# ANNEX 14
# GEOLOGICAL AND PALEONTOLOGICAL HERITAGE OF THE UPPER VOLCÁN AREA

## COMPLEMENTING BACKGROUND

## 1. INTRODUCTION

This report * complements the environmental base line background about goods and natural sites of scientific and cultural interest, specially palaeontology and geology, known or registered in the area identified as Upper Volcán. PHAM contemplates the carry out of some superficial works in this last one. Here is where the concern by the authorities appear, before any mayor interference of the works with paleontological and geological interest area, such as the sediment units of superior Jurassic age (Damas river Formation) which contains important components of geological (e.g. dessication fissures; ripple marks; stratifications of various type) and paleontological type (possible vertebrate footprints).

The goods of archaeological, anthropological, paleontological or anthropo-archaeological types are protected by the Act N° 17.288, on National Monuments, and its Regulation about Excavations and/or Archaeological Prospecting, Anthropological and Paleontological, approved by D.S. 484/90 of the Ministry of Education.

It is important to highlight that given the nature of the fossils (remains or evidences of organisms from the past, in general, abundant in the case of invertebrates) and the paleo-environmental meaning of the sedimented units where they are content in, the information available in terms of its localization is based in general on macro-zones or geological formations of great size or territorial extension, instead of consisting on registrations or geo-referenced findings of fossils or specific sites of interest.

The scientific and cultural importance of the paleontological goods has been recognized by the Owner of PHAM and it has been translated into the practice of special care in the definition of the territories that will be intervened by the superficial works in the upper part of Volcán, in order to protect and prevent the detriment of the goods which so far have been registered or known. At the same time, the Owner has taken the commitment of widening the knowledge of the zone before the start of the projected works, carrying out prospecting studies in the Upper Volcán area, together with due safeguard of the areas registered in there, as well as new possible findings that might have a place due to the root development of the works of PHAM. These activities will not only contribute to the maintenance of the mentioned goods but will favor the setting of the value of the sites where is located.

This report derives a summary and assessment of the available information regarding the heritage components whose acknowledgement and protection is framed within the Acts N° 17.288 (of National Monuments) and 19.300 (of Environment). In a second phase to be developed during the next summer season, previous to the carry out the works projected in the Upper Volcan area, an assessment and on site complementing of the background gathered in this report will be done.

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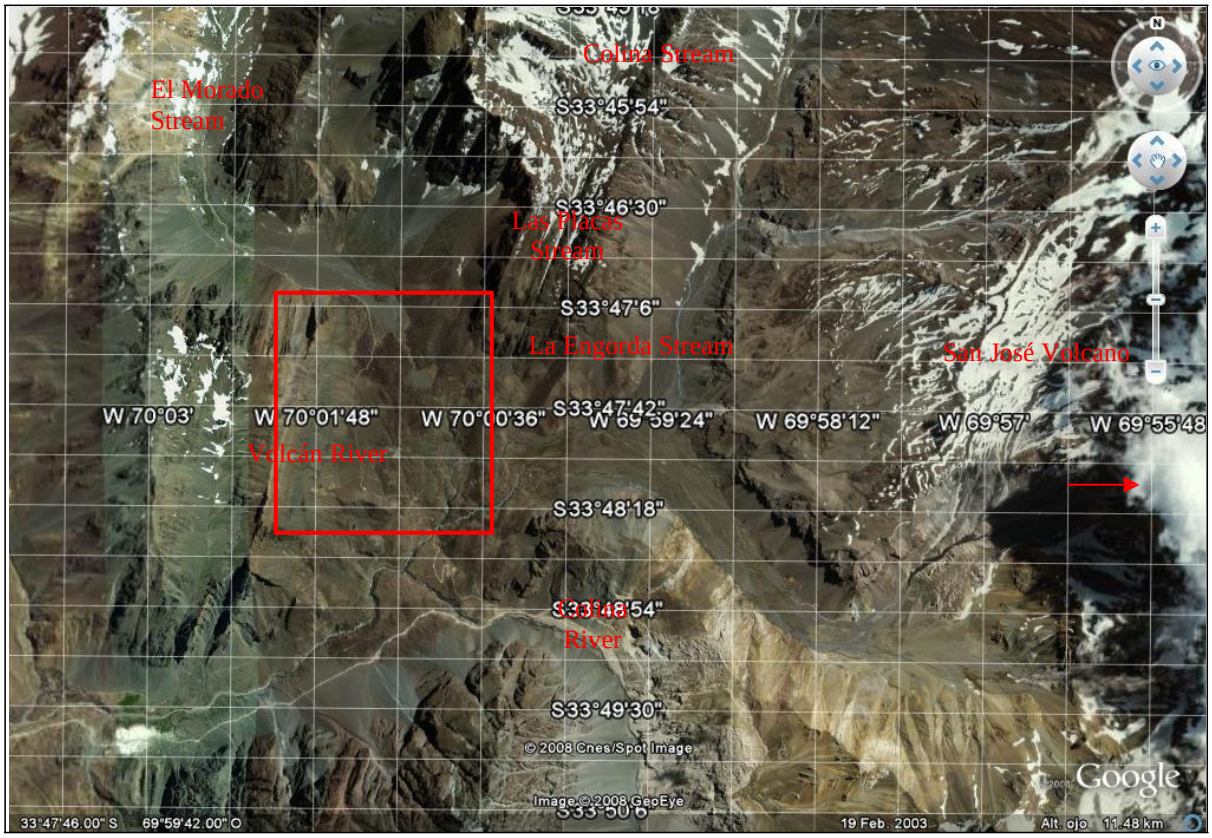
In this way, and within the processing of the EIA framework, this report summarizes the available knowledge about the materials and the most important components for the sciences of the Earth that might be recognized in the area of PHAM and its proximity, and which are part of the natural and scientific heritage of the country. Besides, it mentions the preventive measures and of contingency which will be carried out to minimize the effects that this intervention might have, especially where the heritage meaning of the materials or components present in there justifies it.

## 2. GENERAL BACKGROUND

The area in which this report is referring to is located in the source of the Volcán river, in the area where El Morado, Las Placas, Colina and La Engorda streams confluence to form the Volcán river (Figure 1 and attached map). In the PHAM context, the location is known as "Upper Volcán" and its identified with the access to Las Arenas valley.

**Figure 1**
**Upper Volcán Area, access to Las Arenas. Localization of works area in red square (approximate surface: 5 km2)**



This area corresponds to a relatively reduced area of territory with approx. 5 km2 of surface. Here, many materials and other geological and paleontological objects stand out which may have or have a heritage value, in the first case, either from the lithological, structural geomorphologic and/or landscape standpoint. This strong geological condition, accentuated by the amazing structure of the lithological units (formations) which outcrop in there (and which show an intense cortical tectonic deformation), makes the area to not only being an important access pathway towards other highly attractive mountain range areas, but to be frequently visited by groups of students from different university studies and by individuals admiring its nature.

The detail of the works that PHAM will develop in the Upper Volcán area, according to what has been stated in Chapter 2 of EIA is presented next (Tables 1 and 2).

**Table 1**
**Superficial works by PHAM in the Upper Volcán area**

| Work / installation | Start Coordinates | | Surface (Has) | Description of the Work |
|---|---|---|---|---|
| | Coord. East (UTM) | Coord. North (UTM) | | |
| La Engorda Intake | 407468,28 | 6259751,10 | 0,1 | *Upper mountain intakes, which consist of a sink (or grid chamber) arranged in the run-off direction and located in the river bed of the stream, in order that water will be collected in the bottom of the waterway. The sink discharges the collected water to a pipe, which at the same time directs them to a "gravel chamber" to remove particles of a diameter over 0.3 mm (see section 2.2.2 of EIA).* |
| Las Placas Intake | 406780,41 | 6260782,87 | 0,05 | |
| Colina Intake | 407181,00 | 6260081,00 | 0,15 | *Intakes of side type, which are referred to the construction of a frontal barrier to the run-off. Adjacent to the side take, two "gravel chamber" gates are considered. The side take consists of a grid section which discharges the collected water to a transition canal which ends up in a concrete pipe, which directs them towards the "gravel chamber" (see section 2.2.2 of EIA).* |
| El Morado Intake | 405768,18 | 6261231,16 | 0,21 | |
| Camp site and installation of works Nº1 - El Volcán Area | 405492,00 | 6260429,00 | 1,91 | Will count with approximately 200 workers. It will be enabled for accommodation of the personnel that will work in the construction works; will count with hygienic services, potable water, first aid rooms, canteen and leisure areas (section 2.3.2.4 of EIA). |
| Muck disposal area Nº 1 - Volcán V1 | 405385,00 | 6260845,00 | 1,84 | Located near the Access Arcade of the Volcán tunnel, this area is arranged under the road which leads to El Morado intake. It has been planned to dispose material from the Volcán tunnel excavations and surplus material from the construction of the access road (see details in section 2.3.2.6 and Annex 6 of EIA). |
| Tunnel Arcade Volcán V1 + Facing work | 405250,00 | 6260880,00 | 1,00 | Excavation front where the equipment and necessary machineries will be installed for making the Volcán tunnel (section 2.3.2.2 of EIA). |

## Table 2
## Lineal works by PHAM in Upper Volcán area

| Works / installation | Start Coordinates | | End Coordinates | | Length (km) | Description of the work |
|---|---|---|---|---|---|---|
| | Coord. East (UTM) | Coord. North (UTM) | Coord. East (UTM) | Coord. North (UTM) | | |
| Engorda-Colina Aqueduct | 407434 | 6259751 | 407231 | 6260071 | 0,47 | Directs the waters collected in La Engorda intake by a circular pipe of reinforced concrete of 1.4 m diameter and 470 m length towards Colina intake, which is connected with the Volcán aqueduct which starts in this intake. This aqueduct will be buried in a trench, which will be later filled with granular material so the superficial run-off and under the surface which feeds the summer grazing areas of this sector will not be interrupted. Finally, a vegetation layer of soil will be placed (see section 2.2.1 and 2.3.2 of EIA). |
| El Volcán – Tranche I Aqueduct (Colina Intake- Las Placas) | 407127 | 6260092 | 406765 | 6260780 | 1,76 | It consists of a circular pipe of reinforced concrete of 2.4 m diameter and 1.760 m length which conducts the contribution of La Engorda and Colina intakes towards tranche II of the aqueduct which starts in Las Placas intake (see Figure 2.2.10 and section 2.2.1 and 2.3.2 of EIA). |
| El Volcán – Tranche II Aqueduct (Las Placas Intake– El Morado) | 406765 | 6260780 | 405817 | 6261091 | 1,06 | It consists of a circular pipe of reinforced concrete of 2.4 m diameter and 1.060 m length which conducts the contribution of La Engorda, Colina and Las Placas intakes towards Tranche III of the aqueduct which starts in El Morado intake (see Figure 2.2.10 and section 2.21 and 2.3.2 of EIA). |
| El Volcán – Tranche III Aqueduct (El Morado Intake – El Volcán Arcade Tunnel) | 405817 | 6261091 | 405250 | 6260880 | 0,65 | It consists of concrete box of 2.6 x 2.6 m and 646 m length which conducts the contribution of all the intakes of the system towards El Volcán tunnel (see Figure 2.2.10 and section 2.2.1 and 2.3.2 of EIA). |
| Existing service road | - | - | - | - | 7,1 | It connects the intake zone with the access arcade of the Volcán tunnel with Route G-25 (see section 2.3.2.5 of EIA). |

# 3. SUMMARY OF THE GEOLOGICAL AND PALEONTHOLOGICAL KNOWLEDGE OF THE UPPER VOLCÁN AREA

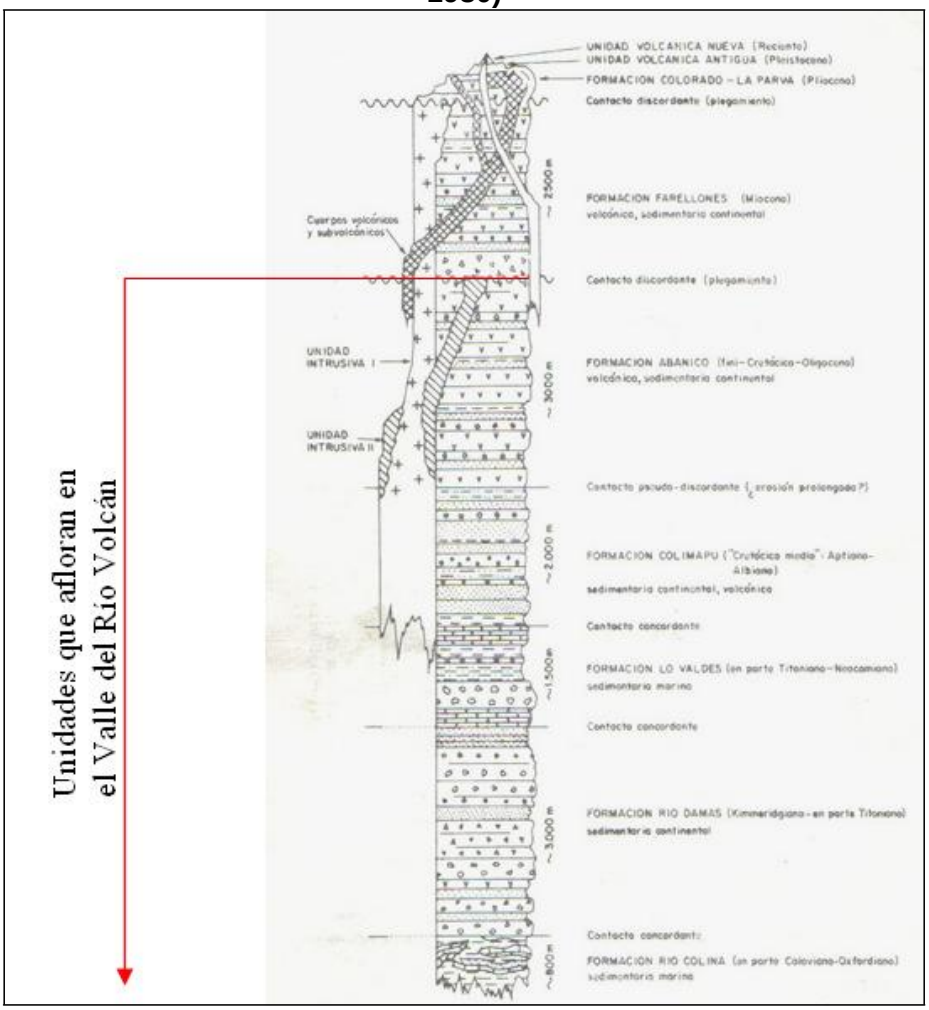
## 3.1 Introduction

The first published geological study about the Volcán River corresponds to González (1963), who made a lithographic characterization of the area. In that same year it was published the micro-paleontological study of Martínez and Osorio (1963) about the Colimapu formation, in front of Morales ravine. Later on, Biró-Bagóczy (1964) performed a paleontological and stratigraphic study of Lo Valdés formation, in Lo Valdés location. Finally, Thiele (1980) published the Santiago Sheet to scale 1:250.000, which includes the Volcán river valley area. Other published works of the geology of Volcán zone are the structural studies of the dumped fold of the Abanico formation to the east of San Gabriel, carried out by Baeza (1999), and the "meso-cenozoic" contact in the Colimapu formation, performed by Bustamante (2001). Finally, there are several other unpublished documents, excursion guidelines, etc., referred to geology and specially to palaeontology (mentioned further on), which as a whole give geologic and palaeontology knowledge of the area of the Volcán river valley.

In the Volcán River valley region (between its confluence with Maipo River in San Gabriel area, and the Chile-Argentina border) volcanic stratified and sedimentary rocks outcrop (continental and marine) profusely crossed by dykes and vein sheets. 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 are extended in direction bands N-S to N-NE (Figs. 2 and 3).

Due to the east-west direction of the longitudinal shaft of the Volcán river valley, the series can be crossed almost orthogonally, which allows an appreciation of its whole magnitude the tectonic deformation which has been subject to complete sequence. An structural profile performed along the valley (Fig.4) lets to appreciate in first place, from west to east, the San Gabriel batholiths conducting to the Abanico formation, unit which is still in vertical position. Towards east, these same strata are folded in an anticlinal dumping to the west and then again they rise reaching a vertical position to a sub-vertical from the contact with Colimapu Formation. This structural arrangement is kept in Lo Valdés and Damas rivers formations.

**Figure 2**
**Generalized Stratigraphic Column of the Sheet of Santiago, scale 1:250.000 (Thiele, 1980)**




A summarized description of the lithology and other characteristics of the rock units which come into the surface of the area are presented next. As it has been stated, from the oldest to the newest, these are:

## 3.2 Colina River Formation

This unit was defined by González (1963) in the Colina river valley (south-east of Upper Volcán), as "a group of classical marine sediments, fossiliferous, with alternations of powerful evaporite lens (gypsum)". Its base is unknown and its roof corresponds to the concordant contact with the Damas River Formation.

**Figure 3**
**Geological Map of the area to be intervened. In the red square the PHAM area, name of the geological formations present in red**

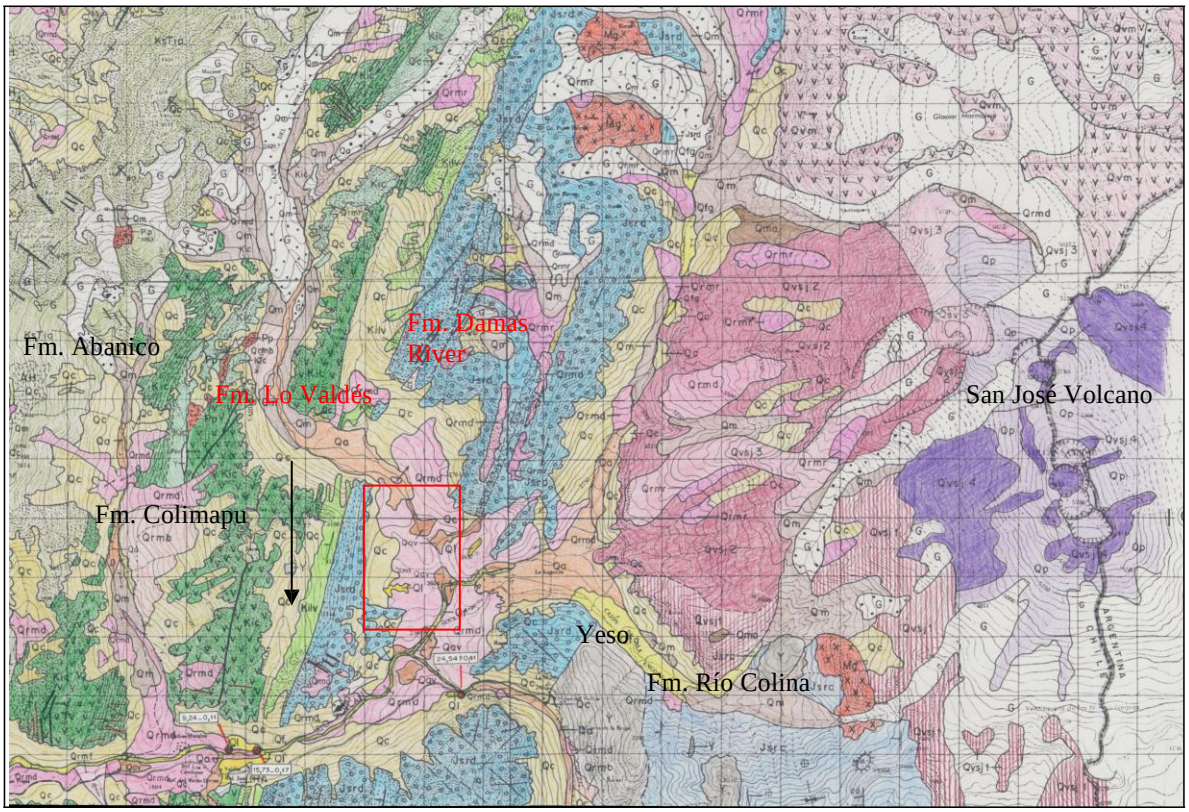
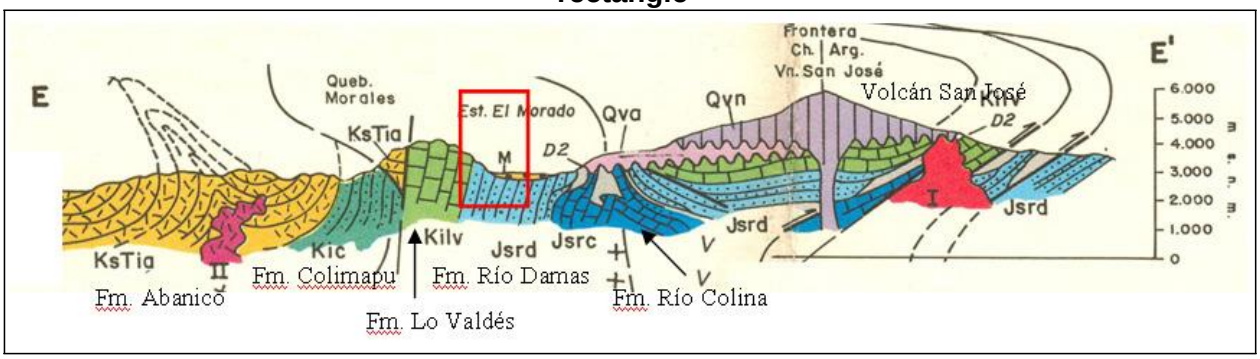



**Figure 4**
**Geological profile of the Volcán river valley. PHAM area in the red rectangle**



The sedimentary rocks are presented in a sequence of calcareous limestone and lutite dark grey, stratified fissile lutite, sandy and fine conglomerates and alternation of Andesitic volcanic rocks. The group shows some inter-stratified gypsum lenses. Gypsum is observed in diapiric dome shapes which treat and cut the series. The sequence, thus defined, is recognized with regular normality in the south-east extreme of Upper Volcán area, in its section type (to the South of San José volcano), location where it has been able to estimate a visible thickness not over 800 m.

The fauna studied by Tavera (unpublished report, 1968), specially collected in the Azufre Stream and constituted by ammonites of the Perisphinctidae Family, allowed to designate an oxfordian age (Late Jurassic) to the superior levels. Over the base of new paleontological background (e.g. Álvarez et. al., 1997), this formation would cover the Callovian - Oxfordian.

The works projected by PHAM in the Upper Volcán area will be carried out in an area where there is no outcrop of this formation, so heritage goods such as fossils which are content in there will not be affected.

### 3.3 Damas River Formation

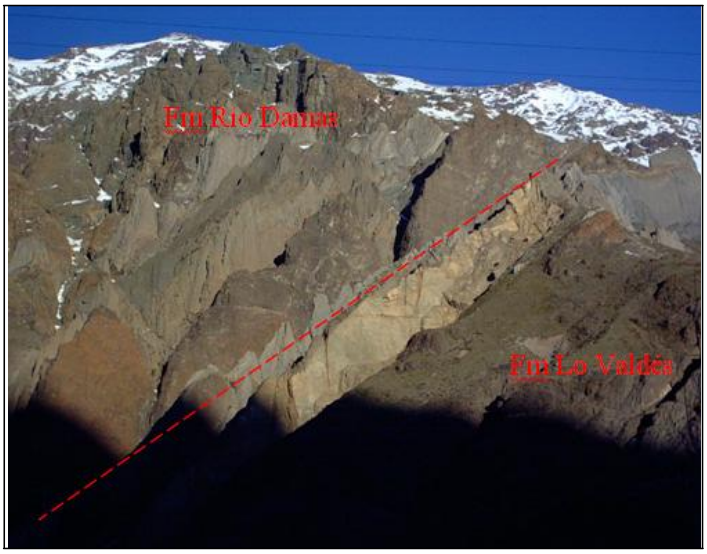
The formation of Damas river was defined by Klohn (1960), in the homonym river valley, in the Province of Colchagua (35°00' Lat. S; to the south of Santiago Sheet), as a "complex of clastic sediments, fines and coarse, and sporadic chemical sediments". These are deposits formed essentially in a terrestrial, sub aerial, and lake environment. For the Volcán area the same denomination is maintained, because we are dealing with a unit whose outcrop is extended along the same road from its section type. Its base is concordant with the Colina River Formation and its roof with Lo Valdés Formation (Figure 5).

The formation presents as a conglomerates succession and clustered breccias, coarse to mean ones, of reddish and greenish colors, with powerful alternations of sandies and siltstones, from light purple to brown colors. There are also alternations of abundant Andesitic volcanic rock levels. It is also recognized, small gypsum lenses. The sedimentary rocks are characterized, in general terms, by a mayor presence of quartz (55 to 70%) and by iron oxide cement. The size of the clasts in the conglomerates is commonly of 2 to 15 cm, even when, exceptionally, are over 50 cm.

Its age have been able to be delimited due to its concordantly under the marine layers of Lo Valdés formation (whose deposit started in the lower Tithonian) and it is over, also concordant, Colina River Formation (Oxfordian). A Kimmeridgeiana (Thiele, 1980) age was given as consequence.

The most fine sedimentary rocks, primary structures are seen, such as graded stratification, desiccation or mud crevasses, ripple and probable impressions of rain drops which point out the continental deposition environment. (Figs. 6 to 9). The approximate power of the group of 3000 m (Thiele, 1980).

**Figure 5**
**Vertical stratum of Damas River Formation, in the south hillside of the Volcán river valley, in concordant contact (segmented line) with Lo Valdés Formation**




In a previously unknown way, it has been registered in this unit structures which seen to correspond to vertebrate footprints (Moreno, unpublished report, 2007). These are located in two isolated blocks in the west side of the confluence with Las Placas, Colina and La Engorda streams (Figs. 1, 3, 10 and 11), which mainly come from the Mesoncito Valley scarp where part of this formation is exposed.

The possible fossils footprint (paleoicnitas) would have been originated by representatives of different vertebrate groups (Moreno, op. cit.). A set was assigned in a preliminary way to a dinosaur of the Sauropoda Order (Fig.12). Other impressions seem to be part of a small size lizard (Fig. 13).

The possible paleoicnitas would increase the scarce registration of continental vertebrates, known up to the date as Gondwana, in the Late Jurassic. Other contemporary sedimentary rocks which present vertebrate footprints 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 PHAM in the Upper Volcán area includes the excavation of a tunnel which will got through some sediment levels of this formation.

**Figure 6**
**Desiccation fissures in the fallen block of Damas River Formation**

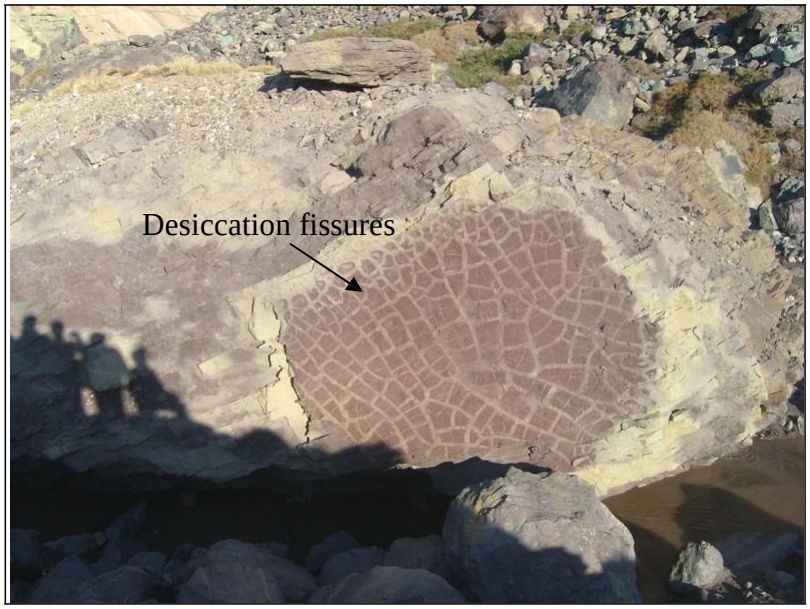



**Figure 7**
**Negative of desiccation fissures in the fallen block of Damas River Formation**

**Figure 8**
**Interference ripples**
**(Moreno, unpublished report, 2007)**

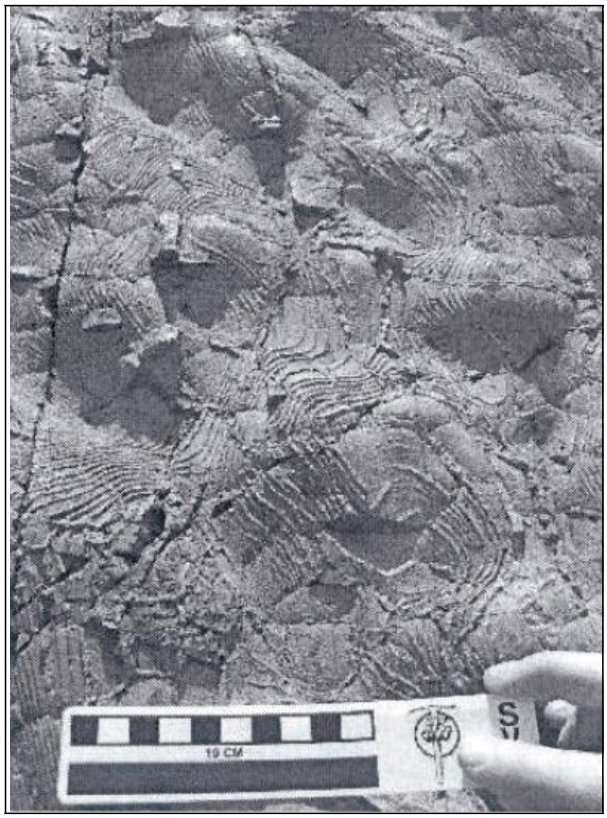



**Figure 9**
**Ripples and rain drops marks**
**(Moreno, unpublished report, 2007)**

**Figure 10**
**Location of the blocks with possible vertebrate footprints**
**Photograph taken from the La Engorda stream waterfall road**
**(Moreno, unpublished report, 2007)**

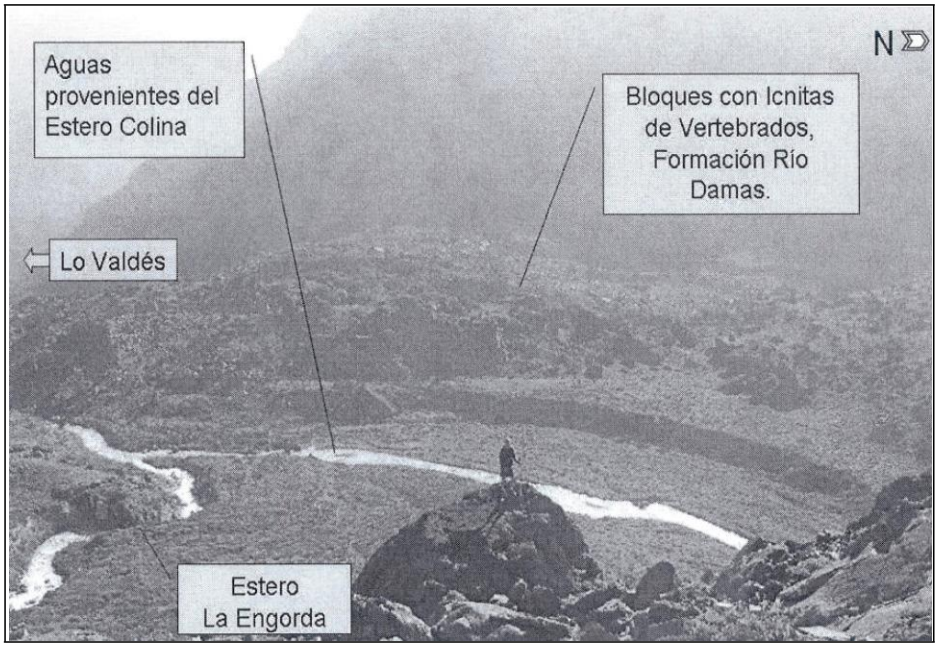



**Figure 11**
**Location of two blocks with possible vertebrate paleoicnitas**
**(Moreno, unpublished report, 2007)**

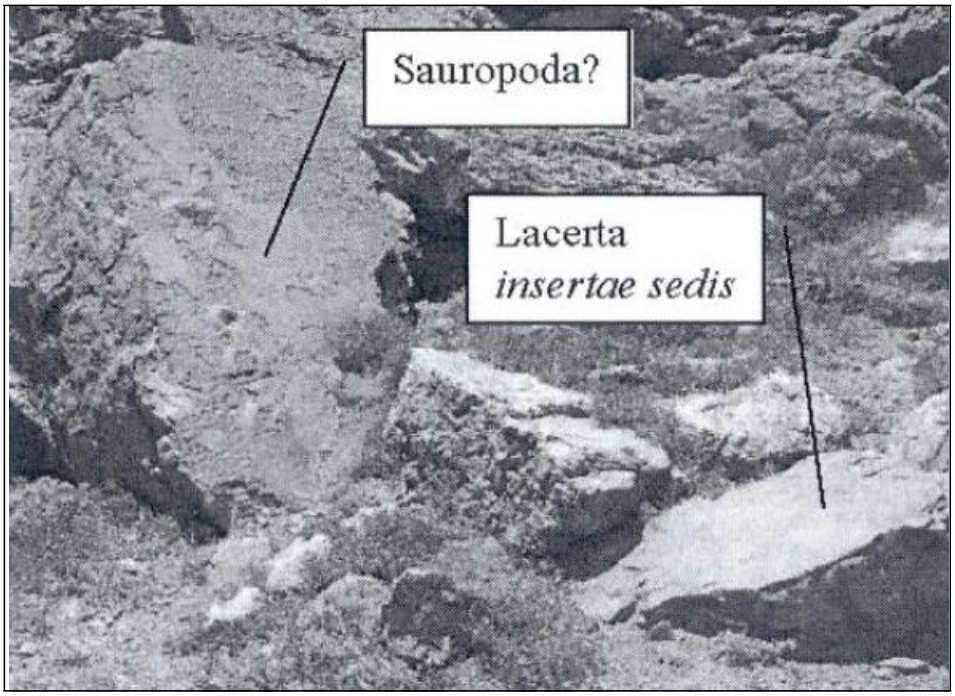
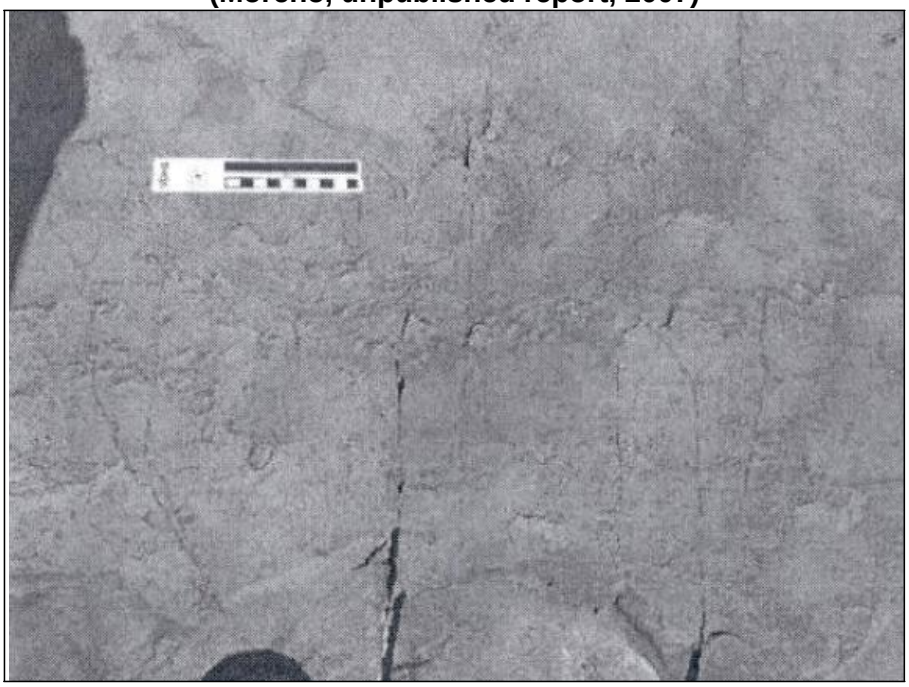


**Figure 12**
**Possible paloicnitas of a dinosaur from the Sauropoda Order**
**(Moreno, unpublished report, 2007)**

**Figure 13**
**Possible paleoicnitas assigned to a small size reptile**
**(Moreno, unpublished report, 2007)**



## 3.4 Lo Valdés Formation

This unit was defined by González (1963) in the homonym place, in the Volcán river valley, as a "sediment fossiliferous group, constituted by three members out of which the intermediate is comprised of clastic sediments" 14). Its base is concordant with the Damas River Formation and its roof with Colimapu Formation.

The sequence is comprised of limestone, calcilutite, lutite, calcareous sandstone, conglomerates and breccia. Limestones are of grey-bluish color and are presented in compact strata, conchoidal shape and regular thickness. The limestone and fossiliferous calcilutite are of blackish color and finally appear laminated. The lutite and sandstone are predominant in the mean area of the profile and are of light grey to purple color. There are also alternations of abundant Andesitic volcanic rock levels. Towards the late part there are small lenticular layers of inter-stratified gypsum ("in transition gypsum"). The estimated thickness of the formation is 1350 m approximately (Thiele, 1980).

The temporary alternation assigned to this formation is recognized through fossils covering the Titinian - Hauterivian lapse (and possibly Barremian) (Biró-Bagóczky, 1964; Thiele, 1980).

**Figure 14**
**Photograph towards the South of Volcán river Valley, to the east of Baños Morales, in which the superior levels of Lo Valdés Formation is seen.**

The presence of these fossils remains in the strata of Lo Valdés Formation has been mentioned from the beginning of the geological explorations done in the region (Darwin, 1846; Brüggen, 1950, Muñoz-Cristi, 1950; Corvalán, 1957; Gonzalez, 1963). In general terms, the fossils registry found, corresponds to small shells, shells or skeleton pieces of micro-organisms (foraminipherous, radiolarian, tintinidous), sponges (=poripherous), worms (=annelids), molluscs (gastropodous, bivalves, ammonites, nautiloids), ostracoda, echinoderms (crinoids, echinoderms) and vertebrates (sharks (unpublished registration), pycnodintis, ichthyosaurs (unpublished registration) 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). These wide registries highlight the diversity of the bivalves, especially the ammonites.

The invertebrates and vertebrates in this unit have been related specially with species identified in different formations which are part of the so called Neuquina Basin in Argentina (e.g. Weaver, 1931; Corvalán and Pérez, 1958).

The greatest part of the information available about the fossil registry before mentioned, is contained in the bio-stratigraphic studies in the ammonites 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 allowed to precise the age of the rocks which are content in it as well as to identify new species of these organisms (Biró-Bagóczky, 1976, 1980b).

The works projected by PHAM in the Upper Volcán area includes the excavation of a tunnel which will got through some sediment levels of this formation.

### 3.5 Colimapu Formation

The Colimapu Formation was defined by Klohn (1960), in the homonym ravine, affluent of the Maipo river, as a "sediment group of terrestrial origin", which is concordantly superimposed and in gradual transition to the strata in Lo Valdés formation, and concordantly infra-lies to the Abanico formation. It can be interpreted that its roof corresponds to an important surface of erosion, considering a space of time which would represent the contact with the underlay unit.

The sequence is comprised by a succession of sandstones and red lutites, grey reddish conglomerates of sandstone matrix, red lutites with aerial pyroclastic rocks levels and some andesitic lavas and limestone, in laterally discontinuous layers. The possible estimated thickness is 2000 mts. The minimum tentative age, determined through fossils would be albian (Martínez and Osorio, 1963; according to Thiele, 1980) and its maximum age would be hauterivian, according to the aged assigned in Lo Valdés Infra-laid Formation (Thiele, 1980).

The work projected by PHAM in the Upper Volcán area will be done in an area where this formation does not appear.

### 3.6 Abanico Formation

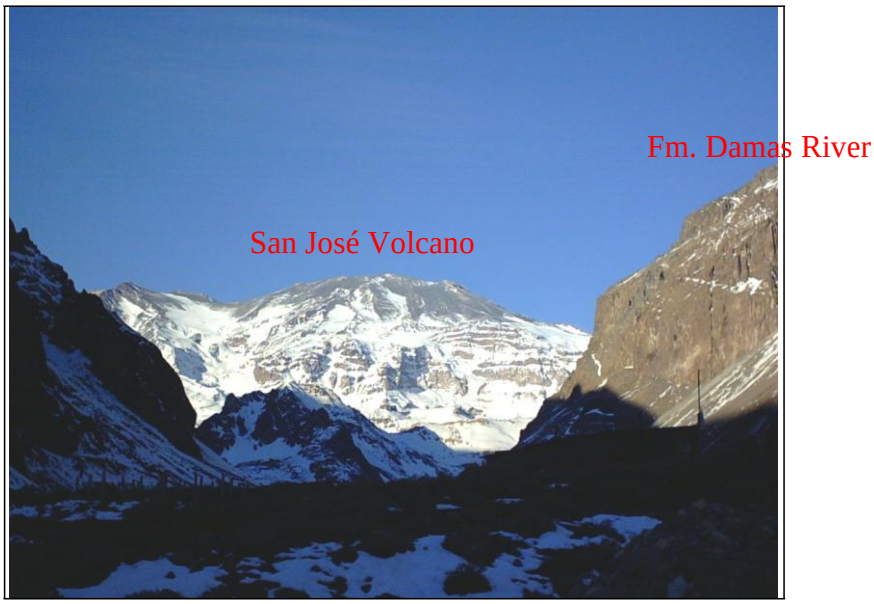
This formation was defined by Aguirre (1960), in the province of Aconcagua, as a "sequence of volcanita and clastic terrigenous sedimentary rocks of brownish-grey grey and red- greyish purple predominant colors". The base of this formation is concordant to the Colimapu formation and its roof is marked by an angular discord with the Cliffs formation, out of the Volcán river valley area.

The sequence is formed by tuff and volcanic breccias, purplish and grey, with alternations of lava and clastic sedimentary rocks. In its lower part, breccias and coarse tuff are predominant over the lava and volcanoclastic sedimentary rocks. Lavas are andesites and riolites. The clastic sedimentary rocks were preferably developed in the upper part of the sequence and are comprised by mid to fine grain sandstones, lutites and finely stratified silt, with carbonaceous remains and fossil flora. The group thickness is estimated in 3000 m (Thiele, 1980).

### 3.7 New Volcanic Unit (Thiele and Katsui, 1969)

Volcanoes presenting historical eruptions and which, currently, emissions are acknowledge are distinguish under this name. They are comprised by fresh andesitic streams, with alternations of breccias sheets and minor pyroclasts (pumps, lapili and ashes), predominantly dark. In the Upper Volcán area, the San José volcano-stratum (5880 masl), built over the Marmolejo hill (Thiele, 1980) which is extended northern in the border range (Fig.15).

**Figure 15**
**View from Lo Valdés towards the east. At the bottom the San José volcano is seen, and in foreground the glacial valley of Volcán river (in U shape).**



### 3.8 Glacial deposits

In most of the head of the streams, approximately at elevation 2500 masl, glacial deposits are recognized. These consist of marginal moraine and detritus accumulations from rock glaciers. These are located in cirques or niches in the high summits. Terminal and recessional moraines are accumulated in the El Morado, Las Placas, Colina and La Engorda, and Volcán river valleys streams. These glacial deposits are related with the last changes of the last glaciations (between 12.000 and 15.000 years ago).

## 4. SUMMARY OF THE COMPONENTS WITH HERITAGE VALUE LOCATED IN THE UPPER VOLCÁN AREA OR THAT WILL BE INTERVENED BY PHAM WORKS

The information before presented (point 3 of this report) allows to point out that in the Upper Volcán area, where PHAM has planned to develop superficial works and drilling, there are protected paleontological goods in direct form by the Act N° 17.288 (from National Monuments), as well as other significant components from the natural and cultural scientific point of view (Table 3A).

Although, the possible fossils that might be found in the surface of such area (Damas River Formation) are nor abundant, these are located in a restricted area (Figs. 10 to 13) and usually lack of good preservation. However, the predominant materials and/or structure components which can be recognized as part of the natural heritage (because of their genesis, location and integration to the landscape) and scientific and culture of the country (because of its preservation degree, meaning for knowledge of the geological evolution of the zone and high qualities for teaching and disclosure of the sciences of the Earth) (Table 3B).

The predominance of these last ones over the paleontological goods, whose main meaning lies in the moment that knowledge of the geological events which is linked to its presence (instead of contributing with bio-stratigraphic information and/or relevant paleo-biological), allows to point out that in the Upper Volcán area a heritage above all is geological type is located.

**Table 3**
**Components of high meaning present in the Upper Volcán area or which will be intervened by PHAM**

| **A. Goods directly protected by the Act N° 17.288 (Non-renewable Natural Heritage, Paleontological type)** | |
|---|---|
| **Formation** | **Fossil type** |
| Lo Valdés (intervened through excavation) | Skeletal remains (small shells, teeth, bones) ad signs of presence or biological activity (moulds, excavations) belonging to vertebrates and specially to invertebrates |
| Damas River | Possible paleoicnits of at least two group of vertebrates |

| **B. Components with geological and environmental meaning (Natural and Scientific. Cultural Heritage)** | | |
|---|---|---|
| **Components of geological, geomorphological and landscape structures** | **Origin and/or Meaning** | **Discipline with which are directly linked and which gives them its meaning** |
| Streams | Thaws | Hydrogeology, Geomorphology |
| Morphology in U of the valley; terminal and recessional | Processes and glacial deposits | Geomorphology, Geological Evolution |
| Rocky massif blocks of the Fm. Damas River with primary sedimentary rocks structures such as: graded stratification, mud fissures, ripples and possible rain drop impressions | Mass removal deposits Various facies and sedimentary rocks structures present in there are proper form continental environments | Geomorphology, Geological Evolution |

In fact, such sector is characterized by the massive presence of mass removal deposits of the rock falling type, from the rocky massif of the Damas River Formation. Rock block slides and detritus falling are facilitated by the vertical structural disposition of the sequence, obliquely cut by the big sloping fracture plane between 45° and 50° in favor of the slope (Fig. 16).

Finally, the landscape is very attractive due to the amazing sequence of vertical strata which are extended from south to north, the east view of the San José volcano and the rocky massif of diapiric gypsum which outcrops to the south of the volcano, attributed to the Colina River Formation (Fig. 17).

**Figure 16**
**Photograph to the east of Lo Valdés area, by the Volcán river valley. In the foreground of the Damas River, Formation strata and slides in blocks and detrites falls can be seen towards the central part of the valley**

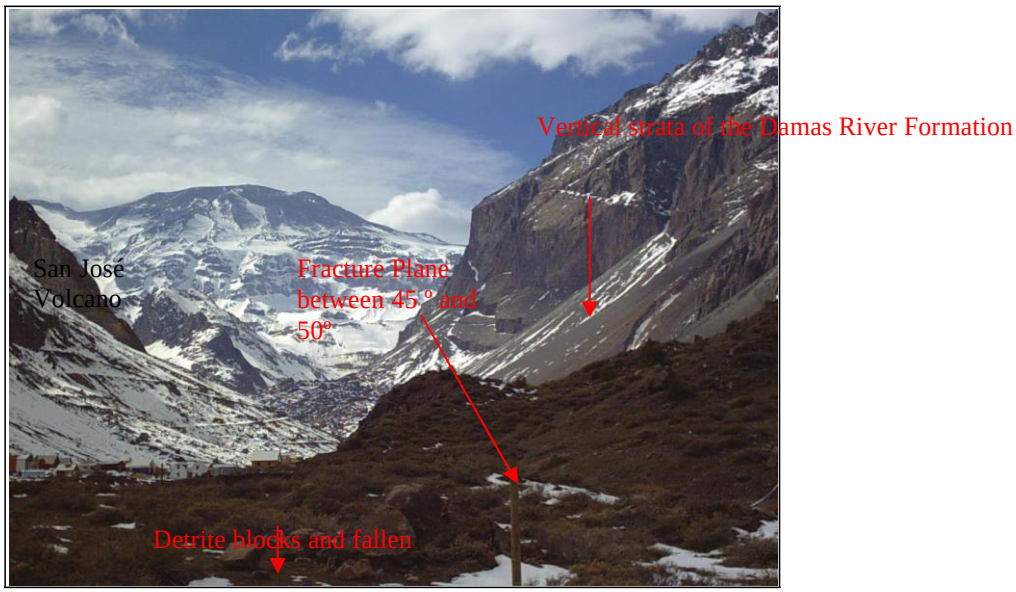
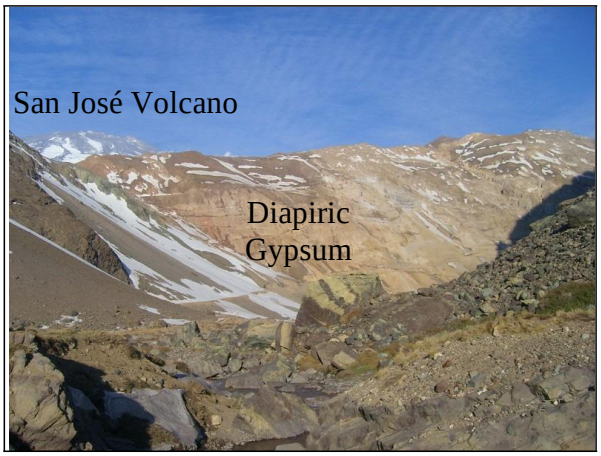



**Figure17**
**Photograph looking at the east of the confluence area of El Morado, Las Lajas, Colina and La Engorda Streams with El Volcán river. In foreground, the gypsum diapir of Colina River Formation and in background the San José Volcano can be seen**



# 5. RISK ANALYSIS OR PHAM IMPACT IN THE UPPER VOLCÁN

## 5.1 Effects of the superficial works of PHAM in the Upper Volcán area

In the surface before mentioned, the most abundant significant material components consist of big blocks of rock from Damas River Formation, which have abundant and various sediment rock structures (Figs. 6 to 9; attached map; Table 3). However, the possible vertebrate footprints found so far, are located in a restricted sector (Figs. 10 to 13; Table 3).

Over the base of the available information, the superficial works consisting of intakes, temporary road and headrace canal will not affect in a significant way the goods or paleontological and/or geological sites presents in there, as will be carried out in non-consolidated detritic deposits of rain origin and mass removal associated to rock falls and detrites belonging to the Damas River Formation, which do not affect significant components recognized in this unit (Table 3).

The Colina River and Lo Valdés formations do not outcrop in the Upper Volcán area, so they will not be intervened by superficial works of PHAM.

The above will be confirmed through land prospecting (directed to specify the abundance and location of the heritage goods such as fossils) and monitoring (for instance, about the development of the works and the maintenance of the restricted access areas; see point 5.1.1 of this report), before and during the execution of the projected works, and directed or supervised by professional palaeontologists.

## 5.2 Effects of the underground works of PHAM in the Upper Volcán area

The arcade and the first 700 m of the underground works of the "El Volcán" tunnel will be excavated in rocks of the Damas River Formation. Between 700 and 1.200 m of its run, the tunnel will cross strata from Lo Valdés Formation, unit which has an abundant registration of fossils in this Andean range area (point 3.4 of this report; Table 3), although big part of it consist of poorly preserved remains and fragmented. Therefore, this activity can get to intersect fossils (skeletal pieces or footprints) or faunal banks of very varied organisms (specially invertebrates).

Although the Act N° 17.288 (of National Monuments) takes in the materials present in the subsoil, from the scientific activity standpoint in palaeontology and especially considering the characteristics of fossil registration of the invertebrates (the most abundant in Lo Valdés Formation), the material obtained through drilling can be relevant while consists in representatives of organisms or taxons, not registered in this area so far, and specially is its finding has bio-stratigraphic or paleo-biological implications. Without this meaning, and lacking the possibility of performing a detail sampling based on the geological profile, the contribution to the scientific knowledge of such organisms such as bivalves found there, is much reduced.

Taking in consideration that the Lo Valdés Formation strata present frequent lateral changes of facies (so the paleontological content is not similar in every place) as well as the reduced section or magnitude of the tunnel, it is not possible to ensure that the projected excavation will intercept the fossiliferous material. Nevertheless, in that eventuality of occurrence and over the base of the possible scientific relevance that the found material might have, a management plan in order to reduce any loss or damage to the significant material is proposed, thus enabling its study and safeguard (See details in point 5.1.1 of this report).

It is important to state that in the first 1.200 m of the construction of the "El Volcán" tunnel a traditional excavation method will be used which allows to obtain muck blocks of greater size, letting a lower damage to the paleontological material which might be found.

Finally, it must be pointed out that the start from Damas River and Lo Valdés Formations are widely distributed along the Mountain range zone in central Chile, so the drilling will not constitute a risk for the continuity of these units or to get to have available unique and significant pieces for science and education.

**Figure 18**
**View towards the north of the Volcán river valley, where La Valdés Formation start can be seen**

# 6. IMPACT CONTROL ACTIONS/HERITAGE

## 6.1 Preventive measures of the heritage impact

The proposed measures to prevent that the intervention of PHAM will become a negative impact to the heritage value sites located in the Upper Volcán area are presented next, thus minimizing the damage that might happen due to non-programmed or unwanted interventions.

The permits for the development of these measures will be duly requested to the National Monuments Council.

### 6.1.1 New paleontological studies of greater resolution in Upper Volcán area

Although the preliminary background available to the date point out that the works projected by PHAM will not affect the registered areas or recognized by specialists of the Upper Volcán area, Gener contemplates the carry out of a paleontological base line study previous to the execution of the works, thus the corresponding permit will be requested to the National Monuments Council. This commitment was taken by the Owner in the EIA and was described in section 7.2.6 of it.

The paleontological and geological base line study will count with the following points:

- Soil studies for the paleontological carry out in an approximated area of 6 km2 between the UTM N6262000 - N6259000 and E405000 - E407000 coordinates, and the adjacent areas that might be important for the geological contextualization.

- Ratify, with geo-referenced information, the wide resolution of the paleontological and geological background registered in Upper Volcán area up to the date, where the works of PHAM are projected.

- Widening the land knowledge of the areas or sites of paleontological and geological interest in the zones next to the works of PHAM, in the Upper Volcán area.

- Complementing, specify and/or ratify the proposed actions to preserve, protect and spread the material of heritage value that might be detected.

The total amount of works will be done between December 2008 and February 2009, taking into consideration the climate conditions before the beginning of the works in the sector[1].

The first task of the topographic carry out will consist on the most specific location and detail characterization of the blocks of paleontological and geological interest (sedimentological) 2 in comparison to the information available so far for the area of PHAM. Special attention will be given to the poorly known, up to the date, fossil detection

[1] This will depend on the RCA obtaining and the conditions that this one sets.

in the zone, unique and new specimens for the sciences, or that might present an unusual conservation.

The soil studies reports will specify the location and extension of the prospective area (UTM-Datum, location, municipality, province) in a map to an adequate scale. On the other hand, details of the new materials gathered and an analysis of its meaning compared to the paleontological and geological background known up to the date for the area will be included, summarized in this report (see points 3 and 4 of this report).

In case of detection of new areas or sites of paleontological and geological relevance in the Upper Volcán area, the team in charge of the study will provide new actions for its adequate registration and protection or safeguarding, which will be notified to the National Monuments Council.

The result of the study and recommendations will be sent to the National Monuments Council in a report of the paleontological base line for its approval, as stated in Act N° 17.288 of National Monuments.

### 6.1.2 General preventive measures

i) Restriction zone for the members of the contracting company

Will be comprised of the area next to Upper Volcán sector where the works of PHAM will be carried out, known as Valle de Las Arenas (Valley of the Sands). This will be called by the Owner as "restriction zone" for the Contractors (see attached map), whose members will be banned from access to it and prohibition of carrying out permanent or temporary works (section 6.3.3 of EIA). This zone will be marked on site with clearly distinguishable signs and visible to all the people employed by the Contractors in the construction stage.

ii) Delimitation of buffer zones

During the next summer season previous to the start of the works, a professional paleontological team will carry out an inspection visit and will identify and limit the land with areas presenting heritage interest material (e.g. where landslides blocks are concentrated in Damas River Formation, between which those presenting possible vertebrate footprints are in there). A buffer zone will be marked around the area or located site using centralized signs prohibiting the entry, as a way to prevent any accidental intervention to the significant goods by members of the contracting company or by privates that might circulate in the place. Its implementation implies the commitment by part of the contractors in order to comply with such restriction. Besides, these ones will have to signed this prohibition to the respective contracts.

The Owner will be able to make the decision of nearing the areas or sites of paleontological or geological interest as it might be required, avoiding the intervention of them in a negative way.

iii) Monitoring of the "El Volcán" tunnel excavation

A monitoring of the extracted material during the drilling of PHAM will be carried out, in concordance to the progression of the works. Such monitoring will be done by professional palaeontologists in a frequency of no less than 15 days, with breaks due to the interruption or halt of the drilling activities. The frequency which this monitoring will have, will depend on the estimated regular progress for drilling, about 150 m per month. This implies that every 15 days a review of the volume of mucks corresponding to the progress in about 75 m of the tunnel will be done, which will be conditioned in the pre-determined sites within the area foreseen for the muck disposal, but separated from the final storage.

The blocks and fragments of rock with fossils obtained through this means, will be grouped according to the quality of preservation and amount of specimens, and the most relevant ones will be transported to an institution for its cleaning, study and eventual safeguard (e.g. National Museum of Natural History; SERNAGEOMIN). Yet, the excavated material that seems less relevant will be analyzed and assessed in the same location of its finding.

On the other hand, previous to the start of the drilling works, the personnel participating in the excavation and recognition of fossils and significant associations, especially vertebrates, will be trained. It is worth to reiterate that the vertebrate fossils are very scarce in Damas River and Lo Valdés Formations, to a large extent due to the sedimentary environment in which such deposits were originated. Nevertheless, due to this scarcity and because of dealing with remains, generally, more fragile than the skeleton structure of the marine invertebrates, any finding of a bone piece will imply the paralysation of the works in the area of the finding. People in charge of monitoring the progress of the excavation such as, if not present, the paleontological team that might be carrying out periodic monitoring will be reported about it. Together with reporting to the National Monuments Council about this situation, the corresponding safeguard measures will be taken next.

## 6.2 Contingency measures

In the case of finding fossil material in situations not contemplated in item 5.1.1 of this report, the national Monument Council and the paleontological team carrying out the paleontological monitoring will be reported and assess the procedures that might be necessary to carry out and as per stated in Act N° 17.288 and its Regulations.

## 6.3 Compensation measures

i) Cultural material production for spreading

As part of the commitments taken in the EIA, Gener has foreseen to elaborate a Tourist Guide of the Maipo Canyon (issuing 5.000 copies), where a chapter related to the paleontological and geological heritage present in the zone will be included, and this will be elaborated by specialists.

ii) Lookout construction

The Owner is committed to enable an observation point or lookout that will favor the teaching and spreading of the natural and scientific cultural heritage components available in the zone (see point 4 of this report). The location of this lookout will take advantage of the authorized storage area. This lookout will include different observation points and informative panels, whose content will be prepared by specialists.

iii) Interpreting pathway

An interpreting pathway will be prepared in order to inform the units and geological structures present in the area, as well as information about its meaning for the sciences of the Earth. This pathway will count with informative panels designed by specialists.

## 7. REFERENCES

Aguirre, L. 1960. Geology of the Central Andes of Chile, Province of Aconcagua. Institute of Geological Research, Bulletin 9:70 p.

Aguirre-Urreta, M.-B.; Charrier, R. 1990. Stratigraphy and ammonites of the Tithonian - Berriasian in the sources of the Maipo river, Main Mountain Range of Central Chile. Ameghiniana 27(3-4):263-271, 1 Lam.

Aguirre-Urreta, M.B. 1993. Neocomian ammonite biostratigraphy of the Andean basins of Argentina and Chile. Spaniard Paleontological Magazine 8(1):57-74, 7 Lams.

Aguirre-Urreta, M.B.; Álvarez, P. 1997. Lo Valdés Formation in upper Colina river, Metropolitan Region, central Chile. Chilean Geology Congress, N° 8, 1:411-415. Antofagasta.

Aguirre-Urreta, M.B. 2001. Marine Upper Jurassic-Lower Cretaceous stratigraphy and biostratigraphy of the Aconcagua-Neuquén Basin, Argentina and Chile. Journal of Iberian Geology 27:71-90.

Álvarez, P.; Godoy, E.; Aguirre-Urreta, M.B. 1997. Marine Jurassic of the high Mountain Range of central Chile, Metropolitan Region. Argentinean Geology Congress, N° 13, and Hydrocarbons Exploration Congress, N° 3, 5:181.

Baeza, O. 1999. Stratigraphy and structural analysis of the Abanico Formation in the Yeso river area, Metropolitan Region. Memoir, Department of Geology, Universidad de Chile, 116 p.

Biró-Bagóczky, L. 1964. Study about the limit between the Tithonian and Neocomian in Lo Valdés Formation, Province of Santiago, mainly based on ammonoidea. Universidad de Chile, School of Geology, Memoir exam to obtain the degree of Geologist (unpublished), 118 p., 28 Lams.

Biró-Bagóczky, L. 1976. Titanites chilensis n. sp. in Lo Valdés formation, Tithonian - Neocomian, Province of Santiago, Chile. Chilean Geology Congress, N° 1, 3:L11-19.

Biró-Bagóczky, L. 1980. Study about the limit between the Tithonian and Neocomian in Lo Valdés Formation, Province of Santiago (33°50' lat. South), Chile, mainly based on ammonoidea. Argentinean Palaeontology and Bio-stratigraphy Congress, N° 2, and Latin American Palaeontology Congress, N° 1, 5:137-152. Buenos Aires.

Biró-Bagóczky, L. 1980. Some new ammonites in Lo Valdés Formation, Tithonian - Neocomian, Province of Santiago (33°50" Lat. South), Chile. Argentinean Palaeontology and Bio-stratigraphy Congress, N° 2, and Latin American Congress of Palaeontology, N°1, Act, 1:223-242. Buenos Aires.

Biró-Bagóczky, L. 1984. New palaeontology and stratigraphy background of some Tithonian Necomian outcrops of the Chilean Mountain Range, between 33°45' and 35° lat. South International Geological Correlation Programme Project 171. Circum-Pacific Jurassic Report, No. 2, Special Paper, 3:16 p.

Brüggen, J. 1950. Fundamentals of Chile's Geology. Military Geographic Institute, 374 p.
Bustamante, M. 2001. Meso-Cenozoic Contact Analysis in the Volcán river valley, Andes Mountain Range of the Metropolitan Region. Memoir, Department of Geology, Universidad de Chile, 54 p.

Corvalán, J. 1957. Ueber marine Sedimente des Tithon un Neocom der Gegend von Santiago. Geologische Rundschau 45(3):919-926.

Corvalán, J.; Pérez, E. 1958. Chilean Fossils Guide. Tithonian - Necomian. Institute of Geological Research, Manual 1:48 p.

Darwin, Ch. 1846. Geological observations on South America. Smith, Elder and Co. 279 p.

Gasparini, Z. 1985. Jurassic marine reptiles of South America. Ameghiniana 22(1- 2:23-34.

Gasparini, Z. 1996. Biogeographic evolution of the South American Crocodilians. In: Contributions of Southern South America to Vertebrate Palaeontology (Arratia, G., editor), Münchner Geowissenschaftliche Abhandlungen (A)30:159-184.

Gasparini, Z.; Vignaud, P.; Chong, G. 2000. The Jurassic Thalattosuchia (Crocodyliformes) of Chile: a paleobiogeographic approach. Bulletin de la Societé Géologique de France 171(6):657-664.

González, O. 1963. Geological observations in the Volcán river valley. Minerals Magazine 80:20-61.

Hallam, A.; Biró-Bagóczky, L.; Pérez, E. 1986. Facies analysis of the Lo Valdés Formation (Tithonian-Hauterivian) of the High Cordillera of central Chile, and the paleogeographic evolution of the Andean Basin. Geological Magazine 123(4):425-435.

Klohn, C. 1960. Geology of the Andes Mountain Range of Central Chile, Province of Santiago, O'Higgins, Colchagua and Curicó. Institute of Geological Research (Chile), Bulletin 8:95 p.

Martínez-Pardo, R.; Osorio, R. 1963. Preliminary considerations about the presence of fossil charophytas in Colimapu Formation. Mineral Magazine 82:28-42.

Moreno, K. 2007. Preliminary Report. Paleontological Interest material in the Upper Volcán river area. Unpublished, 7 p.

Moreno, K. 2008. Value and state of conservation of mesozoic vertebrates footprints in Chile. First Palaeontology Symposium in Chile, 4 p.

Muñoz Cristi, J. 1950. Geology. In: Economic Geography of Chile. Development Corporation of Production 1:55-127.

Pérez, E.; Biró-Bagóczky, L.; Reyes, R. 1987. New background about Virgotrigonia Alleman, 1985 (Bivalves; Trigoniidae) and presence of V. hugoi (Leanza) in Chile. Geological Magazine of Chile 30:35-45.

Philippi, R.A. 1899. Secondary fossils of Chile. F.A. printer's Brockhaus, Leipzig, 104 p., 42 Lams.

Reyes, R.; Pérez, E. 1978. The trigonias of the Tithonian and Lower Cretaceous of the Andean basin of Chile and its cronoestratigraphic value. Geological Investigations Institute, Bulletin 32:105 p., 5 Lams.

Schultze, H.P. 1981. A pycnodont dentition (Pisces, Actinopterygii) from de Lower Cretaceous of El Volcán region, south east of Santiago, Chile. Geological Magazine of Chile 12:87-93.

Tavera, J. 1968. Study-report about the paleontological material from Colina and Colorado rivers in the Upper Mountain Range of the Province of Santiago. Universidad de Chile, Department of Geology (unpublished), 9 p., Santiago.

Thiele, R. 1980. Santiago Sheet, Metropolitan Region. Institute of Geological Research, Geological Charts of Chile 39:51 p., 1 map 1:250.000.

Thiele, R. y Katsui, Y. 1969. Contribution to the knowledge of the post-Miocene volcanism of the Andes in the Province of Santiago, Chile. Universidad de Chile, Department of Geology, Published 35:23 p.

Weaver, C. 1931. Paleontology of the Jurassic and Cretaceous of west central Argentina. University of Washington, Memoir 1:1-469, 62 Lams