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Geoconservation Guidelines for Patagonia Verde (southern Chile): Towards its recognition as a UNESCO Global Geopark.

Tomás Andrés Martínez Ortega

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**Universidade do Minho**
Escola de Ciências

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Dissertação de Mestrado
Mestrado em Geociências
Património Geológico e Geoconservação

Trabalho efetuado sob a orientação do
**Professor Doutor Paulo Pereira**
**Professor Doutor Manuel Schilling**

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## Direitos de Autor e Condições de Utilização do Trabalho por Terceiros

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**GEOCONSERVATION GUIDELINES FOR PATAGONIA VERDE (SOUTHERN CHILE): TOWARDS ITS RECOGNITION AS A UNESCO GLOBAL GEOPARK.**


## Abstract

Patagonia Verde is a territory located in the Southern Andes, conformed by the municipalities of Cochamó, Hualaihué, Chaitén, Futaleufú and Palena. It has 19,212 km$^2$ and a population density of close to one inhabitant per square kilometre. This area has an outstanding natural diversity, and a significant part of Patagonia Verde's territory is devoted to conservation, where its five protected areas cover about 28% of the region. Between 2017 and 2020, a project named "Development of geotourism products in the Patagonia Verde tourist destination" was underway to document and assess its geodiversity, especially those sites of geotourism value. The objective was to elaborate, together with the guides of the territory, on different routes that could create a new alternative for economic development. However, other sites of scientific and educational value emerged during the project and were documented by the project's team, made up of an interdisciplinary group of professional and undergraduate students. The present work compiled and integrated all the generated information and produced an inventory of 91 sites of interest organised according to their attributes. Subsequently, a quantitative analysis of these attributes allowed the generation of management categories and the proposal of an action plan. Together with this, a management structure is proposed to carry them out and ensure the sustainable use of the identified geological resources. Based on the results obtained, it is concluded that the Patagonia Verde destination has geological values of national and international relevance, and most of the sites have the potential to be used in education and geotourism programmes. It is hoped that the proposed geoconservation guidelines contribute to the consolidation of the Patagonia Verde Geopark project, which is currently promoted by the Association of Local Guides of the territory.



Keywords: Patagonia Verde, Geodiversity, Geological Heritage, Geoconservation, Geotourism, Guidelines

**DIRECTRIZES DE GEOCONSERVAÇÃO PARA A PATAGONIA VERDE (SUL DO CHILE): PARA O SEU RECONHECIMENTO COMO UM GEOPARQUE GLOBAL DA UNESCO.**


## Resumo

A Patagónia Verde é um território situado nos Andes do Sul, compreendendo as comunas de Cochamó, Hualaihué, Chaitén, Futaleufú e Palena. Tem 19.212 km2 e uma densidade populacional de cerca de um habitante por quilómetro quadrado. Esta área tem uma extraordinária diversidade natural, e uma parte importante do território da Patagónia Verde é dedicada à conservação, onde as suas cinco áreas protegidas cobrem cerca do 28% da região. Entre 2017 e 2020, foi lançado um projecto denominado "Desenvolvimento de produtos de geoturismo no destino turístico da Patagónia Verde" para documentar e avaliar a sua geodiversidade, especialmente os sítios de valor geoturístico. O objectivo era elaborar, juntamente com os guias do território, diferentes rotas que pudessem criar uma nova alternativa para o desenvolvimento económico. No entanto, durante o projecto, outros sítios de valor científico e educativo emergiram e foram documentados pela equipa do projecto, formada por um grupo interdisciplinar de profissionais e estudantes universitários. O presente trabalho compilou e integrou toda a informação gerada e produziu um inventário de 91 sítios de interesse organizado de acordo com os seus atributos. Subsequentemente, uma análise quantitativa destes atributos permitiu a geração de categorias de gestão e a proposta de um plano de acção. Juntamente com isto, é proposta uma estrutura de gestão para os levar a cabo e assegurar a utilização sustentável dos recursos geológicos identificados. Com base nos resultados obtidos, conclui-se que o destino Patagónia Verde possui valores geológicos de relevância nacional e internacional, e que a maioria dos sítios tem potencial para ser utilizada em programas de educação e geoturismo. Espera-se que as directrizes de geoconservação propostas contribuam para a consolidação do projecto Geoparque Patagónia Verde, actualmente promovido pela Associação de Guias Locais do território.



Palavras-chave: Patagónia Verde, Geodiversidade, Património Geológico, Geoconservação, Geoturismo, Directrizes.

**DIRECTRICES DE GEOCONSERVAC8IÓN PARA PATAGONIA VERDE (SUR DE CHILE): HACIA SU RECONOCIMIENTO COMO GEOPARQUE MUNDIAL DE LA UNESCO.**


**Resumen**

Patagonia Verde es un territorio ubicado en los Andes del Sur, conformado por las comunas de Cochamó, Hualaihué, Chaitén, Futaleufú y Palena. Tiene 19.212 km2 y una densidad de población cercana a un habitante por kilómetro cuadrado. Esta zona cuenta con una destacada diversidad natural, y una parte importante del territorio de Patagonia Verde está dedicada a la conservación, donde sus cinco áreas protegidas cubren alrededor de 28% de la región. Entre 2017 y 2020 se puso en marcha un proyecto denominado "Desarrollo de productos geoturísticos en el destino turístico Patagonia Verde" para documentar y evaluar su geodiversidad, especialmente aquellos sitios de valor geoturístico. El objetivo era elaborar, junto con los guías del territorio, diferentes rutas que pudieran crear una nueva alternativa de desarrollo economico. Sin embargo, durante el proyecto surgieron otros sitios de valor científico y educativo que fueron documentados por el equipo del proyecto, formado por un grupo interdisciplinario de profesionales y estudiantes de pregrado. El presente trabajo recopiló e integró toda la información generada y produjo un inventario de 91 sitios de interés organizados según sus atributos. Posteriormente, un análisis cuantitativo de estos atributos permitió generar categorías de gestión y proponer un plan de acción. Junto a esto, se propone una estructura de gestión para llevarlas a cabo y asegurar el uso sostenible de los recursos geológicos identificados. En base a los resultados obtenidos, se concluye que el destino Patagonia Verde posee valores geológicos de relevancia nacional e internacional, y la mayoría de los sitios tienen potencial para ser utilizados en programas de educación y geoturismo. Se espera que las directrices de geoconservación propuestas contribuyan a la consolidación del proyecto de Geoparque Patagonia Verde, que actualmente impulsa la Asociación de Guías Locales del territorio.



Palabras clave: Patagonia Verde, Geodiversidad, Patrimonio Geológico, Geoconservación, Geoturismo, Directrices

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*“Quando despersonalizamos o rio, a montanha, quando tiramos deles os seus sentidos, considerando que isso é atributo exclusivo dos humanos, nós liberamos esses lugares para que se tornem resíduos da atividade industrial e extrativista “*

- Aliton Krenak -

## Introduction

Patagonia Verde is a territory of 19,212 $km^2$ that belongs to the Lake District (*Región de Los Ríos*) in southern Chile and includes the municipalities of Cochamó, Hualaihué, Chaitén, Futaleufú and Palena. To the east is the Great Island of Chiloé, and between the two territories, the Gulfs of Ancud and Corcovado flood the central depression and give rise to many islands, fjords and canals. It has a population density of close to one inhabitant per square kilometre, and around 28% of its territory is protected by the Pumalín, Hornopirén and Corcovado National Parks and the Futaleufú and Lago Palena National Reserves. Patagonia Verde is characterized by a pristine landscape, with small towns and villages that maintain their customs and traditions linked to fishing and cattle raising. Patagonia's ecological and cultural scenic values are recognized worldwide and visited by hundreds of thousands of tourists annually who visit and travel along the well-known Carretera Austral (INE, 2022). However, much of it is concentrated in consolidated destinations and attractions such as the Llanquihue Lake basin, the Cerro Castillo National Reserve and the Torres del Paine National Park.

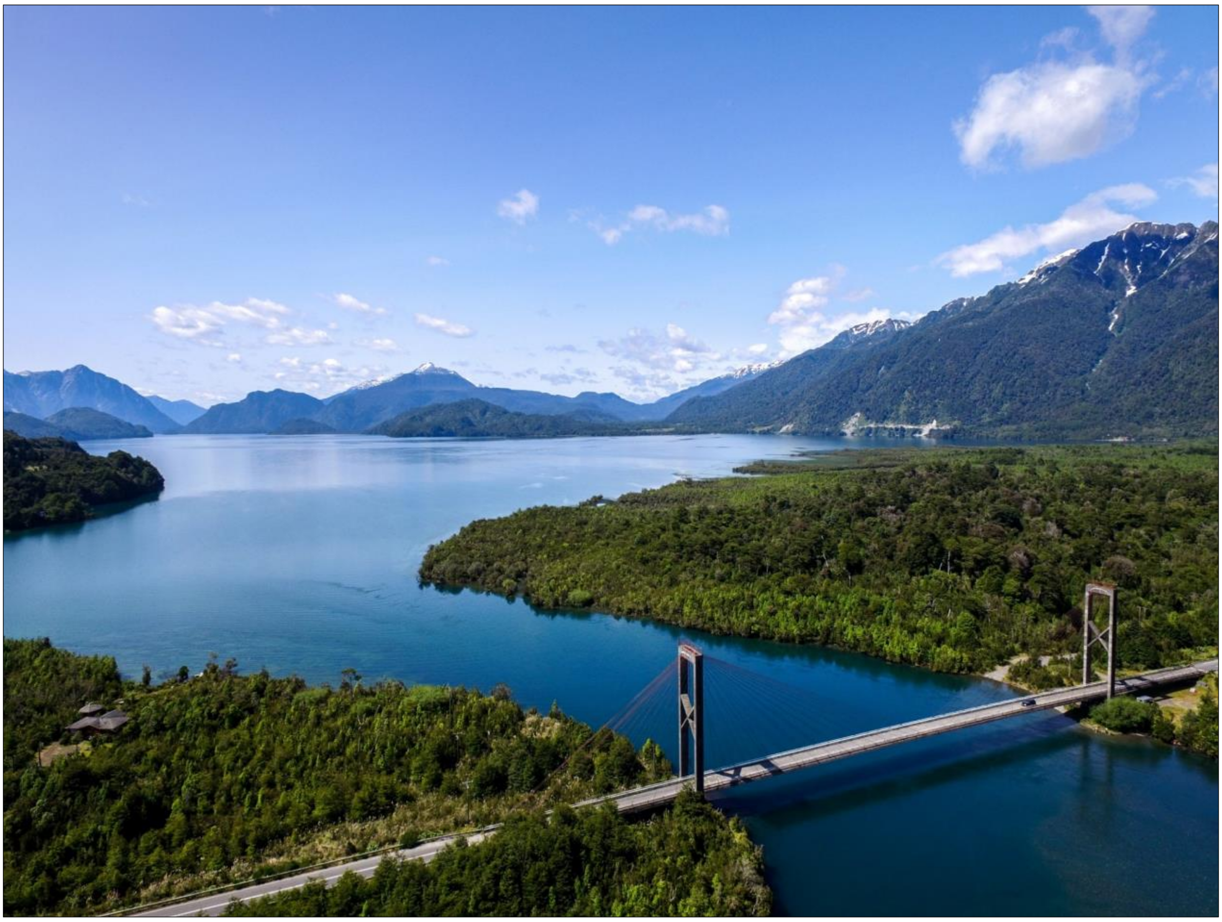


*Figure 1 Built in 1989, the Yelcho suspension bridge connected southern Chile's pristine and previously inaccessible territories.*

Since 2015, through the governmental initiative called "Sustainable development destination, Patagonia Verde", the aim has been to enhance the value of nature, culture, and gastronomy of the territory to establish sustainable tourism as a fundamental tool for economic development.

In this area of the Andes, geology and its diversity are prominent in the landscape. Colossal granite mountains, fjords, glaciers, rivers, hot springs, and volcanoes form a rugged landscape with unique ecosystems and life forms adapted to frequent volcanic eruptions, earthquakes, and landslides. Understanding these processes and the geological evolution of this territory is fundamental for land-use planning and geohazard response.

Between 2017 and 2019, a multidisciplinary team from the Austral University of Chile made an inventory of some relevant elements of geodiversity. The inventory was part of the project "Development of geotourism products for the destination Patagonia Verde, Lake District" and aimed to create several routes to visit some of the territory's main attractions and improve the existing geological narrative by training local guides. Thus, geotourism was promoted to generate informal education instances and boost the local economy (Schilling et al., 2020).

Moreover, opportunities for collaboration were generated between the guides, the municipalities and professionals of the institutions of the territory (e.g. National Forestry Corporation (CONAF), National Geology and Mining Service (SERNAGEOMIN), National Tourism Service (SERNATUR) in different workshops and meetings, where common objectives and development perspectives were outlined in the Declaration of Hualaihue (Annex 7.4)

At present, the local tour operators of Patagonia Verde have formed an association that aims, among other issues, to promote the consolidation of the Patagonia Verde Geopark project. To this end, although significant progress has been made in identifying and characterising sites, compiling the different documents generated is still necessary. The homogenisation and creation of a systematic inventory, together with the definition of guidelines for the sustainable use of these geological resources, are fundamental steps to achieving this ambitious objective. In this context, the present thesis work is developed, which seeks to satisfy these territorial needs.

## 1.1 Objectives

### A. Main Objective

Develop guidelines for the sustainable management of geodiversity in Patagonia Verde that will serve as a basis for the establishment of the Patagonia Verde Geopark, currently led by the Association of Patagonia Verde Local Tourism Guides.

### B. Specific objectives

i. Characterize Patagonia Verde, its geology, geodiversity, and the threats that may affect it.
ii. To generate an inventory of the geodiversity of Patagonia Verde and analyse the use potential of the different sites inventoried.
iii. Propose guidelines for the management of the geodiversity of Patagonia Verde.

## 1.2 Methods

### A. To achieve the specific objective i:

Different types of existing publications in the study area were collected and analysed for the development of a summary with a holistic view of the territory of Patagonia Verde, with an emphasis on geology, its geodiversity and threats. In addition, the author's notes and observations from the various fieldwork campaigns, workshops, meetings and seminars carried out in Patagonia Verde have been used.

### B. To achieve the specific objective ii:

The documents generated by the technical team of the Patagonia Verde Geotourism project with unpublished data collected by the author in the different territorial activities were compiled and analysed to build up the inventory of Patagonia Verde. The workflow of this work is based on the proposal of Brilha (2016, 2018), where the following stages were carried out: Defining the topic, the value, the scale, and the aim of the inventory; Definition of geological contexts; Background collection; Site Selection Criteria; Fieldwork: identification, selection and preliminary inventory of sites; Inventory Proposal Quantitative Assessment and Data Analysis.

### C. To achieve the specific objective iii:

The quantitative assessment results were used to generate different management categories. Then, a geodiversity action plan was proposed to manage the inventoried sites. Finally, an administrative structure to implement the action plan was proposed.

## 1.3 Concepts

### A. Geodiversity

Geodiversity – the variety of geological (rocks, minerals and fossils), geomorphological (landforms, topography and physical processes), pedological and hydrological elements (Gray, 2004) - constitute the substratum that supports and conditions the different forms of life. In this way, nature is composed of a living, and an abiotic part, whose relationship is inseparable. Moreover, in some cases, the heterogeneity of living organisms is conditioned by the variety of abiotic elements (Bailey et al., 2017).

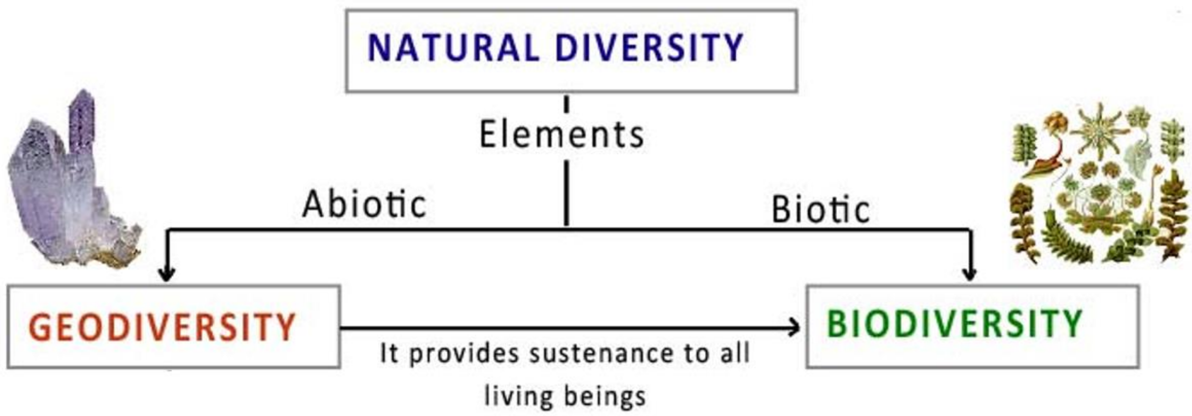



*Figure 2 Schematic depicting the link between geodiversity and biodiversity*

### B. Geodiversity Values

Geodiversity can be valued according to its characteristics and utilities for human activities. Typically, the economic value is the most widely recognised, given the direct benefit to society from the extraction, use and sale of geological resources. However, the geological resource can also be used in other ways without necessarily being extracted. In this way, other values, such as heritage value, usually broken down into three values: scientific, cultural and aesthetic (linked to tourism), can also be fundamental for developing societies and local economies.

A complete analysis of the values of geodiversity implies that there are many more aspects to consider. Brilha (2005), based on Gray's (2004) work, sets them out as follows:

- **Intrinsic value:** Refers to the belief that geodiversity has value simply because of what it is, independent of whether or not it has any use by humans.
- **Cultural value:** Conferred by humans when a strong interdependence is recognised between social, cultural or religious development and the surrounding physical environment.

- **Aesthetic value:** Subjective attribution related to the perception of a place, the sensation it can produce or the beauty attributed to it.
- **Economic value:** More objective and related to the possibility of generating an economic benefit through a geological resource.
- **Functional value:** Generally not applicable to nature conservation and linked to the practical value that geodiversity has for humankind or as a support for physical and ecological systems on the earth's surface.
- **Scientific and educational** value where geodiversity is a fundamental tool for understanding the Earth's history, necessary for scientific research and formal and non-formal education.


*Figure 3 Examples of Geodiversity and different types of values.*

## C. Geosites & Geoheritage

Brilha (2016) propose that the geodiversity's most relevant elements, given their scientific value to contribute to understanding the different processes occurring on Earth, are called Geoheritage. When these elements are in their place of origin, they are referred to as Geosites. Otherwise, essential elements of geological heritage, such as fossils and minerals stored in collections, are called Geoheritage elements. All sites that do not have exceptional scientific value would be referred to as "Geodiversity sites".

The author strongly agrees with Brilha (2016) that the term Geosite should be restricted to sites of outstanding scientific value, and another term should be used for sites which, given other values, are also candidates for a geoconservation strategy. This reasoning seems consistent with the spirit and purpose of the international Geosites programme, where the desire is:

"*to identify and document, not token examples, but those features, sites and areas which give an in-depth understanding of the Earth's evolutionary story, that show broader patterns, and which allow comparisons and correlations. In our balanced compilation of a regional or global inventory, we look therefore to include sites/terrains which show significant stages and events, the special and, especially, the representative"* Wimbledon (1999, p7)

In this sense, and according to Brilha (2018), this distinction can avoid giving the authorities the impression that a geosite is not rare or unique and, therefore, no particular management actions are needed

*Figure 4 Geosite of Patagonia Verde. Marine rocks of Ica Island. Its origin is related to the most relevant marine transgression of the Cenozoic in Patagonia, which occurred during the late Oligocene and early Miocene.*

Also, it is worth noting that in Chile, as in many other countries, there are different management categories in the current legislation to protect "geodiversity sites" for their natural, cultural or aesthetic value. For instance, Natural Monuments, Nature Sanctuaries or Paleontological sites, among others, allow activities such as geotourism and education. In this sense, a geotourism programme could be composed of visits to geosites and other sites on the territory.

So, instead of using the term "geodiversity site" as a category for those sites worthy of other values, the author prefers to use one of the already indicated terms (e.g. Nature Sanctuary or potential Nature Sanctuary). The reason for this is that “diversity” is related to a variety of features and does not necessarily better represent some “geo-occurrences” like "a stone shaped like a hand" or a “The bride's waterfall veil”. Therefore, the author believes that the term “geodiversity site” is not only incorrect from a linguistic point of view but also creates a new category that overlaps with existing ones, generating confusion.

## D. Geotourism

Geotourism is a branch of nature tourism based on understanding geological heritage and appreciating geodiversity. Moreover, it is a tourism niche that stands out for ensuring a scientific culture based on understanding relief, rocks, fossils and other elements of geodiversity in all its dimensions, including aesthetics. In this way, its scope is broader than other types of tourism (Dowling, 2013).

It differs from mass tourism, which is often a catalyst for the degradation of sites because it seeks to educate and make people aware of their environment, the value of the territory, and the geological processes that take place there. Consequently, any modification or damage to the natural heritage is directly detrimental to this discipline.

One of the recently adopted definitions is that of Arouca (2011), that defines Geotourism as "Tourism that supports and enhances the identity of a region, considering its geology, environment, culture, aesthetics, heritage and the well-being of its inhabitants. Geological tourism is one of the multiple components of geotourism".

Geotourism seeks to showcase geological heritage to all audiences and be a dynamic agent of the local economy. It is also an innovation opportunity for the tourism industry, with new challenges for new destinations because the profile of tourists is constantly evolving and the usual destinations with transformations in the environment (e.g. engineering works, buildings, urbanisation) are becoming less and less valued.

Unlike other disciplines, such as ecotourism, which only occurs in natural areas, Newsome and Dowling (2010) argue that geotourism occurs in natural and human-modified areas. In this way, it is possible to take up traditional tourism attractions (activities, accommodation, visits, and others) in favour of understanding and conservation of nature.


*Figure 5 Geotourism and birdwatching in the Río Negro wetland, Hualaihué.*

Pereira (2010) points out that the threats to geotourism are also those affecting geological heritage, geodiversity and the rural environment, exhibiting them as:

i. **Educational:** Related to the illiteracy regarding the values of geodiversity and the existence of "alternative conceptions" of sustainable development.
ii. **Political:** Related to the fact that geological heritage, rural areas and natural landscapes are ignored or devalued in land-use planning and development matters;
iii. **Economical**: Due to the exploration/exploitation of renewable and non-renewable resources and unsustainable forms of tourism.

## E. Ecosystem services and Geodiversity.

National Geographic (2022) define an ecosystem as a geographic area where plants, animals, and other organisms, as well as weather and landscapes, work together to form a life bubble. Ecosystems are composed of biotic parts (e.g. plants, animals, and other organisms) and abiotic parts (e.g. rocks, temperature, and humidity).

The proper functioning of ecosystems provides various services to society and the natural environment, such as the water we drink or the soils we cultivate, improving people's health, economy and quality of life. These benefits, resulting from the functioning of ecosystems, are known as Ecosystem Services

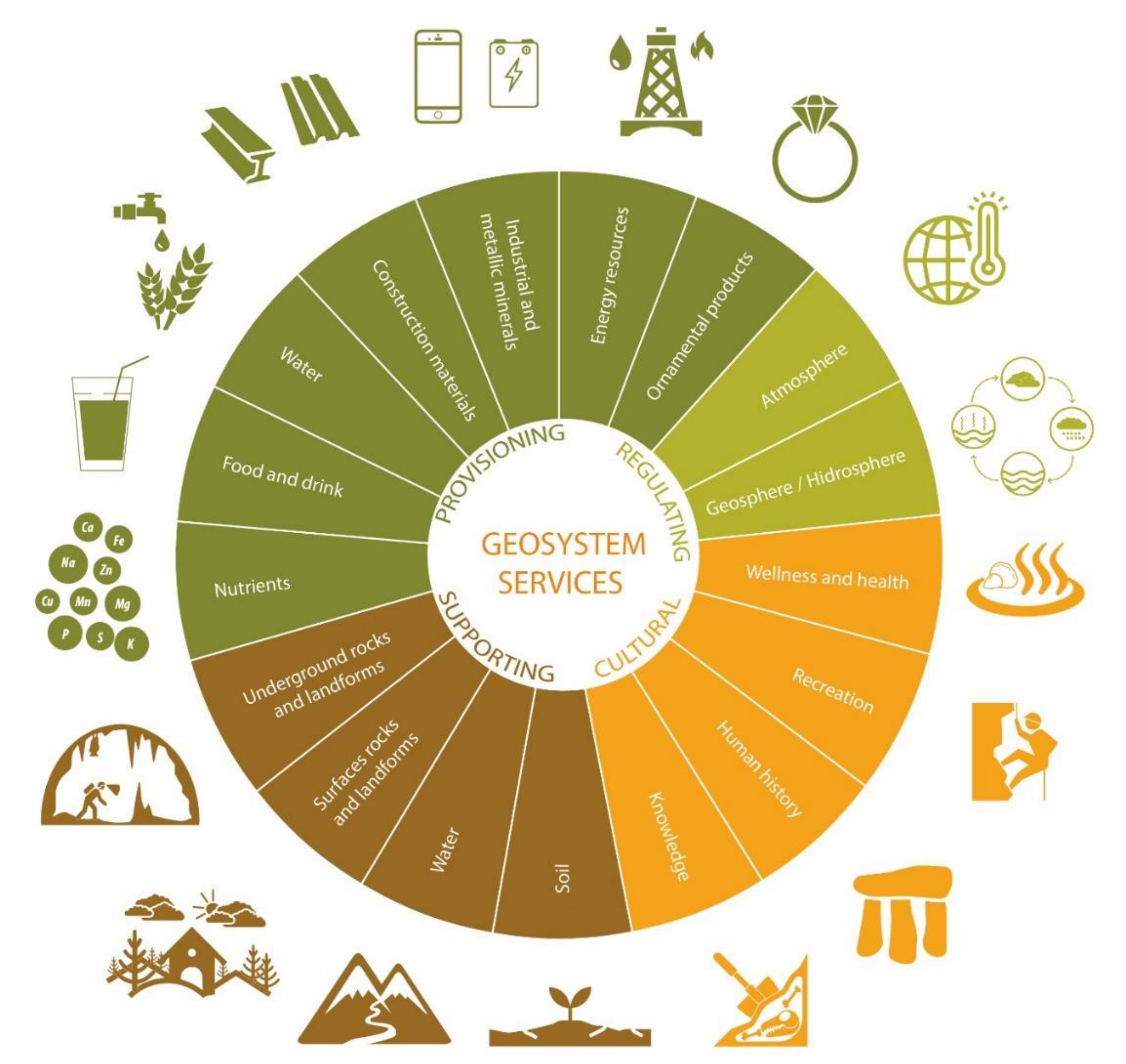



Figure 6 Geosystem services and Divisions. Modified from Brilha et al., 2018, after Gray (2013)

The Natural Capital Coalition defines natural capital as "the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people" (Natural Capital Coalition, 2016). In this sense, natural capital comprises Geodiversity and Biodiversity, as does the ecosystem. So, a more economical approach to ecosystem services considers that natural capital stock flows essential benefits to society (Gray, 2019).

Nevertheless, given the general exclusion of abiotic nature from the ecosystem services approach, Gray (2013) uses the term 'Geosystem Services' to attempt to examine the goods and services related specifically to geodiversity. Then, Geodiversity elements and processes contribute to ecosystem services based on their diversity of values (Figure 3). Gray (2013) presents these values - scientific, educational, economic, cultural and aesthetic, among others. - in detail and establishes the link between the value and the type of use.

Brilha et al. (2018) use the Millennium Ecosystem Assessment system, which classifies ecosystem services into four groups (Figure 6).

- **Regulating services:** how natural processes regulate the environment.
- **Supporting services:** the processes that sustain natural environments
- **Provisioning services**: the natural materials that are used by society.
- **Cultural services** are the non-tangible elements of the natural environment that benefit society spiritually or culturally.

The geodiversity of Patagonia Verde is a consequence of different geological processes, which, in addition to its function as regulator and support of ecosystems or provider of essential resources such as water, is a source of knowledge and culture closely linked to the territory.

## F. Geodiversity & sustainable development goals

The ecosystems can be considered a limited stock of natural resources, essential both for the maintenance of the ecosystem itself and for developing wildlife forms and human societies. It is inevitable to conclude that there must be a balance between the resources extracted and used and those necessary for ecosystems to remain healthy and to continue to provide essential services such as water. Under this argument, the concept of "sustainability" and "sustainable development" arises in which the development of present societies and the use of natural resources do not compromise those of future societies.

In 2015, the so-called Sustainable Development Goals (SDGs) were formally adopted by the United Nations member states (United Nations, 2015). The goals were to end unsustainable consumption patterns, facilitate sustained and inclusive economic growth, social development and environmental protection, and eradicate global poverty over a fifteen-year timeframe (2015–2030).

Maintaining and caring for ecosystems without considering abiotic elements is not enough to achieve the SDGs. Documentation and monitoring geodiversity and geosystem services are also necessary (Schrodt et al., 2019). Gill (2017) first visualised the critical role of geology in all its areas in achieving these goals. In the same way, Schrodt et al. (2019) mention that while continuing resource extraction is essential for achieving sustainable development goals (SDGs, Figure 7), trade-offs with biodiversity conservation and human rights need to be explicitly addressed. For instance, to achieve some of the objectives and generate a transition to sustainable cities with renewable energy (SDG 11), the extraction of large quantities of new minerals, many of which are scarce, will be necessary. Therefore, applying the geo-system services approach is necessary to understand the real benefits of these options.


Figure 7 Sustainable Developments Goals, prioritized by the United Nations (2015)

During the 41st UNESCO General Conference in 2021, International Geodiversity Day was proclaimed to celebrate, among other things, the importance of Geodiversity in achieving SDGs. Its website can visualise how geodiversity and its management contribute to that. (https://www.geodiversityday.org/geodiversity-and-the-sdgs).

## G. Geoconservation

Geoconservation is the conservation of geodiversity for its intrinsic, ecological and heritage values. It aims to preserve the geodiversity elements and processes. Also, to maintain the natural rates and magnitudes of change of these features and processes (Sharples, 2002).

This study area understands abiotic components to be as important as those that are living. Furthermore, as Sharples (2002) states, geoconservation is the basis of bio-conservation in that it provides a variety of environments and environmental conditions that directly influence the development of life. Nevertheless, geodiversity has value itself, independent of its relationship with life, and therefore needs its own methodologies for its conservation and preservation. Thus, a more holistic view of nature conservation will include both biodiversity and geodiversity conservation, understanding the close link between the two.

### H. UNESCO Global Geoparks

UNESCO Global Geoparks (UGGp) are unique and unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education, and sustainable development. Their bottom-up approach combines conservation with sustainable development and the involvement of local communities (UNESCO, 2022a).

While geoconservation allows the value of the territory to remain over time through safeguarding geodiversity, particularly the selected and inventoried elements, education helps local communities empower themselves with this knowledge and develop new economic activities linked to the conservation of these sites. Among these activities, geotourism stands out as a facilitator of the local economy.

Eder & Patzak (2004) consider that the impact of a geopark area is not only the improvement of the quality of life of the people who live there but also of the immediate rural environment, strengthening people's identification with their territory and boosting cultural revival. Furthermore, they add that, while respecting the environment, Geoparks stimulate the development of local innovation: small businesses, craft industries and new jobs generate new sources of income. This link between geoparks and sustainable local development is reflected in the 177 geoparks recognised by UNESCO, located in 46 countries (UNESCO, 2022a).


*Figure 8 Global and regional distribution of UGGp. Each colour represents a regional network: the Asia Pacific Network (green), the European Network (blue), the African Network (Magenta), the Latin American Network*

# 2 Characterization of the study area

## 2.1 Patagonia Verde is a nature reserve at the end of the world.

Patagonia is a territory located at the southern edge of South America, belonging to the republics of Chile and Argentina. The limits of Patagonia are the Atlantic Ocean to the east, the Pacific Ocean to the west, and Cape Horn to the south. The northern boundary has historically been more ambiguous, although various antecedents suggest that it would be located close to the latitude of the city of Temuco (Schilling et al., 2017)

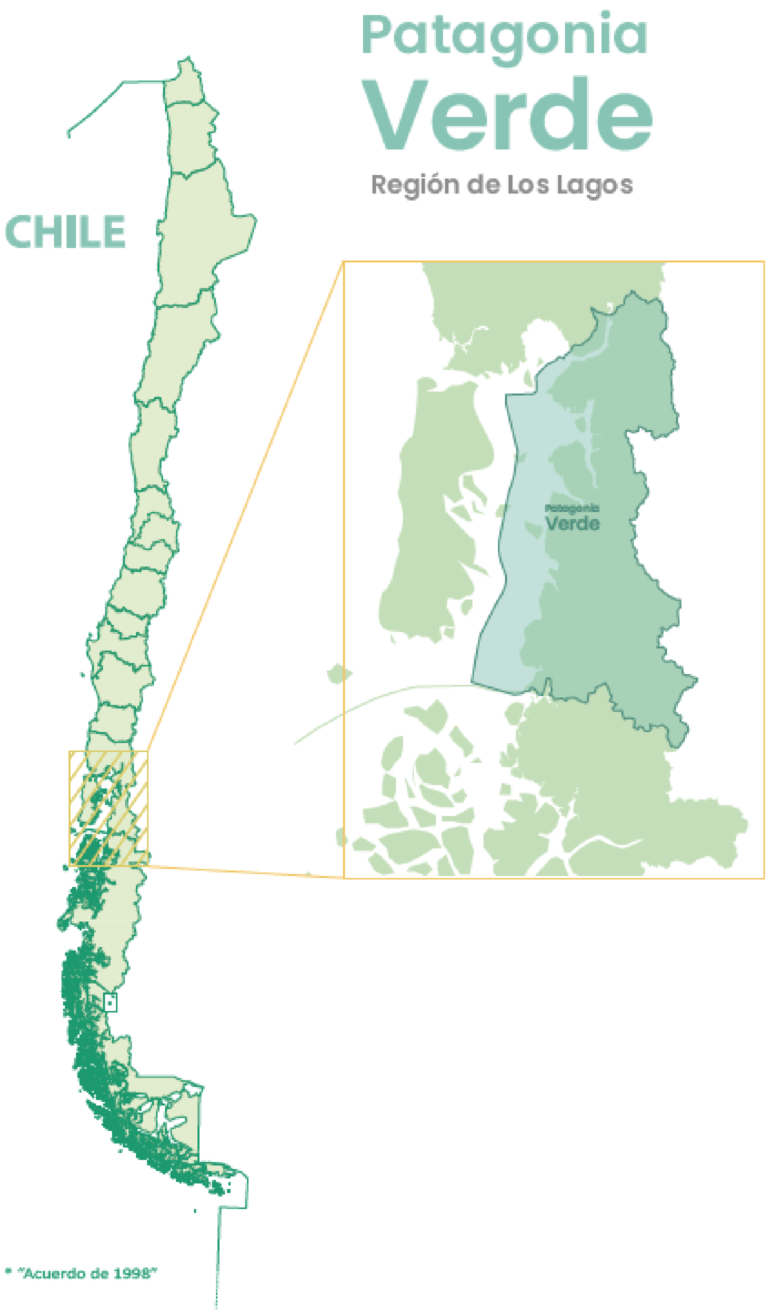



*Figure 9 Location of Patagonia Verde. Taken from Schilling et al. 2020. Design: Daniela Gallardo Diaz.*

Patagonia Verde corresponds to a portion of this mythical region (Figure 9), belonging to the Lake District and includes, from north to south, the municipalities of Cochamó, Hualaihué, Chaitén, Futaleufú and Palena. It covers an area of 19.213 km2 and is home to an estimated population of 22,372 inhabitants, resulting in a population density close to one inhabitant per $km^2$.

It is located in the northern part of the Patagonian Andes Mountain range, between the high peaks and the Pacific Ocean. This condition, unique in the world, allows the meeting of two ways of life, very close in distance but very different in culture. On the one hand, the communities that inhabit the coastal areas of this territory have a greater cultural affinity with the communities of insular Chiloé and the Huilliches traditions, while those in the mountainous areas of the east are close to the gaucho culture also present in Argentina (Gomez, C & Barría K, (Ed.), 2018)

*Figure 10 The riverside carpenters are part of the living heritage of Patagonia Verde and part of the fishing and timber tradition of the territory. Ph: Patricio Contreras.*

Also, the proximity between the mountains and the sea generates a unique climate associated with the high annual rainfall of the oceanic and temperate rainy climates. This condition, in turn, generates a singular endemic forest, known as evergreen or Valdivian, protected under the figure of the Biosphere Reserve of the Temperate Rainforests of the Austral Andes of UNESCO (UNESCO, 2022) which covers much of the territory, dubbing green this part of Patagonia. One of the iconic trees in this reserve is a conifer called *Fitzroya cupressoides*, locally known as Alerce, a tree over 50 metres tall and whose life span is estimated at over 3600 years, which makes it the second most extended living tree after bristlecone pine (*Pinus longeva*) (Lara, & Villalba, 1993).

*Figure 11. The thousand-year-old larch trees were felled and sold for centuries and constituted the main engine of the regional economy and culture. Overexploitation and their disappearance in large areas of the territory led to them being declared a national monument in 1976, prohibiting their felling.*

In Patagonia Verde, the Andes Mountain range is lower than in the northern and central parts of the country, rising slightly above 2,000 m a.s.l., primarily where the volcanoes are located. Between the mountains, the valleys were shaped by glaciers, almost wholly covering the territory before initiating a rapid deglaciation process some 18-19 kyr (Davies et al., 2020). Nowadays, these landscapes shelter several lakes, rivers and human settlements fed by the water of glaciers that survive the retreat on the main summits of Patagonia Verde. In other cases, the sea has flooded and eroded the valleys, mainly in the central depression, resulting in the characteristic gulfs and fjords, which, under their waters, still keep a record of the glacial processes that gave rise to them (Dowdeswell, 2016).

*Figure 12. The high areas of the Michinmahuida volcano host several glaciers. In the photograph, the Amarillo (Yellow) Glacier descends from the mountain and makes its way through the vast valley it undermined in the past.*

The rocks of Patagonia Verde record a fabulous geological history of some 400 million years ranging from the accretion of exotic terrains such as Chaitenia (Herve et al., 2016) to the volcanic eruptions and landslides that have occurred in recent years

Patagonia Verde has a unique tectonic configuration in the world where different geological processes are interrelated, mainly because an enormous active tectonic area along 1200 km, from the Antuco volcano in the north to the Gulf of Penas in the south, known as the Liquiñe-Ofqui Fault Zone. This set of faults has had a close relationship with magmatism (e.g. Pankhurst et al. 1992), active volcanism (e.g. Cembrano & Lara, 2009) and thermalism (e.g. Ruiz, B., & Morata, D, 2016), controlling the occurrence and interconnection of all these processes. In addition, the glaciers that covered the territory during the last glaciations preferentially eroded the rock massif weakened by the tectonic activity (Ghiglione, 2017), generating valleys and fjords in the areas that remained below sea level.

From north to south, the most easily recognisable volcanoes in Patagonia Verde are Yates, Hornopirén, Huequi, Chaitén, Michinmahuida, Corcovado and Yanteles, but there are many others (Annex 7.1). Several of these volcanoes have had historical eruptions. For instance, the Chaitén volcano eruption in 2008 (Major & Lara, 2013) caused the evacuation of the population of Chaiten, a city of approximately 4.000 inhabitants. This evacuation was the biggest performed in Chile to date. Then, this city was partially destroyed due to the lahars formed from the large amount of volcanic material transported by heavy rains.

Historically, numerous landslides have also occurred, some of which destroyed houses and caused fatalities. The most significant landslides in this territory are those that occurred in Lago Cabrera (1965), Buill (2002), Villa Santa Lucía (2017) and recently, El Amarillo (2020).

*Figure 13 One of the largest landslides that occurred in Patagonia Verde was in Villa Santa Lucia on December 2017. This landslide caused 21 deaths, one disappearance, devastated vegetation, covered routes 7 and 235, destroyed houses and infrastructure near the Burritos river and deposited on Villa Santa Lucia.*

A significant part of Patagonia Verde's territory is now devoted to conservation and nature tourism. The Hornopirén, Corcovado and Pumalín Douglas Tompkins National Parks, which form the northern part of the Route of National parks of Patagonia, are located here. Other protected areas are the Futaleufú and Lago Palena National Reserves (see Figure 15).

The main access to Patagonia Verde is Route 7, known as *Carretera Austral* (Austral Highway). It starts in Puerto Montt and continues south through the Aysén Region, ending at Villa O'Higgins in the Magallanes Region. The Carretera Austral is a scenic route recognised worldwide because it allows enjoying forests, fjords, rivers, glaciers, volcanoes and hot springs, having a wide variety of tourist activities, such as hiking, mountaineering, kayaking (Figure 14), rafting, horseback riding, sport fishing, climbing, among many others

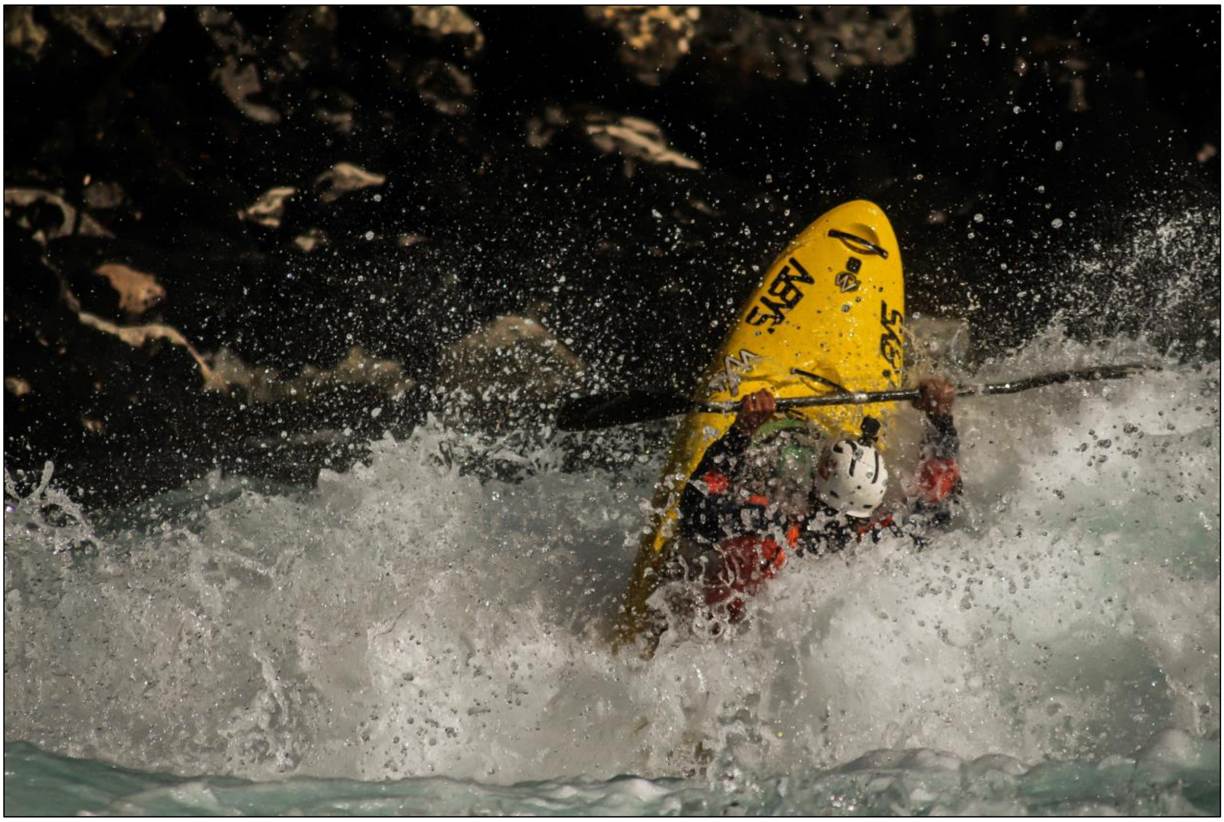


*Figure 14 The Futaleufu River is an internationally recognised destination for rafting and kayaking. Its rapids, class III, IV and V, motivate many athletes who visit Patagonia Verde and challenge the river's waters. Ph: Paulo Urrutia*

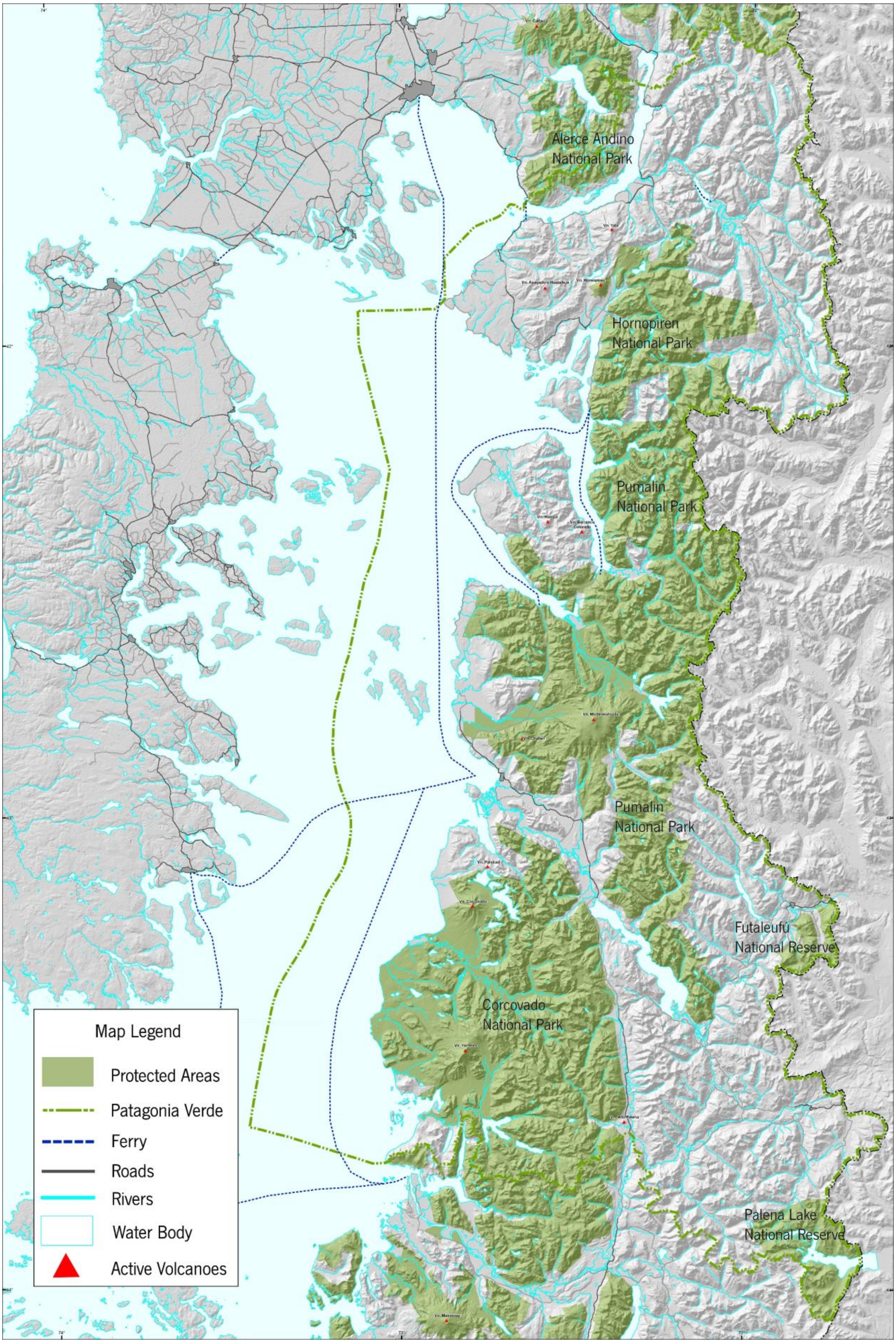



Figure 15 *Patagonia Verde and its National Parks and Reserves.*

## 2.2 Brief of the Geological Evolution

The oldest geological records in Patagonia Verde are Devonian metamorphic rocks interpreted to be derived from an oceanic island arc/back-arc system named Chaitenia (Duhart et al., 2009, Herve et al., 2016). It was formed at c. 395 Ma due to enhanced lithospheric thinning driven by slab roll-back resulting in the rifting and detachment of the North Patagonian Massif's forearc and the formation of a marginal oceanic basin between a remnant continental arc and the outboard Chaitenia island arc (~395 Ma; Herve et al.2016;2018). The closure of the marginal basin and accretion of the Chaitenia island arc against the stable continent occurred during the Mississippian, around 360-340 Ma (Rapela et al., 2021). The rocks recognised as Chaitenia are interpreted as an insular volcanic arc and a shallow seabed surrounding it. The volcanic arc is represented by magmatic-derived rocks found at Pichicolo, Chaitén and Lago Yelcho. On the other hand, the seafloor is characterized by volcanic deposits and sedimentary sequences, such as the Riñihue Fjord's pillow lavas and the Buill locality's slates.

In addition, it is worth noting that these slates contain one of the two fossil records of Trilobites in Chile, which have been fundamental for dating these rocks. (Levi et al., 1966; Fortrey et al., 1992; Duhart et al., 2009).


*Figure 16. Trilobites colected by Fortrey et al. (1992) in the locality of Buill. The exact provenance of these fossils is unknown and of great scientific interest.*

The Carboniferous to Permian geological record in this region evidences magmatism, deformation and metamorphism and, together with the Devonian outcrops, are part of the Main Range Metamorphic Complex (MRMC). Nevertheless, Rapela et al. (2021) suggest that the later events must be separated from the Devonian episodes described above, and probably relate to a different tectonic setting.

At present, little is known of the geological history of Patagonia Verde during the Triassic (250-200 Ma). However, from evidence found further north, it can be inferred that there was magmatic and volcanic activity, along with the formation of continental basins where forests with diverse species of flora developed (Herbst et al., 2005)

The Andean Cycle began in the Jurassic (ca. 200 million years ago). During this period, a prolonged subduction regime was established, which gave rise to intense magmatic activity. This activity generated volcanic and plutonic rocks and depositional basins synchronous or diachronic with the magmatism (Figure 17, Duhart & Quiroz, 2006).

*Figure 17 Tres Monjas Hill. On the high summits of the Futaleufú and Palena peaks, it is possible to find volcanic and sedimentary records of the Jurassic and Cretaceous periods*

Pankrhust et al. (1992) mention that given the geological record, a mid-Jurassic volcanic arc and a possible marine back-arc or pull-apart basin are inferred. These were associated with a strike-slip movement developed within the continental margin east of the late Palaeozoic accretionary complex. Thus, according to these authors, the mid-Jurassic could be the primary development of the Liquiñe-Ofqui fault zone, roughly following an ancient margin between the Palaeozoic accretionary complex and the pre-existing continental block of Patagonia.

The 176 Ma volcanic rocks at Pichicolo belonging to the Pichicolo volcanic formation (SERNAGEOMIN-BRGM, 1995) represent the Jurassic volcanic arc. Subsequently, the extension of the continent related to the opening of the Atlantic Ocean produced thick volcanic sequences between 160 and 150 Ma, which have been grouped in the Ibáñez Formation. These outcrops can be recognised in southern South America and even Antarctica (Pankhurst et al., 1998).

*Figure 18 El Aceite Hill. The fossils found at this locality have helped correlate these rocks with others from the Aysén Basin.*

During the Jurassic tectonic extension, back-arc subsidence and subsequent post-rift thermal relaxation would have been responsible for the opening of the Aysén Basin (Bell and Suárez, 1997). This basin was filled between the Titonian and Aptian with marine and volcanic sedimentary formations grouped under the Coyhaique Group (Haller and Lapido, 1980). This group records a marine transgression (Toqui Formation), deepening (Katterfeld Formation) and subsequent uplifting (Apeleg Formation) period in which volcanic activity would have decreased (Duhart & Quiroz, 2006). Local expressions of these rocks are found in El Aceite (Figure 18), Río Palena and Cerro Díaz Formation (Fuenzalida, 1965, Haller and Lapido, 1980, 1982). As a result, volcanic and marine sedimentary rocks, some of them containing fossils, are currently found in the high peaks of the Andes in the Futaleufú and Palena municipalities, sometimes as roof pendant (SERNAGEOMIN-BRGM, 1995).

*Figure 19 Batolito Nor patagonico observado desde el Cerro Arcoiris. Este Batolito is one of the world's largest subduction-related Cordilleran plutonic complexes (Pankhurst et al. 1999)*

Between 120 and 100 Ma, large bodies of granitic rocks were formed that occupy extensive areas of Patagonia Verde, mainly east of the main trace of the LOFZ. These intrusive rocks, together with others of similar composition and genesis between the Jurassic and Miocene, form the Patagonian batholith (Munizaga *et al.* 1988; Cembrano 1990; Pankhurst *et al.* 1992; Pankhurst et al. 1999; Adriasola *et al.* 2006; Hervé et al., 2007, Adriasola y Stöckhert, 2008, Aragon et al., 2011). The Patagonian batholith lies between 40° and 53° S along the entire length of the Main Andes Mountains. Its segment north of 47° is called the North Patagonian Batholith (NPB) and is the one observed in Patagonia Verde. A gap in the plutonic history of the NPB during the early Cenozoic coincides with a stage of extension, volcanism along the Coastal Ranges and the development of several intermontane basins beneath the Central Valley (Adriasola & Stöckhert, 2008). The plutonic rocks of the North Patagonian Batholith are evidence of the establishment of a new magmatic arc at the Main Cordillera during the Aptian-Albian (120-100 million years ago) associated with active subduction. Volcanism lasted until 100 Ma, when the volcanic rocks in the extreme south-eastern part of the territory were formed, grouped in the formation known as Cordón de Las Tobas (Fuenzalida, 1965; Haller and Lapido, 1980, 1982; Duhart & Quiroz, 2006).

During the late Oligocene and early Miocene, Patagonia's most important Cenozoic marine transgression occurred (Encinas et al. 2014,2018). At that time, the Pacific and Atlantic marine waters flooded most of southern South America, including the present-day Patagonian Andes, allowing, for the first time in the history of this area, a possible transitional connection between the Pacific and Atlantic oceans.

*Figure 20 Ayacara Formation. The sedimentary and volcanic deposits found in this formation have been essential to understanding one of the most critical transgressions of the Cenozoic*

This marine ingression was probably caused by a regional spreading event related to a prime plate reorganisation in Southeast Asia. The non-marine La Silla and La Junta formations and the Traiguen Formation to the south represent early basin compartmentalization (at ~26 Ma), followed by increasing subsidence rates due to the progressive extension and crustal thinning (Encinas et al., 2016). Subsequently, widespread marine flooding of Patagonia reached its maximum extent at ~20 Ma during the deposition of the deep marine Ayacara-Puduhuapi and shallow marine La Cascada-Vargas formations (Encinas et al., 2018, Echaurren et al., 2022). Compressional tectonics start around 18-16 Ma and propagate at ~15-9 Ma, leading to the basin inversion and the Patagonian Andes' growth (Encinas et al., 2018, Echaurren et al., 2022).

In addition, there are extensive records of magmatic and volcanic activity synchronous to this extension and inversion process between the early Miocene and Pliocene. Plutonic rocks are mainly found east of the LOFZ in the North Patagonian Batholith (Munizaga et al. 1988; Hervé, 1994; Pankhurst, 1992,1999), and their emplacement suggests structural control by the LOFZ, which has been active at least since then (Cembrano et al. 1996; Cembrano & Lara 2009). Volcanic and volcano-sedimentary rocks are found on Chiloé (Antinao et al. 2000) and the mainland, in formations representing the time's primary depressions, for instance, Ayacara Formation and Puduhuapi Formation (Encinas et al. 2013;2018).

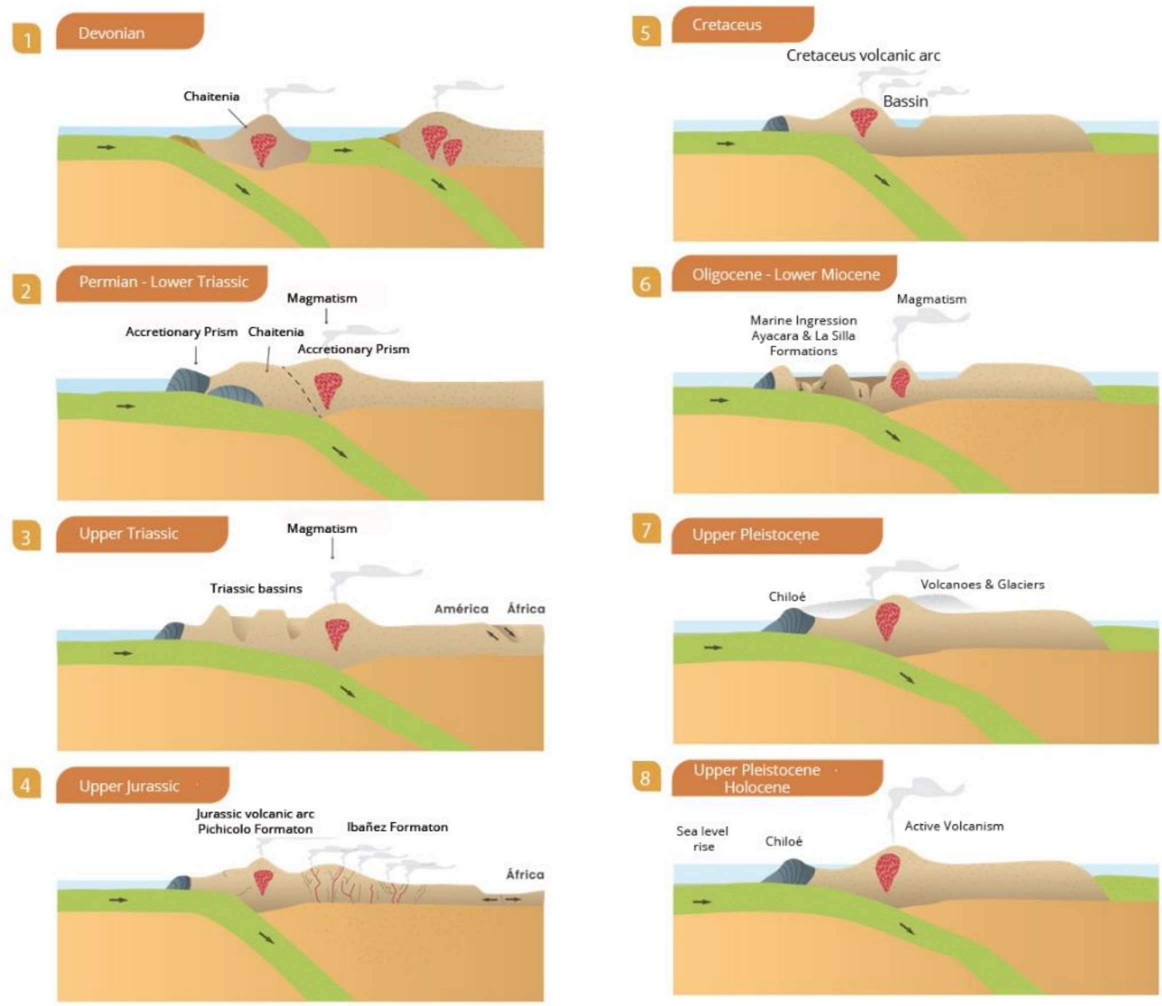



*Figure 21 Geological evolution of Patagonia Verde. Modified from Schilling et al. 2020. Original version design: Daniela Gallardo Diaz.*

During the Pliocene and Pleistocene, volcanism associated with the generation of lavas, pyroclastic deposits and lahars continued, and the predecessor volcanoes to the present-day ones were formed. There was also the formation of stratified sedimentary rocks of continental origin represented by the Llahuen Formation (SERNAGEOMIN-BRGM 1995).

In Patagonia Verde and nearby areas of southern Chile and Argentina, four important glaciations have been recognised that have covered the territory with ice during the Quaternary as a result of relatively lower global temperatures (Mercer, 1976; Porter, 1981; Rabassa and Clapperton, 1990, Clapperton 1994, Harrison & Glasser 2011). These glaciations are known as Caracol, Río Llico, Santa María and Llanquihue (Porter 1981). All these glaciations are separated by interglacial periods. The large masses of ice formed during these glaciations have caused intense erosion and denudation of the relief of this territory, forming U-shaped valleys and depositing various types of moraines on the edges of the glaciers (Ghiglione, 2017). During these cold periods, the Gulf of Corcovado was entirely covered with ice, reaching as far as the island of Chiloé (Davies et al. 2020). In the territory, some outcrops suggest that there may have been an interaction between glaciers and volcanism. For instance, La Silla hill is interpreted in this work as a subglacial volcanic deposit known as a Tuya.

*Figure 22 La Silla hill. Drone photography during fieldwork suggests that the Cerro la Silla may correspond to a subglacial body known as Tuya. A more detailed study is needed to verify this hypothesis.*

Since the end of the Pliocene, there has been an increase in the Earth's temperature and the consequent melting of the large ice masses, causing a significant sea level variation and the formation of lakes, bays, rivers and fjords(Denton et al. 1999, Abarzua et al., 2004, Ghiglione, 2017). In addition, high uplift rates have been reported in Patagonia (Dietrich et al. 2010, Richter et al. 2016) and particularly in Patagonia Verde (Herve & Ota, 1993), possibly linked to isostatic rebound generated by the absence of ice masses. This rebound has generated a series of terraced deposits of a few metres in height with shells, known locally as *"cochales",* which are evidence of this process. Currently, the subduction process of the Nazca plate continues under Patagonia Verde, generating intense volcanic and seismic activity, mainly controlled by the LOFZ (Cembrano & Lara, 2009). The retreat of the ice has exposed the different glacial morphologies and, with it, the relief with steep slopes, which, together with seismic activity and intense rainfall, have generated landslides of varying magnitudes, and with it, an impact on the population (e.g. Buill 2012, Santa Lucía 2019, Amarillo 2021).

*Figure 23 The Chaitén Volcano Eruption (2008) caused the evacuation of the population of the Chaitén village and later its partial destruction. Ph Daniel Basualto*

The spatial distribution of the Patagonia Verde rocks is shown in Figure 24

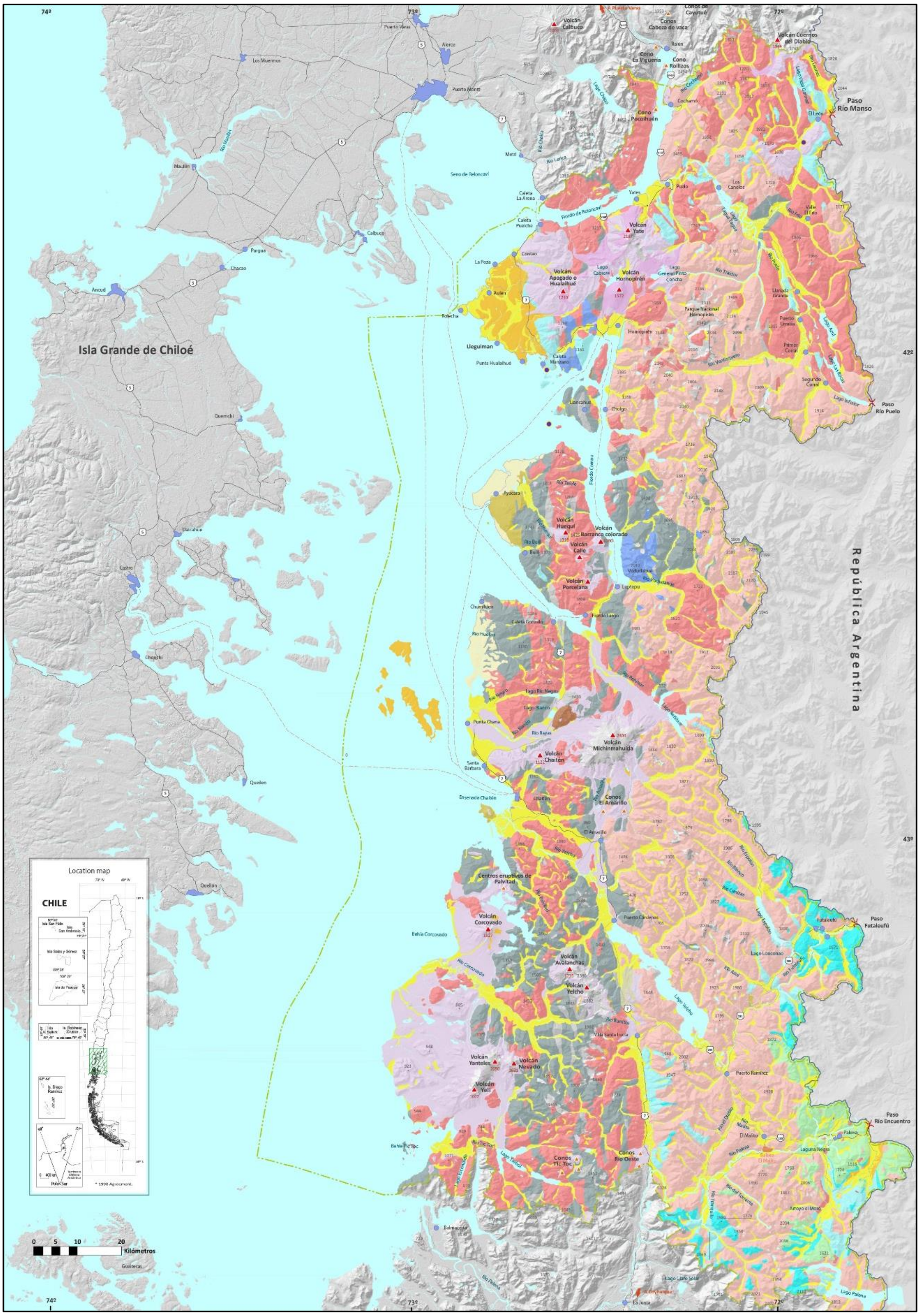



*Figure 24 Geological Map of Patagonia Verde, scale 1:500.000. Modified from Schilling et al. 2020. Original versión design: Daniela Díaz Gallardo. Map Leged Figure 25*

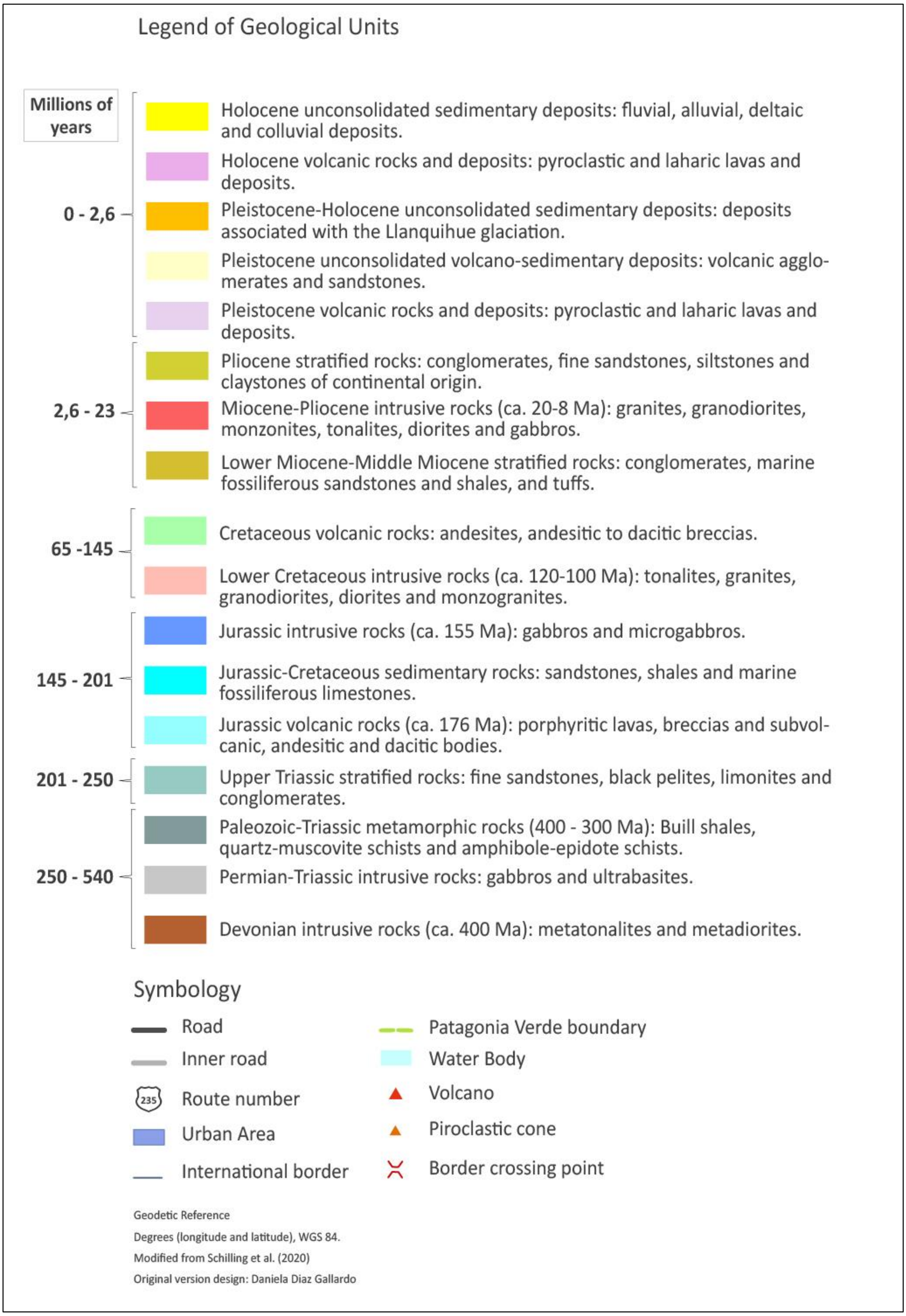



*Figure 25 Map legend*

## 2.3 Threats affecting Geodiversity in Patagonia.

Although geodiversity is composed of durable elements, such as rocks, there are fragile and easily destroyed elements. Moreover, unlike biological processes, most geological processes occur on scales of thousands to millions of years. Thus, the destruction of geodiversity is, in almost all cases, irreversible. As in other territories, in Patagonia Verde, some activities threaten the partial or total destruction of geodiversity and, in particular, some examples of value to society

### A. Energy

As the development of cities progresses and the growth of the population, both residents and visitors, increases, so do the territory's energy needs. Furthermore, considering that the main towns in the territory, Cochamó, Hualaihué, Chaitén, Futaleufú and Palena, use highly polluting energy based on the burning of hydrocarbons, it is necessary to look for alternatives to improve the quality and quantity of energy produced. In this line, there are renewable and clean energy sources available with great potential, such as hydroelectric (Aquatera, 2014), tidal (IDE, 2022), wind (IDE, 2022) or geothermal (Lemus et al., 2015), which should undoubtedly be analysed to move towards sustainable development.

However, given the excellent energy potential, Chilean Patagonia has been threatened several times by hydroelectric megaprojects. Given their size, commercial objectives and planning outside the territory's needs, these projects have been nightmares for the inhabitants. One of the causes of this controversy lies directly in the constitution. The current political constitution, in article 19 N° 24, mentions that "The rights of individuals over waters, recognised or constituted under the law, will grant their owners the property over them", and in this way, the property over the rivers of Patagonia is possible. Consequently, multinational companies, such as ENDESA (now ENEL), owned the water rights of the principal watercourses in the region. Hydroelectric studies and mega-projects were generated around them.

One of the most significant examples was the Hidroaysen project which contemplated the construction and operation of five hydroelectric power plants, two on the Baker River and three on the Pascua River, located in the Aysén region in southern Chile. Even though the project was in the neighbouring region, it contemplated connecting to the Chilean Central Interconnected System. This decision meant constructing a transmission line of almost 3,000 kilometres that would affect six national parks, eleven national reserves, twenty-six priority conservation sites, sixteen wetlands and thirty-two private protected areas. This project was latent for several years until enormous social pressure through the *Patagonia Sin Represas* (Patagonia without dams, https://www.patagoniasinrepresas.cl) movement, supported mainly by the Douglas Tomkins Conservation Foundation, managed to paralyse it.


*Figure 26 Patagonia Sin Represas (Patagonia without dams) movement was one of the most significant environmental movements in Chilean society's history. https://patagoniasinrepresas.cl*

The mobilisation of citizens and the various NGOs in the territory led to the failure of Hidroaysen, the return of water rights by ENDESA (Bevilacqua, 2016) and the cancellation of other emblematic projects such as the Futaleufú river project. In addition, these moves laid the groundwork for other projects, such as the Mediterraneo power plant on the Puelo River, to be shelved (Velásquez, 2018)

To date, data from the IDE (2022) indicate that the only projects approved in the territory are in the Negro River, Hualaihue, including the controversial project of the Río Negro Hydroelectric SPA (Figure 27), which is causing controversy among the inhabitants. (Sepulveda, 2021)

Patagonia's energy potential is still intact, and new projects can and must be generated if the objective is to move towards sustainable development and eliminate fossil fuels, but their success will only be guaranteed to the extent that they are proportional to the needs of the environment and the inhabitants of the different localities


*Figure 27 Energy information map. Source: IDE Energy Institute (2022)*

### B. Mining industry

The mining industry, particularly gold mining, is one of the main concerns of the communities due to the enormous environmental impacts it has historically had in this and other neighbouring countries.

Since the 1990s, several gold explorations in Patagonia Verde have kept the population on alert. While in the Andean part of the country, explorations focus on finding Cu-Pb-Zn belonging to the metallogenic belt, Au-Ag is the resource sought in the placers of the coastal sector (Duhart, 2006).

In 2007, alarm bells went off when Kinross Gold Corporation and Geocom Resources selected the Espolón sector in Futaleufú as a gold mining project with 13 claims totalling 3,800 hectares. (San Cristobal, 2007). Although nothing is known about the execution of the project, among the people who participated in the Patagonia Verde Geotourism project meetings, there was mistrust concerning the construction of new roads in the sector and, in general, of the public works that seek to generate connectivity between Chaitén and Futaleufú.

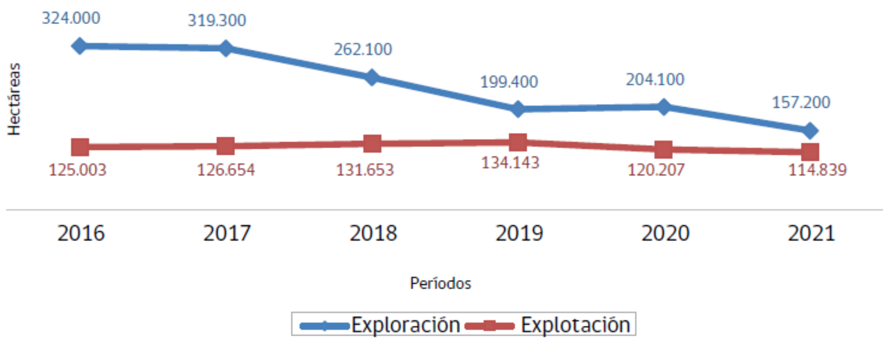



*Figure 28 Evolution of the surface area of mining concessions (ha) in force, Los Lagos region. Source: Sernageomin (2021)*

Nevertheless, in 2021, the Lake District had only 1.4% of the country's exploration concessions and 0.7% of the country's exploitation concessions. With a decreasing exploration activity since 2016 (Sernageomin, 2021), there are no known advances in mountain range projects. However, new exploration and exploitation concessions in the Huequi Peninsula are linked to gold placers.

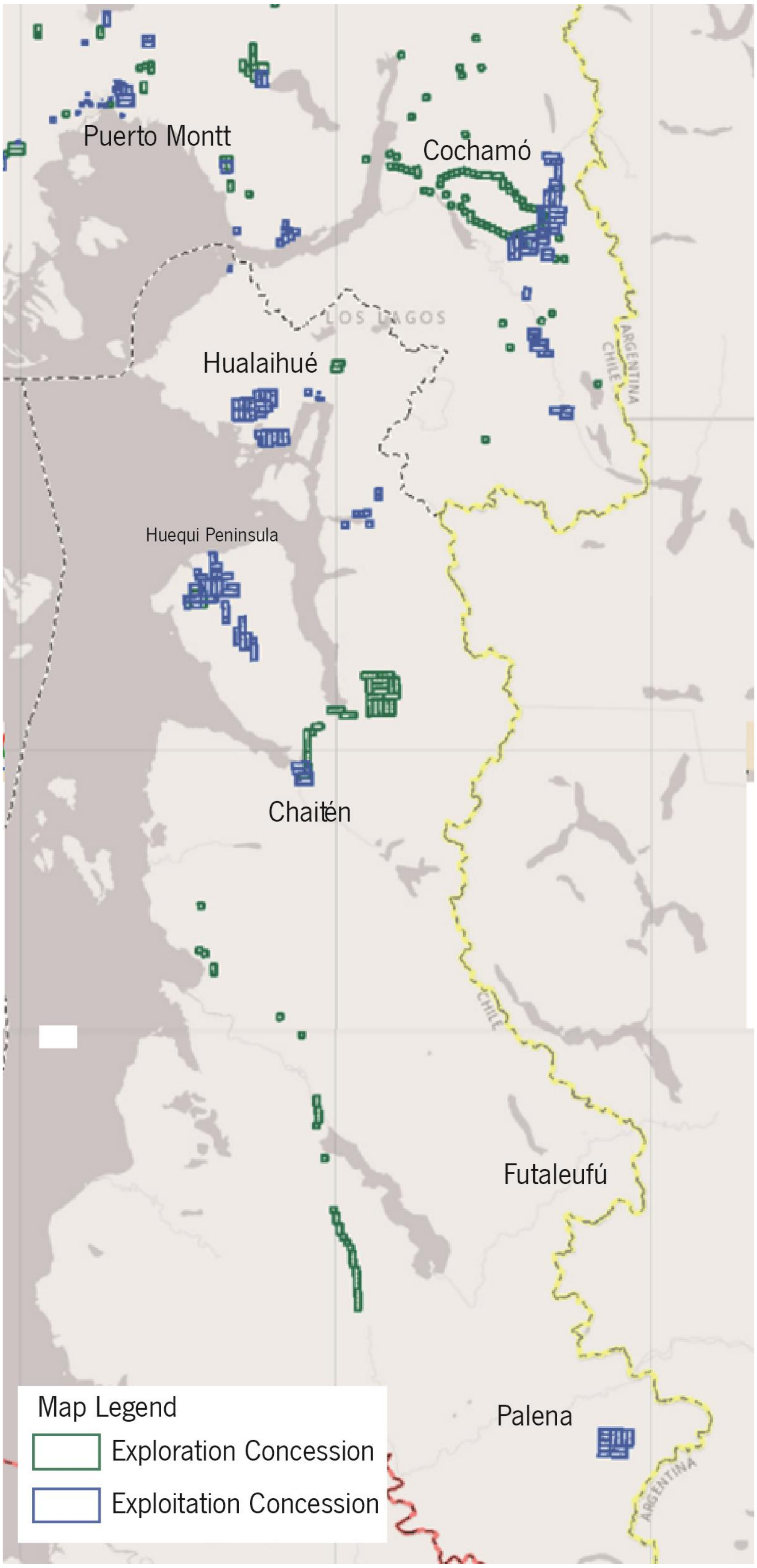



*Figure 29 Estado de las conseciones mineras en Patagonia Verde. Datos obtenidos de Sernageomin ([2022b](#))*

## C. Aquaculture

Fjords are vital ecosystems in Patagonia Verde. They are characterised by high biodiversity in marine species such as benthic organisms, mammals and birds (Häussermann et al. 2013). On the other hand, they also provide essential ecosystem services for developing societies and are very sensitive to climatic and anthropogenic stressors (Bianchi et al., 2020). First, fjords have the highest capacity to bury organic carbon per unit area worldwide (Smith et al., 2015). In addition, they are favourable environments for developing fishing, shellfishing and aquaculture industries.

The aquaculture industry in Chile is in growing development. Given its enormous potential, it is speculated that by the next decade, it could be the second-largest industry after copper (Garcia, 2021).

Aquaculture production is mainly divided into three: 72% salmonids, 26% methylids and 1% algae, and about 55% of the national aquaculture production is located in the Lake District (Sernapesca, 2021). As mentioned by Anbleyth-Evans et al. 2020, the industry's growth and preferential treatment of the fisheries over marine protected areas in Chile through the distinction of Appropriate Areas for Aquaculture (AAA) has placed it on a collision course with conservation, artisanal fisheries and coastal communities.

In Patagonia Verde, there are 551 applications for fishing concessions, of which 307 are granted fishing concessions, 232 with applications in process and 12 applications with SSP resolutions. In addition, according to data from the List of salmonid aquaculture concessions by a grouping of concessions from the Undersecretariat of Fisheries (Subpesca, 2022), there are at least 157 concessions granted with salmonids (Wards 1, 16, 17A and 17B), mainly concentrated in the Reloncavi (Ward 1) and Comau (Wards 17A and 17B) fjords.

The industry concentration in the fjords has had direct biogeochemical impacts on the environment where they are located. Hausserman et al., 2013 reported a large amount of organic waste produced by the accumulation of many aquaculture concessions, causing eutrophication, which, added to the uncontrolled use of large quantities of chemicals and the uncontrolled harvesting of natural mithilid stocks, threatening the fauna of the fjords.

Among the most visible consequences are the increasingly frequent harmful algal blooms in southern Chile, which, although related to climatic factors, are also associated with the increasing eutrophication of coastal areas (Soto et al., 2021).

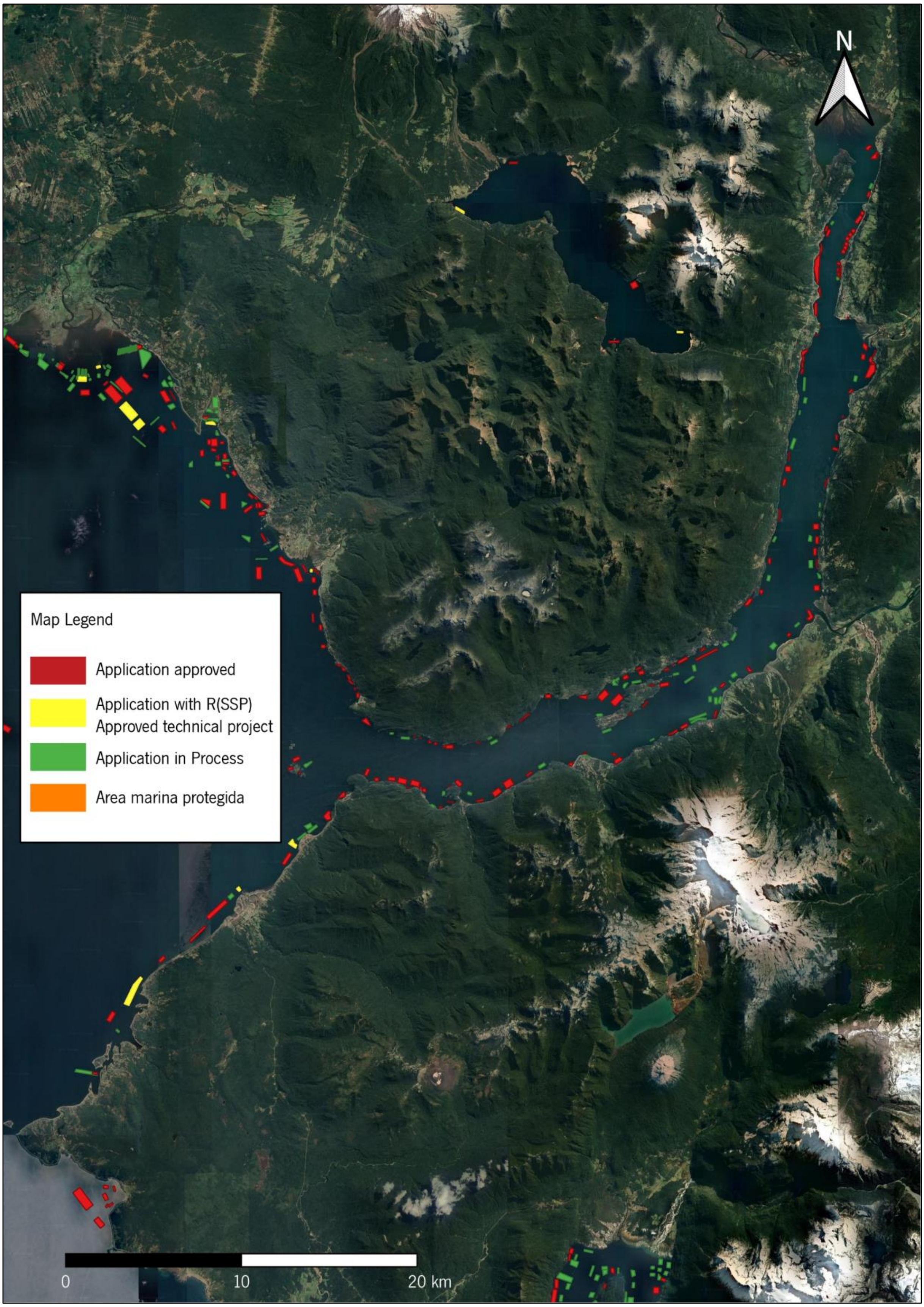



*Figure 30 Current status of fishing concessions in the Reloncavi Fjord. Map created by the authors with data obtained from the geoportal of Subpesca. https://geoportal.subpesca.cl/*

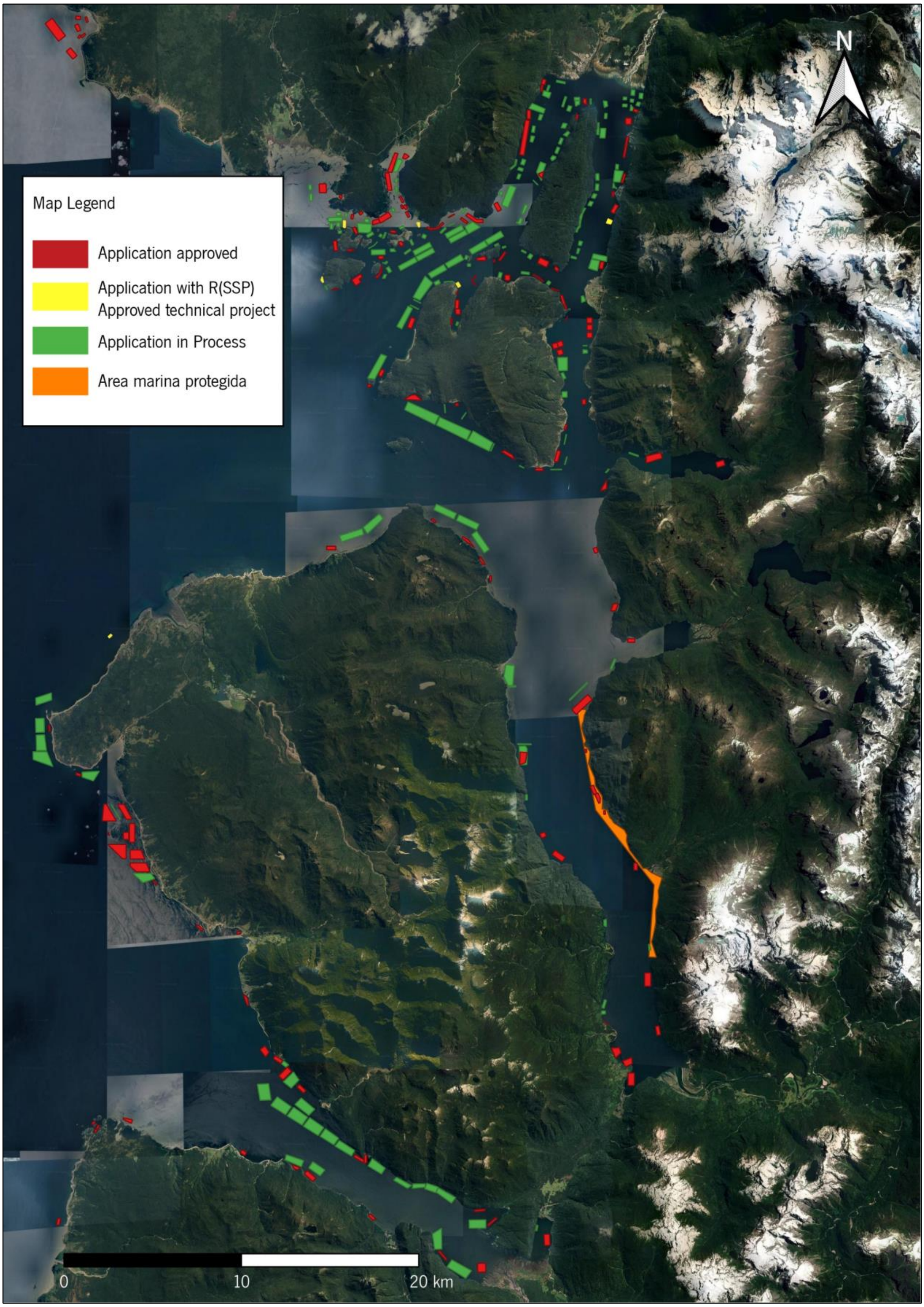



*Figure 31 Current status of fishing concessions in the Comau Fjord. Map created by the authors with data obtained from the geoportal of Subpesca. https://geoportal.subpesca.cl/*

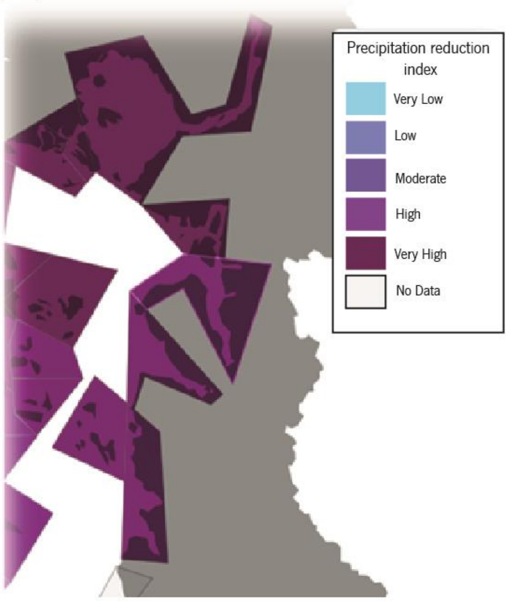
*Figure 32 One of the most striking examples of harmful algal blooms occurred in April 2021 in the Comau Fjord, which led to mortality in the fjord's salmon farms. Taken from Fundación Terram (2021)*

Regardless of the direct or indirect relationship that the aquaculture industry has with algal blooms, Soto et al. 2021 have determined that areas in the Fjords, given different factors (Figure 33), are areas of greater susceptibility to harmful algal blooms.

In this context, it is possible to determine that aquaculture can generate a negative feedback loop with the effects of climate change, which puts the environment at risk with harmful algal blooms and the industries' production, in turn, which may be reduced given the mortality experienced by fish during these events.

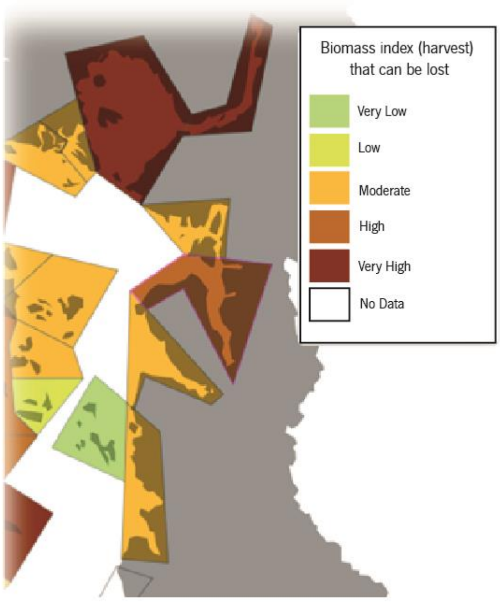
THREAT

Reduced precipitation between the historical (1980-2010) and future climate (2035-2065 under the RCP8.5 scenario) leading to an increase in dry days and higher light availability which would facilitate the occurrence of HAB. Darker colours indicate greater precipitation reduction.



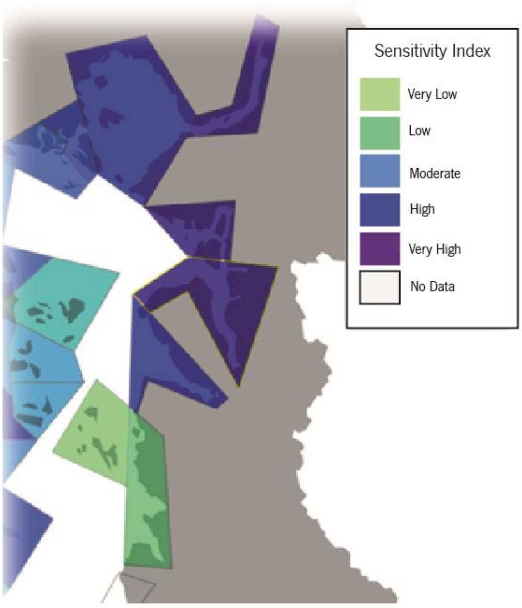

EXPOSURE - PRESENT

Salmon biomass (harvest) based on average 2017/2018 production for each ACS or neighbourhood. Darker colours indicate higher production per neighbourhood.




SENSITIVITY - PRESENT

Physical, biological, oceanographic and production management factors that make the sector more susceptible and could maximise the impact of the assessed threats. Darker colours indicate greater sensitivity.




RISK - PRESENT

Risk of losing biomass (harvest) due to increased Harmful Algal Blooms (HAB) as a result of reduced rainfall for each Salmon Concession Cluster in the regions of Los Lagos, Aysen and Magallanes. The Index ranges from 0 to 1, where 1 is the maximum value.

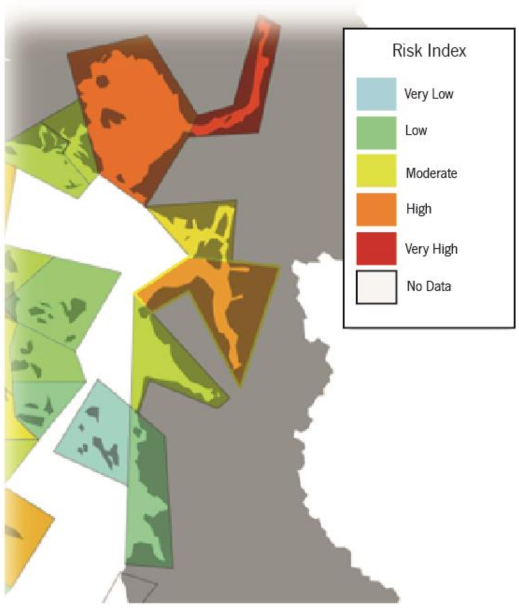



*Figure 33 The map represents the risk chain of losing salmon biomass in the fattening phase (in saltwater) due to the potential increase of Harmful Algal Bloom (HAB) due to decreased rainfall. The analysis is carried out for each Salmon Concession Grouping (ACS) or neighbourhood in the Patagonia Verde territory. Modified from Climate Risk Atlas (ARCLIM, 2022).*

## D. Urban expansion

The expansion of different localities and increased connectivity directly affect the physical environment. Urban development requires materials for the construction of housing, roads and infrastructure in general, and the extraction of resources is necessary. Also, most works, especially those related to constructing roads between localities, need to overcome geographical features, sometimes having to dynamite, undermine, stabilise or remove rocks and sediments. These actions may affect or destroy outcrops, change the landscape or modify some active geological processes (e.g. sedimentation of a river). On the other hand, the effect can be beneficial, and new outcrops, which were previously covered, can now be seen thanks to new road cuts. These options must be considered when generating works that directly impact geodiversity.

*Figure 34 To modernize and pave Route 7, several cuts were made on the slopes of the hill, removing rocks and sediments. This action exposed several outcrops but also generated significant instability on the slopes. The stabilisation of the road may result in the permanent modification of the landscape. For instance, using shotcrete may permanently lose the visibility of some outcrops. Photo: Ruta 7, Chaitén, taken from Diario el Huemul (2018).*

## E. Didymus

Although more research is needed on Didymo, its causes and consequences, the Servicio Nacional de Pesca y Acuicultura (Sernapesca, 2022) identify *didymsphenia geminata* or commonly called "Didymo" as an algal species that threaten Chile's rivers and their ecosystems.

Didymo is a microalgae native to the northern hemisphere that attaches itself to rocks employing a slimy-looking foot. It forms large masses that cover large areas of river and lake bottoms, persisting for months. This alga has a high power of propagation and, therefore, a high invasive capacity in short periods, quickly becoming a pest. In this way, the spread of Didymo strongly impacts inland water ecosystems, displacing fish to other sectors, thus altering the local food web and changing landscape units and tourism-related activities. This facility to spread is because it thrives easily in a wide variety of physical and chemical conditions in rivers and lakes, making it very difficult to eradicate (Sernapesca, 2022).

Currently, in Chile, the pest is present in some points of sub-basins located from the Biobío region to Tierra del Fuego in Magallanes. Although it is impossible to say for sure, it is thought that its origin is due to fishing equipment contaminated with didymo from other latitudes (Sernapesca, 2022).

*Figure 35 Manifestations of Didymo. Taken from http://www.sernapesca.cl*

The Didymo is present in the main rivers, such as the Puelo and Futaleufú. Eradicating these invasive algae is a real challenge for the future, and given the task's difficulty, efforts and campaigns (e.g. Sernapesca, 2015) focus on prevention and limiting its spread (Sernapesca, 2022).

## F. Afforestation and deforestation.

Brilha (2005) mentioned that afforestation is an action that can contribute to hiding certain geological features. On the other hand, deforestation can also have negative impacts on geodiversity. In

Patagonia Verde, deforestation of native forests does not directly affect geodiversity. However, it does make exposed soils in areas that have been cleared more susceptible to erosion and mass movements on steep slopes. Illegal logging of native forests in Patagonia Verde is mainly linked to extracting native timber for firewood, charcoal and sawn logs for personal use or commercialisation (Reyes 2018). Another factor in deforestation is fires. Although they are not as recurrent in Patagonia Verde as in other areas of the country where high temperatures and monoculture plantations trigger them, there have been large-scale fires caused by volcanic eruptions. For instance, the one in Chaitén affected the volcano's surrounding areas.

*Figure 36 In Chaitén, deforestation was triggered by the volcano's eruption. The accumulation of material on the slopes and deforestation caused small landslides that can be seen in the photograph. Forest rapid recovery has allowed the soil to be protected again from erosion.*

## G. Natural Hazards

Although most threats to geodiversity come from the direct or indirect action of human activity, there are some natural processes whose magnitude can eliminate part of the visible diversity of a territory. Examples of this are landslides, volcanic eruptions, glaciations, tsunamis or earthquakes, the magnitude of which can be such that they end up burying or destroying a large part of the diversity of geological elements of a territory.

Given the geodynamic context of Patagonia Verde, these processes occur more frequently than in other parts of the world. As mentioned (Lizama et al. 2022), mainly due to active tectonics, in the last 62 years, Patagonia Verde has been affected by three earthquakes, Valdivia, Chiloé, and Aysén, with magnitudes of 9.5Mw and 7.6Mw Richter respectively. In addition, between 2008 and 2009, this area of the Patagonian Andes was the epicentre of one of the most explosive volcanic eruptions in recent times caused by the Chaitén Volcano. On the other hand, glacial and periglacial relief in the Patagonian Andes is occurring at an accelerated rate due to climate-induced changes. Thus, the interaction of atmospheric phenomena such as warm rains above typical elevations has generated increasing landslide activity that has impacted communities and ecosystems in northern Chilean Patagonia (e.g. Lago Cabrera 1965, Buill 2011, Santa Lucia 2017 el Amarillo, 2020).

Thus, while it is true that all these processes contribute to the diversity of Patagonia, in the short term, some inventoried sites may be affected, and it is for this reason that these factors must be considered.

*Figure 37 The landslide in Santa Lucía did not only affect the town of Villa Santalucía. The mud covered large areas of the territory, altering riverbeds and the soils.*

# 3 Inventory of geodiversity

## 3.1 Previous work: 17BPCR-73220 " Development of geotourism products in Patagonia Verde" project

A few years ago, the Regional Government of the Lakes District, southern Chile, proposed a delimitation of the territory that defines five tourist destinations based on their attributes and level of development. Patagonia Verde is one of these zones and is integrated by the municipalities of Cochamo, Hualaihue, Chaitén, Futaleufú and Palena, and an approximate surface of 20.000 $km^2$

Between 2017 and 2019, a multidisciplinary team from the Universidad Austral de Chile carried out an inventory of some relevant elements of geodiversity. The aim was to identify, characterise and value the geodiversity of the Patagonia Verde to promote the geotourism and education in Earth sciences. This inventory was framed in a project called "Development of geotourism products for the destination Patagonia Verde" (Schilling et al. 2018).

Given the large territory area, this project generated a report with preliminary results (Martinez & Schilling 2018) and subsequently divided into three different reports of the technical team in the municipalities of Cochamo-Hualaihue; (Gonzalez, 2019), Chaitén (Gonzalez 2019) and Futaleufú-Palena (Santos, 2019).

From the three inventories mentioned above, 64 sites and 36 viewpoints were proposed to support the development of various tourism activities. From the joint work between the team and the project beneficiaries, most of them tourist operators, 21 georoutes were designed for visiting the sites and viewpoints. During 2018, educational activities were carried out in seven territory schools, where some of these points of interest were visited.

To provide a holistic view of Patagonia Verde and support the development of tourism and informal education, a Geotourism Guide was created (Schilling et al. 2020). This guide attractively presents the Natural and Cultural Heritage of Patagonia Verde and the different georoutes that can be visited. The guide also incorporates a geological map and volcanic hazards map co-designed with SERNAGEOMIN and a geotourism map co-designed with the local community. The maps support and complement the interpretation of the landscape in the different tourism and educational activities.

## 3.2 Patagonia Verde Inventory

### A. Defining the topic, the value, the scale, and the aim of the inventory

The first step in any geoconservation action is to carry out inventories. The process of inventorying geodiversity includes identifying, assessing and analysing the site's information, followed by a comprehensive description of those sites that present an added value concerning the others. This process must be carried out for a specific purpose so that the selection of sites occurs under the same criteria. It is proposed to consider four elements (Lima et al. 2010): Topic, referring to what is being inventoried; Value, closely related to the potential use of the site; Scale, related to the geographical area where the inventory occurs; Use, Related to the intended use of the inventory. For developing this inventory, the following topic, value, use and scale are considered:

*"Develop a geodiversity inventory to support scientific, tourism and educational activities in the Patagonia Verde destination".*

### B. Definition of geological contexts

One of the aims of the Patagonia Verde inventory is to identify the most valuable sites of significant scientific value. To this end, geological contexts help establish a point of comparison between selected future sites.

In Chile, Mougues et al. (2012,2016) propose national geological frameworks to guide the search for associated geosites. However, this does not deny, for smaller scale inventories, the possibility of defining regional geological frameworks (p.ej Aysen Region, Quezada et al. 2018) or thematic areas (p.ej Cajón del Maipo thematic areas Benado, 2013; Vergara et al. 2022)

Based on the proposal of Mourgues et al. (2012,2016), the regional geological information (SERNAGEOMIN-BRGM, 1995), the proposal from the neighbouring region of Aysen (Quezada et al. 2018) and the background compiled for this work, a proposal of 14 geological frameworks was elaborated that sought to represent the main geological events of the territory.

The elaboration of these contexts was determined to meet the following criteria (Quezada et al. 2018):

i. be framed by a similar geotectonic context or process;
ii. present a common genesis (e.g. depositional environment, geological nature);
iii. be of similar age;
iv. present the same type of lithological associations;
v. present a coherence in their spatial distribution (e.g. in structural zones, palaeo-basins, or bounded areas).

Thus, the geological contexts proposed for Patagonia Verde are described in Table 1.

*Table 1 Patagonia Verde Geological Frameworks. Examples of each context are presented in Annex 7.3*

| N° | Context | Description | Code |
|---|---|---|---|
| I | Chaitenia accretionary metamorphic complex | It groups rocks of the Palaeozoic age belonging to the Chaitenia accretionary complex. Magmatic bodies such as Pichicolo, Chaitén and Yelcho, the Buill sedimentary rocks and the pillow lavas of Riñihue, among others, are included in this context | CHA |
| II | The Palaeozoic metamorphic complex of the Main Range | It groups the Carboniferous to Triassic metamorphic rocks, whose genesis is not related to the Chaitenian metamorphic complex | CMCP |
| III | Triassic outcrops | It groups the few known outcrops, particularly the sedimentary series of the Piedra Guallante Unit, located in the vicinity of Pichicolo, composed of quartz conglomerates and elements of metamorphic rocks. These outcrops could be associated with the Panguipulli and Tralcan Formations north of the Lake District and represent similar formation environments. | Tr |
| IV | Mesozoic Volcanic Arc | Subduction-generated igneous rocks represent this context. These rocks were generated in an extensional geotectonic context during the middle and late stages of the fragmentation of Gondwana. It includes the volcanic record of the Pichicolo Formation, the Ibañez Formation and the intrusive equivalents to these formations (e.g. Punta Sirena) and the volcanic rocks in the extreme south-eastern part of the territory grouped in the Cordón de Las Tobas Formation. | AvMz |
| V | Austral Basin Record. | It comprises the rocks and fossils that account for the transgression-marine regression cycle that occurred in the back-arc during the Titonian to lower Aptian, coeval with the break-up of western Gondwana. It includes the record of the Coyhaique Group (Toqui, Katterfeld and Apeleg formations) or equivalents. | CA |
| VI | Patagonian Batholith | It groups Jurassic-Cretaceous to Neogene subduction-related granitic intrusive rocks of the so-called Patagonian Batholith and other minor intrusive bodies possibly controlled by the Liquiñe - Ofqui Fault system. | BNP |
| VII | Metallogenic Province and its occurrences | The main range comprises the auriferous and the polymetallic belts bounded by the LOFZ. They are mostly related to granitic and volcanic rocks of the Meso-Cenozoic magmatic arc. The Central Depression comprises Quaternary sediments mostly of glacial origin, carrying detrital gold particles concentrated in fluvial and glaciofluvial placers. | PM |
| VIII | Cenozoic marine sedimentary rocks | Represented by the geological formations that show the most significant transgression that occurred in the Cenozoic that possibly connected the Pacific Ocean with the Atlantic Ocean, such as the deep marine Ayacara and Puduhuapi formations, and shallow-marine La Cascada Fm | SMCz |
| IX | Cenozoic continental sedimentary rocks | It groups the continental sedimentary rocks of the Cenozoic, such as the La Silla and Llahuen formations. | SCCz |
| X | Glacial and periglacial environments and records | Related to glaciers and their active processes and evidence include geoforms (e.g. valleys, cirques and boulders) and deposits (e.g. moraines). | AGl |
| XI | Neogene - Quaternary volcanism and thermal manifestations | It groups the different volcanic deposits that give rise to the region's principal volcanoes. Also, the minor eruptive centres and the thermal manifestations such as springs, geysers and fumaroles. | VNQ |
| XII | Tectonic and Neotectonic megastructures | It is related to surface evidence such as lineaments, deformation, and uplift, particularly with the LOFZ. | TEC |
| XIII | Geological Hazards | It groups deposits linked to active geological processes generated by the internal or superficial dynamics of the planet (e.g. volcanic eruptions, landslides, floods, earthquakes, tsunamis). The examples have modified the landscape and the society (e.g. Buill landslide, Santa Lucía landslide, Chaitén Eruption, Amarillo landslide, Lago Cabrera landslide and tsunami). | PG |
| XIV | Hydrological processes | Related to water, its evolution over time, occurrence, distribution, circulation, and physical, chemical and mechanical properties in the oceans, atmosphere and land surface, | PH |
| XV | None | It is related to sites that do not fall within the abovementioned contexts. | None |

## C. Background collection: participatory preliminary listings.

The list of potential sites that guided this work was mainly based on the author's data during the different participation instances generated by the project "Development of Geotourism products in Patagonia Verde". During the workshops, meetings and seminars, several sites were proposed, both by collaborating institutions (SERNAGEOMIN, CONAF, SERNATUR, CORFO, Municipalities) and by inhabitants of the territory (tourist guides, teachers, students and others). In addition, three works carried out by students of the Universidad Austral were used (Gonzalez, 2019; Gonzalez, 2019; Santos, 2019), in which a large part of the sites was characterised and evaluated, providing a first approximation of the inventory carried out in this work.

### D. Site Selection Criteria

While some sites are valuable for their little or no human intervention, there are others where the value lies precisely in a specific community being able to use them. In this sense, the identification of sites must be adapted to the different contexts of a territory, seeking to strengthen both dimensions. Brilha (2018) recommends that a list of sites with scientific value should consider those crucial in some research or unique characteristics. For this purpose, a potential site list must be made from a review of all the published geological information concerning the study area (geological maps, scientific publications, theses). Then, by consulting specialists who have worked on the territory (e.g. Geological survey, nature park managers or university professors).

In the same way, tour operators, educators, and indigenous communities, among others, are critical actors in determining the exact sites to be investigated in terms of tourism, education, or culture. Finally, some sites may emerge from the different fieldwork during the inventory process. The outcome of this first stage is a list of potential sites.

*Table 2 Criteria to be considered to discriminate the potential use of each site. Modified from Brilha (2016)*

| **Geosites** | **Other valuable sites** | |
|---|---|---|
| **Scientific** | **Educational** | **Tourist** |
| Representativeness | Diversity of Processes | Scenic and Cultural Attractiveness |
| Singularity | Didactic Potential | Interpretive Potential |
| Integrity | Accessibility | |
| Scientific Knowledge | Safety | |

Brilha (2016; 2018) states that a clear definition of the main objective is essential to discriminate between different sites of interest. In this way, if the objective is to highlight the scientific value of specific sites/areas (e.g. to create a national geoconservation strategy), it will be necessary to make an inventory based on criteria that seek to highlight that value (Table 2). On the other hand, if the objective is to identify the potential use of sites in educational or tourist programmes, it will be necessary to use specific criteria. This stage is fundamental, as it will be the first filter to determine which sites will be analysed in a future management strategy and which will not.

The search and selection were performed for this work using twelve criteria (Table 2) based on Brilha's (2016) proposal.

Hence, for sites with potential scientific use, the following four criteria should be applied:

- **Representativeness:** The site illustrates a geological detail or process that significantly contributes to understanding a geological topic, feature, event, or context.
- **Integrity:** It is related to the current state of conservation of the site. They are considered natural (e.g. weathering, disturbance, vegetation) and anthropogenic (e.g. scratches, debris, antennae) aspects.
- **Uniqueness:** It refers to a site's rarity concerning others with similar characteristics.
- **Scientific knowledge:** It is associated with published scientific studies on the site reflecting its scientific value for the geoscientific community.

The first three criteria were crucial to discriminate between one site and another. However, as Brilha (2016) states, the lack of prior scientific knowledge does not always show the irrelevance of a site, as the scientific community may not yet have addressed the site. So, these criteria will only positively affect the choice of sites with similar characteristics for two simple reasons. First, the scientific knowledge evidence that the site was valuable for scientific research. Second, the knowledge generated by the scientific community facilitates interpretation in case the site meets the conditions to be used for tourism or educational purposes. Therefore, an ideal location will be one that can maximise the four criteria mentioned above. If two sites have similar characteristics, the one that best fulfils the criteria will be the one that remains on the list.

For the educational use potential, it is considered relevant to highlight the following:

- **Didactic potential.** It is related to the capacity of a geological feature to be easily understood by a student of different educational levels (e.g. elementary, middle, and university).
- **Diversity of geological processes.** There are several different types of geological processes at the same site.
- **Accessibility.** It refers to the access conditions, difficulty and walking time.
- **Safety.** It is associated with visitation conditions, considering the minimum risk for a student.

Finally, to determine whether a site has geotourism potential, it is believed that it should meet at least the following criteria

- **Scenic or Cultural Attractiveness:** Associated with the visual beauty of a geological occurrence or its relation to the identity of a locality.
- **Interpretative potential:** It is related to the ability of a geological feature to be easily understood by ordinary visitors.
- **Accessibility:** It refers to the access conditions, difficulty and walking time.
- **Safety:** It is associated with visitation conditions, considering the minimum risk to visitors.

The sites that best meet the above criteria will be those selected for a future inventory. A place with high educational value will have different geological occurrences with characteristics that students can understand, adequate and comfortable access where students can observe geology and where safety conditions are the best possible. All these criteria vary according to the type of student it is aimed at (e.g. elementary, middle school, university). Similarly, sites with high tourist value will have visual beauty that can be appreciated by a broad public, with geological features that can be easily observed and understood by non-specialists in safe conditions and with easy and convenient access. It is understood that the analysis of other values has better results when multidisciplinary groups of specialists do them.

## E. Fieldwork: identification, selection, and preliminary inventory of sites

Once a preliminary list has been made, fieldwork was necessary to select, based on the above criteria, those sites that will be part of an inventory and those that will not. It is essential to highlight that no fieldwork was carried out during this thesis project. However, documents produced by the author and the technical team in the project "Development of geotourism in Patagonia Verde (Universidad Austral, 2019) were used. It is also relevant to note that Based on conversations, notes and unpublished documents generated by the author in workshops and meetings in the territory, other sites were added to the inventory list and quantitatively evaluated at a later stage without being subjected to any of these stages.

The fieldwork carried out in the campaigns mentioned above was divided into three stages:

### *STAGE I: EXPLORATION*

The first stage aimed to survey the sites selected in the preliminary list. Before this campaign, completing the preliminary sheets should be fulfilled as much as possible (Table 3) since exhaustive desk work made this first campaign even dispensable for getting some information. However, if the resources were available, making a field trip is recommended since it provides an updated view of the environment.

Before going to the field, visit plans were drawn up, and stops were organised to optimise time. For educational and tourism purposes, it was crucial to prioritise stops by considering the sites most likely used by these users. In this sense, all vehicular routes were prioritised, followed by trails that do not require more than a day's work. During this fieldwork, general but relevant data were collected, such as a brief geological description to identify the type of geological process and the thematic area in which each site was framed. Audiovisual material, geographical information, and reports of the environment considering aspects related to the potential use of the site, such as the state of conservation, current infrastructures or the quality of communication routes, was also information that undoubtedly contributed to the development of the characterisation. At the end of this stage, an overview of the different outcrops existing in the territory and the systematised information, according to Table 4, were compiled in unpublished works (e.g. Universidad Austral, 2019).

### *STAGE II: COMPARATIVE ANALYSIS.*

Once the reconnaissance stage was completed, it was possible to obtain an overview of the different manifestations of geodiversity in Patagonia Verde. Thanks to the organisation by contexts of the different sites and the comparative analysis of their criteria, it was possible to establish those sites that represented an additional value concerning the total recognised in the three proposed areas (Science, Tourism, Education).

### *STAGE III: CHARACTERISATION OF RELEVANT SITES*

This last stage aimed to investigate further each of the previously selected outcrops. To this end, it was proposed to qualitatively characterise each site, taking into account some significant aspects, such as geographical distribution, general and specific use characteristics, and an analysis of their risk of degradation. On the other hand, collecting as much information as possible about each site, including sketches and descriptions, was essential.

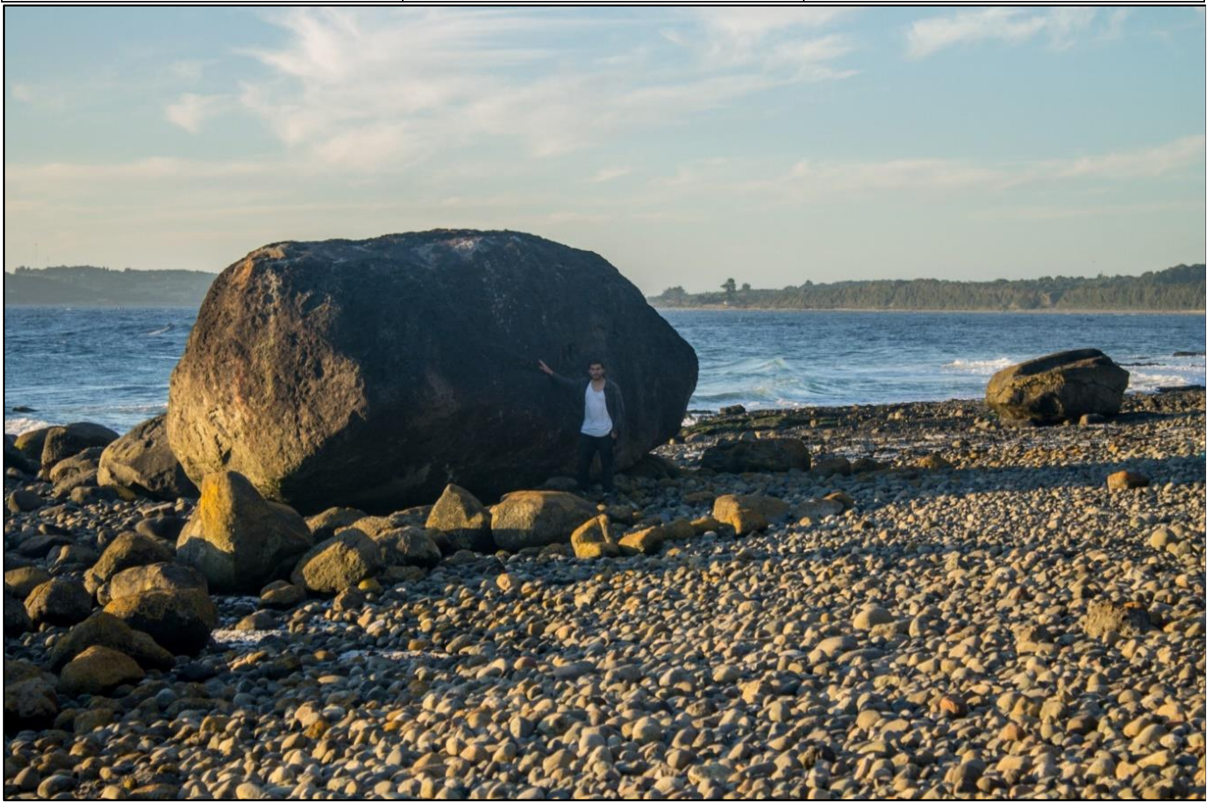
Finally, all those doubts about understanding the site's geological characteristics that require additional information were left as a proposal to guide future research. That, on the one hand, will help to contribute to interpreting each site and, on the other hand, will help future professionals to research local problems of public interest. A qualitative sheet (Table 5) was proposed to guide the fieldwork. Much of this data can be found in the annexes of the final report of the project “Geotourism in Patagonia Verde” (Universidad Austral, 2019) and an unpublished database generated by the author.

*Table 3 Preliminary sheet for the selection of the different sites. This sheet was intended to be completed in the office based on available information and specialists' help. A first field campaign helped to adjust some criteria.*

<table>
<tr><th>Name</th><th>Geographic information (GPS)</th><th>Geological Framework (when it is applicable)</th></tr>
<tr><td colspan="3">Photo</td></tr>
<tr><td>Scientific criteria</td><td>Tourist criteria</td><td>Educational criteria</td></tr>
<tr><td>Representativeness:<br>Indicate which topic, event, feature or context the site allows to illustrate.</td><td>Scenic and/or Cultural Attraction: Mention the main attraction(s) of each site. These may not be directly geological but may be directly related to the site.</td><td>Diversity of geological processes: Mention which geological processes with didactic potential are observed.</td></tr>
<tr><td>Integrity<br>The geological feature(s) may be intact or have a loss of integrity due to(specify):</td><td>Interpretative Potential:<br>A. The site presents geological features whose interpretation is clear and understandable to the general public.<br>B. The site presents geological elements whose interpretation can be understood with basic geological knowledge.<br>C. The site presents geological elements whose interpretation is understandable by the general public with robust geological knowledge.<br>D. The site presents geological elements whose interpretation is understandable by specialised audiences.<br>(Choose)</td><td>Didactic Potential:<br>A. The geological feature(s) to be observed can be understood through the senses.<br>B. Understanding the geological feature(s) requires abstract thinking.<br>(Choose)</td></tr>
<tr><td>Uniqueness:<br>The site is unique if there are fewer than 4 recognised sites with similar characteristics.</td><td colspan="2">Safety: Describe if there are any risks associated with the site visit, e.g. tsunamis, landslides, falling boulders, volcanic eruptions, cliffs, etc. If not, "No risks associated with the visit".</td></tr>
<tr><td>Scientific knowledge:<br>Existence of previous scientific work</td><td colspan="2">Accessibility: Mention aspects related to accessibility, type of means of transport by which it is possible to get to the site, and other characteristics, such asif there is a path, length of the path, difficulty and public or private nature of the site and/or access.</td></tr>
</table>

*Table 4 Example of a preliminary worksheet after Stage I. Since much of the information to characterise scientific, educational and tourist sites overlap, it was practical for this work to develop a single sheet with all criteria. Taken from (Universidad Austral, 2019)*

| Name | GPS Information | National Geological Context |
|---|---|---|
| Erratic blocks of Rolecha beach | 681267E/5352685N UTM | Central and southern glacial processes, geoforms and deposits |



| Potencial de uso Científico | | Potencial de uso Turístico | | Potencial de uso Educativo | |
|---|---|---|---|---|---|
| **Criteria** | **Desciption** | **Criteria** | **Desciption** | **Criteria** | **Desciption** |
| **Representativeness** | LGM | **Scenic and/or cultural attraction.** | Erratic blocks. | **Diversity of geological processes** | Glacial processes. |
| **Integrity** | The main elements: Blocks and morainic deposits, are in a good state of preservation. | **Interpretative Potential** | The site has geological features whose interpretation is clear and understandable to the general public. | **Didactic Potential** | The geological element to be observed can be understood through the senses. |
| **Singularity** | 1-4 similar sites are recognised in the study area. | **Safety** | The site presents no major risk for your visit | | |
| **Scientific Knowledge** | No previous scientific studies of this particular site are known. | **Accesibility** | It can be accessed from route V-875. Walking on the stones is slightly difficult. | | Public |

*Table 5 Field card created by the author to characterise the different outcrops selected in the territory. The following example from Gonzalez, 2019 shows a digitised version of one of the selected sites.*

<table>
<tr><th colspan="8">CONTEXTO GEOLÓGICO LOCAL (si aplica)</th></tr>
<tr><td colspan="8"></td></tr>
<tr><th colspan="8">TIPO DE VALOR CIENTÍFICO</th></tr>
<tr><td colspan="2">Geomorfológico</td><td colspan="2">Paleontológico</td><td colspan="2">Estructural</td><td colspan="2">Sedimentológico</td></tr>
<tr><td colspan="2">Estratigráfico</td><td colspan="2">Hidrogeológico</td><td colspan="2">Tectónico</td><td colspan="2">Geotécnico</td></tr>
<tr><td colspan="2">Volcanológico</td><td colspan="2">Glaciológico</td><td colspan="2">Paleoclimático</td><td colspan="2">Geoquímico</td></tr>
<tr><td>Otro:</td><td colspan="7">Peligros geológicos</td></tr>
<tr><th colspan="4">CARACTERÍSTICA MÁS RELEVANTE</th><td colspan="4">Depósito generado por un flujo de detritos.</td></tr>
<tr><th colspan="4">ESTADO DE CONSERVACIÓN</th><td colspan="4">El sitio se encuentra íntegro, aunque parcialmente cubierto de vegetación.</td></tr>
<tr><th colspan="8">ELEMENTOS GEOLÓGICOS DE INTERÉS CIENTÍFICO</th></tr>
<tr><td colspan="2">Depósito aluvial</td><td colspan="3" rowspan="2">¿Por qué/ para comprender qué?</td><td colspan="3">Para comprender la dinámica de las remociones en masa generada por el transporte descendente de material y los factores que controlan estos procesos en la zona.</td></tr>
<tr><td colspan="2">Litología</td><td colspan="3">Para reconocer la diversidad litológica que existe en el lugar.</td></tr>
<tr><td>Localidad tipo</td><td>Si</td><td></td><td>Secundaria</td><td></td><td>No</td><td>X</td><td>Otro</td></tr>
<tr><th colspan="8">PUBLICACIONES QUE LO INCLUYEN</th></tr>
<tr><td colspan="8">Fernández, M.; Juan Cristóbal; Arenas, M. 2002. El flujo de detritos del 3 de mayo de 2002 Caleta Buill, comuna de Chaitén, X región, a una semana del desastre [informe inédito]. Santiago: SERNAGEOMIN, 2002. 5h. + anexo: il, fot.col.</td></tr>
<tr><th colspan="8">CARACTERÍSTICAS DE USO EDUCATIVO/TURÍSTICO (Sitios relevantes de la geodiversidad)</th></tr>
<tr><th colspan="2">ATRACTIVO ESCÉNICO Y/O CULTURAL</th><td colspan="6">El sitio se encuentra a orillas de la playa.</td></tr>
<tr><th colspan="2">PARTICULARIDAD/RASGOS DISTINTIVOS</th><td colspan="6">Depósito generado por un flujo de detritos.</td></tr>
<tr><th colspan="2">CONDICIONES DE OBSERVACIÓN</th><td colspan="6">Debido a la orientación de la quebrada no se identifica claramente el desprendimiento, por lo que se podría buscar otro punto de observación. Por otro lado, existe vegetación que cubre parte del depósito.</td></tr>
<tr><th colspan="2">POTENCIAL DIDÁCTICO</th><td colspan="6">Los procesos aluvionales recientes pueden ser comprendidos por todos los niveles educativos.</td></tr>
<tr><th colspan="2">POTENCIAL INTERPRETATIVO</th><td colspan="6">La interpretación de los procesos geológicos identificados en el sitio es clara y entendible por el público general.</td></tr>
<tr><th colspan="2" rowspan="2">ACCESIBILIDAD</th><td>Muy difícil</td><td>Difícil</td><td>Moderado</td><td>Fácil</td><td colspan="2">Muy fácil</td></tr>
<tr><th colspan="3">Descripción</th><td colspan="3">Se ingresa a un sendero desde donde se debe caminar 800 m para llegar hasta la playa en la que se encuentra el depósito.</td></tr>
<tr><th colspan="8">RIESGO DE DEGRADACIÓN</th></tr>
<tr><th colspan="2">ACTIVIDAD HUMANA</th><td colspan="6">No se reconoce alguna actividad humana que pueda generar degradación del sitio.</td></tr>
<tr><th colspan="2">PROCESO NATURAL</th><td colspan="6">Remociones en masa o flujos de detritos a futuro, presencia de vegetación y erosión marina.</td></tr>
<tr><th colspan="2">SITUACIÓN DE PROTECCIÓN ACTUAL</th><td colspan="6">Se desconoce.</td></tr>
</table>

## FOTOGRAFÍA DEL SITIO

**Fig. 15.** Abanico aluvial de Buill. Vista desde la barcaza Hornopirén-Caleta Gonzalo.

## DESCRIPCIÓN GEOLÓGICA

Abanico aluvial (Fig. 15) generado a partir del aluvión ocurrido en el año 2002 en la localidad de Buill, península de Huequi. Materiales sólidos como rocas, árboles y detritos fueron transportados ladera abajo llevando todo a su paso resultando en un cono de deyección que abarca un área de aproximadamente 0.5 $km^2$ y tiene una extensión de 1 km en su parte más distal (Fig. 16.).


**Fig. 16.** Imagen satelital que muestra el área que comprende el depósito aluvial de Buill (flecha roja).

Según Hauser (1993) las pendientes iguales o superiores a 25°, la escasez de vegetación, cuencas hidrográficas compatibles con la posibilidad de producir saturación de los detritos y rocas expuestas a un equilibrio límite son factores condicionantes para la generación de flujos de detritos, mientras que la lluvia sería un factor detonante (Fig. 17). Por otro lado, Varnes (1978) define a los flujos de escombros como una forma de movimiento de masas rápido en el que una combinación de suelo suelto, rocas, materia orgánica, aire y agua se moviliza como un lodo líquido que fluye hacia abajo (Fig. 18). Además, estos flujos son causados comúnmente por un flujo intenso de aguas superficiales, debido a la fuerte precipitación o al derretimiento rápido de la nieve, que erosiona y moviliza el suelo suelto o la roca en pendientes pronunciadas.

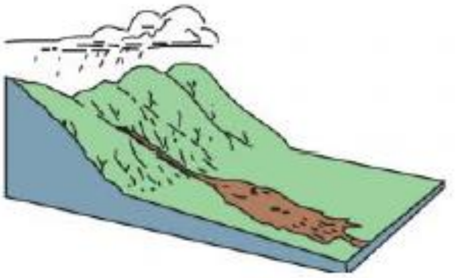


**Fig. 17.** Ilustración esquemática de un flujo de escombros. Tomado de http://pubs.usgs.gov/fs/2004/3072/

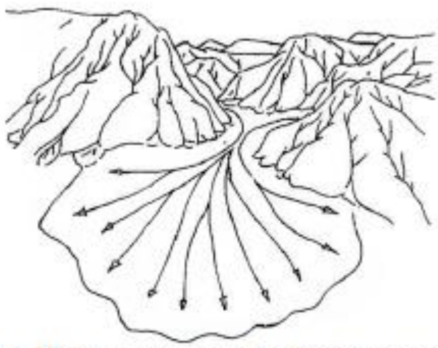


**Fig. 18.** Esquema idealizado del funcionamiento de un abanico aluvial en la salida de una quebrada, con indicación de las direcciones de flujo. Tomado de Pedraza (1996).

Para que estos flujos se comiencen a generar se necesita un área fuente con suficiente material detrítico para constituir un flujo. En segundo lugar, se necesita una zona de acopio de esos materiales en pendientes topográficas abruptas y, en tercer lugar, se precisa un mecanismo que sea capaz de iniciar el movimiento. Este último puede corresponder a lluvias prolongadas que incidan sobre la zona de acumulación de materiales (Beaty, 1970; Bull, 1972, 1977; Hampton, 1975, 1979; Wasson, 1977), para que éstos empiecen a moverse a medida que se va acumulando el agua y superándose el coeficiente de rugosidad de los materiales.

El depósito de unos 2 metros de potencia se encuentra levemente consolidado, presenta matriz soportada, estructura interna masiva, muy mal seleccionado y con un 40% de clastos polimícticos subangulosos a angulosos (esquistos, metareniscas y granitos) cuyo tamaño varía entre algunos milímetros hasta algunos metros (Fig. 19.). Tanto clastos como troncos están inmersos en una matriz fina tamaño limo/arcilla de color naranjo grisáceo (Fig. 20).

**Fig. 19.** Bloques rocosos que fueron arrastrados durante el aluvión de Buill.

**Fig. 20.** Aspecto general del depósito aluvial en donde se aprecia su espesor métrico y la ausencia de estructura interna.

## F. Inventory Proposal

Using the information generated by the different reports framed in the "Geotourism in Patagonia Verde" project for each of the communes of Patagonia Verde, a territorial inventory proposal has been made (Table 6; Figure 39). For this work, each site has been briefly characterised with its name, the municipality to which it belongs, a short description, the geological context it represents and the most outstanding element of the site. It is essential to highlight that the information collected was organised and analysed based on the national contexts proposed by Mourgues et al. (2012;2016). In this way, it was necessary to reorganise all this information to structure it within the contexts proposed by this work. A graph showing the different contexts represented by the 91 sites in the inventory is presented in Figure 38

*Table 6 Geodiversity inventory of Patagonia Verde.*

| N° | Name | Municipality | Description | Main Geological Framework | Secondary Geological Framework | Featured elements |
|---|---|---|---|---|---|---|
| 1 | Reloncavi Fjord | Cochamó | This estuary is the northernmost fjord in Patagonia and one of the most equatorial in the world. Together with the Comau Fjord, it is surface evidence of ice passage and has been a reference for mapping in several studies (e.g. Cembrano & Herve 1993). Its tectonic activity of the LFOZ has generated interest from the point of view of paleo-seismology (e.g. St-Onge, G et al., 2012) and processes that modify its hydrology (e.g. Yevenes et al., 2019). The hydrology of this fjord is also studied and recognised (e.g. Castillo et al. 2016). Its behaviour is vital for its ecosystems and productive activities such as aquaculture (e.g. Díaz et al. 2019, Soto et al. 2021). | TEC | AGI / PG / PH | Fjord |
| 2 | Arcoiris Mountain | Cochamó | It is representative of the North Patagonian Batholith and a reference point in the La Junta area. From a height close to its summit, an excellent panoramic view of the valley can be obtained, representing the Norpatagonian Batholith and the glacial processes that modelled it. This site is a recognised adventure tourism attraction in the Cochamó Commune and is visited by tens of thousands of tourists looking for hiking, mountaineering and climbing. The Cochamó Valley Organisation is the site's main administrator. Thanks to its management, there is a reservation system, access control, signage, delimitation and monitoring of trails, among other things. | BNP | AGI / TEC | Viewpoint of the Patagonian Batholith |
| 3 | Cerro Anfiteatro Glacier Cirque | Cochamó | They are a well-known tourist attraction in the area. Together with La Paloma, they are the best examples of accessible glacial cirques in the commune. They are semicircular morphologies that correspond to the accumulation zones that mark the birth of the ice masses that occupied the territory. | AGI | BNP | Glacial Cirque, Batolith |
| 4 | La Paloma Glacier Cirque | Cochamó | It is a recognised tourist attraction of Cochamó. Together with the Cerro Anfiteatro, they are the best examples of accessible glacial cirques in the commune. They are semicircular morphologies that correspond to the accumulation zones that mark the birth of the ice masses that occupied the territory. | AGI | BNP | Ancient glacial cirque |
| 5 | Toboggans of la Junta | Cochamó | The Toboggans are a well-known tourist attraction in the commune. They are the result of the erosive action of the river that slowly and progressively polished the resistant rocks of the Patagonian Batholith. | PH | BNP | A natural slide caused by Fluvial erosion |
| 6 | The Arch | Cochamó | It is a stone arch formed by the erosion of the volcanic rocks of the Cuernos del Diablo volcano (inactive). It gives its name to the El Arco river. | PH | VNQ | Fluvial erosion |

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| 7 | Pucheguín Lagoons | Cochamó | It is a well-known tourist attraction of the commune. The Pucheguín Lagoons are two Andean lagoons located in an ancient glacial cirque. | PH | AGI | Lagoons in former glacial cirque |
| 8 | Tagua Tagua Lake | Cochamó | The lake is located in a valley of glacial origin with an NW-SE tectonic lineament. It has a surface area of approximately 13.4 km2. Its main tributary and effluent is the Puelo River. | PH | AGI /TEC | Lake |
| 9 | Manso River Valley | Cochamó | From this place, it is possible to see the Manso River and its meanders inserted in an old glacial valley to the north. To the south, it is possible to see the confluence of the Manso and the Puelo Rivers over a vast floodplain. At this point, metamorphic rocks of the Cordillera Principal Metamorphic Complex are possible to observe. | PH | AGI /CMCP | Confluence |
| 10 | Llanada Grande Waterfall | Cochamó | It is a tourist attraction recognized in the locality. It is a waterfall, some tens of metres high, of scenic value. | PH | | Waterfall |
| 11 | Puelo river canyon (Primer Corral footbridge) | Cochamó | Knick-point. The Puelo river canyon is the point where the river is no longer encased by resistant granitic rocks but opens its way through the sediments of the valley, widening its channel and slowing down its speed. It is an excellent place to observe the differential erosion of the river between two types of rocks. On the other hand, the first corral footbridge is located here, a tourist attraction recognised for its scenic value. | PH | TEC | Canyon, Knick- point |
| 12 | Lakes of Llanada Grande (Lago Azul, Las Rocas, Inferior, Blanco and Totoral) | Cochamó | Correspond to a group of lakes that fill depressions formed by ancient glaciers. Internal valleys connect all these lakes, so it is likely to have been a single body of water after the ice retreat. Later, the Andes uprising and the decreased water sources subdivided them into several lakes. | PH | AGI /TEC | Lake |
| 13 | Maar of Puelo | Cochamó | It is a Maar of approximately 160 m in diameter and is the only site in this inventory representing phreatomagmatic processes. | VNQ | | Maar |
| 14 | Candelaria Lagoon | Cochamó | It is an adjacent lagoon to the Puelo's Maar. Tourist activities are carried out here, and the Yates volcano can be observed. | PH | | Lagoon |
| 15 | Landslide of Blanco river | Cochamó | The site is noted for its cultural value. Massive landslide whose remains date back to the 19th century and, according to the inhabitants, was of such magnitude that it completely covered the estuary and could be crossed on foot temporarily on the floating trees that had fallen from the high mountain (oral account). | PG | | Alluvium |
| 16 | Glacial sediments of Aulen Square | Hualaihué | A road cut showing the glacial sediments that underlie the Aulén locality square. | AGI | | Moraine |
| 17 | Nao Island | Hualaihué | Island of approx. 9ha, joined to the coast by a rocky bank that can only be crossed during low tides. Within the different sedimentary deposits of presumed glacial origin, there are shell strata at about 4±1 that may be evidence of the rapid uplift of Patagonia after glacial retreat. | SCCz | TEC | Llahuen Fm (?), Holocene fossils |
| 18 | Quetén ripples | Hualaihué | It corresponds to an outcrop of minor, laminated silt, varved and with the presence of ripples. | PH | AGI | Lacustrine deposits (?) Ripples |
| 19 | Erratic blocks of Rolecha | Hualaihué | These are large erratic blocks located in the Rolecha area on top of other deposits of the Llahuen Formation (SERNAGEOMIN-BRGM, 1995). | AGI | SCCz | Erratic Blocks |
| 20 | Giant Marmites of Puente Lleguiman | Hualaihué | The Basaltos del Puente Lleguiman are a representative site of the erosive action of the rivers. "Giant Marmites", | PH | VNQ | Giant Marmite |

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| 21 | Contao beds | Hualaihué | It is a sedimentary sequence overlying the Ayacara Formation, possibly corresponding to the Contao Strata (Alarcón, 1995) grouped in the Llahuen Formation. | SCCz | | Llahuen Fm (?)Contao Strata |
| 22 | Punta Poe columnar basalts | Hualaihué | These lavas would have been deposited in a shallow littoral environment, entering laterally into the sea and interacting in a low explosive manner with saturated waters and sediments forming peperites at the base. Towards the top, well-formed basaltic columns are observed (Mella et al. 2006). The present position of the peperites qualitatively corroborates the Pleistocene-Holocene coastal uplift (Herve & Ota, 1993). | VNQ | TEC / SMCz | Columnar Basalts and Peperites |
| 23 | La Silla Hill | Hualaihué | Cerro la Silla is a geographical reference for its inhabitants. Its name refers to its saddle-like shape. From the top of the hill, at an altitude of approximately 310 m, it is possible to see the wetlands of Hualaihué Estero, Malomacún Island and a small lagoon that seems like a crater. The first geological investigations indicate that it would be a Tuya, and its genesis would be related to the geosite "Columnar basalts of Punta Poe". | VNQ | AGI /PH | Tuya |
| 24 | Hualaihué Estero wetland | Hualaihué | It is a wetland formed in the delta of the Cisnes River. Most of the sediments dragged by the river and supporting the wetland belong to a lahar from the Apagado Volcano. | PH | VNQ | Wetland |
| 25 | Caleta Manzano sedimentary deposits | Hualaihué | Correspond to sedimentary deposits at a height highlight shell strata (Conchales) at about 5±1 m above sea level that may be evidence of the rapid uplift of Patagonia following the glacial retreat documented by Herve & Ota (1993). | TEC | | Holocen Fossils Discordance |
| 26 | Ignimbrite Lago Cabrera | Hualaihué | It is a pyroclastic deposit of 1880 Ap. from the Hornopiren (?) volcano. | VNQ | | Ignimbrite |
| 27 | Cabrera Lake (1965) | Hualaihué | It is a mountain lake at the base of the Yate and Hornopiren volcanoes. In 1965, a mass of rock and ice detached from the SW of Yate's summit. The failed material was transported south down the confined El Derrumbe valley, which generated a tsunami on the shores of the lake (Watt et al. 2009). This tsunami caused the death of more than 26 people in the surrounding area. An annual ceremony is held to honour the victims | PG | | Tsunami |
| 28 | Chaqueihua Waterfalls | Hualaihué | Also known as Chaqueihua waterfalls, these are waterfalls of approximately 3 m, located on ancient lava flows from the Hornopirén volcano. | VNQ | PH | Lava flows from Hornopiren Volcano |
| 29 | Rio Blanco Canyon and Waterfall | Hualaihué | Knick-point. It is a well-known tourist attraction in the area. In this place, the river goes from being encased in the rocks of the BNP to widening, forming a small lake where a waterfall comes from a small mountain river originating from the snowmelt. | PH | TEC | Knick Point Canyon and Waterfall |
| 30 | Río Negro Wetland | Hualaihué | It is a wetland where birdwatching can be done. | PH | VNQ | Wetland |
| 31 | Lilihuapi | Hualaihué | It is a recognised tourist attraction of the commune. Its central values are related to significant scientific research in biology and diverse housing species (e.g. sea lions). In geological terms, they correspond to rocks of the BNP with evidence of glacial erosion. | BNP | | Island |
| 32 | Isla Llancahué debris flow | Hualaihué | Fan resulting from a past debris flow. It is possible to observe it from tourist boats on their way to the Cahuelmó or Quintupeu fjords. | PG | | Mass Removal |
| 33 | Quintupeu Fjord | Hualaihué | It is a steep fjord with several waterfalls hundreds of metres high, susceptible to landslides (e.g. Villela, 2017). It is known as one of the Seiner Majestät Schiff (SMS) Dresden's hiding places during WW1. Like the other fjords, it is internationally renowned for its biodiversity. | AGI | GH | Fjord |
| 34 | Comau Fjord | Hualaihué | It is a Fjord coinciding with the LOFZ and surface evidence of this. On the other hand, this fjord is representative of the last glacial period. Its unstable condition has generated national and international studies in geological hazards and seismicity (e.g. Lange et al., 2008; Arenas et al., 2008). Like the other fjords, it is internationally recognised for its biodiversity. | TEC | PG /AGI / PH | Fjord |

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| 35 | Cahuelmo Fjord | Hualaihué | It is a steep-walled fjord known for its hot springs (Ruiz & Morata. 2016), possibly related to the activity of the LOFZ and also for being an area susceptible to landslides. Like the other fjords, it is internationally recognised for its biodiversity. | VNQ | GH /TEC/ Agl | Fjord |
| 36 | Huinay Holocene Marine Deposits | Hualaihué | Correspond to a Holocene Fossiliferous succession on the north bank of the Loncochaihua River. They constitute a 12 m thick succession, in which four horizons with marine shells (clams in life position, gastropods, razor clams and mythilids) are observed. The position and age of these deposits could indicate the paleo-seismic activity of the LOFZ (Herve et al., 2015). | TEC | PH | Holocene Fossils |
| 37 | Punta Calle Hot Springs | Chaitén | Hot springs associated with the Barranco Colorado volcano | VNQ | | Spring |
| 38 | Porcelain Geysers | Chaitén | The Porcelain Geysers are a complex geothermal system. It owes its origin to the presence of several faults and fractures that provide high permeability along the entire peninsula, also related to the origin of the Barranco Colorado Volcano. The Porcelain Geysers are the only known site in the world with a system of active travertine pinnacles that precipitate at present and can therefore be considered a singularity. It is a thermal environment, unlike the others found in the territory. In this one, the concentration of calcium and silica allows the formation of travertine columns that exceed 2 m in height as a result of the precipitation of carbonates. They also host microorganisms adapted to extreme temperatures close to 90° (Ruiz & Morata, 2016; Ruiz et al., 2017; Ruiz, 2019). | VNQ | TEC / PH | Travertine pinnacles, hot springs, waterfall |
| 39 | Huequi Lagoon placer deposits | Chaitén | The primary source of the gold at Patagonia Verde would correspond mainly to hydrothermal mineralisation located in the Andes Mountains. However, the gold would have been transported towards the coastal sector by the huge glacial masses that eroded the main mountain range and deposited the gold in the moraines.<br>On the Huequi peninsula, much of the river erosion has re-transported this gold and deposited it in low-energy zones. The Huequi Lagoon and surrounding rivers, such as the Mudo River, are known areas for gold mining, mainly by artisanal gold miners.<br>Currently, there are mining concessions in and around the lagoon. | PM | PH /AGI | Placer de Oro |
| 40 | Marine Rocks of Ayacara Cove | Chaitén | Patagonia's most important Cenozoic marine transgression occurred during the late Oligocene and early Miocene (Echaurren et al., 2022). Around 20 Ma, marine waters from the Pacific and Atlantic would have flooded most of southern South America, including the present-day Patagonian Andes, allowing for the first time in the history of this area a possible transitional connection between the Pacific and Atlantic Oceans. The transition from shallow marine rocks to deep marine rocks of Caleta Ayacara is evidence of this process. It is the completest record of that connection, making it a type locality of the Ayacara Formation (Levi et al. 1966, Encinas et al. 2013). | SMCz | VNQ | Ayacara Fm |
| 41 | Marine rocks of Ica Island | Chaitén | It is the type locality of the Ayacara Formation (upper member). Its origin is related to the most significant marine transgression of the Cenozoic in Patagonia (Echaurren et al., 2022), which took place during the late Oligocene and early Miocene (Encinas et al., 2013) | SMCz | VNQ | Ayacara Fm |
| 42 | Buill conglomerates | Chaitén | A fluvial-alluvial sedimentary deposit is made up of stratified sequences located on the Buill River banks near its mouth. | PH | | Fluvial-alluvial deposits |
| 43 | Buill Cove mass removal (2002) | Chaitén | It is an alluvial fan generated by the 2002 alluvium in the locality of Buill, Huequi peninsula. As a result, five people died, and seven disappeared. | PG | | Mass Removal |
| 44 | Islote Nihuel/ Calto rock | Chaitén | Islote Nihuel / Piedra del Calto is a small island belonging to the Desertores group. Studies at this site are still embryonic, and not much information has been collected, making it an excellent place to develop research. However, given its location in the central depression, Islote Nihuel seems to correspond to a sedimentary | SMCz | TEC / AGI | Island |

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| | | | sequence that could be related to the Llahuen formation, although it is necessary to verify this assertion through research. One of the most relevant aspects is its morphology: the island has a flat roof and forms an authentic cube.<br>Its location close to the coast makes it a small reserve for marine life. | | | |
| 45 | Tronador River Lagoon and Valley | Chaitén | Correspond to a lagoon that fills the glacial cirque. This site is part of one of the tourist attractions of Pumalin Park. | AGI | | Glacial Cirque |
| 46 | Chaitén metatonalite | Chaitén | It is an intrusive body formed by magmatic rocks, aged about 400 Ma, from the Devonian period (Duhart et al., 2009, Herve et al., 2016), being one of the oldest records found in the territory. Its origin possibly represents part of an ancient volcanic island chain that later collided, amalgamated with the mainland, and was named Chaitenia (Herve et al., 2016). Its attributes, such as location and access, make it easy to study, and it is not only of great scientific importance but also of great educational value. | CHA | | Metatonalite |
| 47 | North Lahar Chaitén Volcano | Chaitén | It is a lahar caused by the explosive eruption of the Chaitén volcano in 2008 | PG | VNQ | Lahar |
| 48 | Rayas Glacier, Vn Michinmahuida | Chaitén | It is a glacier valley located on the north-western flank of the Michinmahuida Volcano, corresponding to one of the four main glacial basins found on the volcano (Rayas, Chico, Amarillo, Reñihue). In addition to the different morphologies related to the glacial environment, it is inserted in an active volcanic environment whose interaction has been studied (e.g. Rivera et al., 2012; Rivera and Bown, 2013). | AGI | VNQ | Glacier, Glacier Valley, Aborted Rocks, Moraines |
| 49 | Punta Chana laharic deposits (1984) | Chaitén | Lahar deposits are possibly associated with an eruption of the Michinmahuida Volcano, estimated to have occurred in 1835 (SERNAGEOMIN, 2022a). | PG | VNQ | Lahar |
| 50 | Morro Vilcún volcanic dyke | Chaitén | Wicks et al. (2011) point out that an NNW-oriented conduit would connect the Michinmahuida Volcano, the Chaitén Volcano and the Morro Vilcún. According to those authors, there would be a chain of unclosed rhyolitic plugs, and the most prominent would be the Morro Vilcún, where the fault of the deposit reaches the surface. In this Morro, marine erosion forms caves in which significant archaeological finds are. | VNQ | TEC | Volcanic dike |
| 51 | Chaitén Volcano Dome | Chaitén | Volcanic dome originating from the 2008 eruption. | PG | TEC / VNQ / PH | Volcanic Dome |
| 52 | Santa Barbara Metamorphic Rocks | Chaitén | The Santa Barbara schists are metavolcanic deposits, which, although not dated, have been associated with the Upper Paleozoic Accretionary Prism (SRGN-BRGM, 1995 and references therein) as part of the Main Range Metamorphic Complex. One of the singularities of this site is that a contact can be observed between this unit and the Llahuen Formation (Araya, 1979), which corresponds to a group of much younger volcano-sedimentary sequences of Pleistocene age visible mainly in the coastal sector of Patagonia Verde. This site is essential because it is the only specimen inventoried in this geological context. Its easy access and association with other attractions, such as Playa Santa Barbara or Morro Vilcún, make this place valuable in educational and touristic terms. | CMCP | SCCz | Greenschist |
| 53 | Chaitén Site Museum | Chaitén | On May 10, 2008, intense rainfall removed huge volumes of ashes accumulated in the territory, which were emitted during the eruption of the Chaitén volcano (Major & Lara, 2013). The ashy water was channelled through the main neighbouring rivers, including the Blanco River that flows through the town of Chaitén before emptying | PG | VNQ | Lahar |

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| | | | into the sea. The waters of the Blanco River, laden with volcanic material, overflowed their banks, flooding and sweeping away numerous houses. In the Chaitén site museum, it is possible to see the effects of this lahar on the city and how the houses were affected. The consequences of this eruption generated the interest of the international community. In Chile, it set a precedent in volcanology. It led to the decision to create the National Volcanic Surveillance Network and to considerably modernise the Volcanological Observatory of the Southern Andes (OVDAS) under the administration of the National Service of Geology and Mining (SERNAGEOMIN). The OVDAS is located in Temuco and monitors 45 active volcanoes throughout the country. | | | |
| 54 | Chaitén Lahar (2008) | Chaitén | It is a lahar fan on the coast of Chaitén. The deposits generated a beach and moved the coastline 400m out to sea. | PG | VNQ | Lahar |
| 55 | Abandoned riverbed of the Chaitén River | Chaitén | At this site, the old riverbed of the Río Blanco was clogged by ash and pumice caused by the secondary lahar after the last eruption of Chaitén Volcano. | PG | VNQ | Lahar |
| 56 | Puduhuapí marine rocks | Chaitén | It is the type locality of the Puduhuapi Formation. Its origin is related to the most important marine transgression of the Cenozoic in Patagonia, which occurred during the late Oligocene and early Miocene. | SMCz | | Puduhuapi Fm |
| 57 | El Amarillo pyroclastic cones | Chaitén | It corresponds to 4 pyroclastic cones belonging to the Pumalin National Park Viewpoint Trail. | VNQ | TEC / AGI | Pyroclastic Cone |
| 58 | Amarillo glacier, Vn Michinmahuida | Chaitén | It is a mountain glacier located on the southern flank of the Michinmahuida volcano, corresponding to one of the four main glacier basins found on the volcano (Rayas, Chico, Amarillo, Reñihue). It is located in the Pumalin National Park, has a trail to its base, and is an outstanding tourist attraction in the Commune of Chaitén.<br>Shortly before the eruption of the Chaitén volcano, an unexpected breakthrough began that prompted scientific interest and discoveries. The conclusion of the studies (Rivera et al. 2012) was that the ice displacement could have responded to the increase of geothermal flows in the subsurface before the onset of the eruption. This heating caused the bedrock to rise, and possibly meltwater was produced at the base of the glacier, leading to the slide and the unexpected advance. | AGI | TEC / VNQ | Glacier, Glacier Valley, Aborted Rocks, Moraines |
| 59 | Río Turbio Chico volcanic sequence | Chaitén | It is a pyroclastic succession of approximately 8 m high produced by eruptions of the Michinmahuida and Chaitén volcanoes. | VNQ | | Volcanic Sequence |
| 60 | El Amarillo ignimbrite | Chaitén | Volcanic deposit associated with the post-glacial explosive activity of the Michinmahuida volcano, whose eruption is inferred to be highly explosive (VEI>5) and related to the generation of the volcanic caldera, currently covered by ice (Lara et al. 2009; Amigo et al.,2013). | VNQ | | Ignimbrite |
| 61 | Lake Yelcho | Chaitén | The lake is located in a valley of glacial origin with an NW-SE tectonic lineament. It has a surface area of approximately 116 km2. Its main tributary is the Futaleufú River, and its primary effluent is the Yelcho River. | PH | AGI / TEC | Lake |
| 62 | Río Yelcho Chico Glacier | Chaitén | It is a glacier valley located in the area of the Yelcho chico river in the Corcovado National Park. It is the glacier with the best access in the territory, and it is possible to observe the different characteristics of the glacial environments. | AGI | PH | Glacier, Glacier Valley, Aborted Rocks, Moraines |
| 63 | La Silla Formation | Chaitén | Pliocene continental sedimentary rocks on this site represent the Andes Mountains' uplift. | SCCz | VNQ | La Silla Fm |

| | | | | | | |
|---|---|---|---|---|---|---|
| 64 | Villa Santa Lucía landslide (2017) | Chaitén | On 16 December 2017, a landslide occurred in the Yelcho mountain range. In that event, 7 million m3 of rocks and soil fell onto a retreating covered glacier, depositing 2 million m3 at the glacier's terminus, and the rest continued downstream, triggering a mudflow that hit Villa Santa Lucia in Chilean Patagonia and killed 22 people (Sernageomin, 2018; Somos-Valenzuela et al., 2020). | PG | | Mass Removal |
| 65 | Futaleufú River Delta | Palena | This site is recognised as an attraction of the commune. It is a transition point between a fluvial and a lacustrine environment and marks the end of the Futaleufú River, generating a wetland of ecological value. It is well known for being a place for sport fishing and bird watching. | PH | | Wetland |
| 66 | Arroyo Grande waterfall | Futaleufú | It is one of the two representatives of the La Cascada Formation and the only site where the conglomerate base is seen in contact with Cretaceous outcrops (Encinas et al. 2014). It is overlain by fossiliferous sandstone. In addition, a waterfall can be observed. | SMCz | PH | La Casacada Formation |
| 67 | Azul River Fossils | Futaleufú | Slope outcrop preserving a set of shallow marine sedimentary sequences representative of the La Cascada Formation (Encinas et al. 2018). | SMCz | | La Casacada Formation |
| 68 | Azul Falls | Futaleufú | It corresponds to a succession of staggering waterfalls of 250 m of scenic and landscape value from where the Blue Glacier can be seen. | PH | | Waterfall |
| 69 | Glacier and Lago Azul | Futaleufú | It is a mountain glacier of 0.09km3 volume that gives birth to the Rio Azul. At this site, it is possible to see a proglacial lagoon, and the typical characteristics of a glacial environment can be observed. Its access is in terrible condition. | AGI | | Glacier Valley Glacier Lagoon pro glacier |
| 70 | Cerro Redondo / Tamango | Futaleufú | It corresponds to a rocky massif of 1720 m. in altitude. This site is representative of the Aysen Basin and is the contact between the Toqui Formation and the Ibañez Formation. | AvMz | CA | Jurassic Volcanism (Ibañez Fm.) |
| 71 | Cerro Tres Monjas | Futaleufú | It corresponds to an outcrop of approximately 1200m of pyroclastic volcanic rocks corresponding to the Ibañez Formation. It is also notable for a set of glacial geoforms resulting in 3 prominent peaks of 1960m, 1920m and 1890m. It is one of the prominent landmarks of Futaleufú. | AvMz | AGI | Jurassic Volcanism (Ibañez Fm.) |
| 72 | Esponlon Lake | Futaleufú | The lake is located in a valley of glacial origin with an NW-SE tectonic lineament. It has a surface area of approximately 14 km2. Its main tributaries are the Espolón and Blanco rivers, and its primary effluent is the Espolón river. | PH | AGI / TEC | Lake |
| 73 | Teta Mountains | Futaleufú | One of the primary geographic references of Futaleufú (1790m a.s.l.) is part of the Patagonian Batholith, where several forms of glacial origin can be observed. Its main singularity is a Horn locally called "La Teta". It is a well-known tourist attraction in the commune. | AGI | BNP | Horn |
| 74 | Devil's Throat | Futaleufú | It is a knick point of the Espolon River. The Devil's Throat corresponds to where the water from Espolon Lake gives rise to the river of the same name. In this sector, the water flow takes advantage of a possible previous tectonic weakness generating a vertical incision on the rock and giving rise to a canyon up to 15 m high. The mighty watercourse flows turbulently through this narrow channel. Its dangerousness for navigating gives it its name. | TEC | PH | Canyon |
| 75 | Piedra del Aguila | Futaleufú | It is one of the best examples of dykes in the territory. Its composition has allowed a better resistance to erosion than the encasing rock, generating prominence and a viewpoint considered one of the main tourist attractions of Futaleufú. | AvMz | TEC | Dyke |
| 76 | La Puntilla Strata | Futaleufú | It corresponds to a sedimentary sequence of approximately 10 m high, accessible and well preserved, visible thanks to the erosion of the Futaleufú river. The sedimentary records of its strata offer clues to the evolution of the geological processes that gave rise to the valley and its subsequent filling. | PH | AGI / TEC / PH | Fluvio-glacial sediments |
| 77 | Espejo Lagoon | Futaleufú | It is a recognised tourist attraction in the region. Although its morphology has led the inhabitants to believe it is a maar, there is no scientific evidence to support this theory. | PH | BNP | Lagoon |

| | | | | | | |
|---|---|---|---|---|---|---|
| 78 | Futaleufú River Canyon | Futaleufú | Between the Guelves Bridge and the Pozon de Los Reyes, the Futaleufú River makes its way through the rocky massif of the Toqui Formation, through an 800 meters-long canyon. In this canyon, the river decreases its width and increases its speed. Also, abrupt changes in the slope (Knick-points) form a series of "rapids". This canyon is not exclusive; therefore, there are several areas of rapids (e.g. Pasarela la Dificultad). The water quality, colour and rapids make the Futaleufú river an international reference for practising Rafting and Kayaking.<br>The rivers usually start after a tectonic uprising, and in the case of the Futaleufú River, it would be related to the Andes Uplift. | PH | TEC | Canyon |
| 79 | Salto tronador | Palena | Waterfall 200 m high, over a mountainous ravine with scenic/landscape value. Part of a private conservation initiative. | PH | TEC | Waterfall |
| 80 | Cerro Estríado | Palena | It is a roadside hill where it is possible to see glacial striae. | AGI | | Glacier Striae |
| 81 | Valle Palena Quarry | Palena | Quarry for the extraction of aggregates allows seeing the subsoil of the California Valley, particularly deposits of glacial origin. | AGI | PH | Glaciofluvial sediments |
| 82 | El Aceite Hill | Palena | Between the Titonian and Aptian, marine and volcanic sedimentary deposits filled a depression known as the Aysen Basin (Bell and Suárez, 1997). These deposits record a period of marine transgression (Toqui Formation), deepening (Katterfeld Formation), and subsequent uplift (Apeleg Formation) grouped under the name of the Coyhaique Group (Haller and Lapido, 1980).<br>In Patagonia Verde, a local expression of the last period of this basin is found in the locality of Palena, particularly in the Aceite area. There is a small hill where it is possible to observe shallow marine sequences with a large amount of fossil content, denominated El Aceite Formation (Fuenzalida, 1965). | CA | AGI / TEC | El Aceite Fm (Coyaique Group) + Fossils |
| 83 | Cordon de Las Tobas | Palena | It corresponds to a reddish-greyish mountain range with an average height of 1500 m, 24 km of longitudinal extension and summits that reach 1860 m. It is the type locality of the Las Toqui Formation. It is the type locality of the Las Tobas Formation (Fuenzalida 1965, Haller & Lapido 1980) and is the only representative site of active volcanism 100Ma ago in Patagonia Verde. | AvMz | AGI / BNP | Cordon Las Tobas Fm. (Divisadero Group) |
| 84 | Palena River Valley (Cerro La Cruz) | Palena | The Palena River Valley stands out for its evidence of ice passage in the last glacial period. From the viewpoint of Cerro la Cruz, in the city of Palena, it is possible to have a panoramic view of it. | PH | AGI | Post-glacial Fluvial Valley |
| 85 | La Bandera Hill | Palena | It is a summit of reference for the inhabitants of Palena, of recognised landscape value, whose top provides a panoramic view of the city and the valley of the river Palena. The volcanic and volcanoclastic sequences that make up this site and the ages assigned, which place it between the Toqui Formation and the Katterfeld Formation, suggest a volcanic environment synchronous with the formation and deepening of the Aysén Basin. | CA | | Toqui and Katterfeld Fm |
| 86 | Valle de California Glaciolacustrine Deposits | Palena | It is a roadcut that allows seeing glacial sediments, possibly of glaciolacustrine origin. | AGI | PH | Glaciolacustrine Sediments |
| 87 | California Valley Quarry | Palena | It is a quarry for the extraction of sand that allows seeing the subsoil of the California Valley, in particular deposits of glacial origin. | AGI | PH | Glaciofluvial sediments |
| 88 | Aborregada Rocks of El Tigre River Valley | Palena | They are a series of well-preserved rocks visible in the valley of the Río el Tigre. | AGI | PH | Aborted Rocks Canyon |
| 89 | Moro Peak | Palena | It is a geographical reference for the inhabitants of Palena, whose highest peak exceeds 1800 metres above sea level. It is composed | AvMz | AGI | Volcanism and Horn |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | of Lower Cretaceous volcanic sequences (BRGM, 1995). It is also a good example of a Horn in the territory. | | | |
| 90 | Palena Lake. | Palena | This binational lake of 135km2 is considered the main attraction of the Lake Palena National Reserve. It is an Andean glacial lake occupying a long valley, a relict of an ancient glacial tongue allied to neighbouring glaciers (e.g. Tempano). Its main tributaries are the Huemul River and the Ice River. A particularity is that its waters flow eastwards (Argentina) and then travel northwards to cross the Andes again and flow into the Pacific Ocean. | PH | AGI | Lake |
| 91 | Confluence of Río Palena and Río Frio. | Palena | It corresponds to the confluence of two of the principal rivers of the commune, the Palena and the Frío. It stands out for its hydrological characteristics and its landscape value. | PH | | Confluence |

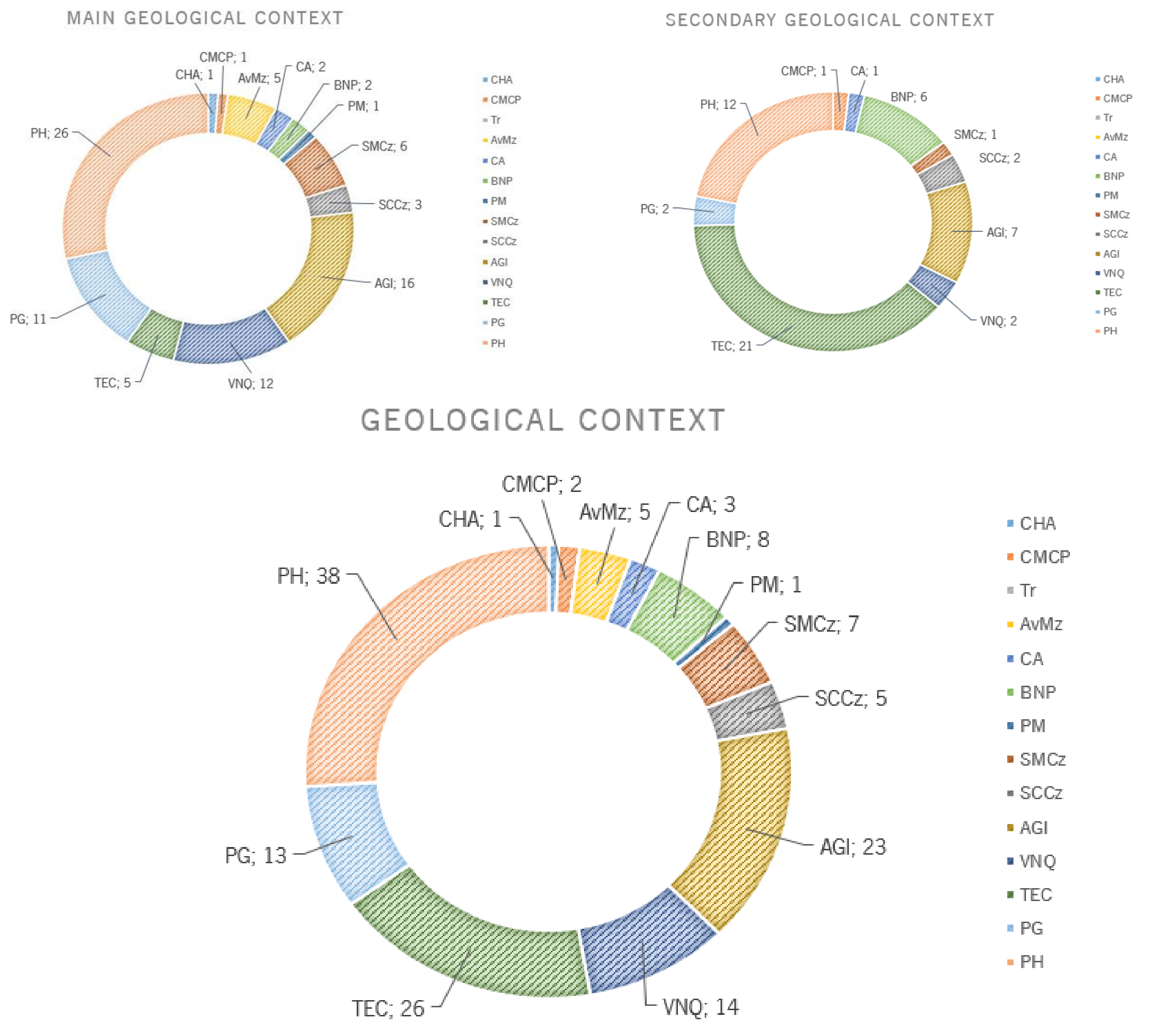



*Figure 38 Graphs showing the geological contexts represented by the sites of the territory. All 91 sites represent at least one geological context. In that sense, the first graph, "Main Geological Context", represents each site. The second graph, "Secondary Geological Context", is representative of those sites whose geological diversity allows them to represent totally or partially other contexts besides the main one. Finally, the Geological Context graph is a total of the above graphs and provides a view of all the geological contexts represented across the 91 s.*

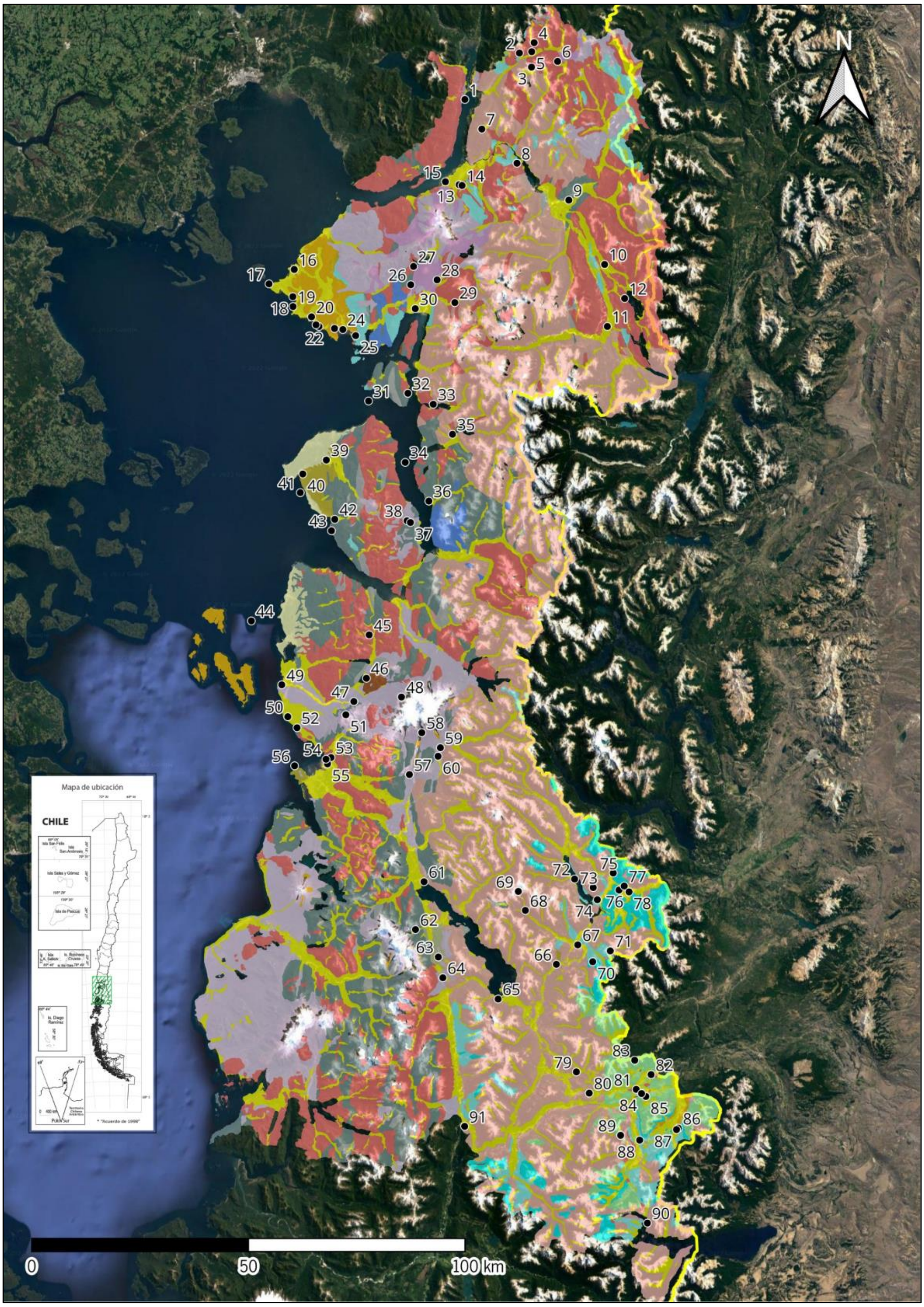



*Figure 39 Spatial distribution of the inventory in Patagonia Verde. The symbology of the geological units can be reviewed in Figure 25*

### G. Quantitative Assessment

Firstly, the results of this assessment are presented in Figure 40, where the scientific value, the potential for educational use, the potential for tourism use and the risk of degradation were calculated from the weighted sum of the parameters based on Table 7. Furthermore, to have a broad and easy-to-analyse view, a qualitatively low value has been defined as "less than 2 points", a moderate value for data between 2 and 3, and a high value for data exceeding 3 points. In addition, the average value obtained in each bar chart in Figure 40 has been indicated. This average value is only intended to provide a second point of comparison, this time between the elements analysed.

*Table 7 Weight assigned to the parameters of each category*

| **Scientific Value (SV)** | **Educational Use Potential (EUP)** | **Touristic Use Potential (TUP)** | **Degradation Risk (DR)** |
|---|---|---|---|
| A. Representativeness (30%)<br>B. Key locality (20%)<br>C. Scientific knowledge (5%)<br>D. Integrity (15%)<br>E. Variety of geological elements (5%)<br>F. Rarity (15%)<br>G. Use limitations (10%) | A. Seasonality (5%)<br>B. Limitations (5%)<br>C. Road Type (5%)<br>D. Distance (5%)<br>E. Difficulty (10%)<br>F. Safety (10%)<br>G. Scenery (5%)<br>H. Uniqueness (5%)<br>I. Association with other values (10%)<br>J. Observation conditions (10%)<br>K. Didactic potential (20%)<br>L. Geological Diversity(10%) | A. Seasonality (5%)<br>B. Limitations (5%)<br>C. Road Type (5%)<br>D. Distance (5%)<br>E. Difficulty (5%)<br>F. Safety (10%)<br>G. Scenery (15%)<br>H. Uniqueness (10%)<br>I. Association with other values (10%)<br>J. Observation conditions (10%)<br>K. Interpretative potential (15%)<br>L. Proximity of recreational areas (5%) | A Vulnerability (30%)<br>B. Proximity to areas/activities with the potential to cause degradation (15%)<br>C, Legal protection (20%)<br>D. Density of the population (5%)<br>E. Road Type (7.5%)<br>F. Distance (7.5%)<br>G. Economic interest (15%) |

Secondly, Figure 40 shows the overall results of the criteria analysed to be able to roughly detect which criteria influence the different categories better or worse.

Finally, a table with a qualitative analysis has been done to easy-visualise which attributes the sites stand out.

### H. Data Analysis

A detail of these results can be grouped into three categories:

#### *Scientific Value*

Seven criteria were parameterised (Annex 7.2) and weighted (Table 7) to obtain the scientific value. From the results, the average scientific value is 2.3 out of 4 points. Of the total number of sites analysed, 13 have a high scientific value, 42 sites have medium values, and 36 sites have low values.

The site with the highest value (3.8 points) is the Chaiten Metatonalite site, one of the oldest outcrops in the territory, the only one in the inventory that represents the CHA context and with studies of international relevance. It is also a roadside site, has no limitations for its use, and its good state of conservation allows the generation of helpful quality samples to generate more knowledge. On the other hand, the site with the lowest value (1.15 points) corresponds to the Lilihuapi, a small island between Llancahue Island and the Ayacara Peninsula. Its access is only by boat, and it has been inventoried as a natural attraction of the commune of Hualaihué, occasionally used as a tourist resource for sighting sea lions.

Concerning the criteria employed, use limitations (3.69 points) and integrity (3.62 points) obtained high values, representativeness (2.7 points) and uniqueness (2.34 points), medium values and scientific knowledge (1.26 points), geological diversity (1.24 points) and key locality (0.48 points) low values.

The results obtained for this value meant that Patagonia Verde is a territory whose sites represent an interest in science. Moreover, the scientific value of 55 sites averages more than 2 points and can undoubtedly be referred to as potential Geosites. The lack of scientific knowledge concerns most of the sites in the territory, which translates into an opportunity for scientific research that could bring benefits not only for the development of earth sciences but also to improve the interpretative and didactic potential of the sites. Also, recognising these sites and their increased knowledge can lead to them becoming national and even international references, improving the "Key locality" criterion.

***Educational /Tourist use Potential***

Twelves criteria were parameterised (Annex 7.2) and weighted (Table 7) to obtain the educational use potential. The results show that the average educational use potential value equals 2.80 points out of 4 possible points, a medium-high value, with the lowest value being 1.55 and the highest value being 3.7 points. Of the total number of sites analysed, 26 have high values, 57 have medium values, and only 3 have low values.

Also, twelve criteria were parameterised (Annex 7.2) and weighted (Table 7) to obtain the Tourist use Potential. The results show that the average tourist use potential value equals 2.78 points out of 4 possible values, a medium-high value, with the lowest value being 1.30 points and the highest value being 4 points. 36 sites have high values, 49 have medium, and only 6 have low values.

Regarding the criteria obtained, the highest values are concentrated in "Association with other values (4 points), Seasonality (3.66 points), Safety (3.45 points) and Observation conditions (3.57 points) criteria. Average values for Road type (2.21 points), Distance (2.89 points), Difficulty (2.71 points) and low values for the criteria Uniqueness (1.52 points) and Scenery (1.22 points).

The educational criteria "Educational Potential" and "Geological Diversity" score 2.70 points and 1.32 points, respectively.

For those related to tourism, Interpretative Potential and Proximity to Recreational Areas obtain values of 2.75 points and 3.64 points, respectively.

It is worth noting that the site with the lowest values for both educational and tourist use is *Pico Moro*. This site is an inaccessible peak in the territory, which, even if it has limited uses, has been inventoried as a geographical reference and has a geomorphological value.

On the other hand, the Chaitén site museum obtains the best scores, is located in the centre of the Chaitén locality and was designed exclusively to be an interpretative and didactic space.

Almost all the sites in the inventory have some interest in educational or tourist activities. In addition, a particularity of this territory is that it is possible to find other ecological or cultural values in relative proximity. This condition is mainly because of three reasons. First, Patagonia Verde is connected through a single route (Route 7). Second, 25% of the territory is a national park. Third, the project "Patagonia Verde, Culture and Identity for Tourism Development" (Gomez and Barria, 2018) has recently rescued the local memory, generating points of interest in several places close to the inventory of this work. In addition, most sites have good viewing conditions and can be visited throughout the year. Access to these sites is mostly good, although the road is sometimes gravel. Where there are trails, access is not complex, and the security conditions are adequate for developing educational or tourist activities. This condition is mainly because many of the trails are located in Natural Parks or private initiatives where maintenance is carried out.

Regarding education, the sites have at least two geological elements with didactic potential, generally associated with secondary geological features where the source of origin is not necessarily discernible. Their study is mainly focused on teaching the fundamentals of geology.

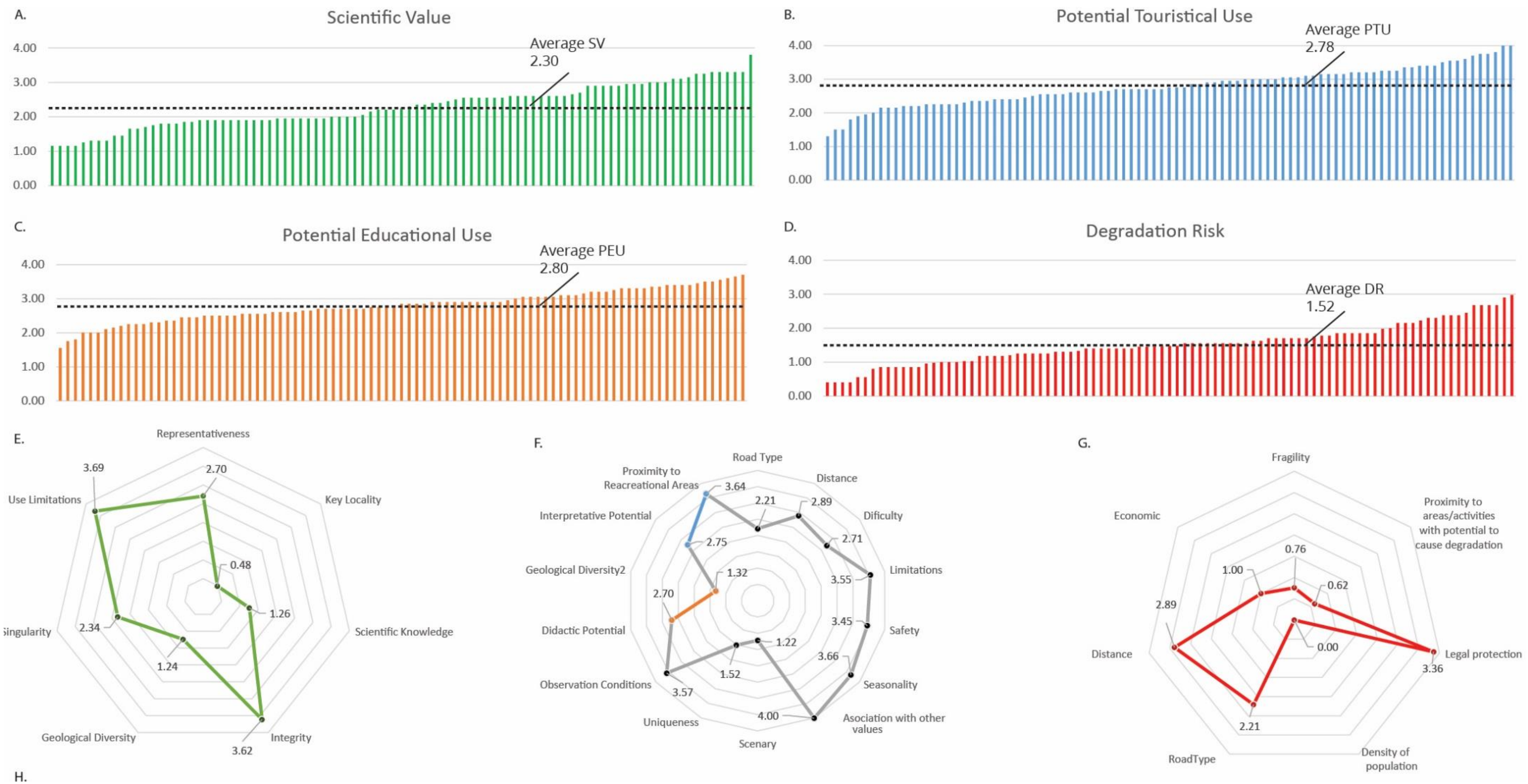
Concerning geotourism, it is enough to have some notions of geological processes to understand the sites, and in almost all cases, it is possible to find recreational areas nearby. Finally, being a territory in the tourism development process, the attractions are not yet consolidated at a national level. However, most of them present characteristics that are at least uncommon in the country but compete with neighbouring regions such as Araucanía, Los Ríos, Aysén and Magallanes.

### *Degradation Risk*

Eight criteria were parameterised (Annex 7.2) and weighted (Table 7) to acquire degradation risk values. From the results, the average value of the degradation risk is 1.56 points out of 4 possible values, a low value, with the lowest value being 0.40 and the highest value being 2.98 points. Of the total number of sites analysed, 74 have low values, and 17 have medium values, with no sites among the high values.

Concerning the analysed criteria, Legal protection obtained high values (3.36), Distance (2.89 points) and Road Type (2.21 points), medium values, Economic interest (1.00 points), Fragility (0.76 points) and Proximity to areas/activities with potential to cause degradation (0.62 points) low values. The criterion Density of the population received a value of 0 points.

Another general analysis indicates that, even without legal protection, just few sites are at high risk of degradation, with an average in the moderate risk and almost half of the sites with low risk scores. This result makes sense since the population in Patagonia Verde is low, and access to sites often requires travel away from population centres and main access roads. If accessibility and infrastructure conditions are improved in the future, it will be necessary to assess the impact this would have on each site.




H.

| Site N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SVT | ✓ | ✓ | ! | ✗ | ✗ | ✗ | ✗ | ✗ | ! | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ! | ✓ | ! | ✓ | ✓ |
| PUT | ✓ | ✓ | ✓ | ✓ | ✓ | ! | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ! | ✓ | ! | ! | ! | ! | ! | ! | ! | ✓ | ! |
| PUE | ✓ | ! | ! | ! | ! | ! | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ! | ! | ✓ | ! | ! | ! | ✓ | ✓ | ! | ✓ | ! |
| DRT | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ! | ✓ | ✗ | ! | ✓ | ✓ | ✓ | ✓ | ! | ✗ | ✓ | ! | ! | ✗ | ✓ |

| Site N° | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SVT | ✓ | ✗ | ✗ | ✓ | ! | ! | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ |
| PUT | ✓ | ✓ | ! | ! | ✓ | ✓ | ✓ | ! | ✓ | ✓ | ✓ | ✓ | ! | ✗ | ! | ! | ! | ! | ! | ✓ | ✓ | ✓ | ✓ |
| PUE | ✓ | ✓ | ! | ✓ | ! | ✓ | ✓ | ! | ✓ | ! | ✓ | ✓ | ! | ! | ! | ! | ✓ | ✓ | ! | ✓ | ✓ | ! | ✓ |
| DRT | ✗ | ! | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ | ✗ | ! | ✓ | ! | ✗ | ! | ! | ! | ! | ! | ! | ✓ |

| Site N° | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SVT | ✗ | ! | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ |
| PUT | ✓ | ✓ | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ! | ! | ✓ | ! | ! | ✓ | ✓ | ! | ✓ | ✓ | ! | ! | ! | ✗ |
| PUET | ✓ | ✓ | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ! | ✓ | ✓ | ✓ | ! | ✓ | ✓ | ! | ✓ | ✓ | ! | ✓ | ! | ! |
| DRT | ! | ✓ | ✓ | ✓ | ✓ | ! | ✓ | ! | ! | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ! | ! | ! | ! | ! | ✓ | ✓ | ✓ |

| Site N° | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | Avrg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SVT | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ! | ✗ | ✗ | ✓ | ✗ | ✗ | **2.3** |
| PUT | ✗ | ✗ | ✓ | ! | ✓ | ! | ! | ✓ | ✓ | ! | ! | ! | ! | ✗ | ✓ | ! | ! | ! | ! | ✗ | ! | ! | **2.8** |
| PUET | ✗ | ✗ | ✓ | ! | ! | ! | ! | ✓ | ✓ | ✓ | ! | ✓ | ✓ | ✗ | ✓ | ! | ! | ! | ! | ✗ | ! | ✓ | **2.8** |
| DRT | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ! | ! | ✓ | ✓ | ✗ | ! | ✓ | ! | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ! | **1.5** |

*Figure 40 The overall quantitative assessment results of the inventoried sites are shown. The bar graphs represent the total values resulting from the weighting of the different criteria. In contrast, the radial graphs represent the average values of the evaluated criteria related to scientific value (E), Use Potential (F) and Degradation Risk (G). Finally, table H qualitatively indicates those sites with scores above the average value ✓; above two, below the average !; below 2 with an ✗.*

# 4 Discussion

## 4.1 Inventory and Assessment

While many people understand the benefits of documenting and conserving Biodiversity as fundamental to humankind's existence, survival, and sustainable development, the principles of geodiversity (Brilha et al., 2018) do not yet seem to get a similar reception in society. However, like biodiversity, geodiversity also has different values (Brilha, 2005) and a fundamental role in maintaining ecosystem functioning and services (Gray et al. 2013, 2019). So, its documentation is also essential to understand these attributes and seek solutions to global environmental challenges and natural resource demands, particularly concerning human well-being moving towards the sustainable management of territories (Schrodt et al., 2019).

The documentation of Geodiversity, understood as the identification, characterisation and assessment of different is a recent and increasingly recurrent topic, with various national experiences (e.g. Benado, 2013; Parterrieu, 2013; López, 2016; Martínez et al. 2017; Vicencio et al. 2017; Schilling et al. 2020; Vergara et al. 2021). Even though most of the studies have different objectives and assessment methods, all develop an inventory as a first step. It makes sense since to know the value of geodiversity in each area and establish priorities for its management is necessary to understand what exists, what it is like, where it is, and what value it has.

To make the search geosites effective and efficient, Wimbledon et al. (2000) point out that all sites should be evaluated in an objectively identified context and not in isolation. Along the same lines, Lima et al. (2010) recommend that the search for geosites should be associated with geological frameworks in large areas.

Countries such as Portugal (Brilha et al., 2005) or Spain (Garcia-Cortez et al., 2005,2001) are examples of large areas which have done their inventories with this methodology

The choice of developing contexts for Patagonia Verde and not classifying them based on the Mourgues et al. (2012) proposal has three main reasons. The first is that the contexts proposed by Morgues et al. (2012) have received constant modifications (e.g. Alfaro and Sepulveda, 2015; Mourges et al., 2016) without receiving a consensus from the scientific community. Secondly, the National Geology and Mining Service is working on a new proposal. Thirdly, sites have been identified in the surrounding Aysén region based on different geological contexts proposed for the region (Quezada et al.2018). Thus, the contexts proposed in this work are based on Aysen's proposal, allowing a point of comparison between both territories.

Pereira (2010) notes that the vast majority of methodological discussions consist of quantifying sites of interest and a few concerning the criteria for selecting places that will form part of the final inventory. Lima et al. (2010) also emphasise this idea and note that although the geoconservation list literature is abundant in examples of geosite inventories, it seems familiar that the criteria used for selecting sites of interest are not adequately explained or are simply absent.

It is considered that inventorying the geodiversity for scientific, tourism, educational and cultural purposes makes sense as they serve as an additional element in land-use planning. Thus, strategic conservation of geodiversity is necessary when it makes sense for a particular community and their well-being. This reasoning implies that there are sites with different scales, interests, dimensions of use, and conservation characteristics.

In this sense, one of this work's particularities is that all the inventoried sites come from the co-creation with the different actors of the Patagonia Verde through workshops and meetings. This characteristic is highly significant since those who have participated in collecting a preparing the information have used academic knowledge not to impose a list of sites based on our ideas. However, we have analysed each of the proposed sites, using scientific knowledge to provide added value to places that were already relevant for the community.

Thus, the proposed selection criteria (Table 2) were not implemented unilaterally but discussed and validated by the territory. Thanks to this, it is possible to be sure that there are no irrelevant elements in this inventory and that there is always at least one group of people who consider it necessary to conserve the site. In this sense, the author strongly believes that to conserve the inventoried areas effectively, the active participation of the target public is necessary not as observers of the process but as co-creators of the inventory.

The decision to conduct a quantitative assessment of geodiversity minimises subjectivity in the selection stages. Also, it is a numerical tool to support that the inventory effectively reflects a set of relevant sites.

For Pereira (2010), the valuation of nature is a highly anthropocentric and functional practice, as it is established from the human perspective on how a human can potentially use natural elements. Furthermore, he adds that it is also subjective, as it depends to a large extent on the criteria adopted by the evaluator and their weightings. Additionally, Gudynas (1999) stresses that measures of nature will always be incomplete, and their use always runs the risk of reductionism. The latter occurs when it is assumed that the measure best represents the whole system, all its components, and the processes that occur there. This idea implies that the measurement would allow access to the essence of what is measured. Therefore, what the author calls an "expanded translocation" is observed. Under this condition, the measurement of an attribute is expanded until it is postulated to represent almost the entire measured object, which is not a fact.

Furthermore, it is necessary to understand the incommensurability of nature resulting from its plurality of values. As Gudynas (1999) states, it is imperative to put an end to the assumption that a measurement can reveal the essence (and diversity) of nature, highlighting that valuations are plural, with multiple elements in consideration, some of which are measurable while others are not. Even in measurement cases, the usable measures vary, and their indicative value can be ambiguous. Moreover, as the measurements are partial, they cannot be transposed to the whole.

In this way, we can establish that quantifying the values of nature is a non-trivial practice that needs to be constantly analysed. Because of this, several methodological exercises for a quantitative valuation have been published (e.g. Brilha, 2005, 2016; Pralong & Reynard, 2005; Carcavilla, 2007; Bruschi and Cendrero, 2009;), but they all have in common the ability to establish points of comparison and priorities in the management of geodiversity.

Bruschi et al. (2011)state that there are two quantitative assessments: direct and indirect or parametric. The first one is generally carried out by a group of experts in charge of the valuation, and their main advantage is that they are convenient and straightforward in obtaining results. The disadvantage is that it is possible to know what was got but often not how or why a result was reached.

The indirect ones are those that establish a series of parameters that are often evaluated separately through scores. These are assigned a value that is then integrated into the site value. On the one hand, the great advantage of this method is that it is more transparent than a direct method, eliminates (not all) subjectivity and allows results to be replicated to a large extent. On the other hand, the disadvantage is that it becomes more complex to evaluate each site and takes a great deal of time.

Based on the abovementioned idea, a parametric method has been chosen, particularly the one proposed by Brilha 2016. This tool has provided a point of comparison between the inventory sites and a fundamental source of information to generate management strategies at a future step.

The results obtained using this method have been fundamental to establishing a point of comparison between each site. Thanks to the data obtained, it is possible to make visible that each site has at least one total value above the mean (Figure 40, H), i.e. all have valuable attributes in some of the areas analysed. Furthermore, this valuable data mathematically support that the inventory process, through co-creation, leads to socially relevant results.

## 4.2 Management categories proposal

Given the results obtained in the quantitative assessment, it is possible to categorise them based on their attributes and determine the type of use (scientific, educational, tourism).

*Table 8 Proposed categories and constraints related to the quantitative assessment.*

| | Category | Constraints |
|---|---|---|
| | **Geosite (G):** Refers to those sites representative of a particular geological context, unique within that context, and in a good state of conservation. In addition, most of them have scientific knowledge of national or international relevance. Given their scientific value, they contribute to understanding the different processes occurring on Earth and are considered the most valuable elements of geodiversity. | $[(SV \geq 2 \wedge Representativite \wedge Rarity \wedge Integrity \wedge Knwoledge \geq 2)] \vee (Representativity \wedge Rarity \wedge Integrity = 4)$ |
| | **Research (I):** Refers to those sites where no robust scientific knowledge and research could generate significant findings for the development of geoscience and enhance the potential for educational and scientific use. There are three levels of priority. | $Scientific\ Knowledge \leq 2 \wedge \text{Representativity} = 4$ * <br> **This number is 2 for Cl.2 and 1 for Cl.3."* |
| | **Science (S):** Refers to sites with low dissemination potential because of their logistical conditions or the complexity of their nature. However, they are national or international references, so it is necessary to ensure their preservation. These sites need a strict protocol for scientific activities requiring physical intervention on the site. The implementation of interpretation support can generate added value in the site's potential use. | $(Scientific\ Knowledge \geq 2) \wedge (\text{PUE} < \text{Average PUE}) \wedge (\text{PUT} < \text{Average PUT})$ |
| | **Geoscience Education (E):** In addition to their didactic potential, these sites meet the conditions of accessibility, safety and logistics for their use for geoscience-related educational activities. The specific interventions the sites require for their proper educational use (signs, panels, railings) should be listed, and the key concepts to be discussed according to the target audience. | $(\text{PUE} \geq \text{Average PUE}) \wedge (\text{Fragility} < 2)$ |
| | **Geotourism (T):** In addition to their interpretative potential, these sites meet the conditions of accessibility, safety and logistics for developing Geotourism activities. Site-specific interventions (signs, panels, railings) should be analysed based on their attributes and target audience. | $(\text{PUT} \geq \text{Average PUT}) \wedge (\text{Fragility} < 2)$ |
| | **Protection (P):** Refers to sites of high scientific value whose scientific studies are of national or international relevance and whose degradation is intrinsically linked to the fragility of the geological elements. Educational or tourism activities should be restricted or regulated with strict protocols to preserve the geological features, and a competent authority should only authorise their use. In some cases, implementing infrastructure is necessary to achieve these objectives. | $(\text{SV} \geq 2) \wedge (\text{Fragility} = 4)$ |
| | **Regulation (R):** Existing or future economic activity is incompatible with scientific, educational and tourism activities, as their operation generates partial or total degradation of the site. It is necessary to reach agreements, norms or laws that can determine whether it is possible for activities to coexist on the same geological resource or to choose the best for the benefit and well-being of the communities in the territory. | $[(\text{SV} \geq 2) \vee (\text{PUE} \geq \text{Average PUE}) \vee (\text{PUT} \geq \text{Average PUT})] \wedge [\text{Proximity to recreational areas} \vee \text{Economic Interest}) = 4]$ |
| | **Secondary (Sc):** Sites whose scientific value is irrelevant and does not meet the essential characteristics to be in categories E or G. However, these sites can be complementary supporting activities, and their use should be analysed based on the objectives of each programme. Improving access and security conditions, together with infrastructure to help interpretation, can enhance the value of this site. | $(\text{SV} < 2) \vee (\text{PUE} < \text{Average PUE}) \vee (\text{PUT} < \text{Average PUT})$ |

In addition, the analysis of their risk of degradation is fundamental to determine, based on the type of use, the level of interaction between users and what measures are necessary for these activities to be sustainable over time. In this way, based on a combination of the type of use and its limitations, it is possible to establish categories (e.g. Vergara et al. 2021, Moura et al. 2021). For this work, eight categories of use have been set (Table 8)

Based on the quantitative assessment results, the proposed categories and their conditions, an analysis has been carried out for all sites in the inventory, as shown in Table 9.

*Table 9 Management categories for Geodiversity Inventory sites.*

| Site N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.I | | ● | | | | | | | | | | | ● | | | | ● | ● | | ● | | ● | ● |
| C.I2 | | | ● | ● | ● | ● | | ● | ● | ● | ● | ● | | | ● | | | | ● | | ● | | |
| C.I3 | | | | | | | ● | | | | | | | ● | | ● | | | | | | | |
| C.S | | | | | | | | | | | | | ● | | | | ● | ● | | | ● | | ● |
| C.E | ● | | | | | | | ● | ● | ● | ● | ● | | | ● | | | | ● | ● | | ● | |
| C.G | ● | ● | ● | ● | ● | | | ● | ● | ● | ● | ● | | ● | | | | | | | | ● | |
| C.R | ● | | | | | | | ● | ● | | ● | | | | | | | | | | | ● | |
| C.P | | | | | | | | | | | | | | | | | | ● | | | | | |
| C.Sc | | | | | | ● | ● | | | | | | | | | ● | | | | | | | |
| Gs | ★ | ★ | | | | | | | | | | | | | | | | | | | | | |

| Site N° | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.I | ● | | | | | | | | | | | | ● | | | ● | | | ● | | | | |
| C.I2 | | ● | | | ● | ● | ● | | ● | ● | | ● | | ● | | | | | | ● | ● | | |
| C.I3 | | | ● | | | | | ● | | | | | | | | | | | | | | ● | |
| C.S | | | | | | | | | | | | | ● | ● | ● | ● | | | ● | | | | |
| C.E | ● | ● | | ● | | ● | ● | | ● | | ● | ● | | | | | ● | ● | | ● | ● | | ● |
| C.G | ● | ● | | | ● | ● | ● | | ● | ● | ● | ● | | | | | | | | ● | ● | ● | ● |
| C.R | ● | | | | | | ● | | | ● | ● | ● | | | | ● | | | | | | | |
| C.P | | | | | | | | | | | | | | | ● | | | | | | | | |
| C.Sc | | | ● | | | | | ● | | | | | | | | | | | | | | | |
| Gs | | | | ★ | | | | | | | ★ | ★ | | ★ | ★ | ★ | ★ | ★ | | | | | ★ |

| Site N° | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.I | | | | | | ● | | | | | ● | | | ● | ● | | | | | | | | |
| C.I2 | | | | | | | | | | | | | | | | ● | | | ● | | | ● | ● |
| C.I3 | | | ● | | | | | | | | | | | | | | | | | | | | |
| C.S | | | | | | | | | | ● | | | | ● | | | ● | | | ● | | | |
| C.E | ● | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | ● | | ● | ● | | ● | ● | | | | |
| C.G | ● | ● | | ● | ● | ● | ● | ● | ● | | | ● | | | ● | ● | | ● | ● | | | | |
| C.R | | | | | | | | | | | | | | | ● | | | | | | | | |
| C.P | | | | | | | | | | | | | | | | | | | | | | | |
| C.Sc | | | ● | | | | | | | | | | | | | | | | | | | ● | ● |
| Gs | | ★ | | ★ | ★ | | ★ | | | ★ | | ★ | ★ | | | | ★ | ★ | | ★ | ★ | | |

| Site N° | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.I | ● | | | | | | ● | | ● | | | | | | ● | ● | | | | | | | 20 |
| C.I2 | | | ● | ● | ● | ● | | | | ● | | | | | | | ● | | ● | ● | ● | ● | 36 |
| C.I3 | | | | | | | | ● | | | ● | ● | | | | | | ● | | | | | 11 |
| C.S | ● | ● | | | | ● | ● | | | | | | | ● | | ● | ● | | | ● | | | 22 |
| C.E | | | ● | | | | | ● | ● | ● | | ● | | | ● | | | | | | | ● | 45 |
| C.G | | | ● | | ● | | | ● | ● | | | | | | ● | | | | | | | | 43 |
| C.R | | | ● | | | | | | | | | ● | | | | | ● | ● | | | | | 16 |
| C.P | | | | | | | | | | | | | | | | | | | | | | | 2 |
| C.Sc | | | | ● | | | | | | | ● | | | | | | | ● | ● | | ● | | 13 |
| Gs | | ★ | | | | | | | | | | | ★ | ★ | | | | | | ★ | | | 30 |

Of the results obtained, 67 sites correspond to Category I (Research), 22 to Category S (Science), 45 to Category E (Education), 43 to Category G (Geotourism), 16 to Category R (Regulation), 2 to Category P (Protection) and 13 to Category Sc (Secondary).

In addition, 30 sites have been classified as Geosites within Category Gs. Also, six sites have been added to this list without fulfilling the criteria. These are the sites Arcoíris Mountain, Futaleufú River Canyon, Santa Barbara Metamorphic Rocks, Calto Rock or Nihuel Islet and Huinay Holocene Marine Deposits. The first five have been chosen as the only or best representative of the geological contexts. In contrast, the Huinay Marine Deposits have been added as geosites due to their recognition by the Chilean Geological Society.

## *Geosites*

The sites belonging to category Gs, Geosites, are the best representative of each context and have been chosen to be proposed as a Geosite of National Significance.

These sites have been briefly characterised, identifying the context to which they belong, their outstanding features, their type of interest, the ecosystem services they provide and the SDGs they can achieve if properly conserved and managed. In addition, indications for their management and the key bodies to carry it out are proposed (Annex 7.3).

Sites in this category are a priority, and all measures should be taken to ensure that they can be used by communities on a case-by-case basis, assessing the different conditions of fragility and vulnerability of the site.

**METATONALITE OF CHAITÉN | CHAITÉN | X LOS LAGOS DISTRICT** | **WGS84 EPSG:3857** | **X: -8081939** | **Y: -5273704**

**METATONALITE OF CHAITÉN : The oldest magmatic in Patagonia Verde**

| S | T | E | DR |
|---|---|---|---|
| 3.8 | 3.3 | 2.9 | 1.40 |

It is an intrusive body formed by magmatic rocks, aged about 400 Ma, from the Devonian period (Duhart et al., 2009, Herve et al., 2016). being one of the oldest records found in the territory. Its origin possibly represents part of an ancient volcanic island chain that later collided, amalgamated with the mainland, and was named Chaitenia (Herve et al., 2016). Its attributes, such as location and access, make it easy to study, and it is not only of great scientific importance but also of great educational value.

*Outcrop on the side of Route 7. Photograph with the pupils of the Almirante Juan J. Latorre basic school.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | CHA | Deformed tonal intrusive | Metamorphism, Magmatism, Tectonics, Stratigraphy | • Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12 |
| Secondary | TEC | | | | |

| | |
|---|---|
| **Management proposal** | As it is on the side of the road, its safety conditions could be improved in order to establish both a safe path from the car park (Camping Lago Blanco) and a stop at the site. Complementary information, such as an interpretation panel explaining Chaitenia could be helpful to support educational activities and take advantage of the geotourism potential of the outcrop. |
| **Key conservation partners** | J.J La Torre school, Municipality of Chaitén, Patagonia Verde Guides Association. |

*Figure 41 Example of the characterisation of the different geosites presented in Annex 7.3.*

## *Research*

The Research category is linked to the scientific development of the territory and seeks to promote investigation among the selected sites.

Of the 67 sites that form part of the category "I", Research, three subcategories related to the level of knowledge of these sites have been determined (Table 8). In this sense, those sites in category "I" are considered the most representative of each context. Further research could be fundamental to advance the knowledge of these sites, which in turn leads to a better understanding and eventually greater didactic and interpretative potential.

Secondly, the sites in category “I.2” are sites that have not been studied either. Nevertheless, their representativeness is less than in the previous class. Even so, they are good examples of each of the geological contexts defined.

Finally, those sites that are not so representative and, therefore, the last priority for research are part of the category “I.3”.

It is hoped that research work, mainly linked to universities at different levels of specialisation, can be promoted around the sites in this category.

### *Sciences*

Without necessarily being geosites, the sites in this category are valuable to the scientific community as they have been part of studies of national and international relevance. However, their potential for use is limited by physical conditions or the risk of degradation posed by carrying out activities there.

Thus, it is suggested that all sites belonging to this category can be managed in two different ways.

1. For those sites that also belong to category P, it is recommended that they should not be promoted for use, with exceptions to be assessed on a case-by-case basis by competent authorities. It is also possible that an investment in infrastructure may eventually change this situation. For decision-making, expert advice is necessary not to damage their scientific values.
2. For the rest of the sites, it is recommended to evaluate case by case and implement all necessary measures (e.g. infrastructure, access improvement, infographics) so that the potential use of these sites allows at least educational activities. Such implementation must be carried out with expert advice in order not to damage the scientific values of the site.

### *Education*

The sites in this category present an educational potential above the average of the territory and meet the condition that, if they exist, their risk of degradation is not related to the educational activities that may be carried out in these places. As such, these sites are a priority for generating educational programmes that include them.

### *Geotourism*

The sites in this category have a potential for tourism use above the average for the territory and meet the condition that, if they exist, their risk of degradation is not related to the tourism activities that may be carried out in these places.

Thus, these sites are a priority in generating geotourism programmes that include them. It is recommended that sites belonging to category G are the first to be implemented as their added value can help both attributes.

### *Regulation*

Sites in this category are located in an environment where a specific activity affects the site and its use potential. There needs to be a comparative evaluation on which type of activity (e.g. industry, geotourism, education) generates the most significant benefits to the surrounding communities or generates agreements for the coexistence of both interests.

It is hoped that competent actors will be able to generate agreements and decision-making around the activities carried out on these sites.

### *Protection*

Those sites that have been identified in this category have fragile geological elements, and both the taking of samples for scientific activities and the development of educational or tourist activities can generate the partial or total destruction of the features that give the site its value.

The future potential use of these sites will be determined by the ability to safeguard the elements that give them value. Examples of such measures include being subject to strict local control, with registration, fines and mandatory guided visits with trained guides, and zoning of the sites.

### *Secondary elements*

The sites in this category have low scientific values. However, their potentials for educational and tourist use, although below average, have medium values (between 2 and 3). Thus, it is expected that these sites can support educational and tourism activities.

Without being a priority, proper management and investment to improve their conditions (e.g. access, security conditions, logistics) can substantially enhance their potential for use.

## 4.3 Management structure proposal

Among the alternatives for managing geodiversity in Patagonia Verde, this paper proposes the creation of a Geopark.

Geoparks operate with different governance and management models and therefore do not have a structure determined a priori; what works for one territory may not work for another. In this case, Patagonia Verde must create its system based on the reality of its associative possibilities.

Currently, the principal promoters of the development of a Geopark in Patagonia Verde are the tourist guides of the territory through their Association of Guides of Patagonia Verde. Within their association, a working group has been created called the Patagonia Verde Geopark Commission, in which the author of this paper participates as an advisor.

For the model to be successful, it is necessary to have a structure capable of executing an action plan with well-defined activities, goals and objectives. In this sense, it is required to have a body with a budget and people dedicated to coordinating and executing these activities, and the existing commission should promote this process.

This thesis intends to propose a management model, not to deliberate unilaterally on its implementation. The above is because it goes against the spirit of a geopark (bottom-up approach), and a multi-stakeholder vision is needed. However, it is possible to propose at least some ideas that the author believes are necessary for the project to be successful.

In this sense, it is proposed that Patagonia Verde Geopark should be formalised as an association and consider the following management and decision-making bodies: The Geopark Association, the Geopark scientific-educational committee, the Local Board, and key partners (Figure 42) Patagonia Verde management structure

### A. Patagonia Verde Geopark Asociation

It is proposed that, for decisions to be binding, the Geopark should be directly related to the administration of the territory. In this sense, the Regional Government and a future Association of Municipalities of Patagonia Verde should be the leading managers of a future Geopark, as it also has financial backing. There are successful examples where Geoparks are constituted solely by the Association of Municipalities (e.g. UGGp Kutralkura), and decisions are deliberated among the different municipalities. Nevertheless, there are also successful public-private models that this proposal rescues (e.g. UGGp Arouca, Villuercas-Ibores-Jara) where in addition to this administrative body, there are other public and private entities that have the right to voice and vote within the management.

In this sense, exploring these possibilities with some key institutions and associations that have participated in the "Geotourism Patagonia Verde" project is suggested. Sernageomin, the Austral University of Chile, the Association of Patagonian Guides, SERNATUR, Procultura and CONAF, among other entities that could be interested in participating and financing the Geopark, are good candidates.

The idea of creating a partnership is that each party can allocate part of its budget and human resources to develop Geopark's action plan. For instance, the association of municipalities can make available resources and a fraction of the workload of some of its professionals (e.g. tourism, environment, education, culture) for managing and coordinating activities in the different municipalities. In the same way, other entities, such as SERNATUR, can derive part of their budget from the association for promoting the territory and generating training for tourist guides. CONAF, for its part, could align itself with the conservation objectives of the Geopark and support with a fraction of its budget and human resources the development of activities within the Natural Parks.

It is recommended that this association have a professional team composed of at least two people in the first stage, which would allow the coordination of the territory (territorial coordinator) and the technical bodies (scientific-educational coordinator).

This association should implement the different activities of the plan and generate at least one board meeting per semester.

### B. Local Board

The objective of the Local Board or Territorial Commission is to ensure that the Geopark is managed as closely as possible to the real needs of the territory. In this sense, this committee, without necessarily being a legal entity, will be made up of representatives and entities located within the Geopark territory. Among its primary functions, it will have to contribute to the action plans by proposing activities for the Geopark and monitoring their implementation.

### C. Scientific and Educational Committee

The Scientific-Educational Committee comprises representatives from universities, research centres and individual researchers and works directly with Geopark's scientific-educational coordinator. It is an advisory body whose function is directly related to promoting scientific research, providing technical opinions regarding the conservation of the sites and the environment, collaborating with the development of educational programmes, and supporting scientific-educational dissemination, among others. It is composed of representatives from universities, research centres and researchers and works in close collaboration with the scientific-educational coordinator of the Geopark.

### D. Key Partners

These are all those entities (e.g. institutions, companies, organisations, enterprises, museums, among others) whose actions align with Patagonia Verde Geopark's vision. Their relationship is formalised through agreements, and their contributions are directly related to the action plan's promotion, development and execution.

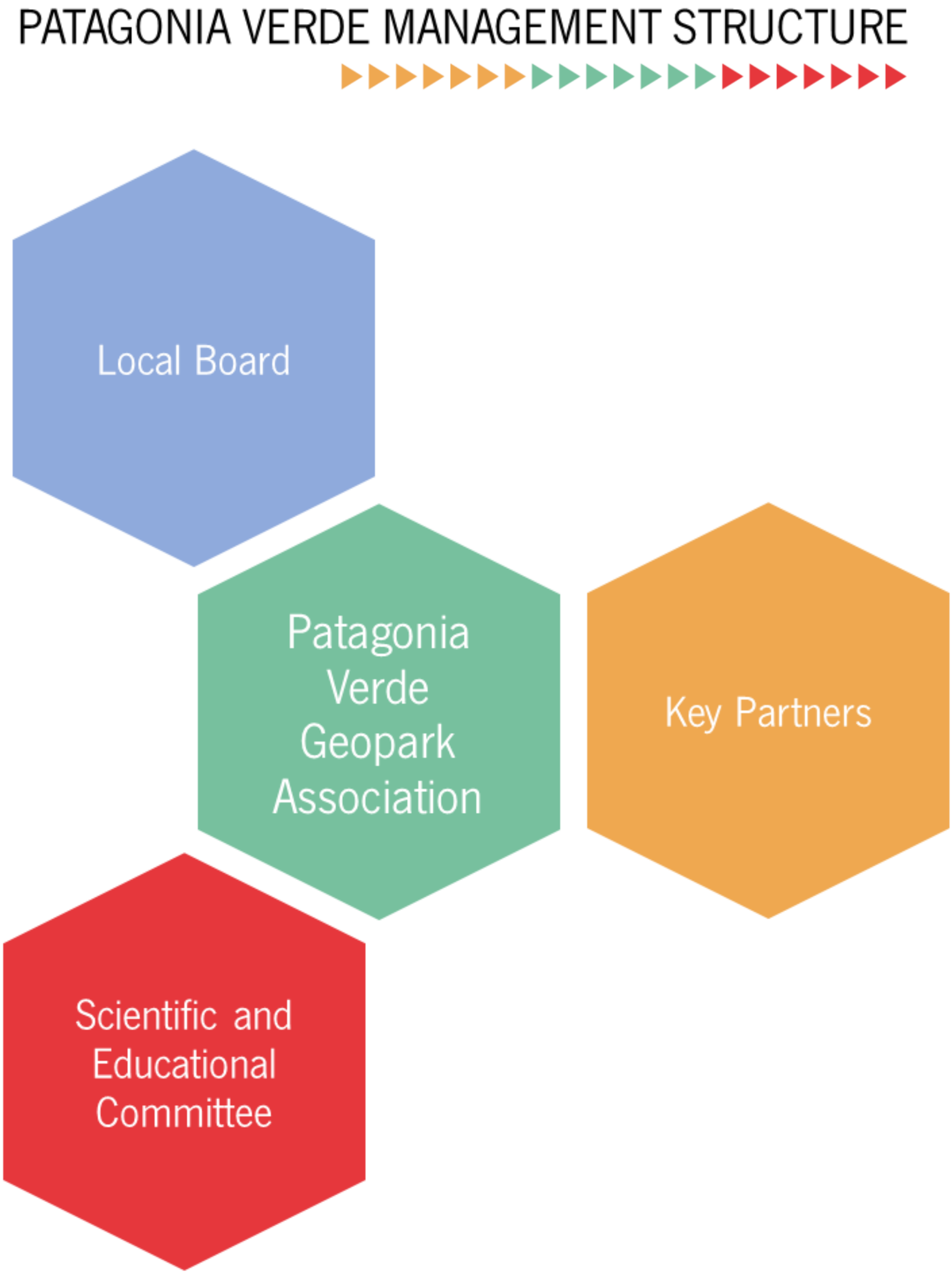



*Figure 42 Generalised management structure of Patagonia Verde Geopark*

## 4.4 Local Geoconservation Action Plans (LGAPs) proposal

### A. Introduction

For Croft et al. (2020), Geoconservation is the practice of conserving, enhancing and promoting awareness of geodiversity and geoheritage, and it is primarily concerned with conserving features and elements with exceptional value. Also, these authors stress that the actions to protect geodiversity can contribute to maintaining biodiversity and functioning healthy ecosystems.

It is essential to note that Geoconservation depends on actions. Burek and Prosser (2008) describe geoconservation as all actions taken to conserve and enhance geological and geomorphological features, processes, sites and specimens for the future. In other words, it is taking an active role in safeguarding geodiversity. In this sense, the next step, after generating an inventory, assessing its attributes and classifying them into different management categories, is establishing an action plan for geoconservation.

Burek and Potter (2004) define a Local Geodiversity Action Plan (LGAP) as an integrated, goal-oriented action plan to safeguard the geodiversity of an often county-sized area. Its strength is that it can break down large, complex projects into achievable segments and focus on the actions that matter, allowing problems to be tackled without duplication of effort. Thus, the plan is broken down into a large-scale goal, a measurable objective, a time target and a specific action to achieve the objective. In this sense, the next step, after generating an inventory, assessing its attributes and classifying them into different management categories, is establishing an action plan for geo-conservation. In the same spirit, Dunlop et al. (2018) propose six steps for a successful GAP process which are: Boundary; Partnership; Aims, Objectives; Consultation; Funding and Measuring achievement, so the LGAP cut across interests by setting clear objectives that lead to diverse activities that are often considered separately, establishing agreed actions for geodiversity and associated geoconservation.

### B. Patagonia Verde Geodiversity Action Plans (PVGAP)

Based on diagnostics carried out in this work and the Hualaihué declaration (Annex 7.4), a proposal for an integrated geodiversity management strategy called Patagonia Verde Geodiversity Action Plan (PVGAP) is presented. This proposal is intended as a starting point for developing a final proposal generated by the future Geopark association.

For this purpose, the following stages have been followed based on the proposal of Dunlop et al. 2018

| Patagonia Verde Geodiversity Action Plan | |
|---|---|
| **Steps** | **Description** |
| 1. Boundary | The PVGAP will be established within the boundaries of the province of Palena and the commune of Cochamó. Within these boundaries are included nature parks, nature reserves and other initiatives. The PVGAP will seek to align with the different plans of the territory and establish common development objectives. |
| 2. Aims | Establish a framework for understanding, conserving and utilising the unique wealth of geodiversity resources found in the territory of Patagonia Verde in a way that provides social, economic and environmental benefits to local communities and visitors |
| 3. Consultation and co-creation | Generate instances of broad consultation to obtain different local views, priorities and aspirations concerning geodiversity management and, in this way, modify and validate the PVGAP. |
| 4. Partnership | Generate agreements/arrangements between different organisations, groups and individuals who have an interest or potential interest in the sustainable development of Patagonia Verde to participate in the implementation of the plan. |
| 5. Funding | Identify those activities in the PVGAP that need funding from those that can be achieved through working with partners. For those in need of financial support, seek funding mechanisms based on the priorities in the PVGAP. |
| 6 . Measuring achievement | Establish the monitoring of the plan's progress on an annual basis, establishing the degree of progress (percentage) of each action, reassessing priorities and publishing an update of the plan based on the data obtained. |

Based on the steps described above, a 4-year action plan is proposed, the target objectives and actions of which follow:

| Patagonia Verde Geodiversity Action Plan 2023-2026 | | | |
|---|---|---|---|
| **Aim** | | | |
| Establish a framework for understanding, conserving and utilising the unique wealth of geodiversity resources in the Patagonia Verde territory to provide social, economic, and environmental benefits to local communities and visitors under the Geopark status. | | | |
| **Priorities** | | | |
| Completed | High (2023) | Medium (2023- 2025) | Low (2023-2026) |

| 1. Management and conservation | | |
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| **Objectives** | **Target** | **Action** |
| To establish a model of integrated nature management that allows the establishment of shared objectives for the conservation of geodiversity, linking the different actors of the territory in both the creation and application of agreements, regulations and actions. | A management structure to carry out the different actions of this plan is in place. | Review the existing proposal generated in this work and develop a final proposal validated among the actors involved. |
| | | Generate legal agreements between the parties and implement the management structure. |
| | | Generate the necessary participatory conditions to discuss the action plan, validate it and set it in motion. |
| | Review existing regulations and any shortcomings that may exist in the face of adverse effects of development have been reviewed, assessed, and addressed. | Review of existing regulations and generation of a report that identifies any deficits that may exist. |
| | | To develop regulations to provide legal support to the inventory. |

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| | | Approve and incorporate different standards created into existing regional and national regulations. |
| | Inter-institutional and inter-sectoral coordination on geodiversity management and conservation exists in the territory. | Coordinate and generate alliances between the different territorial initiatives directly or indirectly involved in Geodiversity matters. |
| | | Create a database of projects in Patagonia Verde that will allow for greater fluidity in coordinating the different initiatives that are directly or indirectly related to the geodiversity of the territory. |
| | Citizen participation in decision-making has been integrated into the territory. | Establish a mechanism that allows the territory's inhabitants to mandate and validate, through the local council, different actions related directly and indirectly to geodiversity. |

| **2. Geodiversity Audit** | | |
|---|---|---|
| **Objectives** | **Target** | **Action** |
| To promote research to improve our understanding of Geodiversity in Patagonia Verde – | It has been finalized an inventory of Patagonia Verde's geodiversity | Complete desk, field, and validation work with critical stakeholders in the territory to establish an initial selection of sites. |
| | | Launch and disseminate the report on the initial geodiversity audit of Patagonia Verde. |
| | | Establish a plan for monitoring and updating the inventory. |
| | It has been finished the assessment of the Patagonia Verde Geodiversity Inventory. | To generate categories establishing those sites that are accessible and suitable for local communities, visitors, researchers, students or tourists. |
| | | Establish categories for inventory management |
| | | Keep the valuation updated as the inventory changes. |
| | It has ended an audit of geodiversity archives and resources, including government institutions, national and borough collections in museums, libraries, record centres, galleries and educational institutions; relevant bibliography; ongoing projects; and a network of people with critical skills | Liaise with selected departments and organisations to establish the municipality's national and local geodiversity archives and resources. It should include historical and geological publications, photographic images, paintings and artefacts, specimens, a bibliography, ongoing projects and their available use, and people with critical skills. |
| | | Establish and maintain the register created. |
| | It has finished the research on priority sites | Identify priority sites for research |
| | | Promote research at national and international universities on priority sites. |
| | | Use the information to update the inventory |
| | | Disseminate the results obtained |

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| | Research exploring the evidence on Geodiversity concerning climate change, mainly the Patagonian uplift, has been completed. | Invite researchers from national and international universities to work based on the different sites that demonstrate an upwelling in Patagonia. |
| | | Generate dissemination of the results obtained |
| | It has been finalized research that explores the links between geodiversity and Ecosystem Services | Promote research in national and international universities to identify the ecosystem services of the inventory sites. |
| | The sites are sufficiently implemented to be visited and understood by students and visitors alike. | Identify sites in need of investment |
| | | Develop graphics and infrastructure to implement on the sites. |
| | | Invest in interpretive panels, infographics, and research for mobile application development. |
| | | Implementation of the sites |

| **3. Education -** | | |
|---|---|---|
| **Objectives** | **Target** | **Action** |
| To provide knowledge related to geodiversity to the communities of Patagonia Verde to raise awareness of the values of the territory and its potential for sustainable use. - | Its been established a network of territorial schools. | Coordinate and generate alliances between the educational projects of the different schools in the territory by creating a joint working group. |
| | | Review the different contents established in the national curriculum and, based on them, develop permanent visits to the sites of the territory at the different levels of education. |
| | | Coordinate with the guides of Patagonia Verde the different field trips by the schools to promote geotourism in the low season. |
| | Its been established higher education programmes | Analyse, together with the Universities, the inventory sites for educational routes that allow students to take different courses in different areas of knowledge, particularly those linked to the Earth sciences. |
| | | Set up pilot schemes and generate an evaluation of the results obtained. |
| | | Coordinate with the guides of Patagonia Verde the different field trips by the schools to promote geotourism in the low season. |
| | An inter-institutional management body in education has been established. | Link schools, universities and public services to develop geodiversity-related activities (e.g. fairs, workshops, exhibitions). |
| | | Establish a 5-year work plan |
| | Visitor and interpretation centre built | Evaluate the possibility of using existing spaces (e.g., Chaitén site museum) or generate a new space proposal. |
| | | To generate a script and a museum proposal. |
| | | Set up the interpretation centre and generate activities for its dissemination. |

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| | School materials are developed, and the inclusion of geodiversity in the national curriculum is promoted. | To elaborate on school material explaining the main processes (e.g. volcanism, glaciations, earthquakes), threats (e.g. pollution, global warming), risks for society (e.g. eruptions, earthquakes, tsunamis) and benefits (e.g. thermalism, energy, tourism, culture). |
| | | To create a proposal is to insert Geodiversity and the created educational material into the regional curriculum. |
| | | Promote the insertion of Geodiversity in the national curriculum with the school network. |

| **4. Geotourism** | | |
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| **Objectives** | **Target** | **Action** |
| To promote Patagonia Verde as a tourist destination through sustainable activities that seek an understanding of geodiversity and its values. | Geotourism programmes were established and linked to other sites of natural and cultural significance. | Create geotourism routes that tour operators can use. |
| | | Generate a support guide on the routes and the different sites visited. |
| | | Establish a link between geotourism sites and other natural and cultural elements of the territory through integrated tourism programmes. |
| | | Strengthen the local economy by diversifying and promoting those activities and products that enhance the territory's identity. |
| | There is an Association of territorial guides | Generate meetings that promote the creation of associativity among the guides of the territory. |
| | | Generate an association of guides of Patagonia Verde. |
| | | Establish regular meetings to detect problems and propose solutions that can be presented to the Geopark administration. |
| | The tourist offices work coordinatedly, providing information at the territorial level. | Generate meetings, outings and field visits that promote the creation of associativity among the municipalities and, particularly, their tourism offices. |
| | | Coordinate the networking of the different tourism offices through the Association of Municipalities of Patagonia Verde. |
| | | Unify discourses and provide territorial information to promote visits to the whole Patagonia Verde territory. |
| | | Update the infographic material in the different tourist offices and generate spaces dedicated to the Geopark dissemination. |
| | Geotourism programmes are in place in the low season | Generate a territorial database with events, seminars, congresses, field trips or any other activity that takes place in the territory and |

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| | | encourage hiring local services (e.g. guides, restaurants, accommodation.). |
| | | Coordinate with schools and universities the organisation of different field trips, events and other activities to promote geotourism in the low season. |
| | Geotourism guides are trained and certified. | Generate a permanent training programme for geotourism guides and look for methods to generate the certification. |
| | | Promote and support the development of different training courses for the guides of the territory (e.g. WFA course, Sernatur certification.). |

| 5. Promotion, Communication and networking | | |
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| **Objetives** | **Target** | **Action** |
| To generate the necessary means to inform, disseminate and increase local actors' involvement in the plan's different participatory bodies, the collaborative work with the different partners and encourage networking. | Patagonia Verde Geopark has a communication strategy | Generate a communication strategy with defined objectives, target audience segmentation, design of the different actions and selection of online and offline channels. |
| | | Analysis: once the strategy is implemented, it is necessary to analyse its performance through metrics. |
| | | Constant optimisation of the strategy: |
| | Patagonia Verde Geopark has a graphic identity | Create a graphic identity that relates to the territory's most relevant natural and cultural aspects. |
| | | Validate the graphic identity |
| | | Disseminate the results and incorporate this graphic identity in all products (e.g. reports, infrastructure, products) related to the Geopark. |
| | Patagonia Verde Geopark has a guide | Generate an updated version of the Geotourist Guide of the territory, and give it the name of the Geopark. |
| | | Promote, disseminate and market the geotourism guide in tourist offices and national and international events. |
| | Patagonia Verde Geopark participates, communicates and collaborates with the Chilean Geoparks committees, the Latin American Network and the Global Geoparks Network. | Generate events, seminars, and congresses that promote the dissemination of the Geopark and networking. |
| | | Collaborate with the Geological Society of Chile and the National Geology and Mining Service in developing initiatives related to Geodiversity (e.g. International Geodiversity Day). |
| | | Work towards the candidature of the Geopark to the UNESCO world network. |

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| | | To join the network of the National Geoparks Network (GeaChile), the Latin American Geoparks Network (Geolac) and the Global Geoparks Network (GGN). |
| | | Coordinate visits between different Geoparks nationwide. |

| 6 Resources | | |
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| **Objectives** | **Target (What we want to achieve)** | **Action work needed to achieve a target** |
| To Establish a clear and realistic understanding of the resource needs (money and people) so that project activities can be carried out successfully. | To generate a budget plan to develop the different activities of the PVGAP. | Review all project activities and generate a budget assessment. |
| | | Analyse those activities that may be feasible based on agreements and non-monetary contributions. |
| | | Generate a budget plan |
| | | Seek different funding mechanisms and secure funding. |

| 7. Programme evaluation and monitoring | | |
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| **Objectives** | **Target (What we want to achieve)** | **Action work needed to achieve a target** |
| Evaluate the degree of compliance with the action plan | Completing the action plan | Create an objective system of the degree of compliance with each of the plan's activities. |
| | | Promote compliance with the plan based on the defined priorities. |
| | | Evaluate the degree of compliance with the activities annually and revise/redefine the priorities of the activities. |
| | | Prepare, launch and disseminate a report |

## 5 Final Remarks

Patagonia Verde has outstanding natural diversity. On the one hand, the temperate rainforests of the Austral Andes are internationally recognised as a refuge for the biodiversity of the planet. On the other hand, its configuration is characterised by one of the most salient tectonic faults at national and regional levels, together with a diversity of geological elements, such as fjords, volcanoes, hot springs, glaciers, mountains, valleys and beaches, among others. These geological characteristics have a value that needs to be also recognized and conserved. This work aims to help this recognition be acquired under the figure of a UNESCO Geopark.

To this end, 91 sites have been inventoried and quantitatively evaluated to identify their attributes and use potential. For the sustainable use of those sites, different management categories, a management structure and a 4-year plan has been proposed. Implementing these proposals could help to consolidate the Patagonia Verde Geopark project and bring many other positive externalities.

Currently, the Association of Patagonian Guides is the leading promoter of the Geopark. Today it is the first association in Patagonia Verde that unifies the five communes and therefore has a territorial vision and work.

Since 2017, the Patagonia Geotourism project and now the Patagonia Verde Geopark project has generated and transferred scientific knowledge to the local communities, especially to their tour operators, but have also contributed to sharing knowledge with the local school community. In addition, the Geopark project has worked constantly with public institutions and the inhabitants to reach agreements that allow this project to be carried out. The challenges to consolidating the Geopark depend on the political and economic will necessary to implement a permanent programme in the territory.

It is a desire that this thesis project will contribute generously to elaborating geoconservation policies and serve as a technical basis for their implementation. Also, it is expected that adequate management, monitoring and promotion of the destination and its sites will improve the visitor experience and generate an alternative to the extractivist development that most of the regions of our country have acquired. In this sense, the inhabitants of areas rich in natural resources must be able to make fully informed decisions about their future. To this end, knowledge and instances of participation in governance are fundamental.

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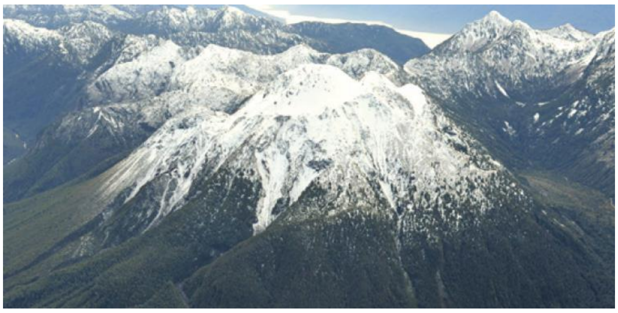
# 7 Annexes

## 7.1 Volcanoes of the territory

| Photography | Description |
|---|---|
|  | The Yate stratovolcano has an altitude of 2,150 m.a.s.l. It is mainly formed by lavas corresponding to basalts, andesites and dacites according to their chemical composition. It has a significant ice cover on its summit and some of its flanks so that it can generate lahars during eventual eruptions, one of the most common dangers associated with volcanoes in southern Chile. |
|  | The Apagado volcano corresponds to a slag cone that would have formed between 2 and 3 thousand years ago due to Strombolian eruptions associated with lava emission, reaching a height of 1,210 m.a.s.l. This slag cone is associated with the last eruptive stage of a larger and older volcano, the Hualaihué volcano. From this background and the fact that a volcano is considered active if it has had eruptive activity during the last ten thousand years, it is far from extinct, as its name suggests. |
|  | The Hornopirén volcano is a stratovolcano with a height of 1,572 m a.s.l. and is composed mainly of lava of basaltic composition. It is located southwest of the Yate volcano in the Hornopirén National Park. |
|  | The Huequi volcano is located in the centre of the Huequi peninsula and is very difficult to access by land. It has a height of 1,318 m a.s.l. and is composed of a group of domes and associated pyroclastic deposits. The products identified are characterised by compositions ranging from andesites to dacites. There are reports of small eruptions in the 1890s and 1920s. Whether this activity was related to the extrusion of magma in the form of domes is unknown. |
|  | Michinmahuida volcano is a voluminous active stratovolcano, 2,405 m high, located 20 km east of Chaitén volcano in the Douglas Tompkins Pumalín National Park. A large caldera-like structure can be recognised at the top of the volcanic apparatus, inside which the central cone has been built. It has some small pyroclastic cones on its flanks, some with associated lava flows. It has a persistent ice cover, with glacier tongues running down all sides, which could generate large lahars during future eruptions. |

The Chaitén volcano has a height of 1,120 m a.s.l. and is composed of a set of domes inside a 3 km diameter caldera, apparently formed by the collapse of an ancient volcano. Its last eruptive cycle occurred between 2008 and 2009. It was associated with the formation of eruptive columns up to 20 km high, being one of the most explosive eruptions recorded in Chile in the last century.

The Corcovado volcano is a 2,300 m high stratovolcano that stands out for its particular sharp shape, deep valleys produced by intense glacial erosion, and a series of lakes on its eastern flank. It is located inside the Corcovado National Park, and no evidence of historical eruptive activity exists. Studies of fall deposits near the volcano indicate that it had medium-sized explosive eruptions between 7,000 and 8,000 years ago.

Yanteles is a 2,050 m high volcanic complex with a relatively large volume covered by glaciers. There is a record of at least one more significant eruption associated with this volcano about 9,000 years ago.

## 7.2 Quantitative assessment criteria and parameters

| Scientific value (SV) | |
|---|---|
| Criteria / Indicators | Parameters |
| **A. Representativeness** | |
| The geosite is the best example in the study area to illustrate elements or processes related to the geological framework under consideration (when applicable) | 4 points |
| The geosite is a good example in the study area to illustrate elements or processes related to the geological framework under consideration (when applicable) | 2 points |
| The geosite reasonably illustrates elements or processes in the study area related to the geological framework under consideration (when applicable) | 1 point |
| **B. Key locality** | |
| The geosite is recognised as a GSSP or ASSP by the IUGS or is an IMA reference site | 4 points |
| The geosite is used by international science, directly related to the geological framework under consideration (when applicable) | 2 points |
| The geosite is used by national science, directly related to the geological framework under consideration (when applicable) | 1 point |
| **C. Scientific knowledge** | |
| There are papers in international scientific journals about this geosite directly related to the geological framework under consideration (when applicable) | 4 points |
| There are papers in national scientific publications about this geosite directly related to the geological framework under consideration (when applicable) | 2 points |
| There are abstracts presented in international scientific events about this geosite, directly related to the geological framework under consideration (when applicable) | 1 point |
| **D. Integrity** | |
| The main geological elements (related to the geological framework under consideration, when applicable) are very well preserved | 4 points |
| Geosite is not so well preserved, but the main geological elements (related to the geological framework under consideration, when applicable) are still preserved | 2 points |
| Geosite with preservation problems and with the main geological elements (related to the geological framework under consideration, when applicable) quite altered or modified | 1 point |
| **E. Geological diversity** | |
| Geosite with more than three types of distinct geological features with scientific relevance | 4 points |
| Geosite with three types of distinct geological features with scientific relevance | 2 points |
| Geosite with two types of distinct geological features with scientific relevance | 1 point |
| **F. Rarity** | |
| The geosite is the only occurrence of this type in the study area (representing the geological framework under consideration, when applicable) | 4 points |
| In the study area, there are two to three examples of similar geosites (representing the geological framework under consideration, when applicable) | 2 points |
| In the study area, there are four to five examples of similar geosites (representing the geological framework under consideration, when applicable) | 1 point |
| **G. Use limitations** | |
| The geosite has no limitations (e.g. legal permissions, physical barriers) for sampling or fieldwork | 4 points |
| It is possible to collect samples and do fieldwork after overcoming the limitations | 2 points |
| Sampling and fieldwork are very hard to be accomplished due to limitations to overcome (e.g. legal permissions, physical barriers) | 1 point |

| Degradation Risk | |
|---|---|
| Criteria / Indicators | Parameters |
| **A. Fragility** | |
| When used in geotourist or educational activities, there is the possibility of deterioration of all elements given the intrinsic characteristics of the site (e.g. size, hardness, quantity). | 4 points |
| When used in geotourist or educational activities, there is the possibility of deterioration of main elements given the intrinsic characteristics of the site (e.g. size, hardness, quantity). | 2 points |
| When used in geotourist or educational activities, secondary elements may deteriorate due to the intrinsic characteristics of the site (e.g. size, hardness, quantity). | 1 point |
| When used in geotourist or educational activities, the elements of the sites present no possible deterioration given the intrinsic characteristics of the site (e.g. size, hardness, quantity). | 0 point |
| **B. Proximity to areas/activities with the potential to cause degradation** | |
| Site located less than 50 m from a potential degrading area (such as Industry, unsustainable tourism, extraction areas) | 4 points |
| Site located less than 200 m from a potential degrading area (such as Industry, unsustainable tourism, extraction areas) | 2 points |
| Site located less than 500 m from a potential degrading area (such as Industry, unsustainable tourism, extraction areas) | 1 point |
| Site located less than 1 km from a potential degrading area (such as Industry, unsustainable tourism, extraction areas) | 0 point |
| **C. Legal protection** | |
| The site is located in an area with no legal protection and no control over access | 4 points |
| The site is located in an area with no legal protection but with control of access | 2 points |
| The site is located in an area with legal protection but no control over access | 1 point |
| Site located in an area with legal protection and control of access | 0 point |
| **D. Density of population** | |
| Site located in a municipality with more than 1000 inhabitants/km2 4 points | 4 points |
| Site located in a municipality with 250–1000 inhabitants/km2 3 points | 2 points |
| Site located in a municipality with 100–250 inhabitants/km2 2 points | 1 point |
| The site is located in a municipality with less than 100 inhabitants/km2 | 0 point |
| **E. Road Type** | |
| The road to the site is paved and has a parking area. | 4 points |
| The road to the site is paved, but there is no parking area, or the road is unpaved but has a parking area. | 2 points |
| The road to the site is unpaved, or to reach the site is necessary to take a Ferry, Cruise or Tourist Boat (usually around 10-15 people). | 1 point |
| A small private boat (max six people) is necessary to reach the site, or It is necessary to do an excursion of more than one day | 0 point |
| **F. Distance** | |
| It is necessary to walk or navigate between 0km to 2 km or between 0 km- 8km from the parking area to reach the site. | 4 points |
| It is necessary to walk or navigate between 2km to 4km or 8 km to 16km from the parking area to reach the site. | 2 points |
| Walking 4km to 6 km or navigating between 16 km- 24km from the parking area is necessary to reach the site. | 1 point |
| Walking more than 6km or navigating more than 24km from the parking area is necessary to reach the site. | 0 point |
| **G. Economic interest** | |
| An explicit intention of intervention or projects under evaluation could affect the site. That could generate a total or partial destruction of the site (e.g. sand extraction, mining, dam, hydroelectric power plants generation, fishing industry, forestry industry, road construction, mining Properties) | 4 points |
| The site is located in areas where research or pre-projects are being carried out that could result in an activity that partially or degrades the site. | 2 points |
| The site and its surroundings could be used for extractive activities in the future | 1 point |
| There are no indications that the site could be damaged by extractive use. | 0 point |

| POTENTIAL EDUCATIONAL AND TOURIST USES | |
|---|---|
| Criteria / Indicators | Parameter s |
| **A. Seasonality** | |
| The site can be visited all year round | 4 points |
| At least three seasons | 2 points |
| At least two seasons | 1 point |
| At least one season | 0 point |
| **B. Limitations** | |
| The site has no limitations to be used by students or tourist | 4 points |
| Students and tourists can use the site after overcoming limitations or paying fees (legal, permissions, physical, tides) | 2 points |
| Students and tourists can use the site after overcoming limitations (legal, permissions, physical, tides) and paying fees | 1 point |
| The use by students and tourists is tough to be accomplished due to limitations to overcome | 0 point |
| **C. Road Type** | |
| The road to the site is paved and has a parking area. | 4 points |
| The road to the site is paved, but there is no parking area or the road is unpaved but has a parking area. | 2 points |
| The road to the site is unpaved, or to reach the site is necessary to take a Ferry, Cruise or Tourist Boat (usually around 10-15 people). | 1 point |
| A small private boat (max six people) is necessary to reach the site, or It is necessary to do an excursion of more than one day | 0 point |
| **D. Distance** | |
| It is necessary to walk or navigate between 0km to 2 km or between 0 km- 8km from the parking area to reach the site. | 4 points |
| It is necessary to walk or navigate between 2km to 4km or 8 km to 16km from the parking area to reach the site. | 2 points |
| Walking 4km to 6 km or navigating between 16 km- 24km from the parking area is necessary to reach the site. | 1 point |
| Walking more than 6km or navigating more than 24km from the parking area is necessary to reach the site. | 0 point |
| **E. Difficulty** | |
| Suitable for all types of visitors, including those with no experience. The surface is hard and compact, and there is little gradient. A maximum walking time of two hours should be estimated for the whole trail. The trail has informative signposting. | 4 points |
| Suitable for most visitors with minimal trail experience. There may be some minor obstacles or stepping stones. Total walking time should not exceed five hours. There is a moderate gradient, and the surface is firm and stable. The trail is signposted. | 2 points |
| Suitable for visitors with trail experience who have adequate equipment and water. There is a variety of trail surfaces. There can be steep gradients, and trails are often longer than five hours. There is little or no information on the trail. | 1 point |
| Suitable for visitors with extensive hiking and orienteering experience. There may be no trail and only a footprint. Walks may take several days. The trail may have a variety of surfaces, such as rocks, wetlands, and clays. No visitor facilities | 0 point |
| **F. Safety** | |
| There is no apparent risk to visitors at the site or on the route. That, due to natural conditions or infrastructure in place, has made it possible to reduce the risks. | 4 points |
| There is no apparent risk to visitors at the site or on the route, but there is no infrastructure to delimit sectors that, if reckless action, could be a latent threat to visitors. | 2 points |
| There is at least one piece of evidence on the site or the route, such as rock falls or unstable fractures in blocks or cliffs. That is a latent threat to visitors. | 1 point |
| Several pieces of evidence, such as rock fall, unstable fractures in blocks, cliffs, etc., are a latent threat to visitors on the site or the route. | 0 point |
| **G. Scenery** | |
| The site is currently used as a tourism destination in national campaigns | 4 points |
| The site is occasionally used as a tourism destination in national campaigns | 2 points |
| The site is currently used as a tourism destination in local campaigns | 1 point |
| The site is occasionally used as a tourism destination in local campaigns | 0 point |
| **H. Uniqueness** | |
| The site shows unique and uncommon features considering this and neighbouring countries | 4 points |
| The site shows unique and uncommon features in the country | 2 points |
| The site shows standard common features in this region, but they are uncommon in other regions of the country | 1 point |

| | |
|---|---|
| the site shows feature relatively common in the whole country | 0 point |
| **I. Association with other values** | |
| Cultural or natural values occur within 100 m of the site (such as ancestral trails, archaeological sites, architectural heritage, ecological sites or others). | 4 points |
| Cultural or natural values occur within 1 km of the site (such as ancestral trails, archaeological sites, architectural heritage, ecological sites or others). | 2 points |
| Cultural or natural values occur within 5 km of the site (such as ancestral trails, archaeological sites, architectural heritage, ecological sites or others). | 1 point |
| Cultural or natural values occur within 25km of the site (such as ancestral trails, archaeological sites, architectural heritage, ecological sites or others). | 0 point |
| **J. Observation Conditions** | |
| All geological elements are observed in good conditions | 4 points |
| some obstacles make difficult the observation of some geological elements | 2 points |
| some obstacles make difficult the observation of the main geological elements | 1 point |
| some obstacles almost obstruct the observation of the main geological elements | 0 point |

| **POTENTIAL EDUCATIONAL USES** | | **POTENTIAL TOURIST USES** | |
|---|---|---|---|
| **K. Didactic Potential** | | **K. Interpretative Potential** | |
| The site has primary geological features linked to the source of the process (Volcanoes, Glaciers, Rivers, Landslides, Fossils, hot springs, and others) that can be seen, heard, felt or touched. In the case of secondary elements, the source of origin can be easily located (e.g. lava flows from a nearby volcano). Elementary aspects of geology and nature can be taught. | 4 points | The site presents geological elements clearly to all types of public | 4 points |
| The site presents secondary geological features (e.g. lava flows, dikes, ancient valleys, moraines, stratified deposits, ichnofacies, and knick-points ) where the source of origin is not necessarily discernible. Their study is mainly focused on teaching fundamental aspects of geology. | 2 points | The public needs to have some geological background to understand the geological elements of the site | 2 points |
| The site presents secondary geological elements, and their value is related to specific characteristics of these deposits generally related to the training of geological specialists. | 1 point | The public needs to have a solid geological background to understand the geological elements of the site | 1 point |
| The characteristics of the site are not of great interest for training in terms of geology, or the lack of studies at the site means that the geological elements are not well understood and research is needed to determine their educational or interpretative potential | 0 point | The lack of studies at the site means that the geological elements are not well understood, and research is needed to determine their educational or interpretative potential | 0 point |
| **L. Geological Diversity** | | **L. Proximity of recreational areas** | |
| More than three types of geodiversity elements occur in the site (e.g. mineralogical, paleontological, geomorphological) | 4 points | Site located the site is located within a radius of at least 5 kilometres of recreational areas | 4 points |
| There are three types of geodiversity elements in the site | 2 points | Site located the site is located within a radius of at least 10 kilometres of recreational areas | 2 points |
| There are two types of geodiversity elements in the site | 1 point | Site located the site is located within a radius of at least 15 kilometres of recreational areas | 1 point |
| There is only one type of geodiversity element in the site | 0 point | Site located the site is located within a radius of at least 20 kilometres of recreational areas | 0 point |

## 7.3 Geosites

The most representative geosites of each geological context (Figure 38) are presented below.

### A. Chaitenia accretionary metamorphic complex

| METATONALITE OF CHAITÉN \| CHAITÉN \| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8081939 | Y: -5273704 |
|---|---|---|---|---|---|---|
| METATONALITE OF CHAITÉN : The oldest magmatic in Patagonia Verde | | | | | | |
| S | T | E | DR | | | |
| 3.8 | 3.3 | 2.9 | 1.40 | | | |

It is an intrusive body formed by magmatic rocks, aged about 400 Ma, from the Devonian period (Duhart et al., 2009, Herve et al., 2016), being one of the oldest records found in the territory. Its origin possibly represents part of an ancient volcanic island chain that later collided, amalgamated with the mainland, and was named Chaitenia (Herve et al., 2016). Its attributes, such as location and access, make it easy to study, and it is not only of great scientific importance but also of great educational value.

*Outcrop on the side of Route 7. Photograph with the pupils of the Almirante Juan J. Latorre basic school.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | CHA | Deformed tonal intrusive | Metamorphism, Magmatism, Tectonics, Stratigraphy | • Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12 |
| Secondary | TEC | | | | |
| Management proposal | | As it is on the side of the road, its safety conditions could be improved in order to establish both a safe path from the car park (Camping Lago Blanco) and a stop at the site. Complementary information, such as an interpretation panel explaining Chaitenia could be helpful to support educational activities and take advantage of the geotourism potential of the outcrop. | | | |
| Key conservation partners | | J.J La Torre school, Municipality of Chaitén, Patagonia Verde Guides Association. | | | |

### B. The Palaeozoic metamorphic complex of the Main Range

| SANTA BARBARA SCHIST\| CHAITÉN \| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8104184 | Y: -5289551 |
|---|---|---|---|---|---|---|
| SANTA BARBARA SCHIST : Upper Palaeozoic accretionary prism | | | | | | |
| S | T | E | DR | | | |
| 2.90 | 2.85 | 3.05 | 1.70 | | | |

The Santa Barbara schists are metavolcanic deposits, which, although not dated, have been associated with the Upper Paleozoic Accretionary Prism (SRGN-BRGM, 1995 and references therein) as part of the Main Range Metamorphic Complex. One of the singularities of this site is that a contact can be observed between this unit and the Llahuen Formation (Araya, 1979), which corresponds to a group of much younger volcano-sedimentary sequences of Pleistocene age visible mainly in the coastal sector of Patagonia Verde. This site is essential because it is the only specimen inventoried in this geological context. Its easy access and association with other attractions such as Playa Santa Barbara or Morro Vilcún, make this place valuable in educational and touristic terms.

*Schist and Santa Barbara beach. In the background, Morro Vilcún.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | CMCP | Green Schist | Metamorphism, Tectonics, Stratigraphy, Volcanology | • Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12 |
| Secondary | SCCz / VNQ | | | | |
| Management proposal | | Although the site is not promoted, the Santa Barbara beach and its proximity to the city of Chaitén and easy access can be a factor of degradation (oversampling, scratches and others) that should be considered when promoting this site. Supporting information for educational and interpretation activities can be considered for the valorisation of this site. | | | |
| Key conservation partners | | J.J La Torre school, Municipality of Chaitén, Patagonia Verde Guides Association. | | | |

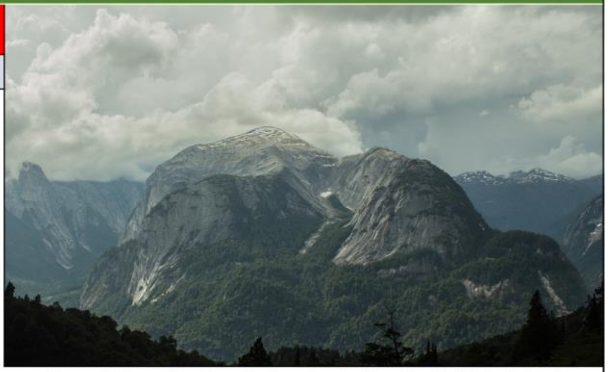
## C. Patagonia Batholith

| CERRO ARCOIRIS\| COCHAMÓ \| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -8032882 | Y: -5073280 |
|---|---|---|---|

**CERRO ARCOIRIS: The North Patagonian Batolith**

| S | T | E | DR |
|---|---|---|---|
| 2.90 | 3.05 | 2.60 | 0.40 |

It is representative of the North Patagonian Batholith and a reference point in La Junta area. From a height close to its summit, an excellent panoramic view of the valley can be obtained, representing the Norpatagonian Batholith and the glacial processes that modelled it. This site is a recognised adventure tourism attraction in the Cochamó Commune and is visited by tens of thousands of tourists looking for hiking, mountaineering and climbing. The Cochamó Valley Organisation is the site's main administrator. Thanks to its management, there is a reservation system, access control, signage, demarcation and monitoring of trails, among other things.



*Panoramic view of the valley of La Junta from the Cerro Arcoiris. Ph: Paulo Urrutia*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | BNP | Batholith, Glacial Geoforms | Magmatism, Glaciology | • Cultural: Contribution of the physical environment to the development of cultural activities | |
| Secondary | AGI | | | | |

| | |
|---|---|
| **Management proposal** | While this site's tourism and educational potentials are of relevance, its use, particularly its educational use, points to the design of supporting infrastructure to improve the site's security conditions. |
| **Key conservation partners** | Cochamó Valley Organisation, Seremi National Goods, Sernatur, Municipality of Cochamó, Escuela Básica Fronteriza Juan Soler Manfredini of Cochamó |

## D. Mesozoic volcanic arc

| CORDON DE LAS TOBAS\| PALENA\| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -7995933 | Y: -5396139 |
|---|---|---|---|

**CORDON DE LAS TOBAS: An important volcanic record from the past**

| S | T | E | DR |
|---|---|---|---|
| 3.25 | 1.8 | 1.8 | 1.70 |

It corresponds to a reddish-greyish mountain range with an average height of 1500 m, 24 km of longitudinal extension and summits that reach 1860 m. It is the type locality of the Las Toqui Formation. It is the type locality of the Las Tobas Formation (Fuenzalida 1965, Haller & Lapido 1980) and is the only representative site of active volcanism 100Ma ago in Patagonia Verde.

*El cordon de las Tobas visto desde el Cerro La Bandera*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | AVMz | Tuffaceous deposits | Volcanology, Estratigraphy | • Cultural: Contribution of the physical environment to the development of cultural activities | |
| Secondary | AGI / BNP / PH | | | | |

| | |
|---|---|
| **Management proposal** | Existen voluntades locales de mejorar las condiciones de acceso de este sitio y generar senderos interpretativos. Apoyar este tipo de iniciativas podría contribuir al aumento del potencial turístico y educativo del lugar, pudiendo generar un impacto positivo en los habitantes |
| **Key conservation partners** | Palena Municipality, Patagonia Verde Guides Association. |

## E. Austral Basin Record.

| EL ACEITE HILL\| CHAITÉN\| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -7990658 | Y: -5400739 |
|---|---|---|---|

**EL ACEITE HILL: A local expression of the Aysen Basin**

| S | T | E | DR |
|---|---|---|---|
| 2.90 | 2.30 | 2.90 | 1.85 |

Between the Titonian and Aptian, marine and volcanic sedimentary deposits filled a depression known as the Aysen Basin (Bell and Suárez, 1997). These deposits record a period of marine transgression (Toqui Formation), deepening (Katterfeld Formation), and subsequent uplift (Apeleg Formation) grouped under the name of the Coyhaique Group (Haller and Lapido, 1980).
In Patagonia Verde, a local expression of the last period of this basin is found in the locality of Palena, particularly in the Aceite area. There is a small hill where it is possible to observe shallow marine sequences with a large amount of fossil content, denominated El Aceite Formation (Fuenzalida, 1965).

*Cerro el Aceite. The stratified layers of scientific and educational interest are found near the summit.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | CA | Marine fossil-containing sequences | Stratigraphy, Tectonics, | • Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12 |
| Secondary | AGI / TEC | | | | |
| **Management proposal** | | This site is currently not being developed and its use requires the creation of such conditions in order not to degrade the site. It is recommended that this site be used in science and guided education programmes. To this end, it is necessary to delimit a path and improve access so as not to degrade the environment. | | | |
| **Key conservation partners** | | Roberto White Gessel school in Alto Palena Municipality of Palena, Patagonia Verde Guides Association. | | | |

## F. Metallogenic Province and its occurrences

| LAGUNA HUEQUI\| CHAITÉN\| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -8094794 | Y: -5203746 |
|---|---|---|---|

**LAGUNA HUEQUI**

| S | T | E | DR |
|---|---|---|---|
| 2.70 | 2.65 | 2.70 | 3.58 |

The primary source of the gold at Patagonia Verde would correspond mainly to hydrothermal mineralisation located in the Andes Mountains. However, the gold would have been transported towards the coastal sector by the huge glacial masses that eroded the main mountain range and deposited the gold in the moraines.
On the Huequi peninsula, much of the river erosion has re-transported this gold and deposited it in low-energy zones. The Huequi Lagoon and surrounding rivers, such as the Mudo River, are known areas for gold mining, mainly by artisanal gold miners.
Currently, there are mining concessions in and around the lagoon.

*Laguna Huequi.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | PM | Gold placer deposits | Metalogenesis, Glaciology, Hidrology | • Provisioning of non-renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12, 15 |
| Secondary | AGI | | | | |
| **Management proposal** | | The Laguna de Huequi and the surrounding area are currently under a mining concession, so it is necessary to monitor the progress of mining operations for the development of other activities. There is the potential for operations to be compatible with educational and mining tourism activities and the management of such an agreement may be important for the development of such activities. | | | |
| **Key conservation partners** | | SERNAGEOMIN, Municipality of Chaitén, Peninsular School of Ayacara. | | | |

## G. Cenozoic marine sedimentary rocks

| CALETA AYACARA\| CHAITÉN\| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8102362 | Y: -5208206 |
|---|---|---|---|---|---|---|
| CALETA AYACARA | | | | | | |
| S | T | E | DR | | | |
| 3.30 | 2.70 | 3.20 | 1.70 | | | |

Patagonia's most important Cenozoic marine transgression occurred during the late Oligocene and early Miocene (Echaurren et al., 2022). Around 20 Ma, marine waters from the Pacific and Atlantic would have flooded most of southern South America, including the present-day Patagonian Andes, allowing for the first time in the history of this area a possible transitional connection between the Pacific and Atlantic Oceans. The transition from shallow marine rocks to deep marine rocks of Caleta Ayacara is evidence of this process. It is completest record of that connection, making it a type locality of the Ayacara Formation (Levi et al. 1966, Encinas et al. 2013).

*Stratyphic outcrop of the Ayacara Formation*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | SMCz | Fossil-bearing sedimentary sequence and volcanic deposits | Sedimentology, ichnology, foraminiferal paleontology, geochronology, tectonics | • Cultural: Contribution of the physical environment to the development of cultural activities |  |
| Secondary | TEC / VNQ | | | | |
| **Management proposal** | The surrounding area is littered, and debris may indicate a lack of awareness of the importance of the site. The proximity to the Peninsula's main town has led to some degradation related to rubbish and debris in the surrounding area. However, this is mainly due to a lack of awareness of the importance of the site. As the site is not particularly fragile, enhancing and disseminating this site in tourism and educational activities can be an excellent awareness-raising mechanism. The support of infrastructure for viewing the site (walkways, railings, steps) and for its interpretation (panels, QR codes) can make this place a space for learning and recreation. There is a local will to improve this site's access conditions and create interpretative trails. Supporting this type of initiative could increase the site's tourism and educational potential and positively impact the inhabitants. | | | | |
| **Key conservation partners** | Municipality of Chaitén, Peninsular School of Ayacara, Patagonia Verde Guides Association. | | | | |

## H. Cenozoic continental sedimentary rocks (?)

| PIEDRA DEL CALTO / ISLOTE NIHUEL\| CHAITÉN\| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8118836 | Y: -5255318 |
|---|---|---|---|---|---|---|
| ISLOTE NIHUEL | | | | | | |
| S | T | E | DR | | | |
| 2.40 | 2.90 | 2.90 | 1.78 | | | |

Islote Nihuel / Piedra del Calto is a small island belonging to the Desertores group. Studies at this site are still incipient, and not much information has been collected, making it an excellent place to develop research. However, given its location in the central depression, Islote Nihuel seems to correspond to a sedimentary sequence that could be related to the Llahuen formation, although it is necessary to verify this assertion through research. One of the most relevant aspects is its morphology: the island has a flat roof and forms an authentic cube.
Its location close to the coast makes it a small reserve for marine life.

*Piedra del Calto / Islote Nihuel*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | SCMz | Island with cube-shaped sedimentary sequences. | Stratigraphy, sedimentology, petrology, geomorphology | • Supporting of life conditions and social development<br>• Provisioning of renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities |  |
| Secondary | VNQ(?) / TEC(?) | | | | |
| **Management proposal** | It is necessary to carry out surveys and studies to determine the origin of the rocks at this site and to find an explanation for their morphology. On the other hand, planned fishing activities in the surrounding area could affect the environment close to the site, so it is necessary to monitor these activities. | | | | |
| **Key conservation partners** | Municipality of Chaitén, Indigenous Peoples' Coastal Marine Area ECMPO, Patagonia Verde Guides Association. | | | | |

## I. Neogene – Quaternary volcanism and thermal manifestations

| PORCELANA GEYSERS\| CHAITÉN\| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -8068916 | Y: -5223208 |
|---|---|---|---|

**PORCELANA GEYSERS: The world's only active pinnacles**

| S | T | E | DR |
|---|---|---|---|
| 3.30 | 2.25 | 2.55 | 1.98 |

The Porcelain Geysers are a complex geothermal system. It owes its origin to the presence of several faults and fractures that provide high permeability along the entire peninsula, also related to the origin of the Barranco Colorado Volcano. The Porcelain Geysers are the only known site in the world with a system of active travertine pinnacles that precipitate at present and can therefore be considered a singularity. It is a thermal environment, unlike the others found in the territory. In this one, the concentration of calcium and silica allows the formation of travertine columns that exceed 2 m in height as a result of the precipitation of carbonates. They also host microorganisms adapted to extreme temperatures close to 90° (Ruiz & Morata, 2016; Ruiz et al., 2017; Ruiz, 2019).

*Pináculos de travertinos ubicados al norte del Río Porcelana Chico.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | VNQ | Travertine pinnacles, hot springs, waterfall | Tectonics, geothermics, geochemistry | • Supporting of life conditions<br>• Provisioning of Geotermal Heat<br>• Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12, 15 |
| Secondary | TEC / PH | | | | |
| **Management proposal** | Hualaihué and Chaitén have promoted this site as a tourist attraction, but its difficult access means that visits to the site are occasional. Even so, local guides report the extraction of one of the pinnacles by visitors, which means a severe loss of the site's scientific value. Given its attributes and potential, this site is a management priority. It is recommended to prohibit access without a tour guide and to establish a visiting protocol. Once this has been done, improving the access could provide greater security and take advantage of the site's educational and touristic potential without endangering the pinnacles. | | | | |
| **Key conservation partners** | Municipality of Hualaihue, Municipality of Chaitén, Patagonia Verde Guides Association. | | | | |

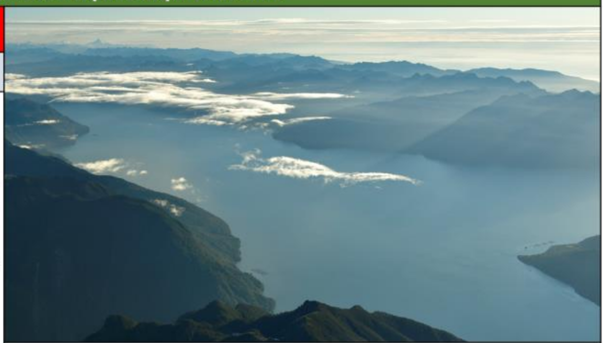
## J. Tectonic and Neotectonic megastructures

| COMAU FJORD \| COCHAMÓ \| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -8069510 | Y: -5204490 |
|---|---|---|---|

**COMAU FJORD : The main track of the Liquiñe-Ofqui fault zone**

| S | T | E | DR |
|---|---|---|---|
| 3.30 | 3.55 | 3.85 | 2.68 |

It is a Fjord coinciding with the LOFZ and surface evidence of this. On the other hand, this fjord is representative of the last glacial period. Its unstable condition has generated national and international studies in geological hazards and seismicity (e.g. Lange et al., 2008; Arenas et al., 2008). Like the other fjords, it is internationally recognised for its biodiversity.

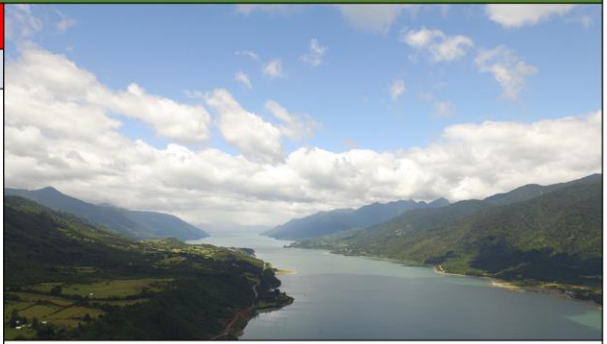


*Comau areal view. Ph. Guy Webner*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | TEC | Fjords, ZFLO Lineament | Tectonic, Glaciology, Geological Hazards, Hidrology | • Regulation: conditions that allow the existence of life and modern society<br>• Supporting of life conditions and social development<br>• Provisioning of renewable and non-renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12, 13, 14 |
| Secondary | AGI / GH / PH | | | | |
| **Management proposal** | The main threat regarding the Comau Fjord is water pollution (e.g. fishery residues, HAB) consequently, the loss of its ecosystem values due to overfishing. Establishing connections with the authorities and making them aware of the site values is necessary to generate the necessary efforts to control the water quality and the ecosystem's balance. | | | | |
| **key conservation partners** | Sernapesca, Sernatur, Municipalidad de Cochamó, Association of guides of Patagonia Verde, Escuela Básica Fronteriza Juan Soler Manfredini of Cochamó | | | | |

| RELONCAVI FJORD \| COCHAMÓ \| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8050384 | Y: -5088171 |
|---|---|---|---|---|---|---|
| **RELONCAVI FJORD : The main track of the Liquiñe-Ofqui fault zone** | | | | | | |
| S | T | E | DR | | | |
| 3.30 | 3.55 | 3.85 | 2.68 | | | |

This estuary is the northernmost fjord in Patagonia and one of the most equatorial in the world. Together with the Comau Fjord, it is surface evidence of ice passage and has been a reference for mapping in several studies (e.g. Cembrano & Herve 1993). Its tectonic activity of the LFOZ has generated interest from the point of view of paleo-seismology (e.g. St-Onge, G et al., 2012) and processes that modify its hydrology (e.g. Yevenes et al., 2019). The hydrology of this fjord is also studied and recognised (e.g. Castillo et al. 2016). Its behaviour is vital for its ecosystems and productive activities such as aquaculture (e.g. Díaz et al. 2019, Soto et al. 2021).



*Reloncavi Fjord, view to the south.*

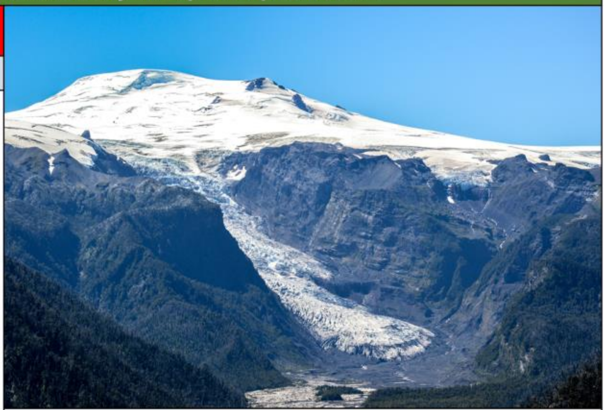
| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | TEC | Fjords, ZFLO Lineament | Tectonic, Glaciology, Geological Hazards, Hidrology | • Regulation: conditions that allow the existence of life and modern society<br>• Supporting of life conditions and social development<br>• Provisioning of renewable and non-renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities |  |
| Secondary | AGI / GH /PH | | | | |
| **Management proposal** | | The main threat regarding the Reloncavi Fjord is water pollution (e.g. fishery residues, HAB) consequently, the loss of its ecosystem values due to overfishing. Establishing connections with the authorities and making them aware of the site values is necessary to generate the necessary efforts to control the water quality and the ecosystem's balance. | | | |
| **key conservation partners** | | Sernapesca, Sernatur, Municipality of Cochamó, Patagonia Verde Guides Association, Escuela Básica Fronteriza Juan Soler Manfredini of Cochamó. | | | |

## K. Glacial and periglacial environments and records

| AMARILLO GLACIER \| CHAITÉN\| X LOS LAGOS DISTRICT | | | | WGS84 EPSG:3857 | X: -8064189 | Y: -5291123 |
|---|---|---|---|---|---|---|
| **AMARILLO GLACIER: A glacial environment controlled by the Liquiñe-Ofqui fault zone.** | | | | | | |
| S | T | E | DR | | | |
| 2.90 | 3.65 | 3.30 | 1.00 | | | |

It is a mountain glacier located on the southern flank of the Michinmahuida volcano, corresponding to one of the four main glacier basins found on the volcano (Rayas, Chico, Amarillo, Reñihue). It is located in the Pumalin National Park, has a trail to its base, and is an outstanding tourist attraction in the Commune of Chaitén.

Shortly before the eruption of the Chaitén volcano, an unexpected breakthrough began that prompted scientific interest and discoveries. The conclusion of the studies (Rivera et al. 2012) was that the ice displacement could have responded to the increase of geothermal flows in the subsurface before the onset of the eruption. This heating caused the bedrock to rise, and possibly meltwater was produced at the base of the glacier, leading to the slide and the unexpected advance.



*View to the North: El Amarillo Glacier descending from Michinmahuida Volcano.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | AGI | Glaciar y componentes de su ambiente (Morrenas, Rocas Aborregadas, Zonas de descarga). Volcán Michinmahuida | Glaciology, Volcanology, Tectonics, Geological Hazards | • Regulation: conditions that allow the existence of life and modern society<br>• Supporting of life conditions and social development<br>• Provisioning of renewable and non-renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities |  |
| Secondary | VNQ / TEC / GH | | | | |
| **Management proposal** | | Include the scientific narrative in the glacier visit experience. This can range from pre-trail briefings provided in the CONAF register, to interpretive infrastructure that allows visitors to get a general idea of the site's attributes. | | | |
| **Key conservation partners** | | Pumalin National Park (CONAF) | | | |

## L. Geological Hazards

| CHAITÉN SITE MUSEUM \| COCHAMÓ \| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -8093297 | Y: -5299103 |
|---|---|---|---|

**CHAITEN SITE MUSEUM:**

| S | T | E | DR |
|---|---|---|---|
| 3.10 | 4.00 | 3.70 | 1.20 |

On May 10, 2008, intense rainfall removed huge volumes of ashes accumulated in the territory, which were emitted during the eruption of the Chaitén volcano (Major & Lara, 2013). The ashy water was channelled through the main neighbouring rivers, including the Blanco River that flows through the town of Chaitén before emptying into the sea. The waters of the Blanco River, laden with volcanic material, overflowed their banks, flooding and sweeping away numerous houses. In the Chaitén site museum, it is possible to see the effects of this lahar on the city and how the houses were affected. The consequences of this eruption generated the interest of the international community. In Chile, it set a precedent in volcanology. It led to the decision to create the National Volcanic Surveillance Network and to considerably modernise the Volcanological Observatory of the Southern Andes (OVDAS) under the administration of the National Service of Geology and Mining (SERNAGEOMIN). The OVDAS is located in Temuco and monitors 45 active volcanoes throughout the country

*Houses completely flooded by the Chaitén lahar preserved in the museum.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | PG | Effects of a Lahar in the city | Geological Hazards, Volcanology | Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12, 13 |
| Secondary | VNQ | | | | |

| | |
|---|---|
| **Management proposal** | The Pro Cultura Foundation currently manages the site museum. As a management measure, it is necessary to generate collaboration agreements with this foundation to develop educational and tourist activities. |
| **key conservation partners** | J.J La Torre school, Pro Cultura Foundation, Patagonia Verde Guides Association. |

## M. Hydrological processes

| FUTALEUFU CANYON \| FUTALEUFÚ\| X LOS LAGOS DISTRICT | WGS84 EPSG:3857 | X: -7997734 | Y: -5342171 |
|---|---|---|---|

**FUTALEUFU CANYON**

| S | T | E | DR |
|---|---|---|---|
| 2.60 | 3.20 | 3.20 | 1.75 |

Between the Guelves Bridge and the Pozon de los Reyes, the Futaleufú River makes its way through the rocky massif of the Toqui Formation, through an 800 m long canyon. In this canyon, the river decreases its width and increases its speed. Also, abrupt changes in the slope (Knick-points) form a series of "rapids". This canyon is not exclusive; therefore, there are several areas of rapids (e.g. Pasarela la Dificultad). The water quality, colour and rapids make the Futaleufú river an international reference for practising Rafting and Kayaking.

The rivers usually start after a tectonic uprising, and in the case of the Futaleufú River, it would be related to the Andes Uplift.

*Canyon of the Futaleufú River. In the background it is possible to see the Batolito Norpatagonico and an ancient glacial cirque.*

| Geological Framework | | Featured Elements | Interest | Ecosystem Services | SDG |
|---|---|---|---|---|---|
| Main | PH | Kick Point Rio Futaleufú & Canyon in Rocks of the Toqui Formation. | Geomorfology, Tectonic | • Provisioning of renewable resources which are fundamental to life and society<br>• Cultural: Contribution of the physical environment to the development of cultural activities | 4, 8, 11, 12, 15 |
| Secondary | CA / TEC | | | | |

| | |
|---|---|
| **Management proposal** | Actualmente el mirador del Pozon de los Reyes (fotografia) se encuentra en territorio privado y es necesario establecer convenios de cooperación para la visita y su uso turístico. Sin embargo, el sitio en el Puete Guelvez permite la observación de este lugar y es posible también concentrar los esfuerzos en generar material de apoyo para la interpretación en dicho lugar, dado que es una parada frecuente entre los visitantes de la Reserva Nacional Futaleufú. |
| **Key conservation partners** | Reserva Nacional Futaleufú, Municipalidad de Futaleufú, Patagonia Verde Guides Association. |

## 7.4 Hualaihué Declaration (2019): Agreements of the "First meeting of guides of Patagonia Verde".

Between 20-22 June, presentations, field trips and spaces for dialogue were developed. That allowed to strengthen the collaboration between the thirty participants. It also was helpful to consolidate the activities and geotourism products implemented to date framed in the project "Development of geotourism products in the Patagonia Verde destination", which is implemented by the Austral University of Chile.

The event included talks by Mauricio Mella from SERNAGEOMIN, Roberto Garrido from CONAF, José Miguel Cepeda from Epu pewen Turismo Sostenible and Manuel Schilling from Universidad Austral de Chile. It allowed participants to tour the Georuta Costera de Hualaihué, which stands out for its geotourism sites such as the erratic blocks of Quetén, Marmitas de Gigante de Lleguiman, the columnar basalts of Punta Poe and Cerro La Silla.

Along with learning about the sites and the processes that have shaped the landscape of Patagonia Verde, the guides discussed the present and future of tourism in Patagonia Verde, concluding the activity with a proposal called "Declaration of Hualaihué: Agreements of the First Meeting of Patagonia Verde Guides". The said document, organised in the areas of education, tourism, conservation and management, brings together the actions to be followed to strengthen and give continuity to the development of geotourism in Patagonia Verde.

### A. Agreements

***Education***

1. Implementation of educational activities that articulate the knowledge acquired by local guides with the schools of the Patagonia Verde territory. These activities imply the deployment of the guides all over the territory
2. To Develop physical and technological implementation of information related to the sites of geotourism interest inventoried in the "Geotourism Patagonia Verde" project. This action involves investment in interpretative panels and applications for mobile devices.
3. Dissemination material: development of educational material and brochures for tourist information centres and schools in the Patagonia Verde territory.

***Conservation***

1. Regional public bodies are requested to make transparent and disclose information regarding water rights and mining claims that could affect the conservation of the territory's commons.
2. Implementing waste recycling and reuse processes is requested to improve waste management.
3. Immediate definition of a mechanism to solve the severe problems of contamination of the beaches along the coast of the Patagonia Verde territory, particularly household waste and waste from fish and shellfish farming, is requested.
4. Greater investment is required for conservation in the protected areas of the territory, in particular, economic resources are required to hire more park rangers during the summer period, and new accesses are also required in Hornopirén National Park and Corcovado National Park.)

***Tourism***

1. Implementing a continuous training course in Geotourism will allow local guides to become more specialised in interpreting the landscape and its geodiversity.
2. Implementing a course (WFA WILDERNESS FIRST AID) First Aid in remote areas is required so that local guides have adequate training adapted to the tourist activities proposed by the Patagonia Verde territory.
3. To implement a network of local guides around the figure of the "Association of Tourist Guides of Patagonia Verde" to standardise knowledge and techniques in developing special interest tourism.
4. Strengthen the local economy by diversifying and promoting those tourist activities and products that give identity and seal to the territory.

***Management***

1. To give continuity to the "Patagonia Verde" programme to consolidate itself as a tourism brand for the whole territory. This action implies deploying public funds for the various needs of the territory in this area.
2. To build and coordinate a schedule of programmed events between the five communes that make up the Patagonia Verde territory.
3. Create the Association of Patagonia Verde Municipalities to coordinate tourism, education and conservation actions that will allow the consolidation of the sustainable development of the territory.

Hualaihué, 21 June 2019

**B. Photographic record of the activity.**