contains only the features that exist after the inventory is compared to the Argentine glacier inventory. The same applies for the Sentinel-2 inventory. For comparison to the previous figures, only features that have an area larger than 0.05 km^2 in the Argentine glacier are included in the ASTER and Sentinel-2 inventories. Figure 20A shows features AGI_06, AGI_25, AGI_31, AGI_32, AGI_33 and AGI_50 in the mining area near the border of Chile. The features that have an orange border are enclosed by a blue border. This means that the features of Sentinel-2 inventory are completely enclosed within the features of the ASTER inventory. The ASTER inventory contains of seven features. In the Sentinel-2 inventory 12 features are mapped.

The ASTER inventory includes 23 features in Figure 20B. The Sentinel-2 inventory contains 29 features in this area. The orange Sentinel 2 features are enclosed by the blue ASTER features and are smaller in dimension.

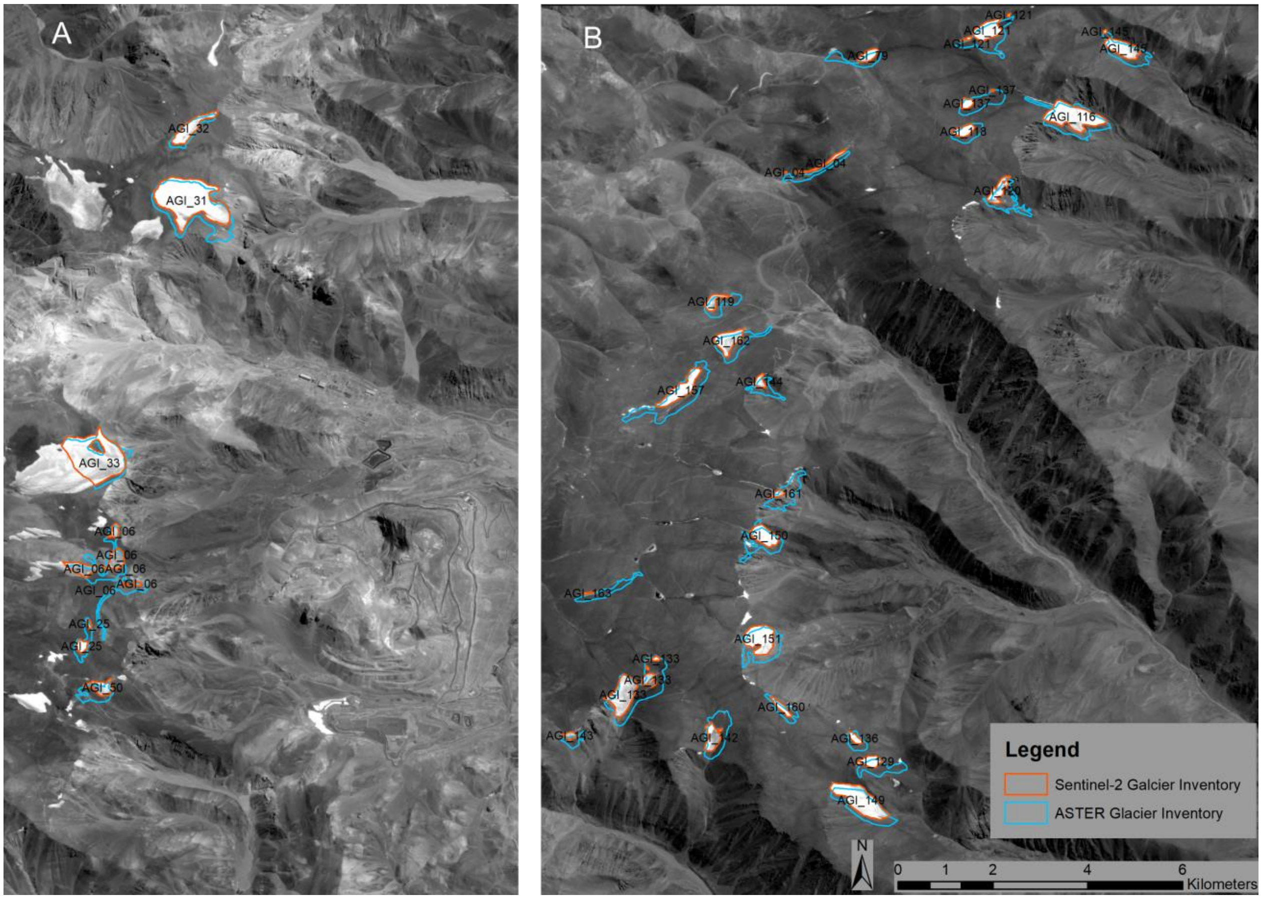

Figure 20: Features that were mapped with the ASTER and Senintel-2 satellite image are shown. The ASTER inventory features are shown blue and the Sentinel-2 inventory in orange. (A) displays features of the ASTER and Seintnel-2 inventories at the Veladero Mine and (B) at the Conconta Pass. The satellite image of the Sentinel-2 was used as background image. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

The results for the four inventories are illustrated in Figure 21. The Argentinean glacier inventory includes only those features that have an area larger than 0.05 km^2. The other three inventories contain only the features that exist after the inventory is compared to the Argentine glacier inventory. At the Veladero mine (Figure 21A) the features AGI_06, AGI_25, AGI_31, AGI_32, AGI_33 and AGI_50 are shown. The Features AGI_06, AGI_25, AGI_31 and AGI_32 have a green, black, blue and orange border. This means that these features appear in all four inventories. The features AGI_33 and AGI_50 each have a green, blue and orange border. These features can be found in the Argentine glacier inventory as well as in the ASTER and Sentinel-2 inventory. However, both of this feature do not appear in the CEDHA inventory. The Feature AGI_32 has, with exception of the CEDHA inventory, almost the same size in all the other inventories. At the Conconta Pass (Figure 21B) the features AGI_129 and AGI_163 are not included in the CEDHA inventory. These features can be found in the three other inventories. All other features are found in all four inventories. However, the features have different sizes and are partly divided into several smaller features. This is especially noticeable in the Sentinel-2 inventory. This observation applies to the Veladero Mine as well as to the Conconta Pass.

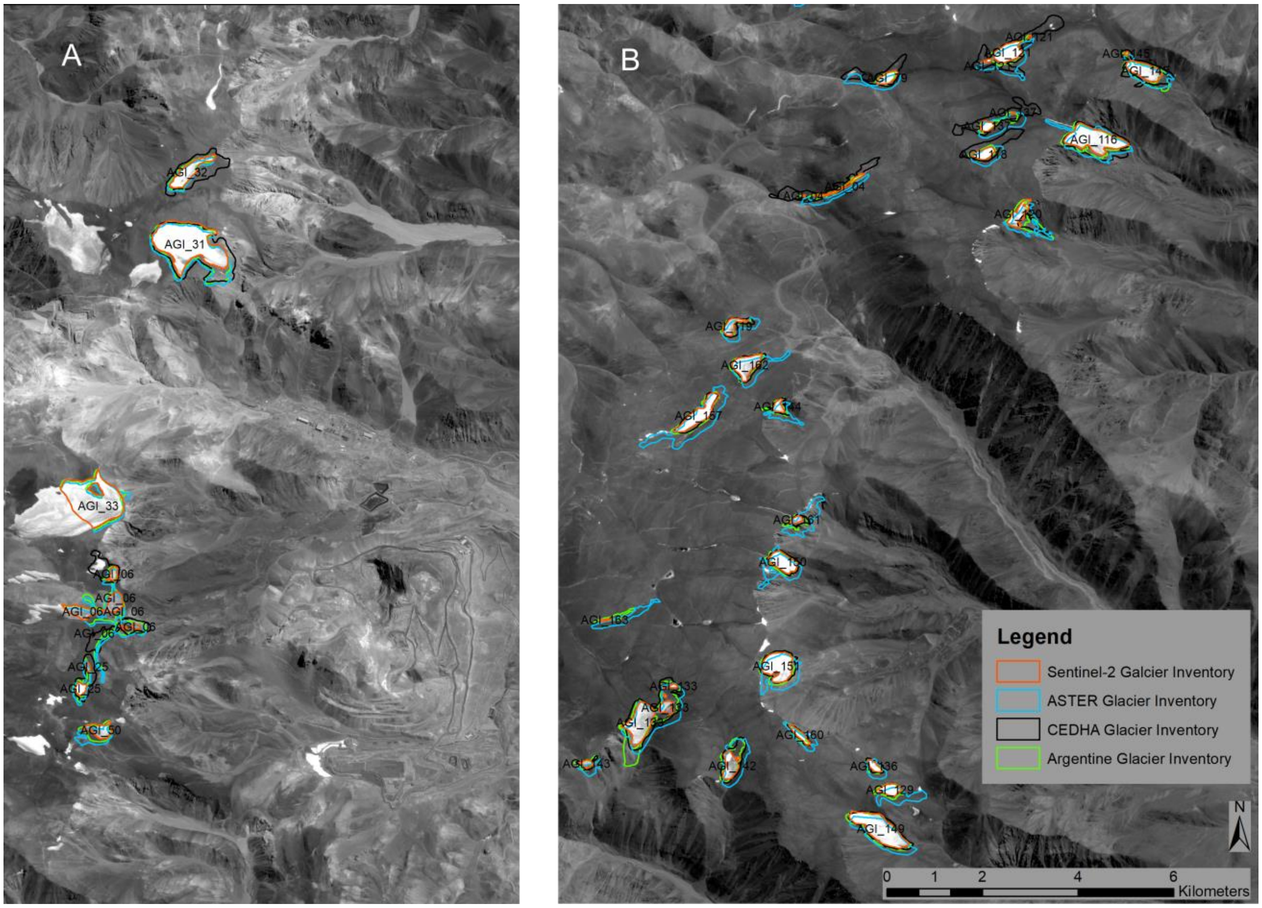

Figure 21: The four inventories are shown to display the difference between each inventory. Argentinean glacier inventory that have an area greater than 0.05km² are displayed in green. The features of the inventory of the organization CEDHA are displayed in black. The ASTER inventory and the Sentinel 2 inventory are shown in blue and orange. (A) displays the features around the Veladero mine and (B) the features at the Conconta Pass. The satellite image of the Sentinel-2 was used as background image. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

Table 25 shows the number of classified features, their area in km^2 and the difference in area of the data sets compared to the Argentine glacier inventory. The first three entries of the table show these values for all elements corresponding to the features in the Argentine glacier inventory that are larger than $0.05km^2$. It is noticeable that the Sentinel-2 inventory has the largest number of classified features, but has the smallest area with 5.62 km^2. In contrast, the CEDHA inventory has the lowest number of classified features, but its total inventory area is the closest with 9.32 km^2 to the Argentine glacier inventory area. The ASTER inventory classifies almost the same number of features as the Argentine glacier inventory. However, the ASTER inventory has a total area size of 10.25 km^2 and thus about 2 km^2 more than the Argentine glacier inventory.
The second half of table 25 shows the same entries when calculated using all features that are present in the Argentinean Glacier Inventory as well as in the other inventories. It is noticeable that all inventories have almost the same amount of features, but differ in their areas. The Sentinel-2 inventory is still the smallest, with and area of only 5.98 km2 it is 0.65 times smaller than the area of the Argentine Inventory. The difference between the two analyses is greatest in the number of features, but the areas have not changed much.

Table 25: A comparison of the number of classified feature, their area size in km^2 and the share of the area compared to the argentine glacier inventory with areas > 0.05km^2 and with all features of the Argentine glacier inventory.

	Argentine glacier inventory	CEDHA	ASTER	Sentinel-2
Number of features > 0.05 km^2	42	35	48	63
Area [km^2] for features > 0.05 km^2	8.30	9.32	10.25	5.62
Difference in area for features > 0.05 km^2	1.00	1.12	1.23	0.68
Number of features total	81	92	91	97
Area [km^2] for all features	9.25	10.18	11.53	5.98
Difference in area for all features	1.00	1.10	1.25	0.65

5.3.3 Inventories with Infrastructures

Figure 22 illustrates the vicinity of the different glacier inventory features to the mining operation. For this purpose all features are displayed, including those smaller than 0.05 km^2 and also rock glaciers. In case of the inventories of CEHDA, ASTER and Sentinel-2 also the feature that were previously excluded are now displayed in Figure 22.

In the data set of the Argentinian glacier inventory two features are directly affected by the mining activity, more specifically due to road construction. In the concession area of the mine there are 17 features for the Argentinian glacier inventory. The inventory of the organization CEDHA has one feature affected by roads. 20 features of the CEDHA inventory are in the area of the mining concession. In the inventories of ASTER and Sentinel-2 no features are directly affected by infrastructure. However, in the ASTER inventory, 14 features are located in the mining concession area. 16 features of Senintel-2 inventory lie in the area of the mining concession (Figure 23).

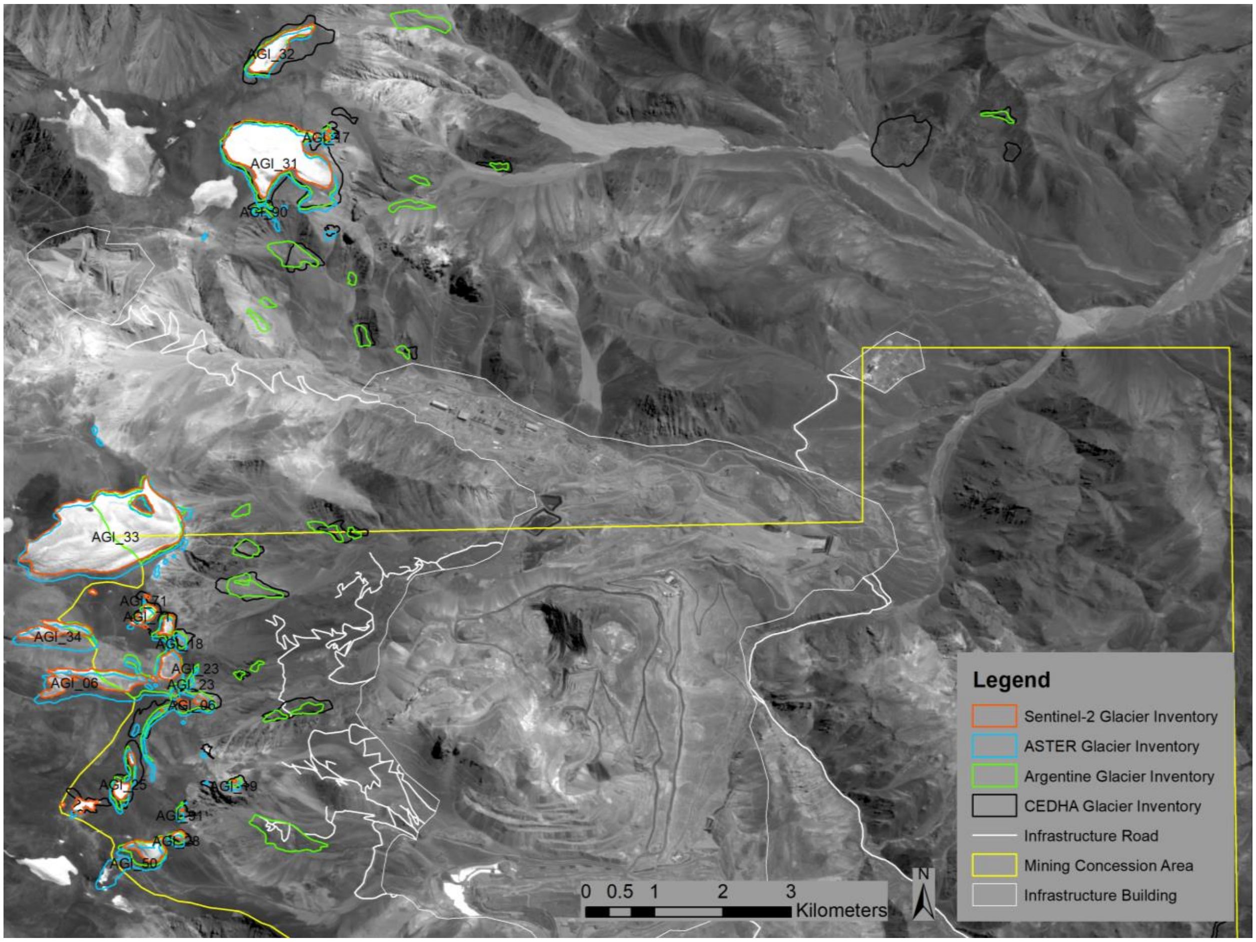

Figure 22: An overview of the classified glacier features in vicinity to the mining site. The features from the Argentinean glacier inventory are displayed in green. The features of the inventory of the organization CEDHA are displayed in black. The inventory generated from the ASTER satellite image have the color blue and the inventory generated from Senintel-2 shown in orange. The road and building form the mining operation are shown in white. The area of the mining concession at the Veladero mine is indicated in yellow. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

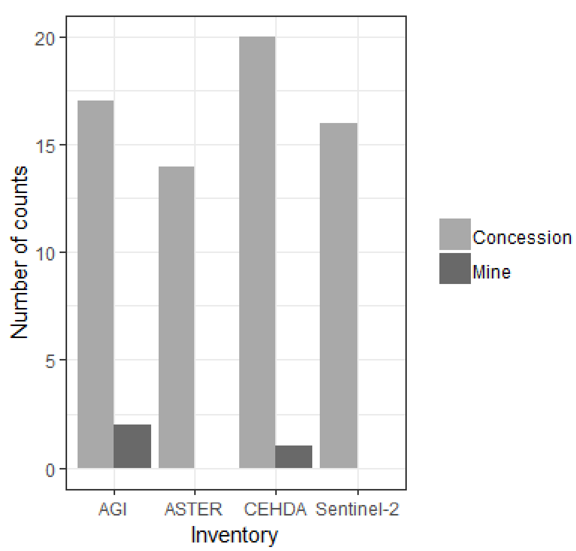

Figure 23: Number of features affected by the mining infrastructure (mine) and the miming concession (concession).

Figure 24 shows the road leading over the Conconta Pass to the mine. The figure shows the four inventories and their vicinity to the road, using all features of all four inventories. There is no feature in the Argentine glacier inventory that is directly affected by the road. One feature each of the CEDHA and the ASTER inventory are directly affected by the road. In the Sentinel-2 inventory no features are affected. However the Figure 24 shows that glacier features can be very close to the road.

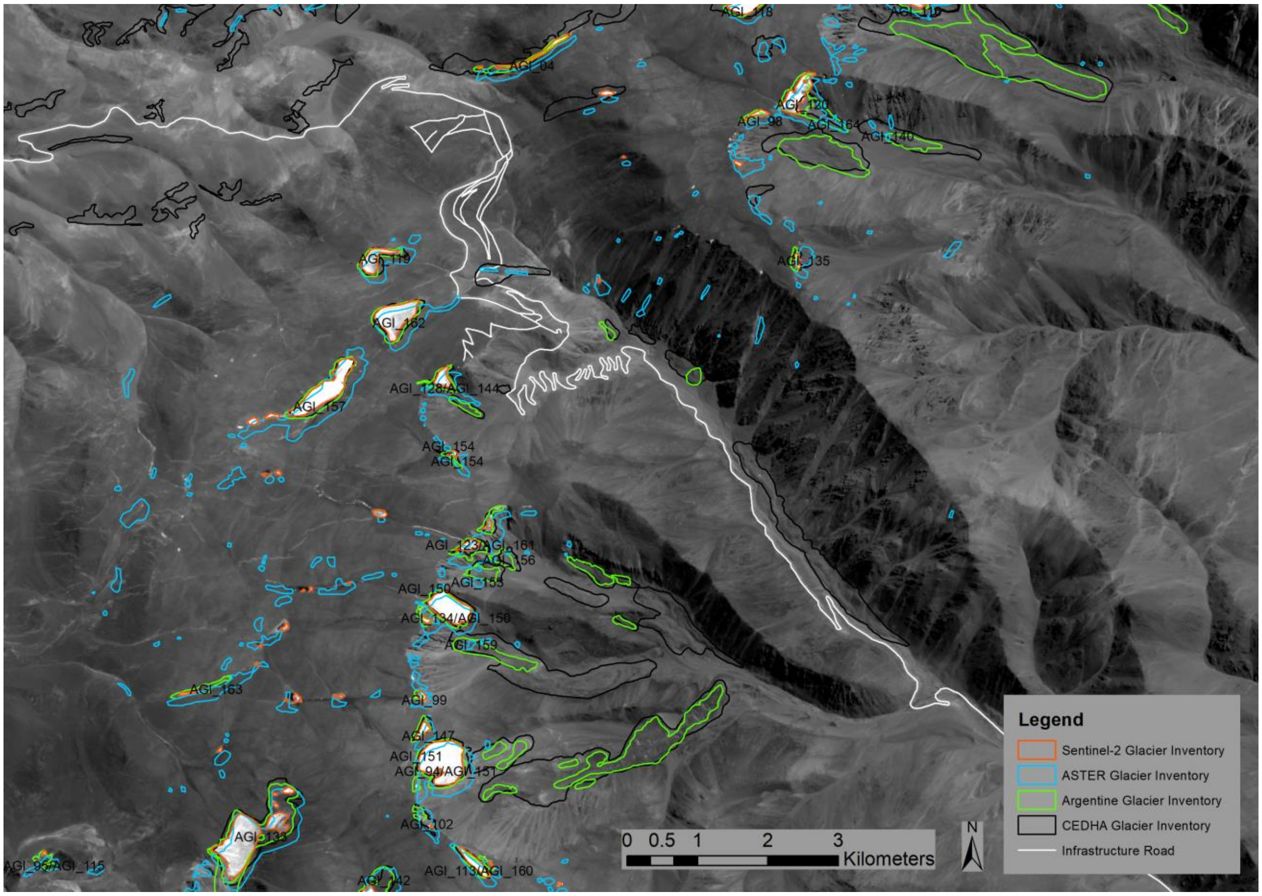

Figure 24: An overview of the classifies glacier features in vicinity to the Conconta pass road leading to the mine. The features from the Argentinean glacier inventory are displayed in green. The features of the inventory of the organization CEDHA are displayed in black. The inventory generated from the ASTER satellite image have the color blue and the inventory generated from Senintel-2 have orange. The road is shown in white. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

The dataset of the permafrost zonation index illustrates the relationship between mining infrastructure and mining concession area and the possibility of permafrost in the area (Figure 25). The permafrost zonation index indicates the conditions under which permafrost is present. The light color, i.e. a value of about 0.01, shows that in this area permafrost is only present under favorable conditions. As soon as the value approaches 1 and turns blue, permafrost is almost abundant everywhere (Gruber, 2012). In the area of the concession as well as of the mine infrastructure, both the light and the dark colors of the permafrost zonation index are present. However, most of the infrastructure lies in the light color.

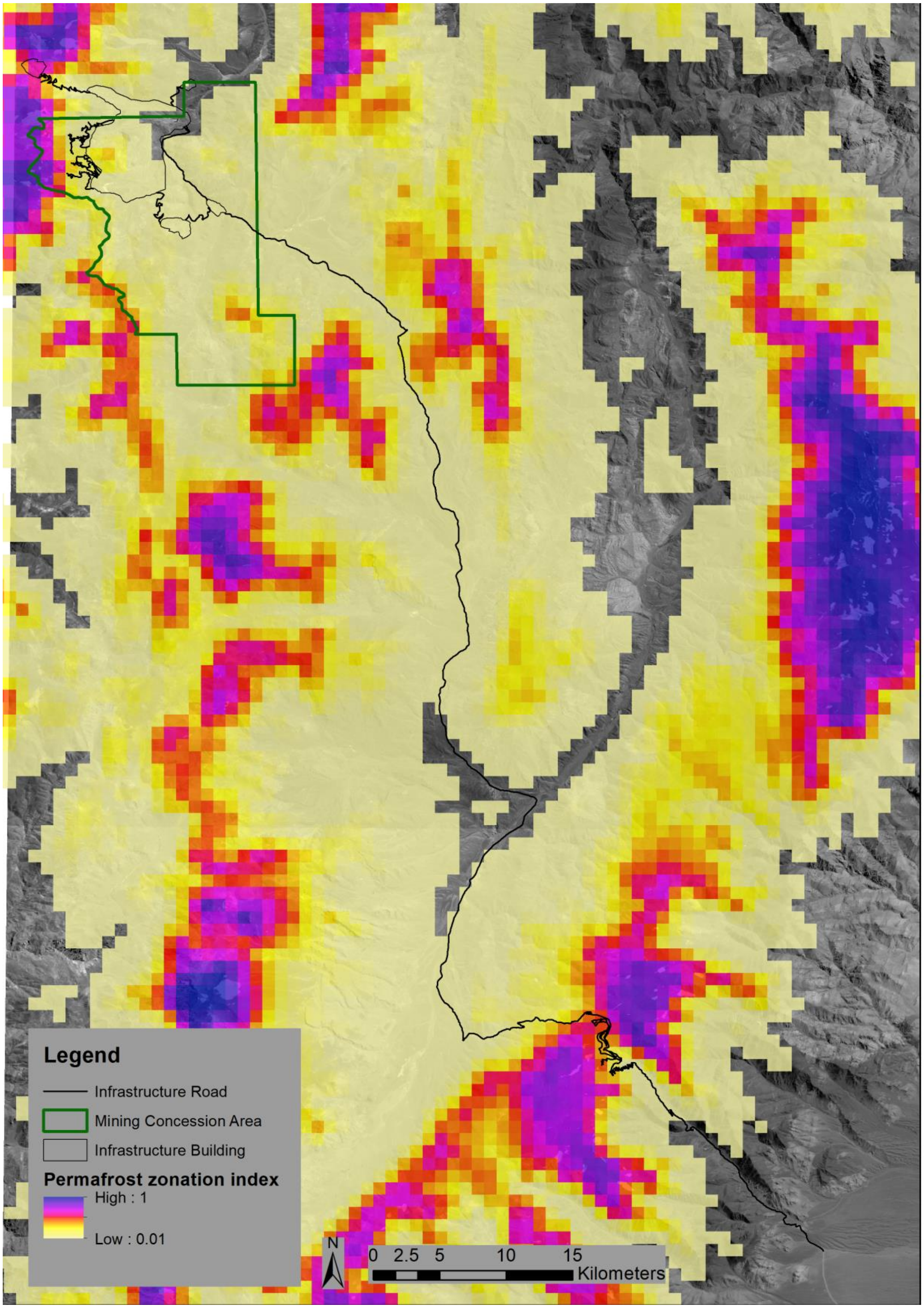

Figure 25: The permafrost zonation index as well as the infrastructure of the Mine and the area of the mining concession. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

In Table 26, the areas of the four different inventories are divided according to the watershed area. A distinction is made whether the water is produced at the mine or further down in the catchment area. The percentage of the area was calculated from the total areas of each dataset. The inventories of CEDHA, ASTER and Sentinel-2 only include features that correspond to the Argentine glacier inventory. It is noticeable, that the areas of the Argentine Glacier Inventory, CEDHA Inventory and ASTER Inventory close to the mine have almost the same size (3.31-3.48 km^2). The CEDHA and ASTER inventory also have almost the same percentage at and below the mine. The Sentinel-2 inventory has the highest percentage of 40.76% at the mine area. In the lower part of the catchment area, the Sentinel-2 inventory has the lowest percentage of 59.24%. For all four inventories, the area and percentage in the catchment area close to the mine is smaller than in the catchment area below the mine.

Table 26: The area by the mine and below the mine in relation to the watershed for each dataset.

	Argentine glacier inventory	CEDHA	ASTER	Sentinel-2
Area by mine [km^2]	3.31	3.06	3.48	2.44
Area by mine [%]	35.83	30.02	30.13	40.76
Area below mine [km^2]	5.93	7.13	8.06	3.54
Area below mine [%]	64.17	69.98	69.87	59.24

5.4 Water equivalent and contribution of all ice/debris landforms

Table 27 lists the water equivalent of the data set of the Argentine glacier inventory over the entire study area and the water equivalent of the Argentinean glacier inventory broken down by watershed. The watershed is divided into the watershed close to the mine and below the mine. Detailed information is given in the appendix D. The glaciers and rock glaciers have almost the same area over the total area and also the water equivalent is in the same order of magnitude. With 3.4145 km^2 snow patches have the smallest area and also the smallest water equivalent with 0.0137 km^3. The glaciers near and below the mine have the same area of around 2.9 km^2 and a water equivalent of between about 0.05-0.06 km^3. Both snow patches and rock glaciers have a smaller area and water equivalent near the mine than further down in the catchment. Rock glaciers have the largest water equivalent below with 0.644 km^3. The snow patches have the lowest water equivalent with 0.0021 km^3 in the mine's catchment area and have a water equivalent of 0.0116 km^3 in the catchment area below the mine, which is about 5 times greater than by the mine.

Table 27: The water equivalent for glacier, snow patches and rock glacier for the Argentine glacier inventory.

	Glacier	Snow patches	Rock glacier
Total area [km^2]	5.8330	3.4145	5.4627
Water equivalent for total area [km^3]	0.1049	0.0137	0.0848
Area by mine [km^2]	2.8969	0.4160	1.4896
Water equivalent by mine [km^3]	0.0482	0.0021	0.0204
Area below mine [km^2]	2.9361	2.9985	3.9731
Water equivalent below mine [km^3]	0.0567	0.0116	0.0644

The water equivalent for the Sentinel-2 inventory was calculated for features in the inventory that are divided by their size (Table 28). By taking a threshold for the division of the feature of 0.01 km^2, the water equivalent for features larger is about 0.0780 km^3 and for features smaller than 0.01 km^2 about 0.0002 km^3.

Table 28: The water equivalent for features >0.01 km2 and features < 0.01 km2 from the Sentinel-2 dataset.

	Area [km^2]	**Water equivalent [km^3]**
Features >0.01 km^2	5.8917	0.0604
Features <0.01 km^2	0.3046	0.0002

6. Discussion and Interpretation

In this section the qualitative and quantitative results are discussed and compared. In a first section the results of the content analysis are compared separately from the Glacier mapping and GIS Analysis. In a second section the results of the Glacier mapping and GIS Analysis are discussed individually. Finally, the different results are related to each other and interpreted.

6.1 Definition, Value and Boundaries of Glacier for different stakeholders

The stakeholders “Law”, “Environmentalists” and “CEDHA” understand glaciers in the same way (Table 21; Figure 15) These three stakeholders include the terms glacier, glacieret and snow patches as a definition for a glacier. This is essential for this stakeholder group. However, the terms glacieret and snow patches have been added because of the form and size a glacier should have according to them. All three actors say that shape and dimension are irrelevant. For this reason, the terms glacieret and snow patches have been included in the definition of glacier for the stakeholders “Law”, “Environmentalists” and “CEDHA”. In contrast, the stakeholders “Guidelines”, “Science community” and “Mining company” define a glacier as the term glacier. Cogley et al. (2011) define a glacier as "A perennial mass of ice, and possibly firn and snow, originating on the land surface by the recrystallization of snow or other forms of solid precipitation and showing evidence of past or present flow". This definition has been used to form the sub-category Glacier. However the definition of Cogley et al. (2011) is used in the stakeholder “Guidelines” as part of the documents. This may result in some bias in the definition of glaciers since the document was used to define categories as well as it was used as information for the stakeholder. This means that the term "glacier" is not independent for the stakeholder "guidelines". The stakeholder “Mining company” did not define the term glacier as an explicit statement. For example, the mining company describes glaciers in the Pascua-Lama project as "[...] the bodies of ice at Pascua-Lama lacked characteristics of "traditional" glaciers such as flow and basal sliding [...] (Li, 2018)”. From this quote the assumption is made that the stakeholder “Mining company” understands glaciers as defined by Cogley et al. (2011). The “Inventory” has chosen a path between the stakeholder group of “Law”, “Environmentalists” and “CEDHA” and the stakeholder group of “Guidelines”, “Science community” and “Mining company”. The “Inventory” includes both glacier and glacieret in the definition of glacier. As with some other stakeholders, the “Inventory” must be handled in the same way as the non-explicit mention of names. The “Inventory” defines glaciers as follows: "Glacier (uncovered and covered): permanent body of ice generated on the ground from the recrystallization of snow and/or ice due to the compaction of its own weight, without or with significant debris cover, visible for periods of at least two years, with evidence of movement by gravity (…) or not (*) and of an area greater or equal to 0.01 km^2 (one hectare). Glaciers can have different morphologies. (*) This definition of glacier includes permanent patches or fields of snow that, as they have no evidence of movement, are generally not considered glaciers. However, permanent blotches or snowfields are significant reserves of solid-state water (IANIGLA -CONICET 2010)". From this statement the allocation to the categories glaciers and glacieret is made, since everything larger than 0.01 km^2 is included in these two categories. The threshold value 0.01 km^2, as used by the stakeholder "Inventory", is the value according to Leigh et al. (2019) used in most scientific publications for mapping glaciers (Table 2).

The definition, values and boundaries play an important role for the inventory of the respective stakeholders (Tables 22 to 24). The analyses revealed that in the category “Definition” the stakeholders “Law”, “Environmentalists” and “CEHDA” included the same sub-categories (Table 22). The important features that need to be included in an inventory according to this group are glaciers, glacieret, snow patches, rock glaciers and periglacial environment. Since the stakeholder’s “Environmentalists” and “CEDHA” always refer to the GPL, it is not surprising that their definitions for an inventory are consistent with the “Law”. On the other hand, the definition of an inventory for the stakeholder “Inventory” includes the categories glacier, glacieret and rock glacier. The term glacieret has been added to the inventory because of its size and the fact that it is not flowing. As mentioned above the “Inventory”group did a compromise between the “Law” and the “Science community”.
In contrast to the Stakeholders “Law”, “Environmentalists”, “CEHDA” and “Inventory”, the “Mining company” only includes glaciers in an inventory. However, it should be mentioned that the available text documents for this stakeholder group were too limited in length and too superficial in terms of defining or including features in an inventory. To obtain more information about this stakeholder in relation to the category "definition", an interview would have to be conducted. It is questionable, however, whether the stakeholder "Mining company" would be willing to do so, because this information could harm the stakeholder.
There are certain differences between the stakeholder “Guidelines” and the “Science community”. Depending on the definition, only glaciers or glaciers and glacierets can be included in an inventory. Furthermore, there are also differences and discrepancies in the Stakeholder “Guidelines” itself. The UNESCO document (1970) describes that rock glaciers as well as glacierets and snow patches should be included in an inventory as soon as they contain a certain volume of ice or have a certain size. These features must be taken into account considering a hydrological purpose.
Other periglacial features have also to be considered (International Commission of Snow and Ice, 1970), depending on the value or the purpose of an inventory (Table 23). Consequently, different purposes require the inclusion of different features in an inventory. For example, if an inventory is used to determine climate change, it is necessary to include the glaciers in this inventory. However, if an inventory aims additionally to observe water resources, all features for water reservoirs (e. g. rock glaciers or snow patches) have to be included. All stakeholders see the “Water resource” as the value for an inventory. However, only the stakeholders “Inventory”, “Environmentalists” and “CEHDA” see the value “Water resource” as the only value of an inventory. In contrast, the other stakeholders have included additional values to an inventory. The “Law” and the “Science community” have defined the values “Archive”, “Environmental” and “Society goods” in addition to the value “Water resource”. In contrast to the “Science community”, the stakeholder group “Guidelines” does not include the value “Environmental” in their values for an inventory. One reason for this could be that the “Guidelines” are kept very general and do not focus on the environment. The “Mining company” also defined the value of an inventory as a “Manageable good”. According to the mining company of the Pascua Lama project and Veladero mine, part of a glacier is removable and can be deposited onto another glacier (Barrick Gold, 2001). This sub-category was therefore defined specifically for mine operators. The other stakeholders do not consider the features as manageable goods.
A very central aspect is the category “Boundaries” (Table 24). The “Inventory”, “Guidelines and “Science community” have defined a threshold for the boundaries of the analyzed features. The “Inventory” elaborates that features smaller than 0.01 km^2 are not included in the inventory (IANIGLA -CONICET, 2010). This boundary of areas also corresponds to the threshold that is

common practice in “Guidelines” and “Science Community”. Leigh et al. (2019) have compiled a list of the thresholds used for glaciers (Table 2). These thresholds range from 0.01 km^2 to 0.25 km^2 (Leigh et al. 2019). In contrast, the Stakeholder “Law”, “Environmentalists”, “Mining company” and “CEDHA” express that there is no size or threshold defined for a feature. In the case of the “Mining company”, however, it could be argued that they assume a certain size or threshold for a feature. One argument is that, as mentioned above, the “Mining company” has a similar definition of glaciers as the “Guidelines”. Furthermore, the stakeholder “Mining company” always speaks of "ice reservoirs”, “ice fields”, “glacierets” and “ice features” which could also imply boundaries between different features. Therefore, this point is very uncertain. The stakeholders “Environmentalists” and ”CEDHA” refer to the statement of the GPL in this point, which says that neither form nor dimension and state of conservation matter (Argentine National Glacier Act, 2010). Therefore, the stakeholder “Law”, “Environmentalists” and “CEDHA” state that there is no boundary or threshold for a feature like glaciers or rock glaciers.

In general, the textual approach has given a good overview of the existence of documents for the different stakeholders. One difficulty was that not the same amount of suitable material was available for all stakeholders. Moreover, some documents were written in Spanish, which was an additional challenge, since part of them had to be translated for better understanding. Furthermore, a limitation of the text analysis is that the text documents were selected and instead of thorough literature review being done beforehand. The approach of Kuckartz (2016) of the “inhaltlich strukturierende qualitative Inhaltsanalyse” has proven to be a good approach to analyze the text documents in terms of definition, value and boundaries. The advantage of this approach is that in a first step the main categories are formed. In a second step the approach allows to create subcategories based on the existing texts. The most important tool is the thematic matrix, which is listed in Appendix B. Tables 21, 22, 23 and 24 and Figure 13 are derived from this matrix.

6.2 Glacier Inventory analysis

The comparison of the four different inventories revealed, that there are only few differences in the classification of the features (Figure 21).
First of all, a shift in the ASTER data that could not be corrected was observed. However, this shift does not play a central role for any analysis made in this thesis, because it is only an offset in the orders of magnitude and not methodologically created. In addition, the NIR band was used instead of the SWIR band for the ASTER Inventory for the mapping of the glaciers which is not a common procedure in the field of remote sensing. The reason for using the NIR band was that a band ratio was formed. This band ratio allowed to automatically map the glaciers with a certain threshold value. In order to check the mapping, the data of the ASTER inventory was combined with the respective satellite images and obviously incorrect mapped glaciers were deleted. This manual adjustment and the fact that the ASTER data may have produced incorrectly mapped features needs to be considered for the analysis.
In general, all features are present in all inventories except AGI_33, AGI_50, AGI_129 and AGI_163. These four features are not present in the inventory of the CEDHA organization (Figure 21). However, since these features are found in the other three inventories, it can be assumed that the classification of these features is valid. The reason why these features are not included in the CEDHA inventory is not apparent from the data and cannot be determined with the help of the report of Taillant (2013).

The feature AGI_32 has almost the same size in the Argentine glacier inventory, the ASTER inventory and the Sentinel-2 inventory, but in the CEDHA inventory this feature is much larger (+ 0.31 km^2). This difference in size between the CEDHA inventory and the other inventories cannot be explained by the time gap of 11 years between the two imaging campaigns for the Argentine glacier and the Sentinel-2 inventory. Indeed, during this time the size and shape of the feature has not changed much in the two inventories. However, in general, the size of glaciers can fluctuate significantly.
The feature AGI_06 has a different sizes in all inventories. Furthermore, this glacier only classified as a single feature in the Argentine glacier inventory and is divided into several features in the other inventories. One possible reason for the separation is that a part of the glacier is covered by debris and could not be identified as a coherent feature by the automatically generated inventories. This is most likely the case with the ASTER inventory, because there is only a small gap between the two parts of the feature AGI_06. This gap is not visible in the Argentinean inventory. However, it is difficult to see if debris covers this feature on the ASTER satellite image. The features of the Sentinel-2 inventory are all located within the Argentine glacier inventory and the ASTER inventory. Nonetheless, it is not possible to conclude whether the ice or snow is covered with debris or just melted. In the CEDHA inventory this feature consists of two characteristics, but the shapes of the features in the CEDHA inventory do not match the shapes of the Argentine glacier inventory. This is partly due to the fact that the areas were not always mapped on the basis of the same satellite image and that probably other criteria were taken into account. Anyway, a limitation of these analyses is that the different inventories can only be compared with each other and no other information from independent studies are currently available.

For the evaluation of the rock glaciers, the high-resolution satellite and aerial imagery provided by ESRI is used. This dataset is of overall good quality, but aerial images of even higher resolution would have been needed for a better evaluation of the rock glaciers. There are also differences in the data sets from the Argentine Glacier Inventory and the CEDHA Inventory. In the first, active and inactive block glaciers have already been marked. This is not the case for the CEDHA Inventory. As with the glaciers, not all features of the rock glaciers are available in both inventories. The CEDHA inventory has not classified nine rock glaciers which are found in the Argentinean inventory at the Veladero Mine (Figure 17). Among these unmapped rock glaciers are five that were classified as "Certain" or "Less Certain" in the Argentinean glacier inventory. The reason why these were not mapped in the CEDHA inventory is unclear. However, these rock glaciers should be included in the inventory as they can be identified with a fairly high degree of certainty as rock glaciers. In addition, the rock glacier that was in turn mapped in the CEDHA inventory, but not in the Argentine glacier inventory, is classified as very uncertain. One possible reason for this is that it looks more like a landslide than a rock glacier on the satellite images. In order to clarify this, high resolution aerial photographs and a field survey would be required.
Moreover, the actual distribution of the assigned features to quality classes in the two inventories is different. The CEDHA inventory also contains features that have the quality criterion "None". These features probably should have been assigned to snow patches. But this was not possible because snow was not always visible on the satellite images. If this quality class would not be considered in the CEDHA inventory, the inventory would include 47 features. Instead, the Argentine inventory has almost twice as many mapped features as the CEDHA inventory. This is probably due to the case, as described above, that not all rock glaciers have been mapped in the CEDHA inventory. However, it is not obvious why these rock glaciers were not included in the CEHDA inventory. Differences in the quality criteria distribution are also to some degree caused

by the different mapping (different size and shapes) of the rock glaciers in the two inventories, which might result in different quality assignments. The different mapping is a result of the fact the rock glacier's boundaries are not always clearly visible on satellite image. As with glaciers, the lack of independent studies make the comparison of the rock glaciers difficult.

The glaciers have a larger distribution in terms of area and difference in height elevation (Figure 19). Most of them have an area between 0.125 km^2 and 1.05 km2 and an elevation difference between 250 and 850 meters. This area range is not unusual for glaciers. However, there is one outlier, which has an estimated area of about 0.075 km^2 and an estimated difference in height elevation of 190 meters. This is much lower than the other glaciers both in area and elevation difference. Therefore, this outlier could have been mapped wrongly as glacier and is rather a snow patch.

In comparison to glaciers, snow patches and debris-covered glaciers have a lower relief and a smaller area. For example, the debris-covered glaciers have an area between 0.075 km^2 and 0.15 km^2, which is much smaller than that of the glaciers. However, two of the three debris-covered glaciers also have a higher relief of a little less than 500 meters. These two debris-covered glaciers are located in the same area where the glaciers are located (Figure 19).

Compared to glaciers and debris-covered glaciers, snow patches are much smaller. Most snow patches have an area of less than 0.015 km^2, only a few exceptions are between 0.15 km^2 and 0.3 km^2. However, most snow patches are quite small, as can be seen by the fact that most snow patches cluster in the lower left corner of the scatterplot. This finding agrees with Cogley et al. (2011) that show that snow patches have a restricted extent. Furthermore, most snow patches have a elevation difference of less than 250 meters. The majority of these snow patches even have a relief of less than 125 meters, which is small compared to glaciers and debris-covered glaciers. An exception is one outlier in the snow patches, which has an elevation difference of about 400 meters, an area of about 0.75 km^2 and a very high relief, This could be an indication that the feature was identified wrongly as a snow patch and is most likely a glacier instead.

To allow for a comparison between the individual inventories, the areas of the four inventories were compared. It can be observed that the threshold value of 0.05 km^2 has no great influence on changes in area, but on the number of features (Table 25). The Sentinel-2 inventory has the smallest area, but the largest number of features compared to the other inventories. One reason for the large number of features in the Sentinel-2 inventory is that this inventory consists of many small features (Figures 20 and 21). Because of these small features, the small total inventory area of the Sentinel-2 inventory can be explained. However, while satellite images from 2020 have been used to map the Sentinel-2 inventory, the Argentine and ASTER inventories are based on satellite images from 2009. Hence, the smaller areas in the Sentinel-2 inventory might be also explained by a general decrease in the size of the glaciers in this area (Rabatel et al., 2011). However, in order to investigate whether this is the reason, the course of precipitation in this region would have to be analyzed.

The ASTER inventory has the largest area. As mentioned above, the usual spectral bands were not used for this inventory, which might have an impact on the resulting size of the inventory and might lead to a slight overestimation of the actual glacier inventory. Indeed, compared to the Argentine glacier inventory the area of the ASTER-Inventory is about 2 km^2 larger. The CEDHA inventory has almost the same area as the Argentine glacier inventory. This is surprising, because as mentioned above, some features are missing in the CEDHA inventory, which are present in the Argentine glacier inventory. This leads to the conclusion that some of the features in the CEDHA inventory are larger than those in the Argentine glacier inventory, which this could be explained by the use of different satellite images.

The spectral analyses revealed how close the infrastructure is to the glaciers and the periglacial environment (Figures 22, 24 and 25). For the mine area itself, only features from the Argentinean glacier inventory and the CEDHA inventory are directly affected by the mining activity. Further comparison reveals that these features are rock glaciers (Figure 17). This explains why the ASTER and Sentinel-2 inventories are not directly affected by the mine, since only glaciers and snow patches are included in these inventories. Between 14 and 20 features, depending on the inventory, are located in the mining concession. The ASTER inventory has the fewest and the CEDHA inventory has the most features mapped in the mining concession area. One reason for the different number of included features could be that the Argentinean glacier inventory and the CEDHA inventory also include rock glaciers, which vary in the different inventories.
The influence of mining operations on these glacial features is difficult to determine as there is no evidence of buildings or roads in the vicinity of these features. However, the features in the mining concession area are potentially threatened by the mining activity as the mining concession allows the mine operators to mine ore and conduct exploration work in the area. In the case of Conconta Pass, features of CEDHA and ASTER inventory are directly affected by the road. Why the Argentine glacier inventory and the Sentinel-2 inventory are not directly affected in that region remains unclear. However, all inventories are close to the road and therefore potentially at risk (Figure 24). In addition, the access road and mining infrastructure are located in the area where permafrost can occur (Figure 25). Most of the infrastructure is located in areas , where permafrost can occur under favorable conditions. However, it is not clear whether the permafrost would be affected by the mine. A field study would be required to better understand the permafrost in this region.

The CEDHA and ASTER inventories have almost the same percentages for the areas above and below the mine (Table 26). For the Argentine glacier inventory, the percentages for the area at the mine are slightly higher and below the mine are slightly lower than in the previously mentioned inventories. One reason for this is certainly that the total area of the Argentine glacier inventory is smaller. However, the area percentage at the mine in the Argentine glacier inventory is almost the same as in the ASTER inventory. The area percentages for Sentinel-2 are about 40% at the mine and 60% below the mine. This is a significant change from the other inventories. One reason may be that there has been greater melting of ice and snow masses below the mine, as the Sentinel-2 inventory is based on images from 2020. Further investigation is needed to determine the reason for those changes. The dust input from the mining vehicles on the access road might have been an influence. Another possibility is that the precipitation regime further down has changed more than at the mine area. However, this needs further investigation and could not be done in the scope of this thesis.

For the Argentine glacier inventory, the water equivalent has been calculated and divided into glaciers, snow patches and rock glaciers. The assessment of the results from the water equivalent calculation for the Argentinean glacier inventory was challenging because only few studies with the same objective exist, and they differ in their study parameters. The area size of the glaciers and rock glaciers is almost equal, 5.83 km^2 and 5.46 km^2, respectively. These areas result in a water equivalent for glaciers of 0.1049 km^3 and 0.0848 km^3. Nicholson et al. (2009) made an inventory for glaciers and rock glaciers in the Upper Huasco Valley. In their study, the areas of glaciers and rock glaciers are estimated at 16.86 km^2 and 6.30 km^2 respectively. The water equivalent for the glaciers is 539.10*10^6 m^3 and for the rock glaciers 75.65*10^6 m^3. In order to compare the water equivalent between the Argentinian glacier inventory and the inventory of Nicholson et al. (2009), the numbers of Nicholson et al. (2009) have been converted into km^3. With this conversion the glaciers in the inventory of Nicholson et al. (2009) have a water equivalent of 0.5391 km^3 and the rock glaciers of 0.07565 km^3. The water equivalent for glaciers of the Argentinian glacier inventory and of Nicholson et al. (2009) are difficult to compare, since the size is very different and the ice volume was calculated differently. However, when comparing the rock glacier of the Argentinean inventory with the rock glacier of Nicholson et al. (2009), it appears that the water equivalent is almost the same. Although the area of the rock glaciers of Nicholson et al. (2009) is larger than the Argentinian glacier inventory, a lower water equivalent was calculated than the rock glaciers of the Argentine glacier inventory. One reason for this is that in the study by Nicholson et al. (2009) assumed the thickness of all rock glaciers to be more than 30 meters and the density of ice to be 0.8 kg/m^3 for the rock glacier. Additionally, they only included active rock glaciers into their inventory. However, in case of the glacier inventory of Argentina also inactive rock glaciers are included in the water equivalent of the inventory. These differences can explain the difference in calculated water equivalents between this and Nicholson's study.

The ratio of the water equivalent from rock glacier to glacier in the Argentine glacier inventory is 1 to 1.24. For comparison, the ratio of the water equivalent from rock glacier to glacier in the Rio Huasco catchment in Chile is 1:1.3 (Azócar and Brenning, 2010) and is thus only slightly higher than for the Argentinian glacier inventory. It shows that the water equivalent is of about the order of magnitude as expected for this region.

Furthermore, the water equivalent has been calculated for snow patches in the Argentine glacier inventory, which is about 0.0137 km^3. However, this water equivalent is difficult to compare, since the volume was calculated with the same formula as the glaciers and the formula is not intended for snow patches. Therefore, the snow patch water equivalent could be overestimated. But because no formula for snow patches was found, the formula for the glacier volume was used as a first estimation. Comparing the water equivalent of snow patches in the catchment area of the mine and below the mine, it can be observed that the water equivalent in the catchment area of the mine (0.0021 km^3) is lower than below the mine (0.0116 km^3). This is probably the case because the area below the mine is at a lower elevation and therefore more snow patches are detected there. As with the snow patches, the water equivalent of the rock glaciers is also lower at the mine than below the mine. For the water equivalent of the rock glaciers the difference is 0.044 km^3. In contrast, the difference is not very high for the glaciers. For the glaciers the water equivalent in the catchment area of the mine is 0.0482 km^3 and below the mine the water equivalent is 0.0567 km^3. In general, however, it can be concluded that the water equivalent below the mine is higher. The reason is difficult to examine. It is possible more features influence the watershed below the mine than above except for glaciers.

In a further step the water equivalent for snow patches from the Sentinel-2 inventory has been calculated. As mentioned above, this formula has been developed for glaciers, which can lead to a overestimation of the volume for snow patches. In addition, the volume of the Sentinel-2 Inventory was calculated by using the mean slope inclination, which affects the size of the volume and thus the water equivalent. For the Sentinel-2 inventory, the water equivalent is divided into features larger than 0.01 km^2 and features smaller than 0.01 km^2. The division was made, because this is the threshold value often used for glaciers. The water equivalent for features larger than 0.01 km^2 is much larger than for features smaller than 0.01 km^2. For features smaller than 0.01 km^2 the water equivalent is 0.0002 km^3 which is about 400 times less than the water equivalent for features larger than 0.01 km^2. However, 0.0002 km^3 water equivalent is about $2*10^8$ liters of water which is still a significant amount of water in an arid area.

6.3 Interpretation

To understand why the conflict in Argentina is so controversial, it is crucial that all data is considered and interpreted together. Only by considering all the data, the conflict can be represented and understood in all its aspects. The text-based analysis unraveled why the conflict has evolved between the different parties (Figure 15). It starts with the definition of a "glacier". For the “Environmentalists", "CEDHA" and "Law" the definition of "glacier" includes even the smallest forms like glacieret and snow patches. On the other hand, there is a strict definition of "glacier" for the stakeholders "Guidelines" and "Science community". Both of them understand the term "glacier" as a definition of "glacier". From Figure 15, we can already derive features that are included in an inventory for the different stakeholders. However, which features are included in an inventory is clearly related to the purpose for which the inventory is used. For the "Environmentalists", "CEDHA" and "Law" not only glaciers but also the smallest forms have to be included in an inventory, especially if water resources are involved. According to these stakeholders, rock glaciers as well as periglacial environment should also be included in an inventory for water resources, since these features also store water. From a scientific point of view, features smaller than 0.01 km^2 do not belong in an inventory. According to the "Science community", rock glaciers also do not belong in a glacier inventory, but they are included in the Argentine glacier inventory. From a pure scientific point of view, only glaciers belong in a glacier inventory. Under certain circumstances, glacieret can also be included in the inventory. Most of the inventories for scientific purposes serve to record glacier fluctuations. These two different perspectives on inventories highlight the fact that such inventories are never created in a social vacuum but are embedded in it. The procedure for the Argentine glacier inventory can also be derived from this social embedding of the inventories. The Argentine glacier inventory has struck a balance between science and the interest groups "Environmentalists", "CEDHA" and "Law". It included rock glaciers and glacierets in the inventory, but no features smaller than 0.01 km^2. This middle ground is visualized in the Figure 15 and Table 22, where the stakeholder "Inventory" lies between the two groups mentioned above. As Côte, Wartmann and Purves (2018) mention in their study, the connection between definitions and values is often silent, but this connection plays an important role. Based on this, it can be concluded that the purpose or value of an inventory plays a central role and defines the integrated features. It became apparent that values of an inventory depend strongly on the stakeholder (Table 23). Because of this dependence on the stakeholder, it is important that the purpose of an inventory is known beforehand, so that specific features can be integrated, which is central for the inventory.

In order to analyze the conflict not only on a verbal level, the ASTER and Sentinel-2 inventories were created. Compared to the ASTER and Sentinel-2 inventories, the Argentine glacier inventory does not seem to lack anything essential, although the sizes of the three inventories are very different. The differences in size can be explained by the use of different satellite images and the mapping of the inventories. Compared to the CEDHA inventory, the Argentine glacier inventory seems to be missing some features. In contrast, the CEDHA inventory lacks some important features that are present in the Argentine glacier inventory as well as in the inventories of ASTER and Sentinel-2. Some questions regarding the CEHDA inventory remain unanswered, e.g. what data was used to create the inventory. However, based on these observations, it can be concluded that the Argentine glacier inventory has covered all the important features. Furthermore, the generated scatterplot does not show any significant features that are missing or incorrectly mapped with respect to glaciers and snow patches (Figure 19). Areas smaller than 0.01 km2 are missing from the Argentine glacier inventory. However, the Argentinean glacier inventory deliberately did not include these and thus used the common practice of science in mapping glaciers. Furthermore, permafrost was not included in the Argentinean glacier inventory. The reason for this is that permafrost, according to the common practice, is also not included in an inventory. The PZI shows that the possibility of permafrost occurs in this region. However, it is questionable whether permafrost should be included in an inventory, as it is not clear how much water is stored in permafrost. All the features included in the Argentine glacier inventory store more or less water depending on their size and type of features. The water resources play an important role in this region. Due to the low precipitation in this region, the stored water plays an important role in the various features of the permafrost, especially because a mine like the Veladero mine consumes a lot of water. With an annual volume of $27*10^6$ tons of mined ores, the Veladero mine requires according to Bleiwas (2012) between $14*10^9$ and $22*10^9$ liters of process water, depending on the application, conservatively calculated. If the liters are converted into km^3, the required process water is between 0.014 km3 and 0.022 km^3. In comparison to the water equivalent of the snow patches, which amounts to 0.0137 km^3, it becomes obvious what a central role these features have, especially in an arid area such as the San Juan region in Argentina.

7. Conclusion

7.1 Answering the hypothesis

This complex case study of the Argentinian glacier inventory and related accusation of the head of that study Ricardo Villalba has shown how important it is to consider physical as well as social dimensions of environmental conflicts. The approach of critical physical geography has given a broad insight into the controversy of that law case by triangulation of qualitative and quantitative datasets. With all the collected information about the conflict, the research questions in light of the defined hypothesis can be answered. First the sub-questions will be addressed, before the main question with regard to the hypothesis are answered.

Sub-questions:

- Why are features of glaciers and the periglacial environment missing in Argentina's glacier inventory that various stakeholders believe should be included?

The reason why features such as permafrost and snow patches smaller than 0.01 km^2 are missing from the Argentinian glacier inventory is that the stakeholders incorporate different perspectives on the inventory. This thesis shows that there is a discrepancy between the stakeholder group “Law”, “Environmentalist” and “CEDHA” and the stakeholder group of “Guidelines” and “Science community”. The Argentinian glacier inventory by Ricardo Villalba tried to find a balance between what is on the one hand legally and on the other hand scientifically justifiable. For example, the Argentinian glacier inventory includes glaciers, glacierets and snow patches larger than 0.01 km^2 as well as rock glaciers, which are normally not included in a scientifically conducted glacier inventory. Therefore, it can be concluded, that it is indeed very relevant to define beforehand what features are wanted to be part of the inventory and what values and purpose the inventory should follow/have. Furthermore, an essential point is that law and inventory definitions need to be uniform in order to avoid conflicts as discussed in this thesis and there should not be a discrepancy between the law and the inventory. This is one way to avoid future conflicts.

- What features of glaciers and periglacial environment that has been missed in the mapping of the glacier inventory in Argentina?

In comparison with the other three inventories, it can be said that no central features are missing from the Argentinian glacier inventory. The greatest uncertainty is that not all rock glaciers have been correctly classified. However, the mapping of rock glaciers is challenging without high-resolution aerial photographs. Based on the glacier boundary criterion that features must be larger than 0.01km^2, smaller features are not included in the inventory. Furthermore, permafrost has not been included in the inventory, although the permafrost zonation index indicated a possibility that permafrost occurs in the study area and therefore is influenced by the mine infrastructure.

7. Conclusion

Research question:

- What are the physical features of glaciers and periglacial environment that made the case of Argentina so contentious?

Hypothesis:

- There are features of glaciers and periglacial environment that explain why the case of Argentina is so contentious

On the basis of the answered subquetions, it can be concluded that especially glacial features which are smaller than 0.01 km^2 have influenced the conflict. Although this threshold is scientifically based, it has to be considered that these small features can have an significant influence on the water supply/reservoir in a dry area such as San Juan in Argentina. In addition, the possible presence of permafrost, which is also part of the periglacial environment, has been completely neglected.
Thus the above mentioned hypothesis can be confirmed that features exist which have contributed to the conflict.

7.2 Outlook

The thesis has discussed and highlighted all the aspects that made the case of Argentina so contentious. Controversial aspects of that conflict are especially exclusion of small glacial features (< 0.01 km^2) and the negligence of permafrost in the inventor. However, to understand why these features are so important in the arid area of San Juan further examination is needed. Moreover, in order to properly examine the influence of these features on the hydraulic cycle, a discharge model would be necessary. Such a modelling approach could show how much these small features actually contribute to the catchment discharge. Furthermore, a validated formula for calculating the accurate volume of snow patches to determine their water equivalent would be of particular use. Such a formula is critical for regions where the access is difficult and the mapping can only be done with remote sensing. The influence of the mining operation could not discussed in detail in the scope of this thesis. An interesting aspect would be to investigate whether the dust from the mining site had any influence on the ablation of glacier and perennial snow patches. All these aspects would give an even more comprehensive picture of this conflict.

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Appendix

A. Translation

Appendix Table 1: The table shows the Spanish translations for the different thermology used in this thesis.

Spanish	English
Glaciar descubierto	Glacier
Glaciar cubierto	Debris covered Glacier
Glaciar cubierto con glaciar de escombros	Debris covered Glacier with rock glacier
Glaciar de escombros activo	Active rock glacier
Glaciar de escombros inactivo	Inactive rock glaciers
Manchón de nieve	Snow patch

B. Theme matrix and summary

Appendix Table 2: The table shows the theme matrix.

Stakeholder	Definition	Value	Boundary
Inventory (IANIGLA - CONICET (2010))	Glacier (uncovered and covered): permanent body of ice generated on the ground from the recrystallization of snow and/or ice due to the compaction of its own weight, without or with significant debris cover, visible for periods of at least two years, with evidence of movement by gravity (crevasses (cracks), ogives, middle moraine) or not (*) and of an area greater or equal to 0.01 km2 (one hectare). Glaciers can have different morphologies. (*) This definition of glacier includes permanent patches or fields of snow that, as they have no evidence of movement, are generally not considered glaciers. However, permanent blotches or snowfields are significant reserves of solid-state water. Rock glacier: body of frozen debris and ice, with evidence of movement by the action of gravity and plastic deformation of permafrost, whose origin is related to the cryogenic processes associated with permanently frozen soil and underground ice or ice from glaciers uncovered and covered, and an area greater or equal to 0.01 km2 (one hectare). Rock glaciers can have different morphologies.	In the territory of the Argentine Republic we can group the strategic water reserves in solid state in two big groups: glaciers (uncovered and covered) and debris glaciers. These big groups contain, both in volume and in covered surface, the biggest water reserves in solid state of the mountain range. Furthermore, due to their physical characteristics, they can be easily identified and delimited. The National Glacier Inventory is hereby created, in which all glaciers and periglacial landforms that act as freshwater reserves on national territory shall be identified along with the pertaining information that is necessary for their adequate protection, control and monitoring.	Glacier (uncovered and covered): permanent body of ice generated on the ground from the recrystallization of snow and/or ice due to the compaction of its own weight, without or with significant debris cover, visible for periods of at least two years, with evidence of movement by gravity (crevasses (cracks), ogives, middle moraine) or not (*) and of an area greater or equal to 0.01 km2 (one hectare). Glaciers can have different morphologies. (*) This definition of glacier includes permanent patches or fields of snow that, as they have no evidence of movement, are generally not considered glaciers. However, permanent blotches or snowfields are significant reserves of solid-state water. Rock glacier: body of frozen debris and ice, with evidence of movement by the action of gravity and plastic deformation of permafrost, whose origin is related to the cryogenic processes associated with permanently frozen soil and underground ice or ice from glaciers uncovered and covered, and an area greater or equal to 0.01 km2 (one hectare). Rock glaciers can have different morphologies.

Appendix

Stakeholder	Definition	Value	Boundary
Law 26.639 (Argentine National Glacier Act, 2010)	Glaciers are perennial stable or slowly flowing ice mass, with or without interstitial water, formed by the re-crystallization of snow. Detritic rock material and internal and superficial water streams are considered to be part of each glacier. Periglacial environment of high mountains are areas with frozen grounds acting as regulator of the freshwater resource. The area functioned as regulator to freshwater sources with ice-saturated ground in middle to low mountain areas.	The following law establishes the minimum standards for the protection of glaciers and the periglacial environment with the objective of protecting them as strategic freshwater reserves for human consumption; for agriculture and as sources for watershed recharge; for the protection of biodiversity; as a source of scientific information and as a tourist attraction. Glaciers constitute goods of public character.	As per the present law, we understand glaciers to be all perennial stable or slowly-flowing ice mass, with or without interstitial water, formed by the re-crystallization of snow, located in different ecosystems, whatever its form, dimension and state of conservation.
Environmentalist (https://jachalnosetoca.com/ [Accessed: 16.12.19])	All ice masses, regardless of shape or dimension, and the periglacial environment must be included in the inventory, according to the definition indicated in the Glaciers Law. The law is very clear: ARTICLE 3 - Inventory. Create the National Glacier Inventory, which will identify all glaciers and periglacial geoforms that act as existing water reserves in the national territory with all the necessary information for adequate protection, control and monitoring. And ARTICLE 2 - Definition. For the purposes of this law, glacier means any stable or slow flowing perennial ice mass, with or without interstitial water, formed by the recrystallization of snow, located in different ecosystems, whatever its shape, size and state of conservation.	Because this law protects glaciers and their periglacial environments as fragile ecosystems and sources of fresh water, a key resource for life. It protects our water sources. It is our water and in its defense we should all be there, all of us, and no one should be missing. Each assembly, each institution, each NGO, each People and each neighbor must know and be aware that the water that is born from our glaciers is the water that runs throughout the national territory, giving life, in the same way that veins and arteries run through our body, giving life. Our mountain range, our glaciers, our water, life. Glaciers are a water resource for surface and ground water. The same political and economic power that punished the rights of the Jachalleros children by successively polluting the water that irrigates all the cultivable surface of Jáchal and that gives water to almost all the population of the rural area of the Department of Jáchal.	Also Glacier that are smaller than 1 hectare have to be included. Form, size and dimension of glaciers do not matter.

Appendix

Stakeholder	Definition	Value	Boundary
Guidelines	A glacier or perennial snow mass, …, consist of a body of ice and snow that is observed a the end of the melt season, or in the case of tropical glaciers after the transient snow melt. All debris-covered parts of a glacier must be included. If no flow takes place between separate parts of a continuous ice mass they should, in general, be treated as separate units, separated at the topographic divide. If snowfields are identifiable, they should be disconnected from the main glacier. Rock glaciers and heavily debris-covered glaciers tend to look similar but their geneses are different. GLIMS does not currently deal with the former, but does include the later. (Raup and Khalsa, 2010); Delineation of visible ice, firn and snow versus rock and debris surfaces as well as delineation of active glacier versus inactive ice (dead ice), as diagrammatically shown in Figure 2, can affect various inventory measurements, particularly for subtropical glaciers. Inactive ice must be included in the inventory for hydrologic purposes. [...] Rock glaciers must be included if evidence of large ice content has been or can be established. Glacierets and snow patches of large enough size, as well as aufeis (nayled)—if perennial—should also be included in the inventory, but must be clearly marked as such (see 'Glacier classification and description', page 16). Valley glacier: Flows down a valley; the catchment area is well defined. Mountain glacier: Cirque, niche or crater type; includes ice aprons and groups of small units. Glacieret and snowfield: A glacieret is a small ice mass of indefinite shape in hollows, river beds and on protected slopes developed from snow drifting, avalanching and/or especially heavy accumulation in certain years; usually no marked flow pattern is visible and therefore no clear distinction from snow-field is possible. Exists for at least two consecutive summers. Rock glacier: A glacier-shaped mass of angular rock in	Not saying anything about value (Raup and Khalsa, 2010); …guidance material for the compilation of a world inventory of perennial ice and snow masses as a contribution to the estimation of the world water balance. Some of the remaining 3 per cent of the glaciered area is, however, of direct importance to mankind, providing water for irrigation, industry, hydropower, recreation and domestic supplies. However, because of the rapidly increasing importance of this ice to human activity a serious effort should be made to obtain improved information on the underground ice in polar and subpolar regions and in high mountain areas. (UNESCO, 1970) Mass-balance information is essential for defining the links between past, present and future climate changes and changes to glaciers in assessments such as those made by the Intergovernmental Panel on Climate Change (IPCC). (Cogley et al., 2011)	Not saying anything about size (Raup and Khalsa, 2010) 0.01km2 -> Glacier data inventory sheet (The objective of the Standard Data Sheet (Fig. 1) is to permit useful and rapid processing of the data for hydrological needs as well as for further use by the various environmental sciences. It is suggested that the information on each glacier or ice mass should be entered on a separate data sheet, from which punch cards of standard format are easily prepared.) The boundaries between continuous and discontinuous permafrost and permafrost-free areas are determined from mapped ground-temperature data, well-log data, the distribution of thermokarst features in cleared fields and changes in plant cover. In the southern fringe of the discontinuous zone the occurrences of permafrost are mostly confined to peat bogs and much of the ground ice is found in paisa. (UNESCO, 1970) Not clear definition: Glacieret < 0.25km2 (Cogley et al., 2011)

Stakeholder	Definition	Value	Boundary
	a cirque or valley either with interstitial ice, firn and snow or covering the remnants of a glacier, moving slowly downslope. Much of the information on underground ice, particularly the more massive forms, will only be available from indirect evidence, i.e. its surface manifestations. Pingos, ice-wedge polygons, paisa, thermokarst mounds and pits lend themselves to aerial photograph recognition and on low-level aerial photographs even smaller permafrost features may be distinguished. However, the lack of permafrost surface features does not indicate the absence of ground ice. (UNESCO, 1970) Glacier: A perennial mass of ice, and possibly firn and snow, originating on the land surface by the recrystallization of snow or other forms of solid precipitation and showing evidence of past or present flow. Glacieret: A very small glacier, typically less than 0.25 km2 in extent, with no marked flow pattern visible at the surface. To qualify as a glacieret, an ice body must persist for at least two consecutive years. Glacierets can be of any shape, and usually occupy sheltered parts of the Landscape. Rock glacier: A mass of rock fragments and finer material in a matrix of ice, showing evidence of past or present flow. Snowfield: A more or less extensive and persistent mass of snow. Snowfields are more extensive than snow patches, but the distinction is not made precisely in common usage. A snowfield that is perennial may be difficult to distinguish from a glacier. Snow patch: A mass of snow of restricted extent, especially one that persists through most or all of the ablation season. Snow patches are less extensive than snowfields, but the distinction is not made precisely in common usage. A snow patch that is perennial may be difficult to distinguish from a glacieret. Rock glacier: A mass of rock fragments and finer material in a matrix of ice, showing evidence of past or present flow.(Cogley et al., 2011);		

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Stakeholder	Definition	Value	Boundary
Science	Crevasses, Flow features, deformed stratification, multiple debris band in ice, ice and Bergschrund (Leigh et al. 2019); At a most fundamental level, glaciers are frozen masses that do not melt annually and flow downhill. (Mark and Fernandez, 2017)	Despite their small area, however, mapping very small glaciers is important for several reasons. First, their widespread distribution and frequent occurrence mean they likely account for ∼80–90% of the total number of glaciers located in mid- to low-latitude mountain ranges. Second, very small glaciers act as a reservoir for water storage, moderating inter annual variability in streamflow constituting a significant part of the hydrological system in mountain areas and, with a warming climate, are critical in terms of increasing concern about future water security. Third, smaller glaciers are highly sensitive to climate change and typically exhibit the shortest response times to a given climate forcing. However, they can also be disproportionately influenced by local topography, such that when they survive in heavily-shaded cirques, they may be sustained for longer than expected. Fourth, monitoring the evolution of very small glaciers could reveal new insights regarding their fate over longer time-scales, e.g. their disappearance versus transitioning into debris-covered and/or rock glaciers, which may also have implications for catchment hydrology. (Leigh et al., 2019); Future glacier shrinkage will diminish water sources, especially during the May-September dry season, which will affect the export agriculture economy, indigenous people's subsistence food production, urban drinking water, industries, and hydroelectricity generation. The decrease of runoff will have the biggest impact on regional water supplies during dry season when little precipitation falls. (Carey et al. 2012); Mountain glaciers are transient hydrologic reservoirs persisting at the habitable extremes of Earth that both document and respond to climate change. They withhold water in solid phase from	Despite their importance and ubiquity, there is very little guidance on how to distinguish very small glaciers (<0.5 km2) from perennial snow patches when compiling remotely sensed glacier inventories or change assessments. In practice, most researchers simply define a minimal size-threshold, commonly somewhere between 0.05 and 0.01 km2 (Table 1). All units below this size-threshold are then ignored or removed, due to the large uncertainty in differentiating between snow patches and glaciers.(Leigh et al., 2019)

Stakeholder	Definition	Value	Boundary
		other reservoirs and ultimately impact sea levels. Moreover, they are valued resources with economic and cultural significance for human societies living below them. They also preserve histories of past climates. [...] Glacier recession in turn affects the hydrology of mountain areas because the shrinkage reduces the capacity of mountain glaciers to naturally store water seasonally and increases the probability of natural disasters. Such changes impact societies that depend upon mountain water resources, imposing adaptation challenges for policymakers, water managers, and local communities alike. Glacier changes also impact societies downslope and imprint culture; glaciers are often assimilated as sacred symbols, exemplars of pristine settings, or as living members of the environment, who “suffer” the consequences of climate changes. [...] (Mark and Fernandez, 2017) In the context of the hydrological cycle, glaciers are temporary storage reservoirs of water. These analyses highlight that regional impacts are most severe to surface water runoff where glaciers provide important reservoirs against seasonal precipitation deficits, such as the western slope of the tropical Andes. [...] The impact of seasonally delayed glacier contribution to streamflow thus has most human impact where glacierized catchments drain to semiarid to arid regions. [...] Mountain glaciers are richly enmeshed within local cultures, and changes to glaciers have very real consequences for people living near them that extend beyond hazards. Glaciers are regarded as holy by some, inform traditional knowledge systems, and have value in resource economies and tourism. [...] Moreover, with progressive climate changes, glaciers as cultural archives are disappearing. Paleoclimate	

Stakeholder	Definition	Value	Boundary
		information sourced in glaciers, particularly those in mid-low latitude mountains near ancient civilizations where relatively high snow accumulation can yield high resolution records, is vulnerable to loss in a warming climate. Zhang et al. (2015) have pointed out that the recent widespread thinning of mountain glaciers globally is erasing the histories of the most recent and intensive interactions between humans and the environment. [...] Studies of Alpine lakes show that recent increases of persistent organic pollutants recorded in glacial-fed lake sediments can primarily be attributed to the release of these substances from melting glaciers. And glaciers hold other remnants of past culture that emerge from melting ice that can both enlighten historical understanding and subsequently impact ecosystems. [...] Sediments and chemicals entrained within, over, and under the ice are both inorganic and organic, providing important nutrients to downstream ecosystems. [...] The origin and processes of transformation of organic material within glacier systems have become an area of active study, with implications for the downstream ecosystems fed by glacier melt. Regardless of whether organic material is autochthonous or allochthones, glacier-derived dissolved organic material has been shown to be significant sources to downstream ecosystems; studies in Alaska have shown that glaciers are a source of ancient and labile organic material to ocean ecosystems. This finding represents a surprising insight into reactivity and age of organic material, as glacier-derived organic material is old yet highly bioavailable. [...] Other recent work in the Himalayas has traced the contribution in glacier meltwater of sources of contamination once deposited from the atmosphere; hence, climate change induced	

Stakeholder	Definition	Value	Boundary
		glacier mass loss is enhancing pollution exposure levels over large and already heavily impacted regions of Northern India. [...] Mountain glaciers are transient relics of surplus accumulated ice - hydrologic reservoirs - that respond with a time lag to climate and are coupled closely within the integrated Earth System. [...]. As mountain glaciers shrink, we may not only lose valuable archives of past climate and culturally relevant landscape features but we may also witness a transformation in the hydrological and biogeochemical cycles that geographers are uniquely poised to appreciate from a truly integrated perspective, using the many tools of observation and methods of tracing over many different scales. In this regard, glacier meltwater is a vital link to society as a water supply, as well as a biogeochemical pathway whereby elements are redistributed between geological and ecological reservoirs. (Mark and Fernandez, 2017)	

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Stakeholder	Definition	Value	Boundary
Mining Company	To counter the campaigns of environmentalist and indigenous groups, company representatives played down the significance of the glaciers, calling them "ice reservoirs," "ice fields," or "glacierets" with an insignificant contribution to the hydrological balance of the watershed. They also argued that the bodies of ice at Pascua-Lama lacked characteristics of "traditional" glaciers such as flow and basal sliding. [...] The company's own publications refer to adjacent "ice features" that include "small patches of remnant glaciers that are steadily melting in recent climates" (ERM, 2006). The implication here is that it is climate change that is causing the melting of the glaciers around the mine site, absolving the company of responsibility for diminishing snowmelt. (Li, 2018)	The following plan describes the method and management disposition of the glaciers sectors that must be removed during the life of Pascua Lama, as the open pit area is extended towards the position of the glaciers in the Rio El Toro river basin. It is estimated that 10 hectares of glaciers must be removed and adequately managed to avoid the instability of slopes and environmental impacts. The thickness of the glacier sectors that must be removed is estimated at 3 to 5 meters. MANAGEMENT PLAN: 2.1 The glacier sectors that must be removed will be determined with the necessary anticipation according to the updated mining plan.; 2.2 The mining equipment shall be employed as needed for each glacier sector to be managed (basically bulldozers and/or r front loaders).; 2.3 The chunks of glaciers shall be removed with the mentioned machinery until the surface is clear (principally rock).; 2.4 If necessary, controlled explosives shall be used, of small size, to remove the ice.; 2.5 The chunks of ice that come apart and that are removed, until the level of the terrain is reached, shall be "pushed" or transported by the same mining machinery to an adjacent area, nearby but outside of the boundaries of the development of the pit.; 2.6 The areas of disposal shall comply with the Basic characteristics cited in Section 3 below. 3 CHARACTERISTICS OF THE SITES FOR DISPOSAL: The sites for disposal of the chunks of glaciers shall comply with the following basic conditions: 3.1 They shall be located at a similar or slightly lower altitude than their original position.; 3.2 They shall not be destined to other works, infrastructure, or project development, nor shall they compromise the safety of these if they are located downstream of the pit.; 3.3 Preference shall be made for sites of low inclination, to	To counter the campaigns of environmentalist and indigenous groups, company representatives played down the significance of the glaciers, calling them "ice reservoirs," "ice fields," or "glacierets" with an insignificant contribution to the hydrological balance of the watershed. They also argued that the bodies of ice at Pascua-Lama lacked characteristics of "traditional" glaciers such as flow and basal sliding. [...] The company's own publications refer to adjacent "ice features" that include "small patches of remnant glaciers that are steadily melting in recent climates" (ERM, 2006). The implication here is that it is climate change that is causing the melting of the glaciers around the mine site, absolving the company of responsibility for diminishing snowmelt. [...] One of these conditions was that "the company shall only access the ore in a manner that does not remove, relocate, destroy, or physically interfere with the Toro 1, Toro 2, and Esperanza glaciers" (COREMA, 2006). To abide by this provision, Barrick modified the limits of the mining pit, reducing gold reserves by approximately 1 million ounces and preventing access to just under 5 percent of the ore. The company stressed that the three "icefields" now lay outside of the mining pit limits and would not be moved or touched. (Li, 2018); The Glacier Estrecho was a few kilometers to the north of the vast pit Barrick was clearing for the mine. To the south was Glacier Guanaco. Within the boundaries of the mine site were three

Stakeholder	Definition	Value	Boundary
		minimize the possibility of downslope shifting. In the pit vicinity there is ample relative level terrain to dispose of the glacier chunks.; 3.4 Notwithstanding the above, retention walls (bermas) shall be introduced and/or machinery shall level the terrain at the extremes, “downstream”, to retain eventual ice collapse and avoid downslope slippage.; 3.5 No gorge floors shall be used or sectors that might present significant surface water flow during the periods of ice melt. 3.6 The characteristics of the terrain or rock surface shall be similar to original sites (prioritizing the same geological formations and geomorphological configuration). (Barrick Gold, Pascua-Lama Project (EIA), 2001) To counter the campaigns of environmentalist and indigenous groups, company representatives played down the significance of the glaciers, calling them “ice reservoirs,” “ice fields,” or “glacierets” with an insignificant contribution to the hydrological balance of the watershed. They also argued that the bodies of ice at Pascua-Lama lacked characteristics of “traditional” glaciers such as flow and basal sliding. (Li, 2018) In its 2005 environmental report, Barrick had proposed getting at some of the buried gold deposits by moving some of this ice by bulldozer and attaching it to another glacier a few kilometers away. (Smith and McCormick, 2019) The glacier pieces will then be transported by truck between two and six kilometers away, to the larger Guanaco glacier, where they’ll be tacked onto its southern face (which gets the most shade in the Southern Hemisphere). “It’s too short a time for the ice to melt,” explains Jeffrey Schmok, a glaciologist and consultant with the international ground-engineering firm Golder Associates, who is advising Barrick on the project. “It’ll be moved at a time of year [with	smaller glaciers, referred to by Barrick as “glacierets” or “ice reserves,” known as Toro 1, Toro 2 and Esperanza. (Smith and McCormick, 2019)

Stakeholder	Definition	Value	Boundary
		temperatures at] minus 6 or 8, and when it's picked up in big blocks, its temperature will stay stable." Schmok says it takes a matter of days for the ice to adhere to the new glacier. [...] But Barrick's vice-president for corporate communications, Vincent Borg, assures that all the necessary studies have been done, and that the relocation has been mapped out by top engineers. "The environmental viability of the ice relocation is not based on any complex energy balances or any sort of unusual hydrological conditions. It's a logistical challenge more than anything," says Borg. [...] Barrick counters that their extensive field studies show there won't be any significant impact on either the quality or the quantity of the surrounding waters. "The impact would be less than 2% of the flow in the nearest flow stations upstream of the agricultural users in the driest months," says Simon Catchpole, environmental supervisor for the Pascua Lama project. "And the project would only need to intervene on 10 hectares…. That represents less than one half of a percent of the total volume of glaciers in that basin." But opinion is divided as to the impact on the region's waterways, to the point that even some of Barrick's own experts acknowledge it could decrease the volume of water in the rivers. "The net effect is a decrease in the surface area of the ice," admits Michael Jones, an engineer with Hydrologic Consulting. He says glaciers are storage facilities for water and relocating them onto a new and larger storage unit will mean less meltwater. "It will slightly decrease [river flow] because it will add storage from these small, fragile glaciers." (Ross, 2005)	

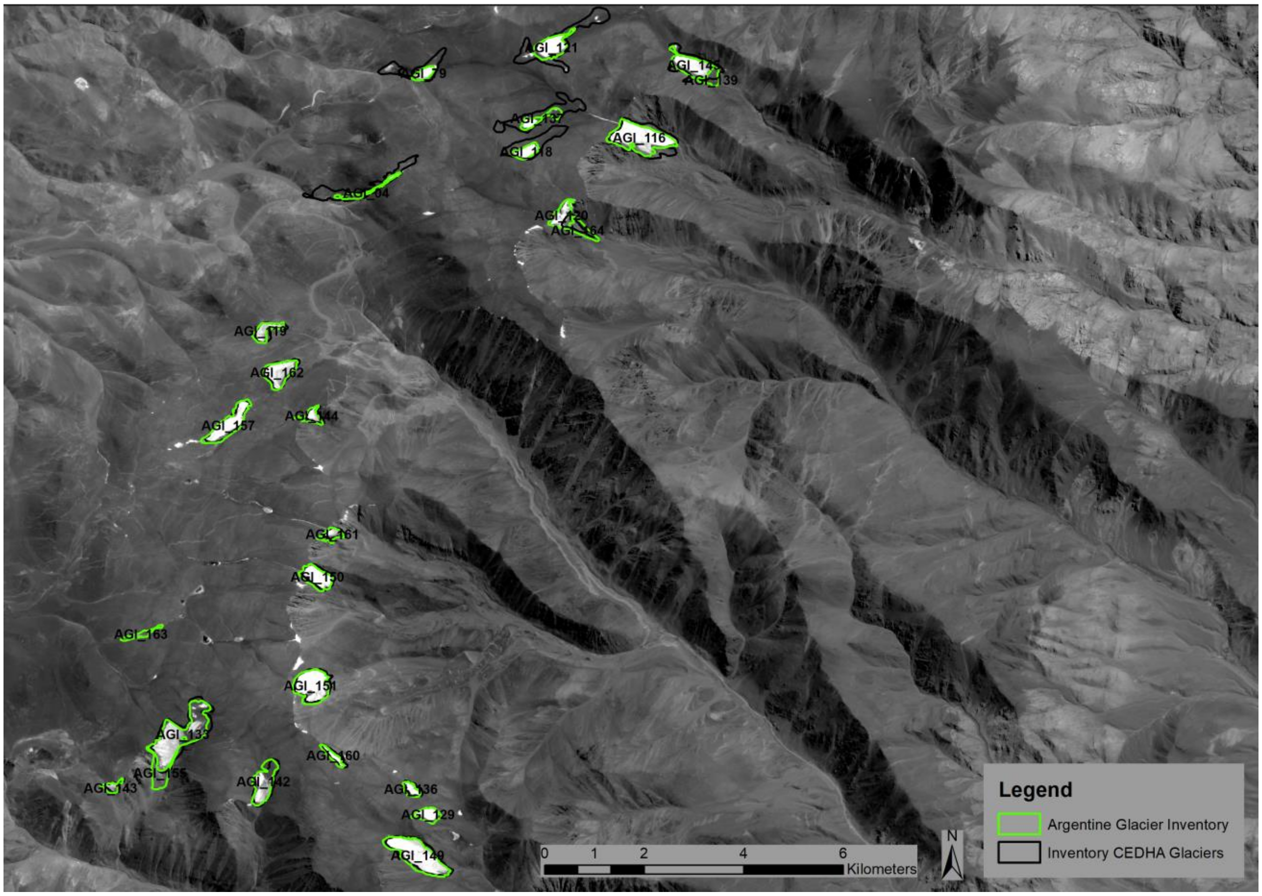
Stakeholder	Definition	Value	Boundary
CEDHA (Taillant, 2013)	In order to determine if an ice body is in fact perennial ice, which could be categorized as a glacier (which means it survives for at least two summers, we sought the following attributes: • That the ice body persist for at least two summer • That the images analyzed be from summer month (preferably at the end of summer) • That the surface of the ice not be only white but show signs of ice persistence • That there be signs of movement of the body (crevasses, etc.) • That the form of the body maintain its shape from year to year We mentioned earlier that Barrick Gold has irreconcilable conflicts with Argentina's new National Glacier Protection Las, not only because of its protection of common uncovered glaciers, but also because the law protects periglacial areas. Periglacial environments are, like glaciers, natural resources that act as hydrological reserves and basin regulators, perhaps even more so than glaciers! [...] The periglacial environment is an area (or ground) that is frozen. It is a strip of land generally located between glaciated area (...) and the forest line where vegetation grows. The periglacial environment includes various frozen elements (cryogenic elements). Amongst these, rock glaciers (active or inactive - which means with or without movement), creeping frozen soil (grounds that move), permafrost (permanently frozen grounds), etc. Rock glaciers are considered to be part of permafrost. This environment may have areas that are permanently frozen 100% of the time, and others which melt and freeze cyclically. These latter areas are evidently actively contributing to water basins. [...]However, one cannot map periglacial environments only by looking for rock glaciers, as it is possible to have periglacial environment without any rock glaciers at all. In this case where no rock glaciers are present, it was nearly impossible to identify periglacial environment	The National Glacier Protection Law defines a glacier as perennial ice, irrespective of its size or form; this is because the sum of small glaciers actually makes a large contribution to water supply. One very valid question we should ask ourselves is just how much water is contained in these relatively smaller bodies of ice. Periglacial environments are, like glaciers, natural resources that act as hydrological reserves and basin regulators, perhaps even more so than glaciers! [...] This environment may have areas that are permanently frozen 100% of the time, and others which melt and freeze cyclically. These latter areas are evidently actively contributing to water basins.	The National Glacier Protection Law defines a glacier as perennial ice, irrespective of its size or form; this is because the sum of small glaciers actually makes a large contribution to water supply. As long as an iced area survives for at least two years it is considered a glacier. The periglacial environment is an area (or ground) that is frozen. It is a strip of land generally located between glaciated area (...) and the forest line where vegetation grows.

Stakeholder	Definition	Value	Boundary
	utilizing satellite imagery alone. The only way was to visit the site and take careful long-term temperature measurements. We've heard technical experts that today must carry out periglacial environment mapping as mandated by the National Glacier Protection Law, say that they cannot do this work in the time allotted due to its complexity and to these technical difficulties. Nonetheless, this great limitation has recently changed with the development of a completely automatic tool development by permafrost experts at the University of Zurich. Scientists have developed an internet-based tool that can accurately map frozen grounds around the world. This tool is so new, that many geologists, geocryologists and other experts that work with permafrost areas, are still learning about the tool's existence and particularities.		

Appendix Table 3: The table shows the theme summaries. The blue words have been implied through other statements.

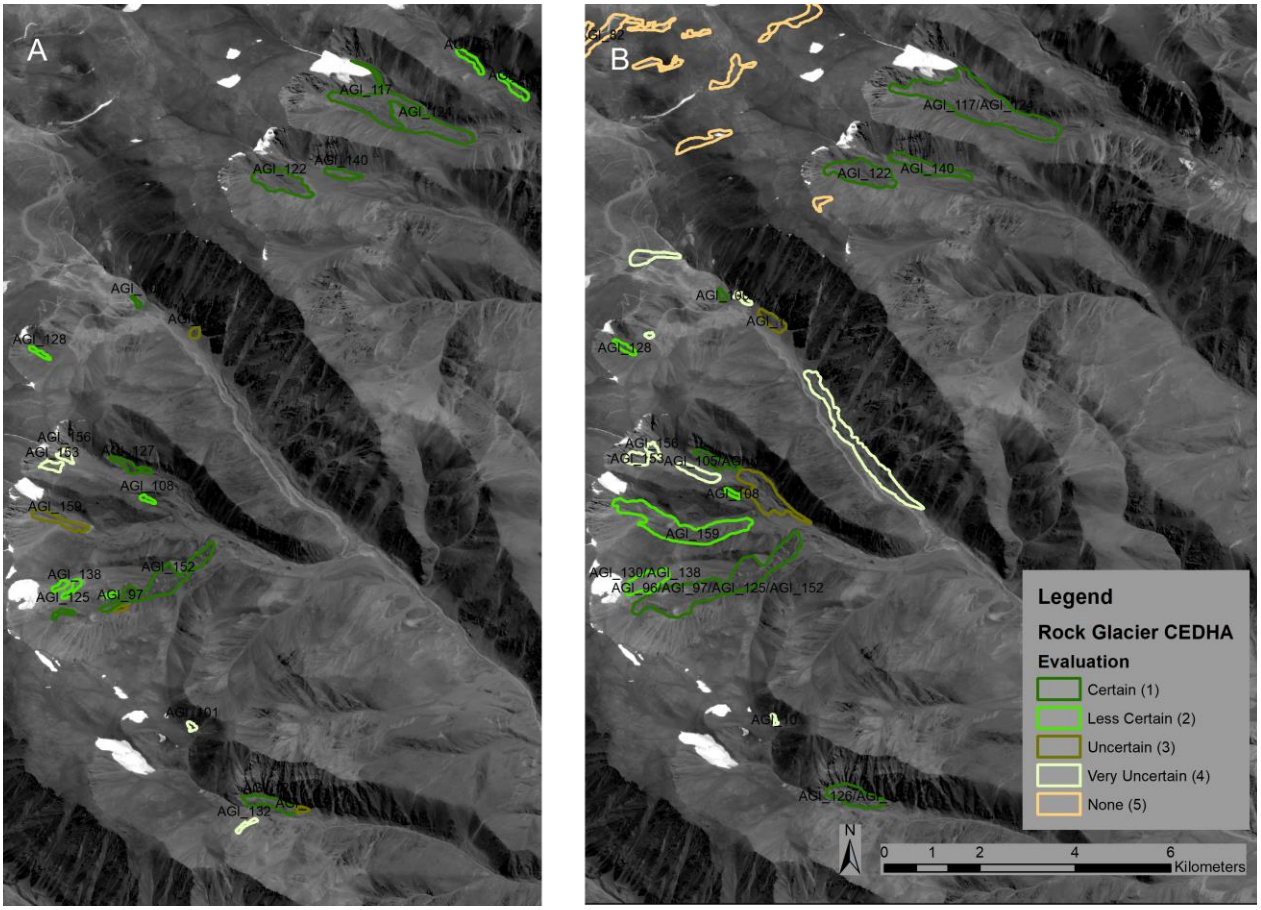
	Definition	**Value**	**Boundary**
Inventory (IANIGLA - CONICET (2010))	Glacier Glacieret Rock Glacier	Water Resource	Number
Law 26.639 (Argentine National Glacier Act, 2010)	Glacier Rock Glacier Periglacial Environment Glacieret Snow Patches	Water Resource Envioronmental Archive Society Goods	No Size
Environmentalist (https://jachalnosetoca.com/ [Accessed: 16.12.19])	Glacier Periglacial Enviornment Glacieret Snow Patches Rock Glacier	Water Resourcs	No Size
Guidelines	GLIMS: Glacier Glacieret UNESCO: Glacier Glacieret Snow Patches Rock Glacier Periglacial Environment Cogley et al.: Glacier Glacieret Snow Patches Rock Glacier	UNESCO: Water Resource Society Goods Cogley et al.: Archive	GLIMS: No Size UNESCO: Number Cogley et al.: Number
Science	Glacier	Water Recources Archive Evironmental Society Goods	Number
Mining Company	Glacier	Water Resource Manageable Good	No Size
CEDHA (Taillant, 2013)	Glacier Rock Glacier Periglacial Environment Glacieret Snow Patches	Water Resource	No Size

C. Results Conconta Pass



Appendix 1: The features from the Argentinean glacier inventory that have an area greater than 0.05km² are displayed in green. The features of the inventory of the organization CEDHA are displayed in black. In this inventory, only those features are shown which correspond to the Argentine glacier inventory. The area is located at the Conconta Pass. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

Appendix



Appendix 2: The classified rock glaciers at the Conconta Pass. The rock glaciers are classified after the quality criteria. (A) displays the rock glaciers for the Argentine Glacier Inventory and (B) shows the rock glaciers form the CEDHA inventory. The satellite image of the Sentinel-2 was used as background image (USGS, 2020c).

D. Water equivalent

Appendix Table 4: The table shows the calculation of the water equivalent in km³ for the glaciers, debris-covered glaciers and snow patches of the Argentine glacier inventory.

consectiv_ number	F [km²]	H max	H min	Δ H	Δ H [km]	L0 [km]	α	τf	hf [m]	hf [km]	hF	V [km³]	Water equivalent [km³]
AGI_04	0.0665	5209	4787	422	0.422	1303	17.945479	0.617917	22.722628	0.022723	0.017846	0.001187	0.000594
AGI_06	0.6192	5156	4865	291	0.291	1618	10.195741	0.440803	28.214978	0.028215	0.022160	0.013720	0.012348
AGI_07	0.0576	4830	4794	36	0.036	297	6.911227	0.062081	5.845421	0.005845	0.004591	0.000265	0.000132
AGI_08	0.0290	5223	5209	14	0.014	666	1.204238	0.027304	14.720117	0.014720	0.011561	0.000335	0.000168
AGI_09	0.0869	4877	4809	68	0.068	722	5.380407	0.112069	13.541513	0.013542	0.010635	0.000924	0.000462
AGI_10	0.0222	4910	4894	16	0.016	365	2.509989	0.030480	7.885640	0.007886	0.006193	0.000138	0.000069
AGI_12	0.0135	4763	4706	57	0.057	291	11.082569	0.094965	5.597505	0.005598	0.004396	0.000059	0.000030
AGI_13	0.0429	5200	5092	108	0.108	345	17.382389	0.173560	6.582366	0.006582	0.005170	0.000222	0.000111
AGI_14	0.0241	4907	4860	47	0.047	168	15.629596	0.079344	3.336759	0.003337	0.002621	0.000063	0.000032
AGI_15	0.0102	5006	5003	3	0.003	178	0.965568	0.009791	6.582936	0.006583	0.005170	0.000053	0.000026
AGI_16	0.1049	5105	5046	59	0.059	240	13.811335	0.098081	4.655036	0.004655	0.003656	0.000384	0.000192
AGI_17	0.0207	5220	5189	31	0.031	135	12.932608	0.054206	2.744216	0.002744	0.002155	0.000045	0.000022
AGI_18	0.0308	5086	5036	50	0.05	161	17.252652	0.084038	3.210403	0.003210	0.002521	0.000078	0.000070
AGI_19	0.0138	5109	5084	25	0.025	156	9.104601	0.044734	3.203090	0.003203	0.002516	0.000035	0.000017
AGI_20	0.1863	5216	4863	353	0.353	1253	15.733795	0.526104	21.982118	0.021982	0.017265	0.003217	0.002895
AGI_23	0.0177	5051	5014	37	0.037	89	22.574138	0.063654	1.878740	0.001879	0.001476	0.000026	0.000013
AGI_24	0.0807	5087	5032	55	0.055	325	9.605204	0.091846	6.236645	0.006237	0.004898	0.000395	0.000198
AGI_25	0.1174	5301	5159	142	0.142	837	9.628750	0.224959	15.238417	0.015238	0.011968	0.001405	0.001562
AGI_28	0.0247	5290	5205	85	0.085	194	23.660357	0.138337	3.905637	0.003906	0.003067	0.000076	0.000038
AGI_31	1.0677	5533	4952	581	0.581	1622	19.707512	0.816979	27.449619	0.027450	0.021559	0.023018	0.020716
AGI_32	0.2080	5425	5345	80	0.08	303	14.790092	0.130632	5.797918	0.005798	0.004554	0.000947	0.000852
AGI_33	0.7734	5350	5110	240	0.24	1331	10.221485	0.368648	23.537667	0.023538	0.018486	0.014297	0.012868
AGI_34	0.0441	5122	5081	41	0.041	484	4.842008	0.069938	9.387815	0.009388	0.007373	0.000325	0.000293
AGI_43	0.0861	4980	4843	137	0.137	610	12.658031	0.217451	11.243271	0.011243	0.008830	0.000760	0.000380
AGI_50	0.1538	5367	5163	204	0.204	506	21.957422	0.316634	9.594432	0.009594	0.007535	0.001159	0.001043

Appendix

consectiv_ number	F [km²]	H max	H min	Δ H	Δ H [km]	L0 [km]	α	τf	hf [m]	hf [km]	hF	V [km³]	Water equivalent [km³]
AGI_69	0.0358	5033	5013	20	0.02	504	2.272450	0.036822	10.521712	0.010522	0.008264	0.000296	0.000148
AGI_70	0.0204	5151	5130	21	0.021	84	14.036243	0.038406	1.794150	0.001794	0.001409	0.000029	0.000014
AGI_71	0.0375	5211	5182	29	0.029	272	6.085751	0.051052	5.455992	0.005456	0.004285	0.000161	0.000080
AGI_72	0.0244	5120	5028	92	0.092	271	18.751497	0.149096	5.254967	0.005255	0.004127	0.000101	0.000050
AGI_73	0.0345	4830	4794	36	0.036	165	12.308016	0.062081	3.299701	0.003300	0.002592	0.000089	0.000045
AGI_74	0.0626	4995	4950	45	0.045	609	4.225998	0.076211	11.717738	0.011718	0.009203	0.000576	0.000288
AGI_76	0.0295	5072	5016	56	0.056	367	8.675760	0.093406	7.015973	0.007016	0.005510	0.000163	0.000081
AGI_79	0.0661	5182	5128	54	0.054	455	6.768280	0.090286	8.679846	0.008680	0.006817	0.000451	0.000225
AGI_81	0.0311	5193	5185	8	0.008	328	1.397181	0.017762	8.253530	0.008254	0.006482	0.000202	0.000101
AGI_82	0.0327	4903	4806	97	0.097	584	9.430500	0.156760	10.839827	0.010840	0.008514	0.000278	0.000139
AGI_84	0.0447	5012	4959	53	0.053	503	6.014935	0.088725	9.593388	0.009593	0.007535	0.000337	0.000169
AGI_85	0.0876	5093	4924	169	0.169	873	10.956103	0.265208	15.810318	0.015810	0.012417	0.001088	0.000544
AGI_90	0.0244	5206	5022	184	0.184	0	#DIV/0!	0.287352	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000000
AGI_91	0.0134	5245	5204	41	0.041	0	#DIV/0!	0.069938	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000000
AGI_93	0.0247	4960	4886	74	0.074	240	17.136275	0.121363	4.666838	0.004667	0.003665	0.000090	0.000045
AGI_94	0.0143	5268	5253	15	0.015	75	11.309932	0.028892	1.669194	0.001669	0.001311	0.000019	0.000009
AGI_95	0.0216	4696	4696	0	0	158	0.000000	0.005000	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000000
AGI_98	0.0194	5244	5214	30	0.03	154	11.023456	0.052630	3.118556	0.003119	0.002449	0.000048	0.000024
AGI_99	0.0108	5118	5045	73	0.073	152	25.653259	0.119815	3.135727	0.003136	0.002463	0.000027	0.000013
AGI_102	0.0199	5319	5308	11	0.011	159	3.957553	0.022536	3.699643	0.003700	0.002906	0.000058	0.000029
AGI_103	0.0242	5287	5273	14	0.014	237	3.380632	0.027304	5.246212	0.005246	0.004120	0.000100	0.000050
AGI_104	0.0149	5108	5088	20	0.02	186	6.137256	0.036822	3.902325	0.003902	0.003065	0.000046	0.000023
AGI_110	0.0143	4841	4791	50	0.05	153	18.097257	0.084038	3.065245	0.003065	0.002407	0.000035	0.000017
AGI_113	0.0123	5316	5315	1	0.001	62	0.924045	0.006598	4.635265	0.004635	0.003641	0.000045	0.000022
AGI_114	0.0167	4961	4961	0	0	151	0.000000	0.005000	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000000
AGI_116	0.4639	5134	4196	938	0.938	3614	14.549860	1.200378	54.137277	0.054137	0.042519	0.019724	0.017752
AGI_118	0.0892	5327	5263	64	0.064	514	7.097576	0.105859	9.707066	0.009707	0.007624	0.000680	0.000340
AGI_119	0.1037	5115	4971	144	0.144	638	12.718843	0.227958	11.731122	0.011731	0.009214	0.000956	0.000478

Appendix

consectiv_ number	F [km²]	H max	H min	Δ H	Δ H [km]	L0 [km]	α	τf	hf [m]	hf [km]	hF	V [km³]	Water equivalent [km³]
AGI_120	0.1479	5279	4806	473	0.473	964	26.135520	0.683667	17.584903	0.017585	0.013811	0.002043	0.001839
AGI_121	0.2062	5263	5181	82	0.082	590	7.912456	0.133716	11.005596	0.011006	0.008644	0.001783	0.000891
AGI_123	0.0410	5055	5000	55	0.055	204	15.088631	0.091846	3.997635	0.003998	0.003140	0.000129	0.000064
AGI_129	0.0993	5254	5065	189	0.189	470	21.906424	0.294698	8.949498	0.008949	0.007029	0.000698	0.000349
AGI_133	0.5842	5144	4682	462	0.462	2051	12.694342	0.669638	34.526150	0.034526	0.027117	0.015842	0.014258
AGI_134	0.0204	5036	4989	47	0.047	189	13.964891	0.079344	3.725151	0.003725	0.002926	0.000060	0.000030
AGI_135	0.0184	5296	5255	41	0.041	72	29.659109	0.069938	1.601352	0.001601	0.001258	0.000023	0.000012
AGI_136	0.0596	5218	5164	54	0.054	385	7.984206	0.090286	7.364691	0.007365	0.005784	0.000345	0.000172
AGI_137	0.0958	5282	5198	84	0.084	779	6.154456	0.136798	14.457194	0.014457	0.011355	0.001088	0.000544
AGI_139	0.0763	4978	4769	209	0.209	977	12.074731	0.323912	17.543999	0.017544	0.013779	0.001051	0.000946
AGI_142	0.2348	5177	5037	140	0.14	961	8.288631	0.221958	17.444691	0.017445	0.013701	0.003217	0.001608
AGI_143	0.0475	4862	4764	98	0.098	217	24.304549	0.158291	4.357432	0.004357	0.003422	0.000163	0.000081
AGI_144	0.0700	5068	4892	176	0.176	374	25.201124	0.275561	7.332505	0.007333	0.005759	0.000403	0.000202
AGI_145	0.2206	4978	4769	209	0.209	977	12.074731	0.323912	17.543999	0.017544	0.013779	0.003039	0.002735
AGI_146	0.0637	4935	4801	134	0.134	400	18.520849	0.212937	7.595211	0.007595	0.005965	0.000380	0.000190
AGI_147	0.0359	5204	5146	58	0.058	411	8.032495	0.096523	7.826458	0.007826	0.006147	0.000221	0.000110
AGI_149	0.4392	5191	4717	474	0.474	1338	19.507205	0.684939	23.240161	0.023240	0.018253	0.008017	0.007215
AGI_150	0.1834	5035	4799	236	0.236	625	20.686536	0.362913	11.639943	0.011640	0.009142	0.001676	0.001509
AGI_151	0.3272	5184	4939	245	0.245	629	21.281270	0.375801	11.731469	0.011731	0.009214	0.003014	0.002713
AGI_154	0.0163	5059	5016	43	0.043	157	15.316860	0.073076	3.134370	0.003134	0.002462	0.000040	0.000020
AGI_155	0.1341	5144	4682	462	0.462	2051	12.694342	0.669638	34.526150	0.034526	0.027117	0.003637	0.003273
AGI_157	0.2707	5173	5119	54	0.054	367	8.370381	0.090286	7.027170	0.007027	0.005519	0.001494	0.000747
AGI_158	0.0629	4935	4867	68	0.068	477	8.113285	0.112069	8.997036	0.008997	0.007066	0.000444	0.000222
AGI_160	0.0571	5337	5301	36	0.036	138	14.620874	0.062081	2.786555	0.002787	0.002189	0.000125	0.000062
AGI_161	0.0741	5038	4862	176	0.176	335	27.716230	0.275561	6.712980	0.006713	0.005272	0.000390	0.000351
AGI_162	0.2122	5148	4991	157	0.157	700	12.641424	0.247382	12.807401	0.012807	0.010059	0.002135	0.001067
AGI_163	0.0529	5120	5069	51	0.051	786	3.712461	0.085601	14.978853	0.014979	0.011764	0.000622	0.000311
AGI_164	0.0989	5279	4806	473	0.473	964	26.135520	0.683667	17.584903	0.017585	0.013811	0.001366	0.001230

Appendix Table 5: The table shows the calculation of the water equivalent in km³ for the rock glaciers of the Argentine glacier inventory.

consective_number	F [km²]	h [m]	h [m] 50%	h [km]	Ice V [km³]	water equivalent [km³]
AGI_01	0.02218691	23.3447567	11.6723783	0.01167238	0.00025897	0.00023308
AGI_02	0.06942632	29.327486	14.663743	0.01466374	0.00101805	0.00091624
AGI_03	0.01425831	21.3689704	10.6844852	0.01068449	0.00015234	0.00013711
AGI_05	0.01778863	22.3356451	11.1678226	0.01116782	0.00019866	0.00017879
AGI_11	0.02748495	24.3662669	12.1831334	0.01218313	0.00033485	0.00030137
AGI_21	0.01390947	21.2633727	10.6316863	0.01063169	0.00014788	0.00013309
AGI_22	0.02992649	24.7845572	12.3922786	0.01239228	0.00037086	0.00033377
AGI_26	0.05957433	28.4434215	14.2217107	0.01422171	0.00084725	0.00076252
AGI_27	0.02157617	23.214796	11.607398	0.0116074	0.00025044	0.0002254
AGI_29	0.01046345	20.0865335	10.0432668	0.01004327	0.00010509	9.4579E-05
AGI_30	0.06440967	28.8908431	14.4454215	0.01444542	0.00093042	0.00083738
AGI_35	0.01896848	22.6243697	11.3121848	0.01131218	0.00021457	0.00019312
AGI_36	0.0274737	24.3642711	12.1821356	0.01218214	0.00033469	0.00030122
AGI_37	0.01085603	20.2350483	10.1175242	0.01011752	0.00010984	9.8853E-05
AGI_38	0.01061112	20.1429131	10.0714565	0.01007146	0.00010687	9.6183E-05
AGI_39	0.01741321	22.2405628	11.1202814	0.01112028	0.00019364	0.00017428
AGI_40	0.02853747	24.5500897	12.2750449	0.01227504	0.0003503	0.00031527
AGI_41	0.02025833	22.9240186	11.4620093	0.01146201	0.0002322	0.00020898
AGI_42	0.03930907	26.1739069	13.0869534	0.01308695	0.00051444	0.00046299
AGI_44	0.01356296	21.156358	10.578179	0.01057818	0.00014347	0.00012912
AGI_45	0.03966644	26.2213261	13.1106631	0.01311066	0.00052005	0.00046805
AGI_46	0.03034659	24.8537536	12.4268768	0.01242688	0.00037711	0.0003394
AGI_47	0.039764	26.2342122	13.1171061	0.01311711	0.00052159	0.00046943
AGI_48	0.12310463	32.8870472	16.4435236	0.01644352	0.00202427	0.00182185
AGI_49	0.04631342	27.0465189	13.5232595	0.01352326	0.00062631	0.00056368
AGI_51	0.03529408	25.6159441	12.8079721	0.01280797	0.00045205	0.00040684
AGI_52	0.01255996	20.8337613	10.4168806	0.01041688	0.00013084	0.00011775

Appendix

consective_number	F [km^2]	h [m]	h [m] 50%	h [km]	Ice V [km^3]	water equivalent [km^3]
AGI_53	0.02867837	24.574285	12.2871425	0.01228714	0.00035238	0.00031714
AGI_54	0.02179281	23.2612279	11.6306139	0.01163061	0.00025346	0.00022812
AGI_55	0.01648119	21.9972161	10.998608	0.01099861	0.00018127	0.00016314
AGI_56	0.03818896	26.0230126	13.0115063	0.01301151	0.0004969	0.00044721
AGI_57	0.07072828	29.4366666	14.7183333	0.01471833	0.001041	0.0009369
AGI_58	0.02645932	24.1816388	12.0908194	0.01209082	0.00031991	0.00028792
AGI_59	0.055769	28.0703986	14.0351993	0.0140352	0.00078273	0.00070446
AGI_60	0.04324989	26.6788435	13.3394218	0.01333942	0.00057693	0.00051924
AGI_61	0.01453653	21.4517224	10.7258612	0.01072586	0.00015592	0.00014033
AGI_62	0.02542574	23.989695	11.9948475	0.01199485	0.00030498	0.00027448
AGI_63	0.13832581	33.6628319	16.831416	0.01683142	0.00232822	0.0020954
AGI_64	0.14062512	33.7740069	16.8870034	0.016887	0.00237474	0.00213726
AGI_65	0.04244241	26.5784723	13.2892361	0.01328924	0.00056403	0.00050762
AGI_66	0.14381615	33.9259126	16.9629563	0.01696296	0.00243955	0.00219559
AGI_67	0.01619067	21.9191129	10.9595564	0.01095956	0.00017744	0.0001597
AGI_68	0.01936725	22.7187053	11.3593526	0.01135935	0.00022	0.000198
AGI_75	0.06242878	28.7109107	14.3554554	0.01435546	0.00089619	0.00080657
AGI_77	0.01725678	22.2004581	11.1002291	0.01110023	0.00019155	0.0001724
AGI_78	0.09841	31.4469006	15.7234503	0.01572345	0.00154734	0.00139261
AGI_80	0.01302556	20.9859829	10.4929914	0.01049299	0.00013668	0.00012301
AGI_83	0.02747728	24.3649067	12.1824533	0.01218245	0.00033474	0.00030127
AGI_86	0.01663445	22.0379767	11.0189883	0.01101899	0.00018329	0.00016497
AGI_87	0.24714754	37.8060464	18.9030232	0.01890302	0.00467184	0.00420465
AGI_88	0.01224446	20.7280245	10.3640122	0.01036401	0.0001269	0.00011421
AGI_89	0.01025106	20.0043185	10.0021593	0.01000216	0.00010253	9.2279E-05
AGI_92	0.02395076	23.7046669	11.8523334	0.01185233	0.00028387	0.00025549
AGI_96	0.01545331	21.715724	10.857862	0.01085786	0.00016779	0.00015101
AGI_97	0.0198726	22.8360489	11.4180244	0.01141802	0.00022691	0.00020422
AGI_100	0.01814866	22.4253349	11.2126675	0.01121267	0.00020349	0.00018315

Appendix

consective_number	F [km²]	h [m]	h [m] 50%	h [km]	Ice V [km³]	water equivalent [km³]
AGI_101	0.02023206	22.9180689	11.4590345	0.01145903	0.00023184	0.00020866
AGI_105	0.01817148	22.4309702	11.2154851	0.01121549	0.0002038	0.00018342
AGI_106	0.02093209	23.0745126	11.5372563	0.01153726	0.0002415	0.00021735
AGI_107	0.01861376	22.539114	11.269557	0.01126956	0.00020977	0.00018879
AGI_108	0.02335753	23.5860596	11.7930298	0.01179303	0.00027546	0.00024791
AGI_109	0.01871745	22.5641698	11.2820849	0.01128208	0.00021117	0.00019005
AGI_111	0.01276809	20.9023542	10.4511771	0.01045118	0.00013344	0.0001201
AGI_112	0.03466072	25.5233409	12.7616704	0.01276167	0.00044233	0.0003981
AGI_115	0.01021435	19.9899691	9.99498455	0.00999498	0.00010209	9.1883E-05
AGI_117	0.61150459	45.315831	22.6579155	0.02265792	0.01385542	0.01246988
AGI_122	0.36272203	40.8211082	20.4105541	0.02041055	0.00740336	0.00666302
AGI_124	0.48424697	43.2497287	21.6248643	0.02162486	0.01047178	0.0094246
AGI_125	0.03751903	25.9310633	12.9655317	0.01296553	0.00048645	0.00043781
AGI_126	0.17594643	35.3220658	17.6610329	0.01766103	0.0031074	0.00279666
AGI_127	0.07435003	29.7321443	14.8660721	0.01486607	0.00110529	0.00099476
AGI_128	0.03200895	25.1202695	12.5601348	0.01256013	0.00040204	0.00036183
AGI_130	0.03444605	25.4916471	12.7458235	0.01274582	0.00043904	0.00039514
AGI_131	0.07393837	29.6991472	14.8495736	0.01484957	0.00109795	0.00098816
AGI_132	0.02858198	24.5577444	12.2788722	0.01227887	0.00035095	0.00031586
AGI_138	0.04551688	26.9528378	13.4764189	0.01347642	0.0006134	0.00055206
AGI_140	0.08934159	30.8447133	15.4223567	0.01542236	0.00137786	0.00124007
AGI_141	0.08259251	30.3639408	15.1819704	0.01518197	0.00125392	0.00112853
AGI_148	0.02498179	23.9053285	11.9526643	0.01195266	0.0002986	0.00026874
AGI_152	0.55467882	44.440437	22.2202185	0.02222022	0.01232508	0.01109258
AGI_153	0.0591311	28.4009717	14.2004858	0.01420049	0.00083969	0.00075572
AGI_156	0.04512246	26.9059642	13.4529821	0.01345298	0.00060703	0.00054633
AGI_159	0.15795885	34.5683617	17.2841808	0.01728418	0.00273019	0.00245717
AGI_165	0.02101686	23.0931712	11.5465856	0.01154659	0.00024267	0.00021841

Personal Declaration

Personal declaration: I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Sandra Werthmüller
Bern, 25. September 2020