ANNEX 8
GEOLOGY AND GEOMORPHOLOGY REPORT

CONTENTS

1 INTRODUCTION

This report provides the main results of the study of Geology, Geomorphology and Natural Risks for the Project "Electricity Transmission Lines S/S Maitenes – S/S Alfalfal and Alfalfal II – S/S Alfalfal," as part of the Environmental Impact Study that will be submitted to the Environmental Impact Assessment System (SEIA).

The Project will be sited in the Colorado Canyon, which contains the river of the same name, located in the Municipality of San José de Maipo, in Cordillera Province in the Metropolitan Region.

In general terms, the Project is located within the Andes Mountains, which has high altitude environments and a young, recent relief. Some of the geological units present in the area of study date to the Tertiary Period of the Cenozoic Era. As such, the Project will be located on alluvial and lacustrine deposits, most of them recent gravitational deposits.

From a geomorphological perspective, the Project will be located on one of the terraces formed by entrainment deposits of the Colorado River.

2 OBJECTIVES

2.1 General Objective

Describe the geological formations and geomorphological units present in the area in which the Project will be located.

2.2 Specific Objectives

The specific objectives of this study are to:

- Characterize the geological formations, sediments and/or geological strata that give rise to the geoforms in the area of the Project, identifying in addition existing faults present in the sector.
- Identify the geomorphological units present in the Project area in order to define potential natural risks that could affect this area.
- Identify potential impacts that the construction and operation of the Project could generate on this environmental component.
- Propose, where appropriate, measures to Mitigate, Repair, and/or Compensate for the impacts identified.

3 METHODOLOGY

The methodology used to characterize the geological and gemorphological units found in the area of study involved the use of several tools and sources of information as well as fieldwork to verify the information collected in the office work stage.

The sections below describe the process that was used to build the baseline for the Project area.

3.1 Geology

The description of the arrangement of geological units (formations, sediments and/or strata) present in the area of study was based on information submitted in the EIS of the Alto Maipo Hydroelectric Project, and includes the Santiago Segment of the Geological Map (*Mapa Geológico Hoja)*. This information was checked and complemented by information collected in the field.

3.2 Geomorphology

The description of the geomorphological component, at both the local and regional scale, was developed as follows:

1. Review and analysis of Chapter 3 "Zonal Geomorphology of the Third Regional Grouping," Central region of basins and glacial-fluvial-volcanic plain in Volume 2 of Geografía de Chile (Börgel, 1982), and other bibliographic information focused specially on the geomorphological description and origin of the Andes Mountains, where the Project is to be located.

2. In order to characterize the local geomorphological scale of the area of study, a triangulated irregular network (TIN) was used. This displays relief elevations, meaning that it offers a characterization of altitudes and exposure of the terrain. This image covers the entire Project area and displays at the local scale the geomorphological units in which it will be located. To generate this graphic information, the coverages (shapes) of topographic lines (3d) in maps E-60, E-67 and E-68 were used in vectoral format at a scale of 1:50,000 to generate an image with the same scale.

3. Based on the Triangulating Network (TIN), a map of gradients was generated for the area of study, which enabled the identification of areas susceptible to landslides, landslips, and rockfall.
The ranges of gradients are based on the classification system used by the Ministry of Agriculture for the Agrilogical Capacity Survey of Soils of Spain, based on the work of Araya-Vergara and Börgel 1972; Young 1975; and Ferrando 1993 as cited in Mesina 2003. The criteria are indicated below:

Table 1 Slope Ranges according to Morphodynamic Thresholds

Slope (degree)	Slope (%)	Type	Geomorphological Threshold
0 - 2	0 – 4.5	Horizontal	Erosion nil to slight
2.1 – 5	4.6 – 11	Gentle	Slight, diffuse erosion. Shett wash. Initiation of rills. Cold solifluction.
5.1 – 10	11.1 – 22	Moderate	Moderate to intense erosion. Initiation of linear erosion. Rill wash or rill development.
10.1 – 20	22.1 – 44.5	Steep	Intense erosion. Frequent linear erosion. Incipient gullies.
20.1 - 30	44.6 – 67	Very Steep	Moderately steep, frequent gullies. Mass movements, creeping.
30.1 – 45	67.1 – 100	Bluff	Colluvium, intense solifluction.
> than 45	> than 100	Steep Bluff to Vertical Cliff	Slope failure and landslides. Corridors of frequent rock fall.

Source: Clasificación de Pendientes. Araya, Vergara and Borgel 1972; Young 1975; and Ferrando 1993. Modified and presented by MESINA 2003.

4. A field visit was conducted on Tuesday, November 11, 2008 to verify the information collected in the office and obtain a photographic record of the sectors where the transmission lines would be located, including their geological and geomorphological features and sectors subject to gravitational processes.

3.3 Natural Risks

Natural risks refer to the likelihood that a natural phenomenon may occur in a given time and place that is potentially dangerous to the community and that could harm people and/or property (Mardones and Vidal, 2001).

The likelihood that these natural risks will occur depends on the type of risk. In this context, two types of risk are identified: geological risks related to the existence of faults, and geomorphological risks that can be inferred from the slope map and observations made in the field.

4 DEFINITION OF THE AREA OF INFLUENCE

The Area of Direct Influence (ADI) of the Project is determined by the geological and geomorphological units on which the transmission towers and electrical substation expansion will be sited.

The Area of Indirect Influence (AII) corresponds to the Colorado Canyon geomorphological unit, some scree slopes and alluvial terraces, and the so-called flat areas where the Project works will be located.

5 GEOLOGY

5.1 General Geology of the Area of Study

The electricity transmission system analyzed herein will be located in a canyon of the Andean Mountain system east of the city of Santiago, specifically on a terrace of the Colorado River valley. The area contains outcroppings of rock, the age of which ranges from the Carboniferous to the Recent Period.

The transmission lines will be built in an area with Paleozoic, Mesozoic, and Cenozoic rock, although the Project works will mainly be sited on Upper Tertiary Cenozoic and Quaternary rock. These rocks have a high degree of exposure and correspond mainly to volcanic strata, and continental volcanic-sedimentary rock such as tuff, volcanic breccias, lava and sediment placed discordantly on previous terrain, and to sedimentary deposits and glaciofluvial infill.

5.2 Geological Units present in the Area of Study

The vast majority of the Project sites are located on sedimentary, volcanic and continental rocks, mainly from the Quaternary Era and in some cases from the Upper Tertiary.

The geological units identified in the Project area correspond to:

- Fluvial, glaciofluvial, alluvial-lacustrine, and gravitational deposits (Q)
- the Farellones Formation (Tsf).

5.2.1 Fluvial, glaciofluvial, alluvial-lacustrine and gravitational deposits (Q)

The fluvial, glaciofluvial, alluvial-lacustrine and gravitational deposits are associated with infill of the Central Depression. Alluvial deposits form large terraces in the valleys of the Maipo River. In the figure below, alluvial deposits can be observed near the Colorado River.

Figure 1: Deposits belonging to Unit (Q), near the Alfalfal S/S

Source: Prepared by the authors.

i) Fluvial and Alluvial Deposits

Fluvial deposits above 1,500 m.a.s.l. are glaciofluvial, with no variation in their essential characteristics. The towers that will be sited on this unit are below this altitude, and therefore only fluvial deposits entrained by the river to form terraces near its channel will be considered (Thiele, 1980).

ii) Lacustrine Deposits

These deposits, which are more limited in size, accumulated on lakes left behind by frontal moraines or are deposits produced by the breakdown of the valleys. Mainly, they are deposits of silt and clay that are found in layers.

iii) Gravitational Deposits

These deposits are the most abundant in the area of study. The most important ones are those caused by creeping of slopes and of the soil to form detritic accumulations at the base of slopes with a low gradient (Thiele, 1980).

The deposits and materials produced by the slopes become more important at higher altitudes in the interior of the valleys; i.e. more of them are found as the altitude above sea level increases. The newest material is completely loose and although many of the deposits are stable, others could generate gravitational processes.

5.2.2 Farellones Formation (Tsf)

The name of this formation derives from the sequence of layers outcropping in the area surrounding the locality of Farellones and it is defined as a major unit comprised of classic terrigenous sediment, andesitic, ryolitic, and basaltic lavas and pyroclastic rocks alternating with sediment derived from the decomposition of these effusive rocks.

The sequence is composed of lava, tuff, and ignimbrites with intercalations of breccias. The lava is clearly predominant over the tuffs and breccias. Alternation of finer clastic volcanic rocks in 4 to 5 meter segments produces a marked stratification in the series, which makes it easy to distinguish from the Abanico Formation, which has a more solid appearance when observed in the field.

The lapilli tuffs are a light grey color and display clasts 4 to 12 mm in diameter, ryolites and porphyric andesites in a fine cineritic matrix. The ignimbrites are a light grey color and display a fluidal texture, with clasts of andesite and obsidian. The volcanic breccia contain angular fragments more than 2 mm in diameter. Locally, these rocks seem altered to clay, limonite, hematine and silica. The lacustrine sedimentites correspond to finely stratified conglomerates, sandstone and lutite, and the outcrops are observed west of Laguna Negra and in the moraine of the same name.

The estimated age of this formation dates it to the Miocene. It is distributed north to south, outcropping in better stratified, less deformed layers than those of the Abanico Formation, and maintaining a sub–horizontal position to a maximum inclination of 25º. In the sequence, slight angular disconformities can be observed that seem to be very common in this kind of volcanic unit.

6 GEOMORPHOLOGY

6.1 General Geomorphology of the Area of Study

The Project will be built in Central Chile, which from a geomorphological perspective presents three basic units that are all well-defined: the Andes Mountains, the Intermediate Depression and the Coastal Mountain Range.

In this area, the Andes Mountains reach up to around six thousand meters, while the Coastal Mountain Range reaches up to two thousand meters in height. The Intermediate Depression is formed of closed basins infilled with glacial-fluvial-volcanic sediment carried and deposited by rivers. The most characteristic basin is the Santiago basin.

The glaciation of the Quaternary period also played a major role in the morphology of Central Chile, as glacial forms predominate in the morphology of the Andean highland valleys, while the surface forms of the longitudinal valley (the so-called Intermediate Depression) are composed of sedimentation from glaciers and glaciofluvial deposits.

The highest peaks in the area are the Nevado Juncal (6100 m), the Nevado de los Piuquenes (6017 m), Cerro Marmolejo (6110 m) and Volcan San José (5880 m).

The Project will be located between 750 and 1500 m.a.s.l., in the limited horizontal zone of these mountains, called the piedmont, more precisely in the Colorado Canyon.

6.2 Geomorphological Units Present in the Area of Study

In general terms the Municipality of San José de Maipo lies within the Andes Mountains and presents a relief that is relatively recent in origin.

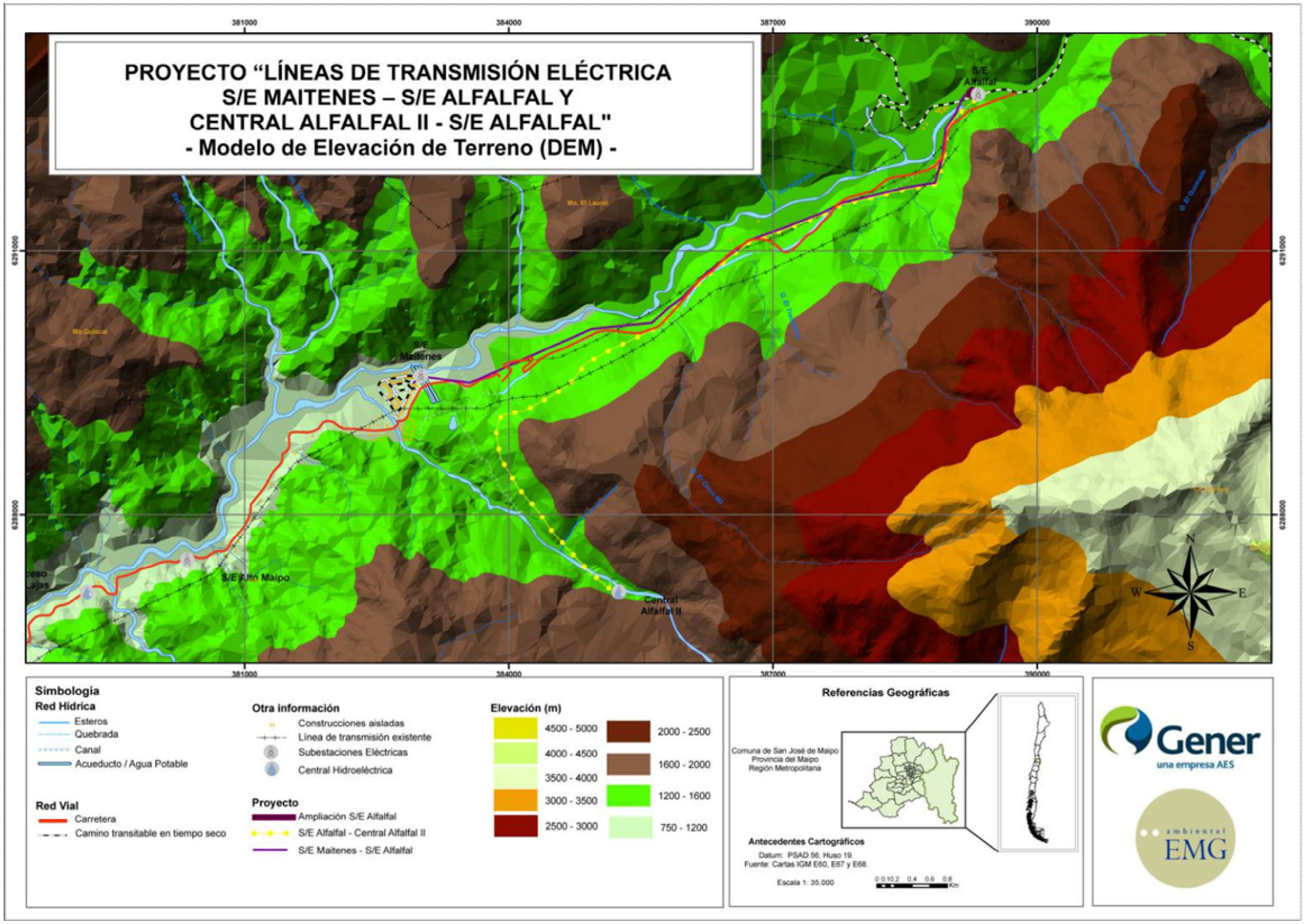
Most notably, this municipality displays a toe-thrust that is expressed in a rugged mountainous landscape with a system of mountain chains and deep valleys called "cajones" (canyons), among these the canyon of the Colorado River, where the Project will be located.

In general, the Municipality of San José de Maipo presents the following geomorphological features: mountains, piedmont, fluvial terraces, ravines, riverbeds and waterways. The Project will be located in the piedmont canyon.

Figure 3 displays the canyon of the Colorado River, the exposure of its steep slopes and the layout of the Project, which will be located on northern-facing slopes where the relief is less pronounced, i.e. where it has a more terraced configuration owing to the heavy accumulation of sediments. The southern-facing slope can be distinguished by its tone, which is darker than the northern-facing one, and in general has a more vertical slope.

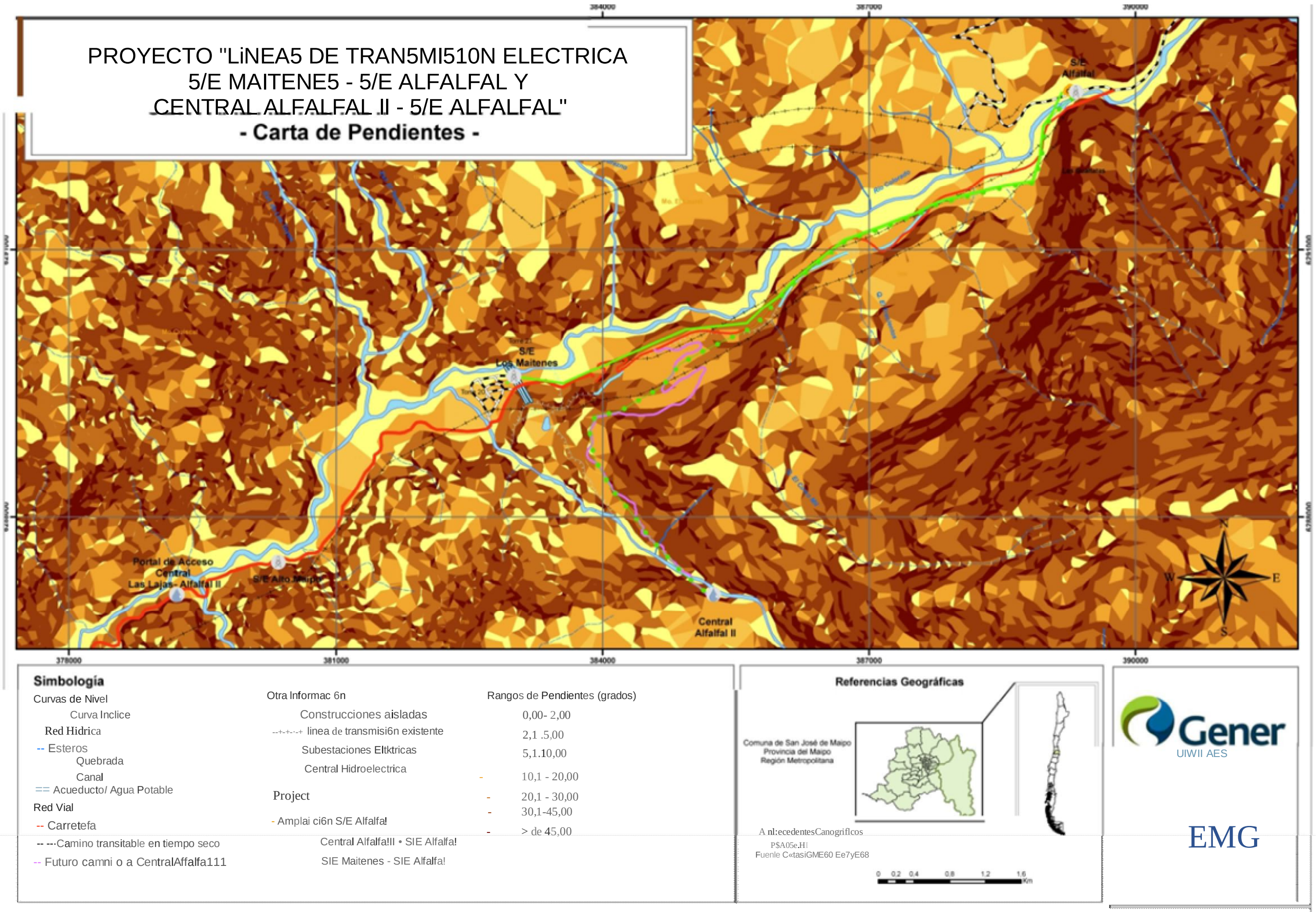
The slope map presented in Figure 4 displays the inclination of the terrain in which the Project will be sited, in order to contextualize potential risks.

Figure 2: Digital Modeling of Elevation



Source: Prepared by the authors based on IGM maps E60, E67 and E68 (1:35,000 scale)

Figure 3: Slope Map



Source: Prepared on the basis of IGM maps E60, E67 and E68 (1:35,000 scale).

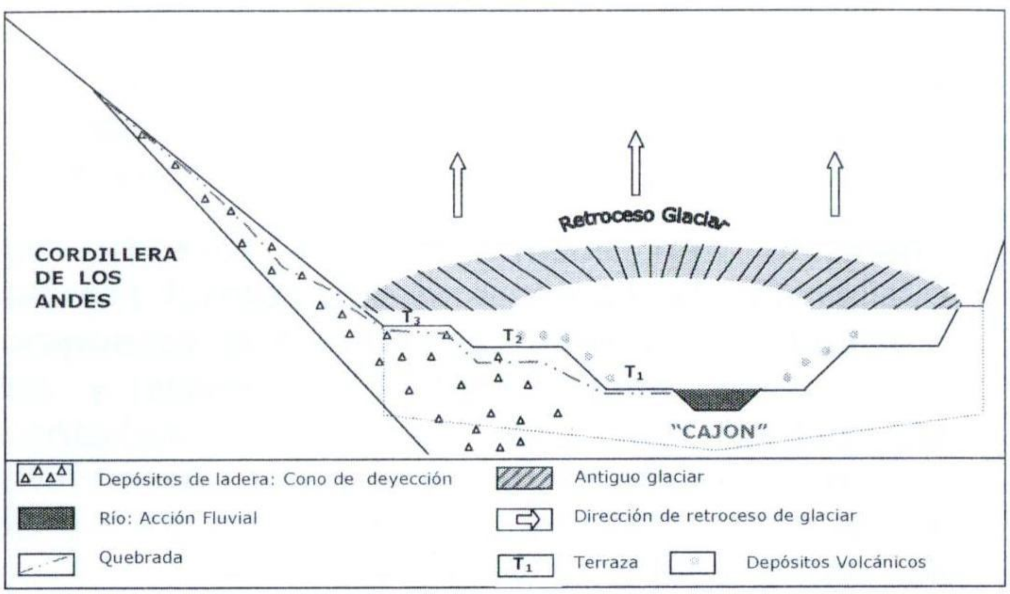
In general, it can be observed that the Project will be located on the flatter zones of the Colorado canyon, where a series of deposits have accumulated; however, some vertices of the transmission line are located in areas with steeper slopes.

Overall, less than 50% of the Project is located in flat zones with a gradient of 0-10%, and most of it is located in sectors with a moderate gradient on northern-facing slopes (sunny side) at altitudes ranging from 750 to 1500 m.a.s.l., which corresponds to a foothills zone.

The section of the line running between the Alfalfal II Power Plant and the Alfalfal S/S is located mainly in areas with a steep gradient and on the steep scree slopes of the Aucayes ravine.

For its part, the geomorphology of the Colorado Canyon was formed as a result of erosive processes, scouring, and tectonic processes that have generated different foldings and separations in different geological ages. Furthermore, the characteristics of the current relief originated in what Börgel calls a "glaciofluvial-volcanic" process. The diagram below illustrates the forces in action that have formed the system of canyons in this zone, including the Colorado Canyon.

Figure 4: Canyon Formation. Diagram of the Glaciofluvial-volcanic Process



Source: Börgel (1986).

The retreat of a glacier led to the formation of an incipient valley as a result of the erosive forces associated with this phenomenon. This retreat produced the main features of the relief, such as the steep slopes of rugged mountains rising beside a deep canyon. Meanwhile, the river generated fluvial action that both eroded and accumulated material, and this dual action formed different levels of terraces (T1, T2, and T3 in the diagram). The action of depositing material on mountainsides has been very dynamic, between linear runoff and the violent arrival of lateral fans that, perpendicular to the main course of the river, have changed it by interrupting the regular geomorphological sequence. The deposition of these materials has formed the alluvial fans and where these join they have formed scree slopes. There is also deposition of volcanic material, which has helped to form different levels of deposition, which has made the relief even more complex. Vulcanism forced masses of material to flow down into the narrow lower valleys, filling them and creating ravines and tributary rivers, different base levels and water bottlenecks.

Thus, the geomorphology of the zone has been the result of the joint action of processes such as the accumulation and erosion of deposits over the years, and one can distinguish throughout the canyon the outline of different geomorphological features that will be described in detail below.

6.2.1 Alluvial fans and debris cones

Alluvial fans and debris cones are the result of the accumulation of sediment in the piedmont of the mountains or simply in the lower zones of slopes. They are produced by erosion and the breaking off of material from higher zones where the rock separates due to freezing-unfreezing processes, and is dragged lower down by the action of gravity or by water runoff.

Alluvial fans are associated with the accumulation of sediments caused by the action of water; while debris cones come from the sliding of sediments under the force of gravity.

The photograph below shows a debris cone that is located on a south-facing slope at the Alfalfal bridge, in front of the Project site. It is part of the Farellones geological formation.

Figure 5: Profile of the debris cone present on the south-facing slope of the Project site, at the Alfalfal bridge.

Source: Prepared by the authors.

Both geomorphological units can be distinguished by the position and size of the sediments. The debris cone can be distinguished by its clasts or rocks and the positioning of generally larger sediment below finer, smaller sediment. This is a result of gravity pushing these kinds of deposits with more energy. The alluvial fan is distinguishable because its finer deposits have been carried to the base of the cone through the action of water, and the larger clasts or deposits remain above the finer clasts.

6.2.2 Scree slope

The union of these cones is called the scree slope. Half of the Project is located on scree slopes with gradients ranging from moderate to steep. A good part of these formations has been colonized by vegetation found in this sector.

6.2.3 Ancient slides

Slides and collapses are gravitational movements of coherent material displaced over a surface at a high speed. They occur when a mobile surface that is overlaying an immobile surface, which could be a joint, a fault or stratification plane parallel to the slope, gives way.

In some areas of the Project ancient slides that are now consolidated or cemented can be observed.

Figure 6: Slide of a consolidated rock mass with alluvial fan below

Source: Prepared by the authors.

The figure above shows a rock mass that corresponds to an ancient slide that is now consolidated, and below it, an alluvial fan with some colonization of vegetation. This image was taken in the Alfalfal sector.

The section of the transmission line included in the Project that runs between the Maitenes S/S and the Alfalfal S/S will also be located on a north-facing slope of the Colorado Canyon. Nevertheless, it will also run along flat areas that correspond to a second-level terrace that was formed later than the current river terrace. This terrace can be called an alluvial terrace, as it was formed from the accumulation of deposits. The alluvial plain or terrace where part of this section of the line will be located corresponds to a system of stepped terraces, with successive incisions of scree and flat-horizontal surfaces that testify to the ancient fluvial plains abandoned by the river.

The section of the planned transmission line that will run between the Alfalfal II Power Plant and the Alfalfal S/S is also located on an upper terrace of the Aucayes Stream, specifically on the north-facing slope. There is also a segment of the line that runs along the south-facing slope, which has a very steep gradient.

6.2.4 Alluvial terraces

This is an area of flat land in the form of an embankment that has been leveled by sedimentary fill carried and deposited by a fluvial current.

7 NATURAL RISKS

Natural risk are deemed to be present when a natural phenomenon could affect a human population or the normal course of human activities, including infrastructure and installations associated with those activities.

Geological risks include the probability of seismic movements in zones near the Project or in its radius of influence (between parallel 33º 00' and 33º 30' and longitude 70º 30' and 71º00'). This likelihood is inferred from the significant seismic movements that have already been recorded and the faults that exist in the zone.

Geomorphological risks correspond mainly to processes that shape geoforms that are described in the section on geomorphology included in the Project, and include slides and collapses, among other events.

7.1 Geological Risks

The occurrence of major earthquakes is caused by the sudden release of accumulated elastic or deformation energy at the point where tectonic plates come into contact with each other. The plates are then displaced as a result of the convective effects of the redistribution of thermal energy.

Major earthquakes in Chile are recorded by the Seismological Service of the Universidad de Chile, which capture all seismic events having a magnitude greater than 7.0 on the Richter Scale. The earthquakes considered in this analysis are those in a 100-km radius of the Project area, approximately.

The following table shows destructive seismic events that have been registered from the year 1570 to May 2005 for the area of study, specifically between the coordinates 33º 00' and 33º 30' Latitude South and 70º 30' and 71º00' Longitude West.

Table 2: Most destructive seismic events recorded in the zone from 1570 to 2005.

Date	Magnitude (Richter Scale)	Location (lat/long)
February 8, 1575	8.3	33º40´ / 70º61
May 13, 1647	8.5	35º / 72º
July 8, 1730	8.7	33º050 / 71º63
November 19, 1822	8.5	33º050 / 71º630
September 26, 1829	7.0	33º050/71º630
April 2, 1851	7.1	33º320 / 71º420
August 16, 1906	7.9	33º000 / 72º00
March 28, 1965	7.4	32º418 / 71º100
July 8, 1971	7.5	32º511 / 71º207
October 16, 1981	7.5	33º134 / 73º074

Source: http://ssn.dgf.uchile.cl/home/terrem.html. Servicio Sismológico, Universidad de Chile.

In the Project's area of influence, 10 major seismic events have been registered by the Seismological Service of the Universidad de Chile, and here, as in other parts of Chile, it is possible that more seismic events could occur.

Based on the information provided in geological map 39 of Santiago (Thiele, 1980), no faults are located along the planned route of the transmission line.

7.2 Geomorphological Risks

It is important to note that geomorphological risks correspond to morphogenetic processes themselves and are associated with the geomorphological features present in the area of study, such as debris cones and alluvial fans, ancient slides and alluvial terraces.

Thus, risks can be classified as collapses, slides, flows and slow movements. The first of these involves material falling freely down a slope as a result of gravity. This process leads to the formation of debris cones, for example. In the area studied, these processes are present particularly in the southern-facing slopes, while on the north-facing slopes (where the Project will be sited) there is less likelihood that they will occur, although in some stretches of ravines this kind of downhill movement of material is does occur.

Flows have a similar logic to that of the abovementioned risk, but in their case sediment is displaced as a fluid because of the presence of water. Events of this kind can occur in winter when snowfall and rainfall are higher. These flows are also called mud flows and they occur when the material on the slope contains excessive water and flows into the bottom of the valley in a catastrophic event

Slides are movements that occur when a mobile surface overlying an immobile surface slides off with the force of gravity.

8 IDENTIFICATION AND ASSESSMENT OF IMPACTS

Based on the characteristics of the Project and its location, no significant effects are expected on the Geology and Geomorphology component during its construction and operational phases. The technical basis for this is explained below.

8.1 Construction Phase

The works associated with the construction of the Project do not involve any relevant effects on the Geology and Geomorphology component, given that the works required constructing the foundations of the transmission towers will be limited and will not compromise geological or geomorphological units in the Project area.

In effect, the earth moving needed to implement the Project is related to the construction of the foundations of 61 mounted transmission towers (considering both lines). To fully implement these works, 1,300 m3 of material will be moved, close to 50% of which will be used as fill for the same foundations. The remaining material will be distributed in an orderly manner near the foundation sites[1], following the original shape of the terrain without altering the topography.

In addition, restoration measures are envisioned to leave the terrain in a condition similar to its prior condition. A series of forestry measures are envisioned to care for the native vegetation in the buffer strip that runs underneath the line, as well as other criteria indicated in Annex 2. In addition, the land will not be left bare, in order to minimize the potential for erosion from precipitation in the area.

8.2 Operational Phase

The operation of the Project does not envision activities that will directly alter the Geology and Geomorphology component, as the activities involved will correspond mainly to maintaining the tower structures.

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1 There will be a layer of excess material approximately 10 cm thick at the tower sites, considering that each tower will occupy an area of approximately 12x12 m.

Thiele, R. (1980): Carta geológica de Chile Nº39, Hoja Santiago, región Metropolitana. Instituto de Investigaciones Geológicas. Scale 1:250,000.