ANNEX 4
GEOLOGICAL AND PALEONTOLOGICAL HERITAGE
ALTO VOLCAN SECTOR

COMPLEMENTATION OF BACKGROUND INFORMATION IN "JANUARY 2009 REVIEW"

1 INTRODUCTION

This report * complements the information in the environmental baseline on natural properties or sites of scientific and cultural interest, particularly paleontological and geological, known or recorded in the area identified as the Alto Volcán sector. The PHAM envisages the location of some surface works in that sector. This is a source of concern to the Authorities, in the face of any major interference of the works with sites of paleontological and geological interest, such as sedimentary units of the Upper Jurassic Age (Río Damas Formation), which contain significant components of a geological type (e.g. desiccation cracks; ripple marks; stratification of varied type) and of a paleontological type (possible vertebrate tracks).

Properties of an archaeological anthropological, paleontological or anthropo-archaeological type are protected under Law No. 17,288 on National Monuments and its Regulations on Excavations and/or Archaeological, Anthropological and Paleontological Prospections approved by D.S. 484/90 of the Ministry of Education.

It should be pointed out that because of the nature of fossils (remains or evidence of organisms from the past, generally abundant in the case of invertebrates) and of the paleo-environmental significance of the sedimentary units in which they are contained, available information about their location is generally based on macro-zones or geological formations of great extent or territorial area instead of consisting of geo-referenced records or findings of fossils or specific sites of interest.

The scientific and cultural importance of the paleontological properties has been recognized by the Owner of the PHAM, and it has led in practice to special care in defining the land that will be intervened by surface works in the Alto Volcán sector, in order to protect and avoid the deterioration of the properties recorded or known thus far. The Owner has also assumed a commitment to expand knowledge of the zone before starting the projected works, carrying out prospective studies in the Alto Volcán sector, accompanied by proper safeguarding of the sites recorded there as well as any possible new findings that might take place as a result of the development of works of the PHAM. These activities will not only contribute to the maintenance of the properties mentioned but will enhance the value of the sites where they are located.

This report provides a synthesis and assessment of the available information about the heritage components whose recognition and protection is framed in the laws No. 17,288 (National Monuments) and 19,300 (Environment), which has been reviewed and complemented with a field campaign carried out on January 1 and 2, 2009.

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In a second phase to be developed before executing the projected works in the Alto Volcán sector, studies will be made in greater detail, which are described in section 6.1.1 of this report.

In the framework of processing the EIS, this report synthesizes the available knowledge about the most significant materials or components to the Earth sciences that can be recognized in the area of the PHAM and its surroundings and are part of the natural non-renewable and scientific, cultural heritage of the country. It also mentions the preventive and contingency actions that will be carried out to minimize the effects this intervention may have, especially where the heritage significance of the materials or components present in that place justify it.

2 GENERAL BACKGROUND INFORMATION

2.1 LOCATION OF PROSPECTED AREA

The area referred to in this report is located at the head of the El Volcán river (commune of San José de Maipo, Cordillera Province, Metropolitan Region), in the area where the El Morado, Las Placas, Colina, and La Engorda streams come together to form the El Volcán river (Figure 1 and attached drawing). In the context of the PHAM, the place is known as the "Alto Volcán" sector (UTM N6262000 – N6259000 and E405000 - E407000), and it is identified with the access to the Arenas valley. The Alto Volcán sector is located approximately 6 km from the locality of Baños Morales.

2.2 GEOGRAPHIC CHARACTERIZATION

The Alto Volcán sector, El Morado, Las Placas, Colina, and La Engorda Streams correspond to an area of confluence of three affluent sub-watersheds to the Volcán River. The most relevant peaks in the sector are the San José Volcano, located to the east with an altitude of 5,856 m.a.s.l. and the Marmolejo mountain in the northeastern sector, at an altitude of 6,108 m.a.s.l., which also has a glacier on its peaks.

On the lower course of the La Engorda, Colina, Las Placas, and Morado streams one can currently see a number of materials generated by processes involving sizeable landslides corresponding mainly to landslides and debris flows (mudslides), which are represented by soils of very heterogeneous granulometry, with a predominance of mega-blocks of rocks with diameters of twenty meters. The origin of these mass waste movements is associated with the instability of the rocks assigned to the Damas River Formation, which surfaces in the nearby mountain chains.

The area shows a dominance of morphogenesis over pedogenesis (predominance of erosive activity and wear). Springs with free, rocky faces and slope are distinguished fundamentally, which show important stabilization processes in some sectors (slopes with eastern exposure in the sector where El Morado – Las Placas flow together), and considerable gravitational activity in others (Valley of the Colina - La Engorda stream). No generalized erosive features are observed in the stable springs or any features that would lead to an assumption of surface instability in the form of gravity cones.

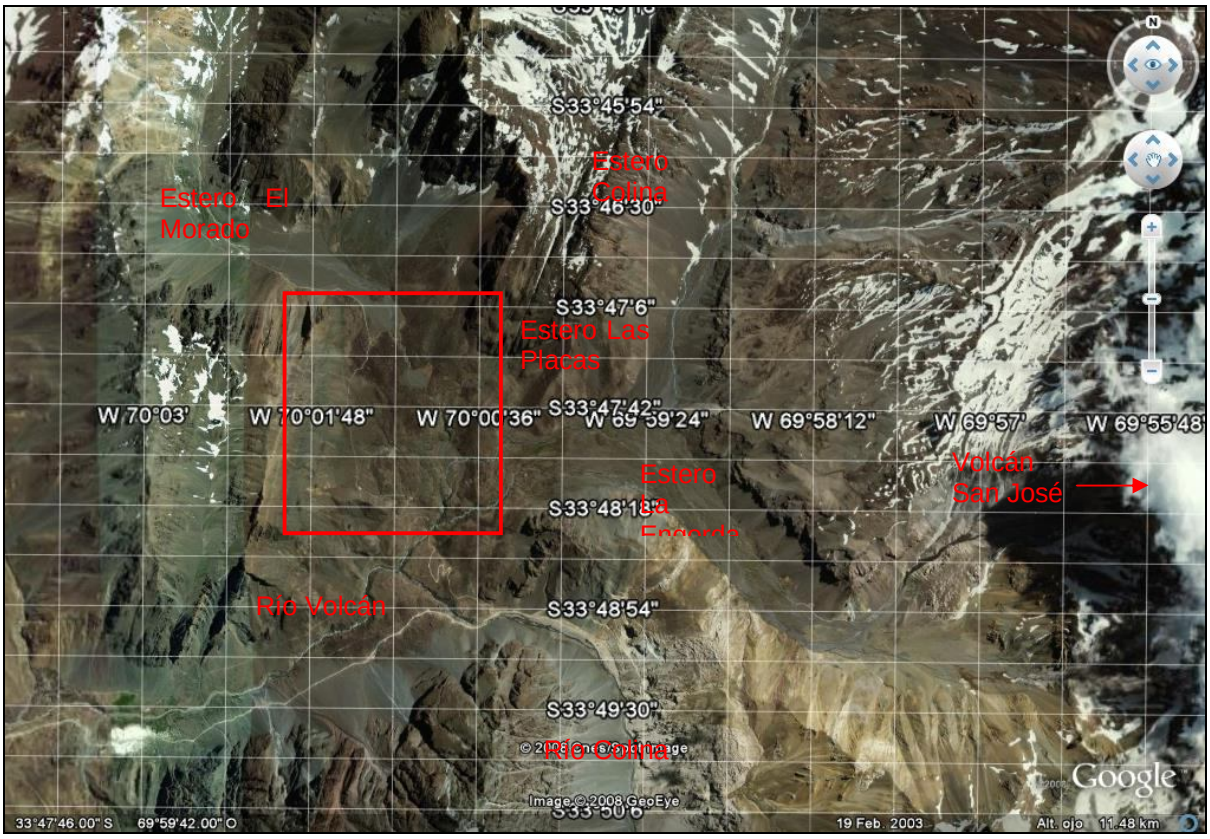
On the contrary, the springs are covered with herbaceous and shrublike vegetational formations in significant densities. This vegetation is small in size, and it partially covers the smaller blocks in the valley. This observation depends on the period observed (January 2009) since the vegetation is seasonal. In any case, high levels of erosion are not observed in the rocks that could be caused by the expansion of vegetation.

The La Engorda, Colina, Morado, and Las Placas streams have a snow regime with an increase in maximum flow during the months of thaw. They are fed basically by the snow on the high peaks of the snowcapped mountains in the sector of the San José Volcano and the Marmolejo glacier.

2.3 ANTHROPIC MODIFICATION

No important modifications of anthropic origin are seen in the Alto Volcán sector, except for the access roads to the valley itself, including the bridge over the El Morado Stream. The zone is widely visited by mountaineers and other individuals, who generally visit the area or stay overnight to camp out.

Figure 1
Alto Volcán Sector, access to the Arenas valley. Area where works are located appears in red square (approximate surface area: 5 km^2)



This area is a relatively small sector of land with approximately 5 km^2 of surface area. Numerous geological and paleontological materials or objects that might have, or do have, heritage value stand out here; the former, either from a lithological, geomorphologic, structural, and/or landscape point of view. This marked geological condition, accentuated by the imposing structure of the lithological units (formations) that surface there (and manifest an intense cortical tectonic deformation) makes the sector not only an important access to other highly attractive mountain areas, but also means it is frequently visited by groups of university students in different courses of study and by individuals who love nature.

2.4 SYNTHESIS OF WORKS PROJECTED IN THE ALTO VOLCÁN ZONE

A detailed list of the works that the PHAM will develop in the Alto Volcán zone is shown below (Tables 1 and 2), as indicated in Chapter 2 of the EIS.

Table 1
Surface Works of the PHAM in Alto Volcán sector

Work/installation	Starting coordinate		Surface area (Hectares)	Description of the Work
	East Coord. (UTM)	North Coord. (UTM)		
La Engorda Water Intake	407468.28	6259751.10	0.1	*High mountain water intakes,* which consist of a sump (or grated chamber) placed in the sense of the runoff and located in the streambed so the water is captured by the bottom of the bed. The sump discharges the water that is collected into a pipe, which in turn carries it to a grit chamber designed to remove particles with a diameter over 0.3 mm (see section 2.2.2 of the EIS).
Las Placas Water Intake	406780.41	6260782.87	0.05	
Colina Water Intake	407181.00	6260081.00	0.15	*Lateral water intakes,* which refer to the construction of a barrier facing the runoff. Adjacent to the lateral intake, there are two sluice gates. The lateral intake consists of a grated panel that discharges the collected water into a transition canal that ends in a concrete pipe, which carries it to the grit chamber (see section 2.2.2 of the EIS).
El Morado Water Intake	405768.18	6261231.16	0.21	
Camp and Installation of No. 1 Work Site – El Volcán Sector	405492.00	6260429.00	1.91	It will have an approximate staff of 200 workers. It will be equipped to accommodate the personnel that will work on the construction works; it will have bathrooms, potable water, first-aid rooms, a cafeteria and recreation areas (section 2.3.2.4 of the EIS).
Muck Disposal Site No. 1 - Volcán V1	405385.00	6260845.00	1.84	Located near the Entrance to the Volcán Tunnel, this site is laid out below the road that leads to the El Morado Water Intake. It is envisaged that material from the excavation of the Volcán Tunnel and surplus material from construction of the access road will be deposited (see detail in section 2.3.2.6 and Annex 6 of the EIS).
Entrance to Volcán V1 tunnel + Work Front	405250.00	6260880.00	1.00	Excavation front where equipment and machinery will be installed that is necessary for construction of the El Volcán Tunnel (section 2.3.2.2 of the EIS).

Table 2
Linear Works of the PHAM in Alto Volcán sector

Work/installation	Starting Coordinate		Ending Coordinate		Length (km)	Description of the Work
	East Coord. (UTM)	North Coord. (UTM)	East Coord. (UTM)	North Coord. (UTM)		
Engorda-Colina Aqueduct	407434	6259751	407231	6260071	0.47	Carries the water collected at the La Engorda water intake through a circular concrete pipe measuring 1.4 m in diameter and 470 m long to the Colina water intake, which is connected to the Volcán aqueduct that starts at this water intake. This aqueduct will be buried in a ditch, which will be filled later with granular material so the surface runoff and runoff under the surface area that feeds the summer pastures in this sector is not interrupted. Finally a layer of topsoil will be put in place (section 2.2.1 and 2.3.2 of the EIS).
El Volcán Aqueduct – Section I (Colina - Las Placas Water Intake)	407127	6260092	406765	6260780	1.76	Consists of a circular concrete pipe measuring 2.4 meters in diameter and 1,760 m long that carries the contribution of the La Engorda and Colina water intakes to section II of the aqueduct that starts at the Las Placas water intake (see Figure 2.2.10 and section 2.2.1 and 2.3.2 of the EIS).
El Volcán Aqueduct – Section II (Las Placas – El Morado Water Intake)	406765	6260780	405817	6261091	1.06	Consists of a circular concrete pipe measuring 2.4 meters in diameter and 1,060 long that carries the contribution of the La Engorda, Colina, and Las Placas water intakes to section III of the aqueduct that starts at the El Morado water intake (see Figure 2.2.10 and section 2.2.1 and 2.3.2 of the EIS).
El Volcán Aqueduct – Section III (El Morado Water Intake– Entrance to El Volcán Tunnel)	405817	6261091	405250	6260880	0.65	Consists of a concrete casing, 2.6 x 2.6 meters and 646 meters long, that carries the contribution from all the water intakes in the system to the El Volcán tunnel (see Figure 2.2.10 and section 2.2.1 and 2.3.2 of the EIS).
Existing service road	-	-	-	-	7,1	Connects the zone of water intakes and the entrance to the El Volcán Tunnel and Route G-25 (see section 2.3.2.5 of the EIS).

3 SYNTHESIS OF GEOLOGICAL AND PALEONTOLOGICAL KNOWLEDGE ABOUT THE ALTO VOLCAN SECTOR

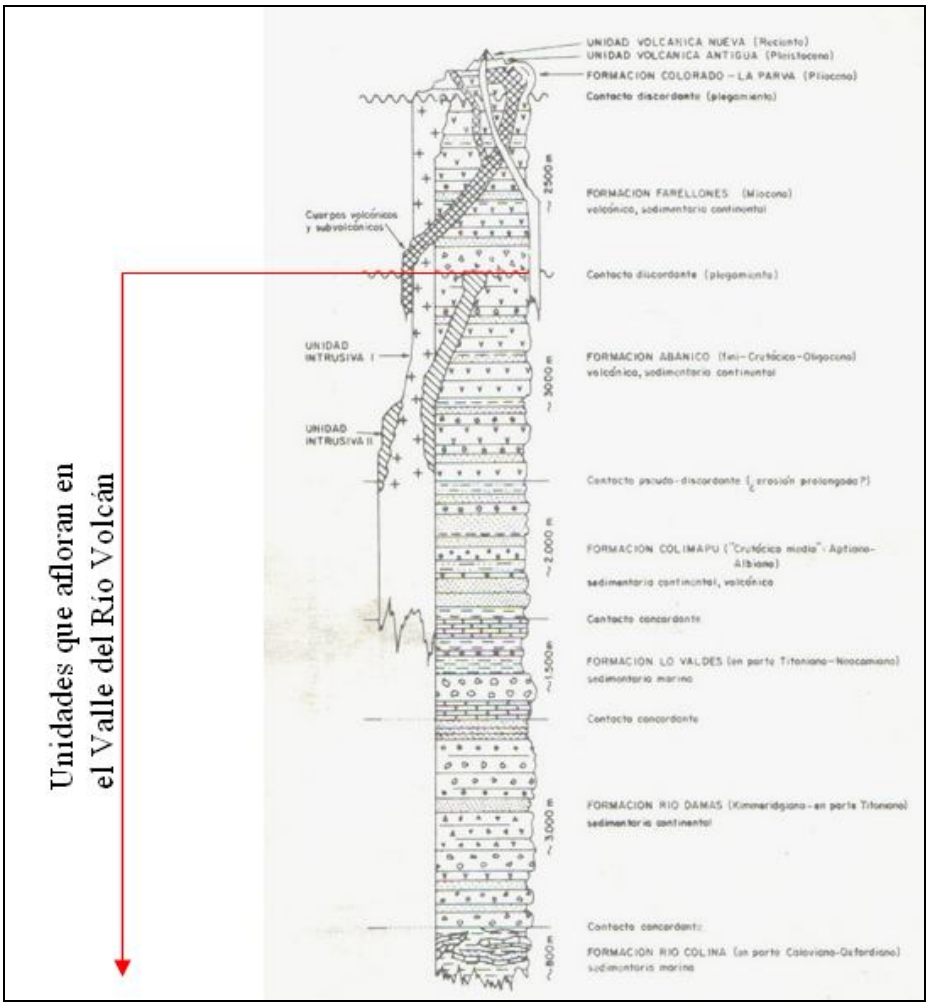
3.1 INTRODUCTION

The first published geological study about the valley of the Volcán river was the study carried out by González (1963), who made a lithostratigraphic characterization of the area. A micro-paleontological study by Martínez and Osorio about the Colimapu formation, located opposite the Morales ravine, was published the same year (1963). Subsequently, Biró-Bagóczky (1964) made a paleontological and stratigraphic study of the Lo Valdés formation, in Lo Valdés. Finally, Thiele (1980) published the Santiago Sheet on a 1: 250,000 scale, which includes the area of the Volcán river valley. Other works published on the geology of the zone of the Volcán are the structural studies of the inverted fold of the Abanico formation east of San Gabriel, done by Baeza (1999), and the “Meso-Cenozoic” contact in the Colimapu formation, done by Bustamante (2001). Finally, there are several other unpublished documents, excursion guidebooks, etc., referring to the geology and especially the paleontology (mentioned above), which together provide a record of the geological and paleontological knowledge about the area of the valley of the Volcán river.

In the region of the Volcán river valley (between its confluence with the Maipo river in the sector of San Gabriel and the border between Chile and Argentina) volcanic and sedimentary stratified rocks (continental and marine) surface, profusely crossed by dikes and manto beds. These rocks are grouped, from east to west and from older to newer, in the Colina river, Damas river, Lo Valdés, Colimapu, and Abanico formations, which extend in bands in a N-S to N-NE direction (Figs. 2 and 3).

Due to the east-west direction of the longitudinal axis of the valley of the Volcán river, the series can be crossed almost orthogonally, which makes it possible to appreciate, in all its magnitude, the tectonic deformation that the whole sequence has been submitted to. A structural profile made of the length of the valley (Fig. 4) makes it possible to see first, from west to east, the San Gabriel batholith intruding on the Abanico formation, a unit that remains in a horizontal position. To the east, these same strata are folded in an anticline bent to the west, and then they rise again until reaching a vertical to sub-vertical position based on contact with the Colimapu Formation. This structural layout is maintained in the Lo Valdés and Damas River formations.

Figure 2
Generalized stratigraphic column of the Santiago Sheet, scale of 1:250,000 (Thiele, 1980)



A summarized description of the lithology and other characteristics of the rock units that surface in the zone are shown below. As indicated, from older to younger, they are:

3.2 COLINA RIVER FORMATION

This unit was defined by González (1963) in the Colina river valley (southeast of Alto Volcán) as “a group of fossiliferrous, marine, clastic sedimentary rocks, with alternating layers of strong evaporite lenses (gypsum).” Its base is unknown and its top corresponds to the matching contact with the Damas River Formation.

Figure 3
Geological map of the area to be intervened. The area of the PHAM is located in the red square; the name of the geological formations present is in red.

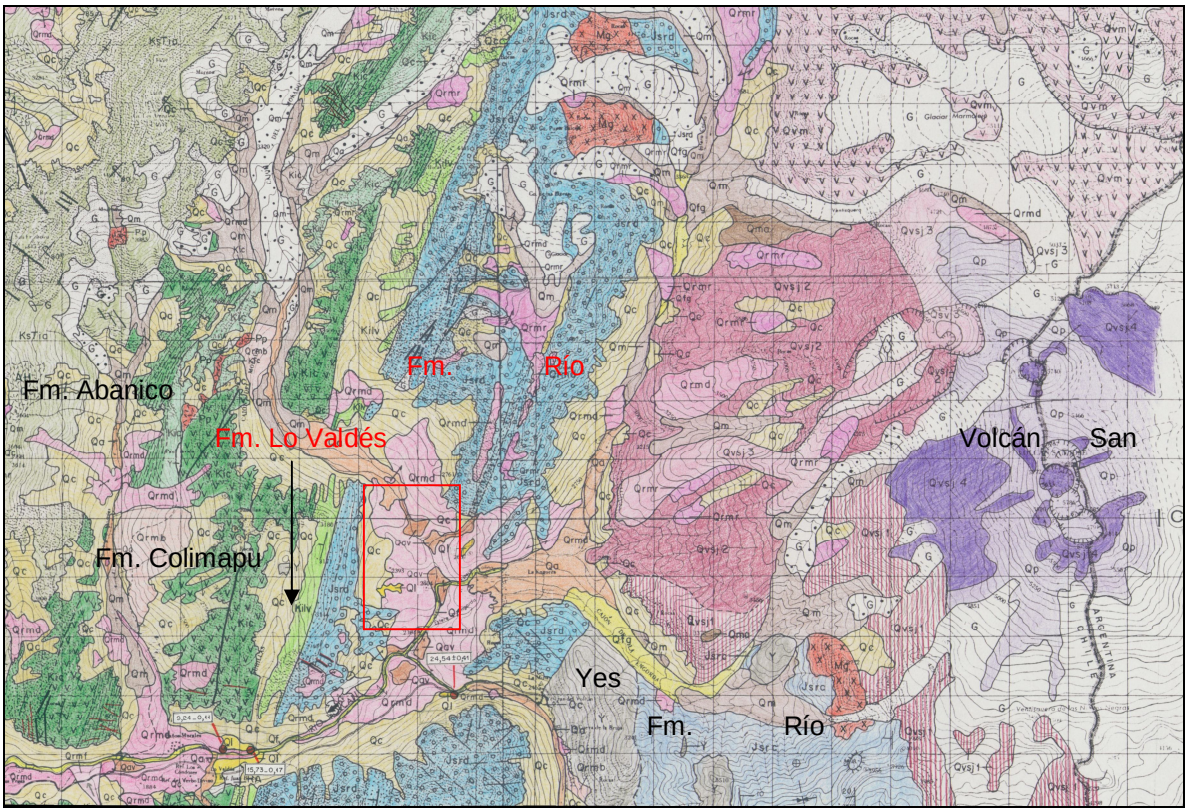
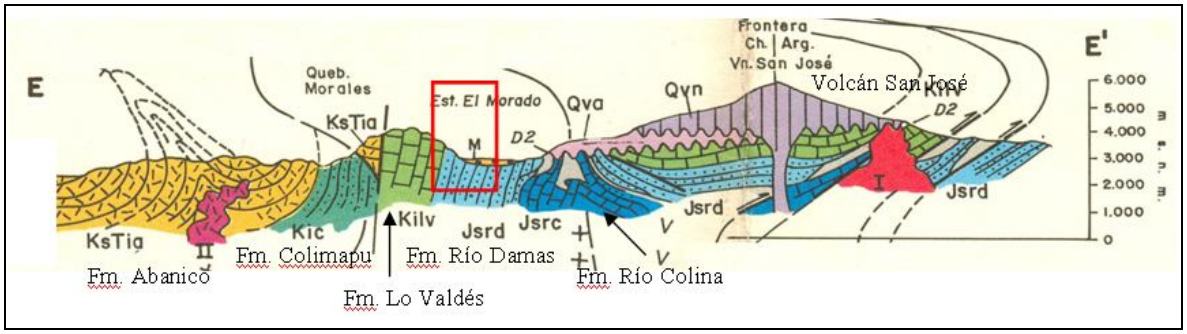


Figure 4
Geological profile of the Volcán River Valley. Area of the PHAM is in red rectangle.



The sedimentary rocks are presented in a sequence of limestone and dark gray, calcareous shale, finely stratified, fisible shale, sandstone and fine conglomerates and alternate layers of andesitic, volcanic rocks. The group shows inter-stratified lenses of gypsum. The gypsum is also seen in the shape of diapiric domes that intrudes and cut off the series. The sequence thus defined is recognized with regular normality only in the far southeastern end of the Alto Volcán sector, in its typical section (south of the San José Volcano), where a visible thickness of no more than 800 m has been estimated.

The fauna studied by Tavera (unpublished report, 1968) collected especially in the Azufre Stream and consisting of ammonites from the Perisphinctidae Family, made it possible to assign an Oxfordian Age (Upper Jurassic) to the higher levels. On the basis of new paleontological data (e.g. Alvarez et al., 1997), this formation would cover the Callovian – Oxfordian lapse.

The works projected by the PHAM in the Alto Volcán sector will be carried out in an area where this formation does not surface so the heritage properties like the fossils that are contained there will not be affected.

3.3 DAMAS RIVER FORMATION

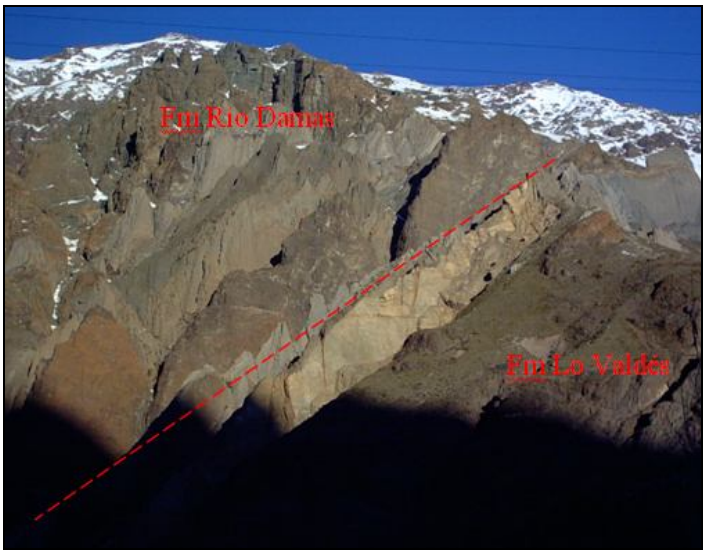
The Damas River Formation was defined by Klohn (1960) in the valley of the same name, in the Province of Colchagua (35º00 Lat. S; south of the Santiago Sheet), as a “complex of clastic sediments, fine and coarse, and of sporadic chemical sediments.” They are deposits formed essentially in land, subaerial, and lacustrine environments. For the Volcán zone the same nomenclature is used as this unit´s outcrops are found in the same sequence within the type section. Its base is concordant with the Colina River Formation, and its top is concordant with the Lo Valdés Formation (Figure 5).

The formation is presented as a succession of conglomerates and conglomeradic breccias, coarse to medium, reddish and green in color, with strong interleaving of sandstone and siltstone, light purple to brown in color. Abundant levels of andesitic volcanic rocks are also interleaved. Small lenses of gypsum are also recognized. The sedimentary rocks are characterized generally by the major presence of quartz (55 to 70%) and by iron oxide cement. The size of the clasts in the conglomerates is commonly 2 to 15 cm, although they occasionally exceed 50 cm.

It has been possible to define its age as it underlies concordantly the marine layers of the Lo Valdés formation (whose deposit started in the lower Titonian), and it overlies, also concordantly, the Colina River Formation (Oxfordian). A Kimmeridgian age was therefore assigned to it (Thiele, 1980).

Primary structures are observed in the finer sedimentary rocks, such as stepped stratification, desiccation or mud cracks, ripple marks, and probable impressions of raindrops, which indicate an environment of continental deposition (Figs. 6 to 9). The approximate strength of the group is 3000 m (Thiele, 1980).

Figure 5
Vertical strata of the Damas River Formation, on the southern slope of the Volcán river valley, in concordant contact (dotted line) with the Lo Valdés Formation



Structures have been recorded in this unit, unpublished, that seem to correspond to vertebrate tracks (Moreno, unpublished report, 2007). They are located in two isolated blocks on the west bank of the confluence of the Las Placas, Colina, and La Engorda streams (Figs. 1, 3, 10 and 11), which come mainly from the escarpment of the Mesoncito valley where part of this formation is exposed.

The possible fossil tracks (paleo-ichnite) would have been generated by representatives of different groups of vertebrates (Moreno, op. cit.). A group was assigned preliminarily to a dinosaur of the Sauropod Order (Fig. 12). Other impressions seem to correspond to a small lizard (Fig. 13).

The possible paleo-ichnites mentioned would increase the limited record of continental vertebrates known thus far in Gondwana in the Upper Jurassic. Other contemporary sedimentary units that show vertebrate tracks in Chile correspond to the Chacarilla Formation (Tarapacá Region), Strata of the San Salvador Formation (Antofagasta Region), and the Baños del Flaco Formation (Libertador Bernardo O´Higgins Region) (e.g. Moreno, 2008).

The works projected by the PHAM in the Alto Volcán sector include the excavation of a tunnel that will cross some sedimentary levels of this formation.

Figure 6
Desiccation cracks in fallen block from the Damas River Formation

Figure 7
Negative of desiccation cracks in fallen block from the Damas River Formation

Figure 8
Ripple marks of interference
(Moreno, unpublished report, 2007)

Figure 9
Ripple marks and raindrop marks
(Moreno, unpublished report, 2007)

Figure 10
Location of the blocks with possible vertebrate tracks.
Photo taken from the road to the waterfall of the La Engorda stream
(Moreno, unpublished report, 2007)

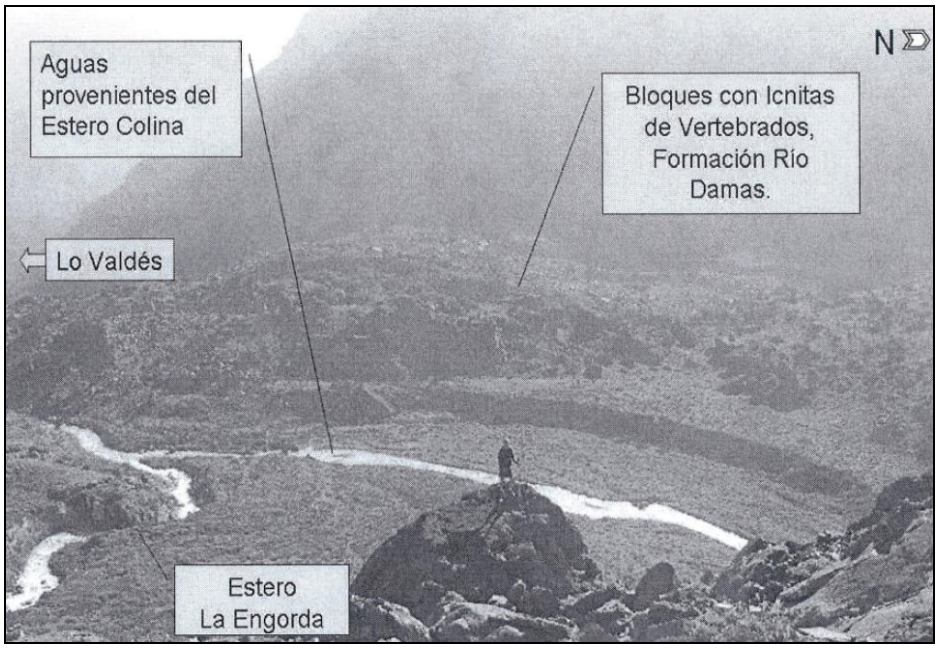


Figure 11
Position of the blocks with possible paleo-ichnites of vertebrates
(Moreno, unpublished report, 2007)

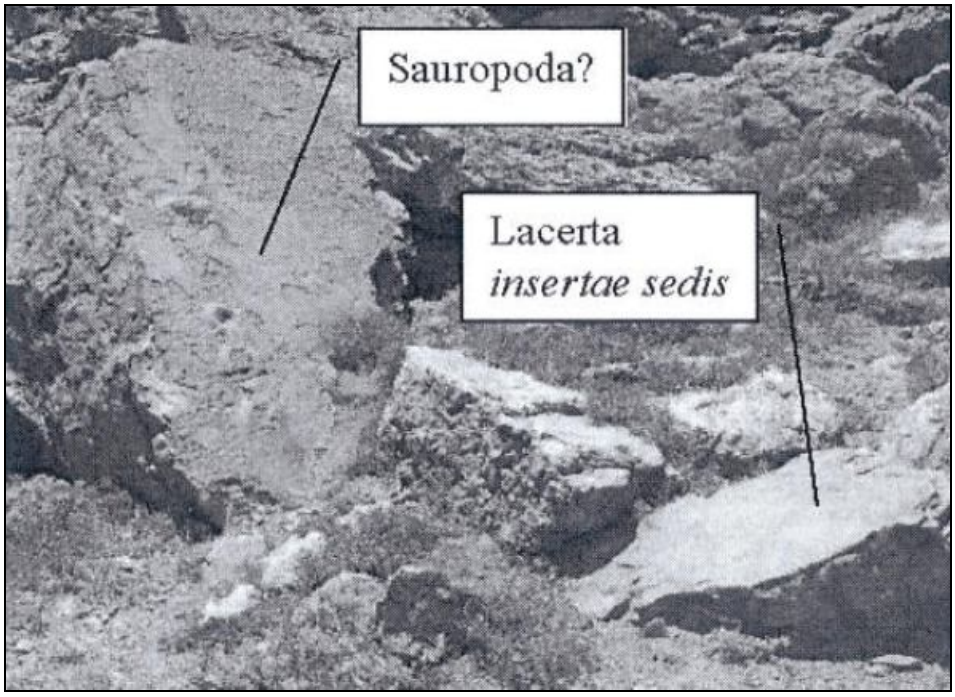


Figure 12
Possible paleo-ichnites of a dinosaur of the Sauropod Order
(Moreno, unpublished report, 2007)

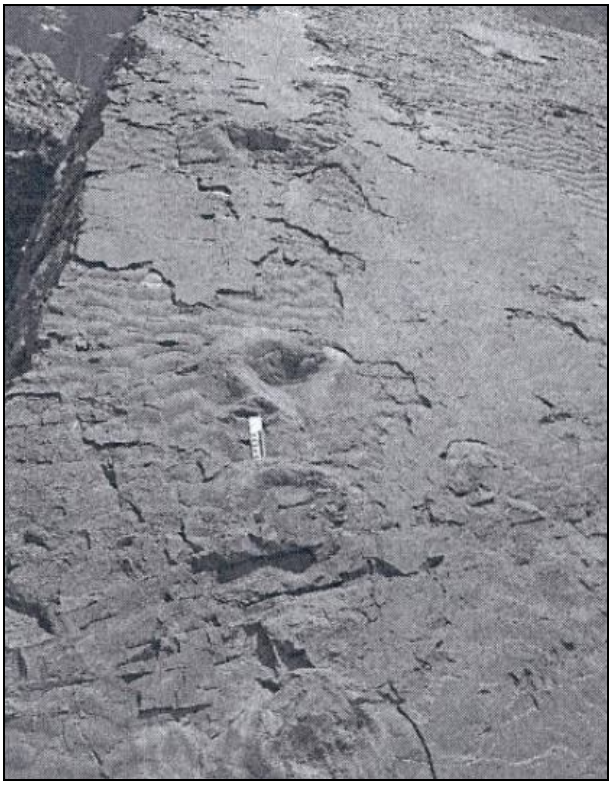
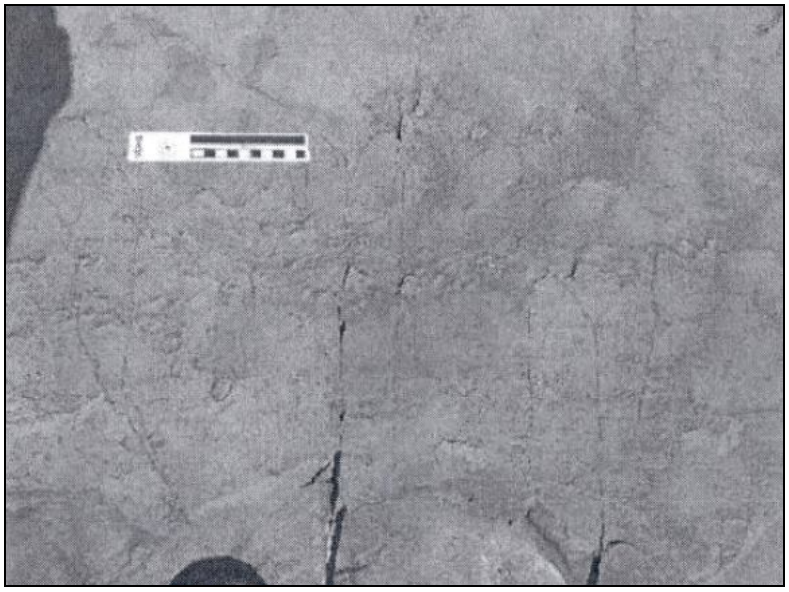


Figure 13
Possible paleo-ichnites assigned to a small reptile
(Moreno, unpublished report, 2007)



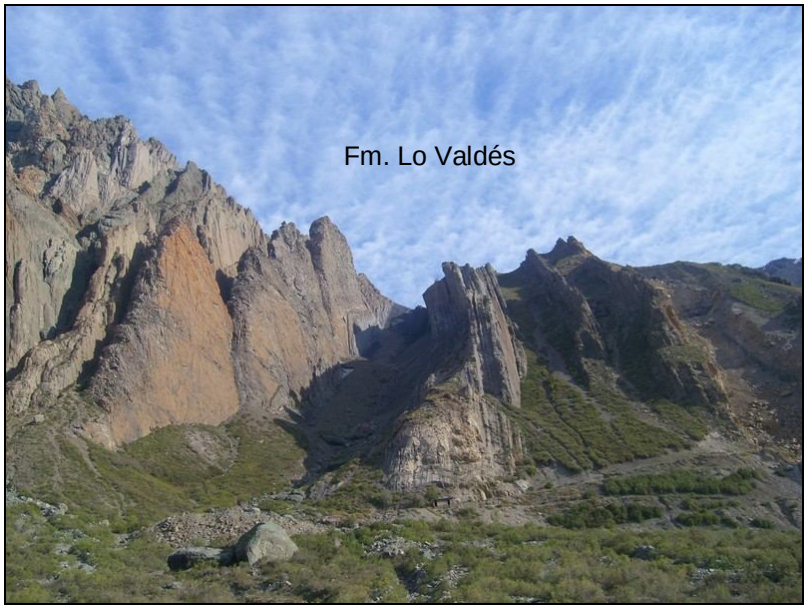
3.4 LO VALDÉS FORMATION

This unit was defined by González (1963) in the place of the same name in the Volcán River valley, as a “fossiliferrous sedimentary group, consisting of three members, the middle of which is composed of clastic sediments” (Fig. 14). Its base is concordant with the Damas River Formation and the top with the Colimapu Formation.

The sequence is composed of limestone, calcilutites, shale, and calcareous sandstone, conglomerates and breccias. The limestone is gray-blue in color, and it is presented in compact strata with concoidal fracture and regular thickness. The limestone and fossiliferrous calcilutites are black in color and appear finely laminated. The shale and sandstone predominate in the middle sector of the profile, and they are light gray to purple in color. Levels of andesitic volcanic rocks are also interleaved. Toward the upper part of the unit there are small lenticular layers of inter-stratified gypsum (‘transition gypsum’). The estimated thickness of this formation is approximately 1350 m (Thiele, 1980).

The time interval assigned to this formation is recognized by means of fossils that cover the Tithonian – Hauterivian lapse (and possibly Barremian) (Biró-Bagóczky, 1964; Thiele, 1980).

Figure 14
Photo towards the south in the Volcan River Valley, east of Baños Morales, where the upper levels of the Lo Valdés Formation can be seen.



The presence of fossil remains in the strata of the Lo Valdés Formation has been mentioned from the time of the first geological explorations made in the region (Darwin, 1846; Brüggen, 1950; Muñoz Cristi, 1950; Corvalán, 1957; González, 1963). In general terms, the fossil record found there corresponds to small shells, shells or skeletal pieces of microorganisms (foraminifera, radiolaria, tintinnids), sponges (= porifera), worms (= anelids), mollusks (gastropods, bivalves, ammonites, nautiloids), ostracods, echinoderms (crinoids, echinoids) and vertebrates (sharks (unpublished record), picnodontids, ichthyosaurus (unpublished record) and crocodiles) (e.g. Philippi, 1899; Tavera, unpublished report, 1968; Biró-Bagóczky, 1964, 1980a; Reyes and Pérez, 1978; Schultze, 1981; Gasparini, 1985; Hallam et al., 1986; Pérez et al., 1987; Gasparini, 1996; Gasparini et al., 2000). The diversity of the bivalves and especially the ammonites stands out in this extensive record.

The invertebrates and vertebrates recognized in this unit have been related especially to species identified in different formations that compose the so-called Neuquen Watershed in Argentina (e.g. Weaver, 1931; Corvalán and Pérez, 1958).

Most of the available information about the fossil record mentioned above is contained in biostratigraphic studies focused on the ammonite fauna (Biró-Bagóczky, 1964, 1976, 1980a, 1984; Aguirre-Urreta and Charrier, 1990; Aguirre-Urreta, 1993; Aguirre-Urreta and Alvarez, 1997; Aguirre-Urreta, 2001), which has made it possible to specify the age of the rocks that contain them and to identify new species of these organisms (Biró-Bagóczky, 1976, 1980b).

The works projected by the PHAM in the Alto Volcán sector include the excavation of a tunnel that will cross sedimentary levels of this formation.

3.5 COLIMAPU FORMATION

The Colimapu Formation was defined by Kohn (1960) in the ravine of the same name, affluent of the Maipo river, as a “sedimentary group of terrestrial origin,” which overlies, concordantly and in gradual transition, the strata of the Lo Valdés formation and underlies the Abanico formation concordantly. It may be interpreted that its top constitutes an important surface area of erosion, considering the lapse that the contact with the overlying unit would represent.

The sequence is composed of a succession of red sandstone and shale, conglomerates with a reddish-gray sandy matrix, red shale with levels of aerial pyroclastic rocks, and some andesitic lava and limestone, in layers that are laterally discontinuous. The possible estimated thickness is 2000 mts. The tentative minimum age, determined by means of fossils, would be Albian (Martínez and Osorio, 1963; according to Thiele, 1980), and its maximum age would be Hauterivian, according to the age assigned to the underlying Lo Valdés Formation (Thiele, 1980).

The works projected by the PHAM in the Alto Volcán sector would be carried out in an area where this formation does not surface.

3.6 ABANICO FORMATION

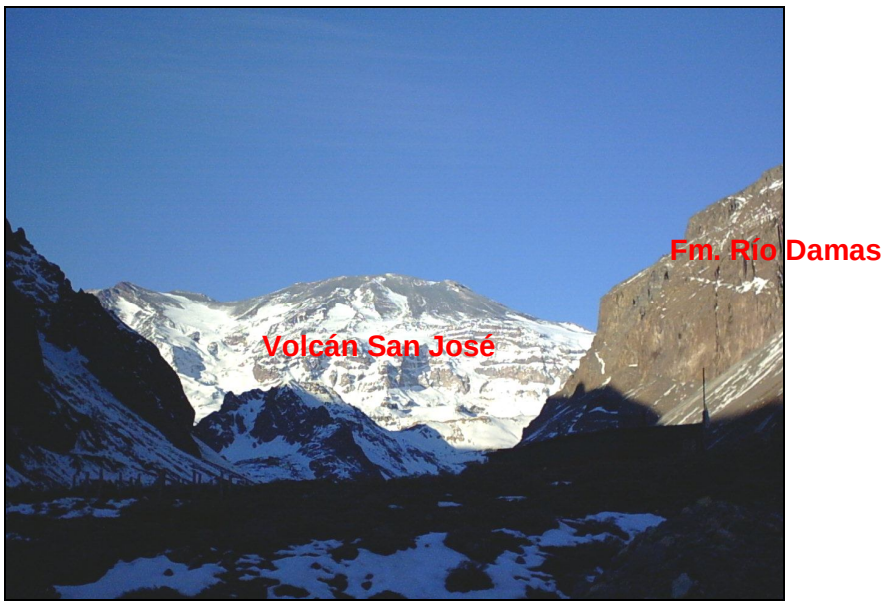
This formation was defined y Aguirre (1960), in the province of Aconcagua, as “a sequence of terrigenous clastic sedimentary and volcanic rocks of predominantly gray, brown and reddish-gray purple colors.” The base of this formation is concordant with the Colimapu formation and its top is marked by an angular discordance with the Farellones formation, outside of the area of the Volcán River valley.

The sequence is formed of volcanic breccias and tufas, violet, purple and gray, with interleaving of lava and clastic sedimentary rocks. In its lower part, thick breccias and tufas predominate over the lava and volcanoclastic sedimentary rocks. The lava is andesites and riolites. The clastic sedimentary rocks are developed preferably in the upper part of the sequence, and they are composed of medium to fine grain sandstone, shale, and finely stratified mud, with carbonaceous remains and fossil flora. The thickness of the group is estimated at 3000 m (Thiele, 1980).

3.7 NEW VOLCANIC UNIT (THIELE AND KATSUI, 1969)

This name distinguishes the volcanoes that present historical eruptions and where emanations are currently recognized. They are formed by fresh andesitic outflows, with interleaving of mantles of breccias and minor pyroclasts (bombs, lapilli and ashes), mostly dark. In the Alto Volcán sector the stratum-San José volcano (5880 m.a.s.l.) stands out, built on the Marmolejo mountain (Thiele, 1980), which extends farther north in the mountain chain on the border (Fig. 15).

Figure 15
View from Lo Valdés to the east. The San José volcano can be seen in the background, and in the foreground the glacier valley of the Volcán river (shaped like the letter *U.*)



3.8 GLACIAL DEPOSITS

At most of the heads of the streams, approximately above the 2500 m.a.s.l. elevation, glacial deposits are recognized. They consist of marginal moraines and accumulations of debris from rock glaciers. They are found in cirques or niches in the high peaks. Terminal moraines and recessional moraines have accumulated in the valleys of the El Morado, Las Placas, Colina, and La Engorda streams and the Volcán river. These glacial deposits are related to the last oscillations of the last glaciation (between 12,000 and 15,000 years ago).

4 SYNTHESIS OF THE PALEONTOLOGICAL AND GEOLOGICAL COMPONENTS LOCATED IN THE ALTO VOLCAN SECTOR (HERITAGE BASELINE)

Heritage components

The information set forth above (point 3 of this report) makes it possible to state that in the Alto Volcán sector where the PHAM has planned to develop surface works and drilling, there are especially significant components from a geological point of view (Table 3). The paleontological properties protected directly by Law No. 17,288 (National Monuments) are very scarce with regard to their location on the surface.

Visual inspection methodology

The inspection visit to the Alto Volcán sector covered two days (January 1 and 2, 2009) and the objective was to make a field assessment of the paleontological and geological components present in the area and their location, considering the activities scheduled by the PHAM in the sector (point 2.3).

The field activities were divided into two parts, and they were carried out by a group composed of six persons, 2 paleontologists and four university students who acted as assistants. The first day (January 1) was allotted for reconnaissance of the area in general and standardization of the criteria for recognition of significant (heritage) components of a geological and paleontological type in the sector. That same day the whole group visited the area corresponding to the water intakes of the El Morado, Las Placas, Colina, and La Engorda Streams, as well as the buried pipe that connects them. The characteristics of the slopes and valley in the Alto Volcán sector were also observed, as well as the layout of the rock blocks present there.

On the second day (January 2) the six participants in this survey made a detailed inspection of the rest of the areas corresponding to the works projected by the PHAM and located especially in the valley of the Alto Volcán sector. The area could be reviewed using the rake technique, where they advanced in line, generally in a north south direction, making observations about the characteristics of the blocks and structures there, with longer stops when a block was found with well-preserved sedimentological structures. The location of the most significant blocks of interest in the area of influence of the works of the PHAM was georeferenced (UTM, datum PSAD 56). A brief description was made and photographs were taken with scale, proportional to the structures of interest from the paleontological, geological, didactic or tourist point of view they presented. The area adjoining these points was also prospected to establish any possible continuity of the structures in other blocks.

The works of the second day were carried out by two groups made up of a paleontologist and two assistants. One group concentrated on the water intake at the Morado stream, its respective siphon, and desander. The other group prospected in the sector adjacent to the possible vertebrate tracks (Moreno 2007). These works were carried out in great detail in sectors near the areas where implementation of the temporary camp, muck disposal (SAM 1), and entrance to the Tunnel is planned. It is estimated that the methodology used is sufficient to generate the paleontological baseline, having covered all of the areas the PHAM would use for its temporary and permanent works.

Of the variables that affect the possible detection of ichnofossils (the only paleontological remains mentioned thus far for the sector, and considered National Monuments by operation of law 17,288), the most important one is luminosity. This factor was avoided by visiting the sector in the morning and in the afternoon, times of day when there is less reflection of natural light, which favors the visualization of those structures. The high number of participants increased the probability of finding tracks, considering the uneven terrain, interrupted by big blocks (over 15 m high).

Main observations in the field

I. Geological origin of the rocks present in the sector. As available information indicated, they turned out to belong exclusively to the Damas River Formation. In the sector visited, the valley is almost totally covered by blocks of rocks from this unit, displaced from their original position by mass waste movements (Table 3). The strata, which are the source of the blocks of rock that cover the northern zone and center of the valley in the sector, surface on the eastern slope in a subvertical arrangement that significantly favors the observation of their lithological characteristics. On the other hand, the blocks of rock present in the southern zone of the sector seem to come from outcrops of the Damas River Formation located on the western slope of the valley.

II. Lithological characteristics of the rock blocks of the Damas River Formation; average dimension and uniformity of size. Blocks over one meter in length and/or thickness were specially reviewed since their structures, especially the geological ones, are better preserved.

The blocks located in the northern and southern area of the valley consist of sandstone and siltstone, light purple to brown in color, and they mostly present structures of sedimentological origin (and, to a lesser degree, paleontological). On the other hand, in the middle area conglomerates and thick conglomeradic breccias predominate, green in color, and most of them lack significant sedimentary structures.

According to preliminary results, larger blocks are found in the northern zone of the valley.

III. Presence of structures of paleontological origin. No significant fossils were observed, besides the possible vertebrate tracks mentioned by Moreno (2007), which would be located outside of the area of direct intervention of the PHAM.

IV. Presence of structures of geological origin. As available information indicated, the structures observed on one or both surfaces of the rock blocks are mainly of a sedimentological nature, and they consist of: stepped stratification, mud or desiccation

cracks, ripple marks (Figure 16-17) and impressions of raindrops (Table 3), to which crossed stratification would be added.

Figure 16
View of block with presence of ripple marks (coordinates 259684 406019)

Figure 17
Block with presence of mud cracks.

Possible impact of works of the PHAM

After the areas that will be intervened by the PHAM have been located, an assessment was made of the impact that might affect the heritage components of a paleontological type (possible tracks) and geological type (blocks resulting from mass waste movements with varied structures) present there (see Table 1). The works that would take place there are the following (see Table 1):

I. Water intakes in the La Engorda, Las Placas, Colina, and El Morado streams. The first three will be located in areas where conglomerates and conglomeradic breccias lacking in structures with heritage significance surface. On the other hand, the El Morado water intake will be built in an area with blocks of sandstone and siltstone that have structures of sedimentological origin. However, this intervention is not considered to be of great significance, due to the abundance and good preservation of those structures in areas near or far from the place where those works will be developed (review restricted areas on attached drawing).

II. Camp and installation of work sites. As projected by the PHAM, these works would be located in the northern zone of the valley, near the area where the bigger blocks of sandstone of the Damas River Formation with well-preserved sedimentological structures are located. However, the Owner has made a commitment to restrict the access of workers and contractors to those places by contractual means, through the appropriate signage and informative talks about restrictions, which seems to be sufficient to guarantee the conservation of those big blocks and their geological structures (review restricted areas on attached drawing). This will be supervised by a professional after the works have started.

III. Muck disposal site. Its location is considered favorable, considering its proximity to the access road and the fact it occupies an area where there are no sandstone blocks from the Damas River Formation. Also, to avoid intervening the landscape, that deposit shall be used to set up a lookout point, after its closing stage has concluded. (See point 6.3, compensation measures).

IV. Entrance to the tunnel. The surface area where part of this work will be developed is near an area where sandstone blocks are large and frequently present such structures as well-preserved mud cracks. Nevertheless, this intervention is not considered to be very significant, due to the abundance and good preservation of those structures in areas near or far from the place where those works will be carried out. The Owner has promised to restrict the access of workers and contractors to sectors adjoining the place where the works will be carried out that are considered restricted areas (see attached map).

V. Pipe buried between La Engorda-Colina; Colina-Las Placas; Las Placas-El Morado; El Morado-Tunnel entrance. The first two shall take place in sectors where conglomerates and conglomeradic breccias from the Damas River Formation surface, lacking in structures with heritage value. On the other hand, the aqueducts located between Las Placas-El Morado and the El Morado-Tunnel entrance will be located in areas with outcrops and blocks of sandstone and siltstone from the Damas River Formation, respectively, where structures of sedimentary origin (e.g. ripple marks; mud cracks) are frequent. Nevertheless, this intervention is not considered to be very significant due to the abundance and good preservation of those structures in areas near or far from the place where those works will be developed. As indicated before, the Owner has made a commitment to restrict access of workers and contractors by contractual means, through appropriate signage and informative talks about restrictions in the sectors that are considered restricted areas (see attached map).

Conclusions

The sector where the works projected by the PHAM will take place was visited completely and intensively, considering the high number of qualified participants (6 persons), the generally small surface of the area involved (5 km2), the generally uniform relief (constituted by a wide valley and slopes with moderate to steep slopes).

The fossils present on the surface of the Alto Volcán sector (Damas River Formation) are very scarce (possible vertebrate tracks), located in a restricted sector (Figures 10 to 13), and they generally lack proper preservation. This situation is very frequent in geological deposits

of continental origin where low sedimentation rates, strong seasonal environmental changes, and frequent events involving rapid accumulation of sediments of different granulometry (e.g. flooding rivers; landslides) reduce the possibilities of acquiring a good record of the organisms that might have inhabited the area.

On the other hand, material components and/or structures predominate there that might be recognized as part of the natural heritage (due to their origin, location, and integration into the landscape) and scientific and cultural heritage (due to their remarkable degree of preservation, significance to knowledge of the geological evolution of the zone, and elevated qualities for the teaching and dissemination of Earth Sciences) (Table 3B).

In fact, the landscape in the Alto Volcán sector is very attractive due to the imposing sequence of vertical strata that extend from south to north, the view to the east of the San José volcano, and the rocky massif of diapiric gypsum that surfaces south of the volcano, attributed to the Colina River Formation (Fig. 17).

The possible impact on some sandstone blocks with sedimentary structures like desiccation cracks and ripple marks in areas of development of works of the PHAM (El Morado water intake; tunnel entrance; buried pipe between Las Placas – El Morado and El Morado – Tunnel entrance) is not considered to be very significant, in view of the abundance and proper preservation of other structures in areas adjoining the works. The location of the blocks with sedimentary structures that were recorded in the areas of works of the PHAM is listed in detail in Appendix 1 of this report. Nevertheless, because of their insignificance (in abundance and preservation) they do not hinder the development of works, and they have not been included in the “Restricted Areas,” which are located in areas near and far from the place where the works will be carried out (see attached map). In addition, the Owner has promised to restrict the access of workers and contractors by contractual means, through appropriate signage and informative talks about restrictions to the sectors that have the largest abundance of blocks of interest (Restricted Areas, see attached map), which seems to be sufficient to guarantee the conservation of these large blocks and their geological structures. This will be supervised by a professional paleontologist while the works are underway.

As stated above, the structures and blocks of interest for protection and preservation are located in areas adjoining the works of the PHAM so a decision has been made to establish “Restricted and Protected Areas,” which contain the structures to be safeguarded (see Annex, South Sector). These areas can be seen on the drawing attached to this report.

A big general area (color green) is indicated on the attached map where the sandstone blocks are present that belong to the Damas River Formation (only one present in the valley and on the eastern slope of the Alto Volcán sector). That area is a buffer zone, not a restricted area, so workers will be able to pass through those sectors only if they need to, but no works can be carried out in those areas. The smaller areas represented there (magenta color) correspond to “Restricted Areas” for the personnel working on the works projected by the PHAM, since the bigger blocks are found there, and they have well-preserved sedimentary structures (mud cracks; ripple marks). When the PHAM is carried out, these restricted areas will be marked off in the field by a professional paleontologist (see attached map), and it will be indicated by suitable signage that is not a major intervention in the landscape and does not call the attention of visitors to the sector.

Also, to guarantee effective compliance with the safeguard measures mentioned, weekly supervision will be provided by professionals or qualified students in Earth Sciences (geologists; paleontologists).

Table 3
Very significant components present in the Alto Volcán sector that will be intervened by the PHAM

A. Properties protected directly by Law 17,288 (Non-renewable Natural Heritage, of a Paleontological type)		
Formation	**Types of fossils**	
Lo Valdés (intervened by means of excavation)	Skeletal remains (shells, teeth, bones) and signs of presence or biological activity (molds, excavations) belonging to vertebrates and especially invertebrates	
Damas River	Possible paleoichnites from at least two groups of vertebrates	
B. Components with geological and environmental significance (Natural and Scientific-Cultural Heritage)		
Geological, geomorphologic, and landscape components	**Origin and/or significance**	**Discipline that they are directly related to or that gives them significance**
Streams	Thaws	Hydrogeology, Geomorphology
Morphology in U of the valley; terminal and recessional moraines	Glacial processes and deposits	Geomorphology, Geological evolution
Blocks of rocky massif of the Damas River Formation with primary sedimentary structures like: stepped stratification, mud cracks, ripple marks, and probable impressions of raindrops	Deposits of mass waste movement. Varied facies and sedimentary structures present there are characteristic of continental environments	Geomorphology, Geological evolution

Figure 18
Photo looking east from Lo Valdés sector, through the valley of the Volcán river. The strata of the Damas River Formation are seen in the foreground and landslides of blocks and fallen debris can be seen in the central part of the valley

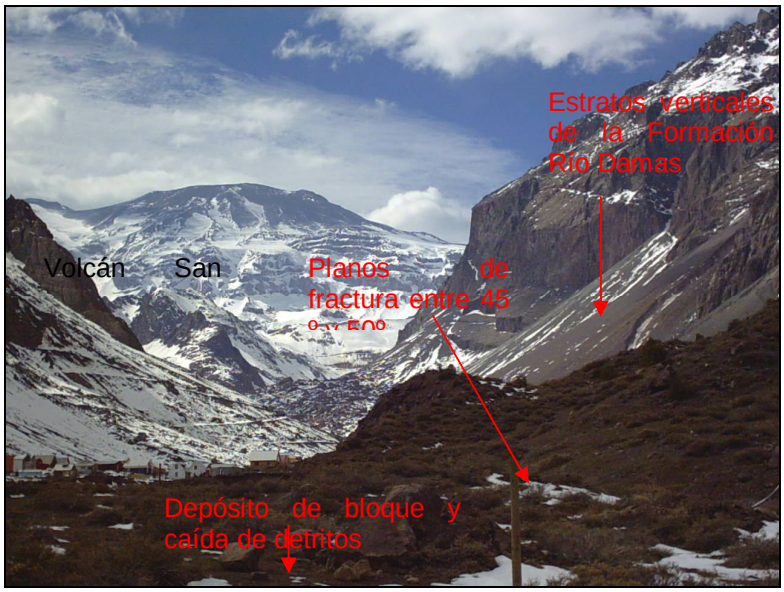


Figure 19
Photo looking east from the area of confluence of the El Morado, Las Placas, Colina, and La Engorda streams with the El Volcán river. The gypsum diapirs of the Colina River Formation can be seen in the foreground and the San José Volcano can be seen in the background.

5 SYNTHESIS OF RISK OR IMPACT OF THE PHAM IN THE ALTO VOLCÁN SECTOR

1.1 EFFECTS OF SURFACE WORKS OF THE PHAM IN ALTO VOLCÁN SECTOR

The most abundant significant material components on the surface of the area mentioned consist of big blocks of rock from the Damas River Formation, which contain abundant and varied sedimentary structures (Figs. 6 to 9; attached drawing; Table 3). On the other hand, the possible vertebrate tracks found thus far are located in a restricted sector (Figs. 10 to 13; Table 3).

On the basis of the available information (see point 4), the surface works that consist of water intakes, camp, and installation of work sites, muck deposit site, tunnel entrance, and buried pipe will not affect the paleontological and/or geological properties or sites there, because they will be located in areas with a small surface where there are no fossil remains or tracks and where the company has promised to restrict access contractually to the adjoining areas where well-preserved, sedimentological structures of interest (restricted areas) are found.

The Colina River and Lo Valdes formations do not surface in the Alto Volcán sector so they will not be intervened by the surface works of the PHAM.

The above will be corroborated by prospections in the field (aimed at specifying the abundance and location of heritage properties like fossils) and monitoring (for example, of the development of the worksites and maintenance of areas with restricted access; see point 5.1.1 in this report) before and during the execution of the projected works and directed, or supervised, by paleontologists.

1.2 EFFECTS OF UNDERGROUND WORKS OF THE PHAM IN ALTO VOLCÁN SECTOR

The entrance and first 700 meters of the underground work of the “El Volcán” tunnel will be excavated in rocks of the Damas River Formation. Between the 700 and 1,200 meter point of its route, the tunnel will cross strata of the Lo Valdés Formation, a unit that contains an abundant fossil record in this sector of the Andes (point 3.4 of this report; Table 3), although this largely consists of poorly preserved, fragmentary remains. Therefore, this activity may intersect fossils (skeletal pieces or tracks) or faunal banks of highly varied organisms (especially invertebrates).

Although Law No. 17,288 (National Monuments) also covers materials present in the subsoil, from the point of view of scientific activity in paleontology, particularly considering the characteristics of the invertebrate fossil record (the most abundant ones in the Lo Valdés Formation), the material obtained by drilling may be relevant if it consists of representatives of organisms or taxons not recorded before in this locality, particularly if the finding has biostratigraphic or paleobiological implications. Without this significance, and lacking the possibility of making a detailed sampling based on a geological profile, the contribution to scientific knowledge of such organisms as bivalves that are found that way is very low.

Considering the strata of the Lo Valdés Formation present frequent lateral changes of facies (so the paleontological content is not the same everywhere) as well as the reduced section or magnitude of the tunnel, it is not possible to assure the projected excavation will intercept

fossiliferrous material. Nevertheless, if that should occur and on the basis of the possible scientific relevance that the material found that way might have, a management plan is proposed in order to reduce any loss or damage of the significant material, enabling it to be studied and safeguarded (See detailed list in point 5.1.1 of this report).

It is important to state that in the first 1,200 meters of construction of the “El Volcán” tunnel a traditional excavation method will be used that makes it possible to obtain larger blocks of muck, permitting less damage to any paleontological materials that might be found.

Finally, the strata of the Damas River and Lo Valdés formations are widely distributed the length of the mountainous area in central Chile so drilling does not constitute a risk to the continuity of those units or to obtaining significant, unique pieces for science and education.

Figure 20
View to the north in the Volcán River Valley,
where strata of the Lo Valdés Formation are seen.

Fm. Lo Valdés

6 ACTIONS TO CONTROL IMPACT/RISK TO HERITAGE

6.1 PREVENTIVE MEASURES AGAINST IMPACT ON HERITAGE

The measures indicated below are proposed to avoid the works of the PHAM constituting any type of impact on sites of heritage value located in the Alto Volcán sector, thereby minimizing any damage that might occur due to unscheduled or undesired interventions.

Permits for the development of these measures shall be requested at the appropriate time of the National Monuments Council, as stated in Law No. 17,288 of National Monuments, decree No. 484 of 1990.

6.1.1 New, more detailed paleontological studies of Alto Volcán Sector

A detailed study of geological characterization and contextualization of the Alto Volcán sector has been envisaged to collect detailed information that will serve as a basis for developing the compensation measures proposed in this report (point 6.3).

These activities shall involve the preparation of a geological and paleontological data base of the Alto Volcán sector and adjoining areas (Colina River, Damas River, Lo Valdés, Colimapu, Abanico formations, volcanic units and glacial deposits); photographic file of relevant geo-paleontological structures and outcrops; preparation of molds of possible vertebrate tracks present in blocks located in the valley of the Alto Volcán sector; among others.

The results of the study and recommendations shall be sent to the National Monuments Council in the form of a characterization report.

6.1.2 General Preventive Measures

i) Restricted zone for members of contractor company

It shall cover the area adjoining the Alto Volcán sector where the works of the PHAM will be executed, known as the Arenas Valley. It shall be called a “Restricted Zone” by the Owner for workers and contractors (see attached map), whose members shall be restricted from accessing it and prohibited from executing permanent or temporary works there (section 6.3.3 of the EIS). This zone shall be marked off *in situ* with clearly distinguishable signage that is visible to everyone who is employed by the Contractor during the construction stage. The Owner may decide to fence off the areas or sites of paleontological and geological interest as needed, thereby avoiding any negative intervention.

ii) Delimitation of buffer zones

With the field works (inspection and identification visit), the team of professional paleontologists identified the buffer zone of prevention and marked it off. That zone is clearly identified on the attached Drawing. The main objective of this measure is to prevent any accidental intervention of the significant properties by the workers or contractor that pass through that place. Its implementation implies a commitment on the contractors’ part to enforce that restriction. This prohibition shall also be stated in the respective contracts.

iii) Monitoring of the excavation of the “El Volcán” tunnel

The material extracted during the drilling of the PHAM shall be monitored, in accordance with the progress of the works. The monitoring shall be done by professional paleontologists no less than every 15 days, with pauses due to the interruption or stoppage of drilling activities. The frequency of monitoring shall depend on the regular progress estimated for drilling, about 150 m per month. This means that every 15 days a volume of muck corresponding to the progress of about 75 meters of tunnel shall be reviewed which shall be prepared in predetermined sites in the area envisaged for the muck disposal, but separate from the final disposal.

The blocks and fragments of rock with fossils that are obtained this way shall be grouped according to the quality of preservation and number of specimens, and the relevant ones shall be transported to an institution for their preparation, restoration, study, and safeguarding (e.g. National Museum of Natural History; SERNAGEOMIN). Excavated material that is not relevant shall be analyzed and evaluated in the place where it is found.

Before the drilling works start, the personnel participating in the excavation shall be trained in recognition of fossils and significant associations, especially vertebrates. The fossil remains of vertebrates are very scarce in the Damas River and Lo Valdés formations, largely due to the sedimentary environment in which those deposits originated. Nevertheless, due to that scarcity and since they are generally more fragile remains than the skeletal structures of marine invertebrates, any finding of an osseous piece shall imply stoppage of the works in the sector of the finding. The latter shall be reported to the personnel in charge of monitoring the progress on the excavation and if they are not present, to the team of paleontologists that is carrying out periodic monitoring. Along with reporting this situation to the National Monuments Council, the respective safeguard measures shall be taken.

6.2 CONTINGENCY MEASURES

If the finding of fossil materials should take place in situations not envisaged in item 5.1.1. of this report, the National Monuments Council and the team of paleontologists that is carrying out the paleontological monitoring shall evaluate the procedures that should be carried out as specified in Law No. 17,288 and its Regulations.

6.3 COMPENSATION MEASURES

i) Production of material for cultural dissemination

As part of the commitments assumed in the EIS, Gener has envisaged preparing a Tourist Guidebook for the Cajón del Maipo (with publication of 5000 copies), which will include a chapter on the paleontological and geological heritage present in the area, prepared by specialists.

ii) Creation of a Lookout Point

The Owner has promised to set up an observation site or lookout point to promote the teaching and dissemination of the natural and scientific-cultural heritage components available in the area (see point 4 of this report). The location of this lookout will take advantage of the muck disposal sector, after it has concluded its closing stage. The lookout will include different observation points and informative panels whose content will be prepared by specialists.

iii) Interpretative Path

An interpretative path shall be set up to introduce the geological units and structures present in the area and provide information about their significance to the Earth sciences. The path will have informative panels designed by specialists.

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ANNEX
LOCATION OF SEDIMENTARY STRUCTURES OF LITTLE SIGNIFICANCE LOCATED IN AREAS WHERE WORKS OF THE PHAM WILL BE DEVELOPED

Annex
Location of Sedimentary Structures of Little Significance Located in areas where Works of the PHAM will be developed

Geological structure	UTM (datum PSAD56)	
	N	E
Sector adjoining works N		
cracks	6259659	404890
cracks	6260602	405238
cracks	6260620	405259
cracks	6260729	405283
cracks	6260805	405496
cracks	6260734	405548
raindrops	6260786	405486
El Morado Water Intake and Desander Sector		
cracks (N boundary of water intake)*	6261266	405744
crossed stratification and ripple marks (side of bridge)*	6261172	405794
cracks and ripple marks (different blocks)	6261123	405782
cracks and ripple marks (different blocks)	6261011	405791
cracks	6261004	405811
cracks	6260990	405836
raindrops	6260961	405800
cracks (+10m)	6260960	405789
cracks (+10 m)	6260914	405806
cracks	6260918	405773
*outside of the surface area to be intervened		
Las Placas, Colina, La Engorda Streams and pipes among them		
Ripple marks	6261061	405939
Ripple marks	6260872	406353
South Sector (valley) – near possible ichnites		
cracks	6259780	405951
ripple mark (figure 16)	6259684	406019
ripple marks and cracks	6259797	405933
cracks	6259695	405921
cracks	6260070	405689
ripple marks	6260095	405678
ripple marks	6260222	405733