



**FINAL REPORT**

**“GEOTECHNICAL DRILLINGS  
ATACAMA COSMOLOGY TELESCOPE”**

**Prepared by**

**EARTH SCIENCE CONSULTANTS**



**APRIL 2006**

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## 1. INTRODUCTION

This document corresponds to the final report of the geotechnical work assigned to EARTH SCIENCE CONSULTANTS (ESC) by AMEC for the development of the geotechnical study of the substrate where a radio telescope will be installed for the “Atacama Cosmology Telescope” Project. This activity took place between the months of March and April of 2006.

## 2. GENERAL ANTECEDENTS OF THE PROJECT SITE

The site is located near the ALMA telescope in Chajnantor, a high mountain range in Chilean Second Region, with an altitude of 5.148 m and the following coordinates: 2295870° S and 6778789° W.

The location is reached from the locality of San Pedro going towards Toconao (approximately 18 Km of asphalt), until the start of the climb in direction towards the ALMA project. Although, the path towards Jama can be used taking Km 36 towards the site of the project. This route is shorter, but it presents more unfavorable conditions for the vehicles.

The ascent to the site of the project by the ALMA route shows the presence of large cacti (2 to 3 meters in height) towards the altitude of 3,400m. Soon the vegetation changes to shorter species such as shrubs to an elevation near 3.700 m and changes to “coirón” (*Festuca pallens*) and “paja brava” (*Festuca orthophylla*) at an elevation over 4.200 m.o.s.l.

Finally the site located at an elevation above 5,000 m.o.s.l is reached and the altitude, winds, and precipitation make the growth of vegetation extremely difficult.

The main characteristics are:

- The site nearly lacks all forms of vegetation except for minor species and lichens spread out scarcely as is shown in the following photographs:





- The site displays large amounts of fragmented rocky material, which has probably rolled from nearby hills. The granite rocks present in the area display processes of exfoliation and thermoplasticity. The ground appears to be very loose the further in depth and in discussion with local contractors they indicate that in nearby projects the depth of the loose material is quite deep.
- The precipitation is of snowy character and in February, March, and April there is still some precipitation. The nearby hills maintain snow in their summit.

- Species of fauna are not seen on a regular basis. Although, during the geotechnical works a fox appeared on the site. Reptiles and birds are rare at this altitude and this characteristic is considered favorable for the environmental assessments that should be carried out.



- In the immediate area of the projects site, neither paleontological nor archaeological rests are valued. This is a positive characteristic for the environmental evaluations that CONAMA (Comisión Nacional del Medio Ambiente) will likely ask for. This would be one of the most important issues to CONAMA according to the ALMA personnel.

- Signs of previous disturbance are appraised and are product of the operation of sulphur mines with preexisting accesses. There are also signs of recent disturbance (probably product of the operation of sulphur mines), such as: bonfires, construction scraps, construction blocks, leftover shelter, barren material for construction, and metal and iron bits and pieces.
- In relation to the access routes, some places before reaching the site are only three meters wide. Although, this did not make the access of the drilling machinery to its location difficult.
- The assignments were carried out with some climatic disadvantages such as strong winds and intense cold which made the task difficult. The drilling contractor took special care to not disturb the sector using plastic tents under the equipment and caring for the health of the workers by means of personal protection equipment and very complete previous medical examinations.







In annex 1 the Geotechnical report is enclosed and properly signed by the geologist specialist.

## **Annex 1**

# **GEOTECHNICAL REPORT**



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# **GEOMINAS**

GEOLOGY, MINING, UNDERGROUND WATERS

**GEOTECHNICAL REPORT**  
**ROCK SUSTRATUM FOR RADIO TELESCOPE FOUNDATION**  
**ATACAMA COSMOLOGY TELESCOPE PROJECT**

Calama, April 2006



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## I. INTRODUCTION

**ESC** requests **GEOMINAS LTDA.**, to carry out drilling activities to determine the geotechnical quality of the rock in the area where a radio telescope will be installed for which drillings to recover compact samples was projected. With this information the different stratigraphic levels to a certain depth will be identified so that the presence of healthy or competent rock can be determined for a future foundation that will give the greatest possible security, in terms of the substrate where the radio telescope will be located.

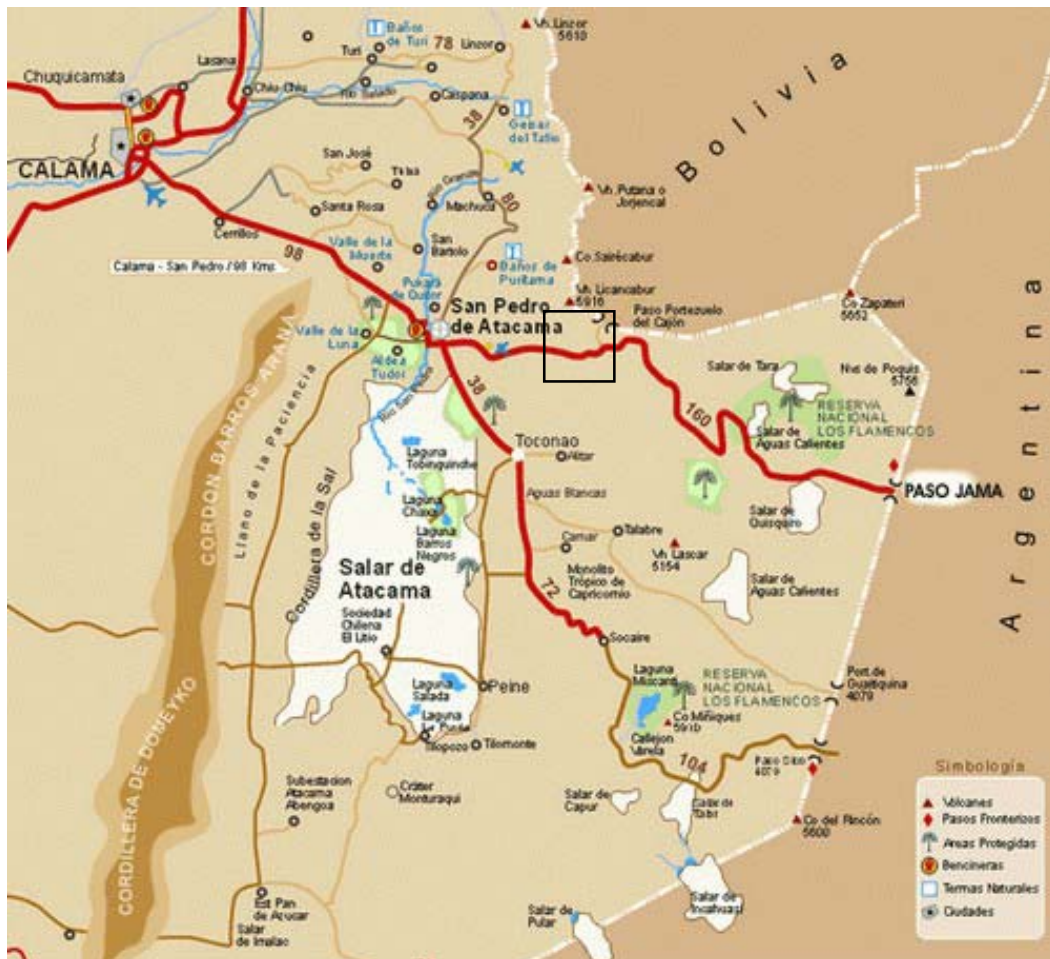
The site where the geotechnical drillings took place is located in San Pedro de Atacama. It is a high mountain range in Chile's Second Region (Andes Mountains), at the foot of TOCO hill, at an altitude of 5,148m and with the following coordinates 2295870° S and 6778789° W (UTM coordinates, North 7.406.891; East 624.471). It is near the site where the ALMA radio telescope is located in Chajnantor, Chile (image N°1).

The access route used was the path towards Jama and then taking Km 36 towards the site of the project.

Image N° 2 that follows, shows the project site, that was previously marked before drilling works starts with flags from the center point (which correspond at the point initially suggested by AMEC for the foundation) and marking circumferences toward the borders, with 29 meters diameter.



Image N°1: General location of the project





**Image N°2:** Project site



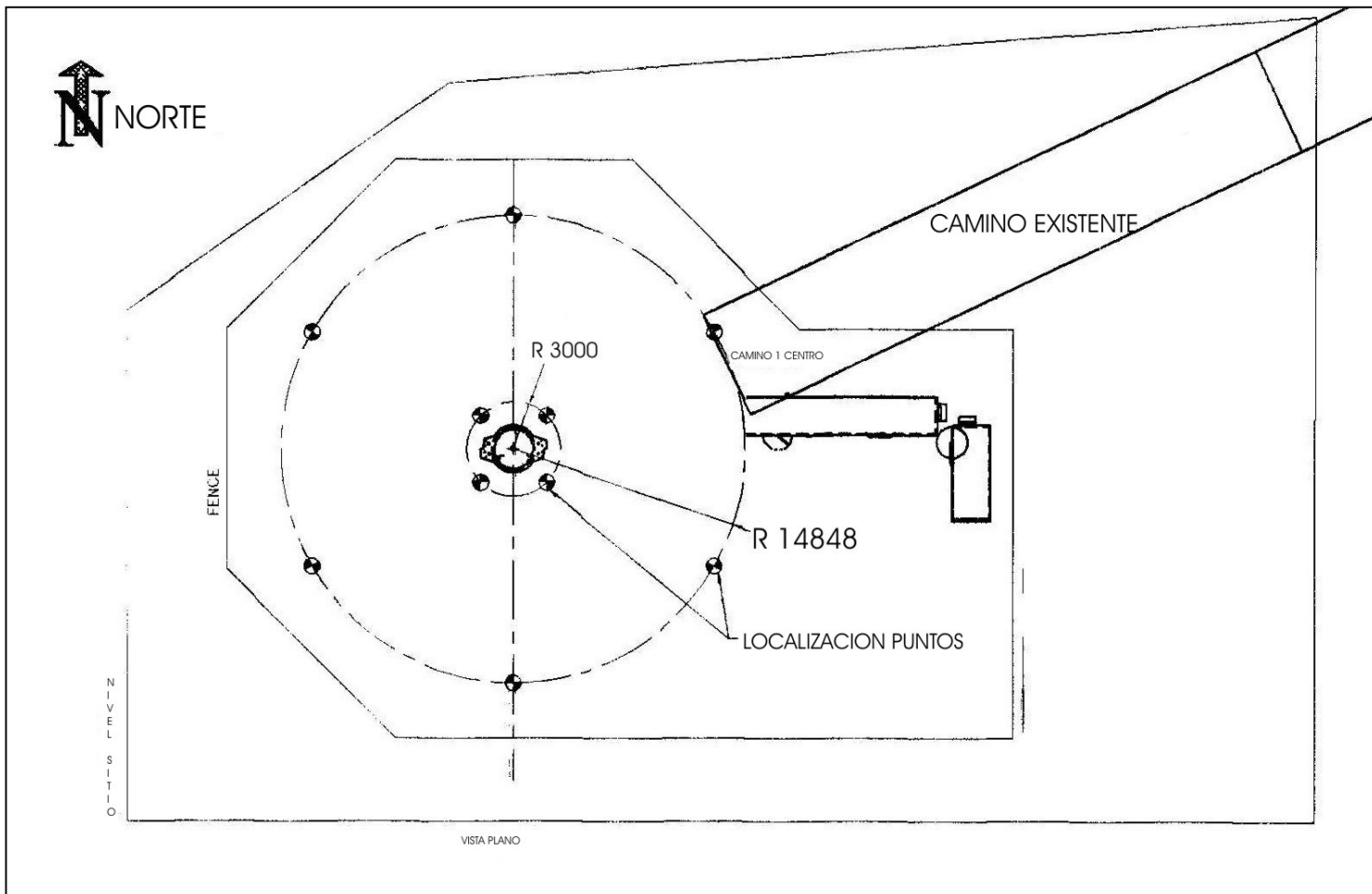




## II. LOCATION OF THE PERFORATIONS

Geominas Limitada drilled eight holes, each one of 7.8 meters depth, in average. The exactly location of the perforations were determined by means of information supply by AMEC (image N°3 following).

**Image N°3:** Initial location of points to be drilled

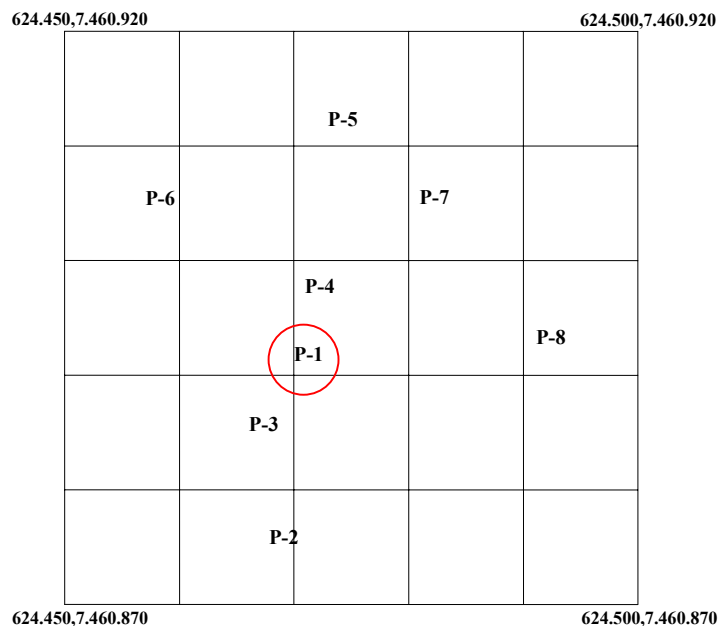




Geominas Limited drilled eight holes, at foot of TOCO hill, at Andes mountain in HQ diameter. The data for each perforation is observed in the following table, where point **P-1** corresponds to the location (center) for the foundation, suggested by AMEC:

| PERFORATION | Coordinates (m)  |                | ELEVATION<br>(m.s.n.m.) | DEPTH<br>(m) |
|-------------|------------------|----------------|-------------------------|--------------|
|             | NORTH            | EAST           |                         |              |
| <b>P-1</b>  | <b>7,406,891</b> | <b>624,471</b> | 5,148                   | 7,85         |
| P-2         | 7,460,875        | 624,469        | 5,148                   | 7,85         |
| P-3         | 7,460,885        | 624,467        | 5,148                   | 7,85         |
| P-4         | 7,460,899        | 624,472        | 5,148                   | 7,85         |
| P-5         | 7,460,911        | 624,474        | 5,148                   | 7,80         |
| P-6         | 7,460,904        | 624,458        | 5,148                   | 7,85         |
| P-7         | 7,460,904        | 624,482        | 5,148                   | 7,85         |
| P-8         | 7,460,892        | 624,492        | 5,148                   | 7,70         |

## Geotechnical Perforations





### III. DESCRIPTION OF THE PERFORATIONS

#### 3.1 PERFORATION P-1

##### 3.1.1 Photography “Rock Samples” – Perforation P-1





### 3.1.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 3,35 | 3,35        | 0,70          | --- | ---  |
| 3,35        | 3,92 | 0,57        | 0,37          | >n  | 0%   |
| 3,92        | 4,75 | 0,83        | 0,83          | 0   | 100% |
| 4,75        | 6,35 | 1,60        | 1,60          | 0   | 100% |
| 6,35        | 7,85 | 1,50        | 1,50          | 0   | 100% |

FF: Fracture Frequency

RQD: Rock Quality Designation

### 3.1.3 Geological Description

|               |  |
|---------------|--|
| 0.00 – 2.80 m | Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.   |
| 2.80 – 3.92 m | Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.   |
| 3.92 – 7.85 m | Dacitic lava, rock without fractures and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size. |



## 3.2 PERFORATION P-2

### 3.2.1 Photography “Rock Samples” – Perforation P-2





### 3.2.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 1,45 | 1,45        | 0,65          | --- | ---  |
| 1,45        | 1,95 | 0,50        | 0,50          | 10  | 24%  |
| 1,95        | 3,35 | 1,40        | 1,30          | 7   | 75%  |
| 3,35        | 4,80 | 1,45        | 1,45          | 5   | 90%  |
| 4,80        | 6,40 | 1,60        | 1,60          | >n  | 100% |
| 6,40        | 7,85 | 1,45        | 1,45          | 2   | 100% |

### 3.2.3 Geological Description

- 0.00 – 1.45 m      Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.
- 1.45 – 2.20 m      Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.
- 2.20 – 7.85 m      Dacitic lava with an andesitic pattern; light grey color in dark sections, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock has a lot of fractures with a pumiced filling that is highly permeable.



### 3.3 PERFORATION P-3

#### 3.3.1 Photography “Rock Samples” – Perforation P-3





### 3.3.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 0,60 | 0,60        | 0,25          | --- | ---  |
| 0,60        | 2,05 | 1,45        | 0,65          | >n  | 7%   |
| 2,05        | 3,35 | 1,30        | 1,45          | 4   | 88%  |
| 3,35        | 4,85 | 1,50        | 1,45          | 4   | 97%  |
| 4,85        | 6,35 | 1,50        | 1,50          | 5   | 87%  |
| 6,35        | 7,85 | 1,50        | 1,5           | 0   | 100% |

### 3.3.3 Geological Description

|               |   |
|---------------|---|
| 0.00 – 1.40 m | Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.  |
| 1.40 – 2.05 m | Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.  |
| 2.05 – 7.85 m | Dacitic lava with an andesitic pattern light grey color in dark sections, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock presents horizontal and vertical fractures. |





### 3.4 PERFORATION P-4

#### 3.4.1 Photography “Rock Samples” – Perforation P-4





### 3.4.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 1,20 | 1,20        | 0,40          | --- | ---  |
| 1,20        | 3,15 | 1,95        | 1,75          | >n  | 72%  |
| 3,15        | 4,80 | 1,65        | 1,65          | 2   | 100% |
| 4,80        | 6,35 | 1,55        | 1,45          | 2   | 94%  |
| 6,35        | 7,85 | 1,50        | 1,50          | 1   | 100% |

### 3.4.3 Geological Description

- 0.00 – 1.20 m      Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.
- 1.20 – 1.60 m      Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.
- 1.60 – 7.85 m      Dacitic lava, light grey color, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock presents horizontal and vertical fractures.



### 3.5 PERFORATION P-5

#### 3.5.1 Photography “Rock Samples” – Perforation P-5





### 3.5.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 0,60 | 0,60        | 0,60          | --- | --   |
| 0,60        | 1,40 | 0,80        | 0,50          | >n  | 31%  |
| 1,40        | 2,90 | 1,50        | 1,10          | 4   | 73%  |
| 2,90        | 4,65 | 1,75        | 1,75          | 1   | 100% |
| 4,65        | 6,25 | 1,60        | 1,60          | 1   | 100% |
| 6,25        | 7,8  | 1,55        | 1,55          | 1   | 100% |

### 3.5.3 Geological Description

- 0.00 – 0,60 m      Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.
- 0.60 – 1.40 m      Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.
- 1.40 – 7.80 m      Dacitic lava with an andesitic pattern; light grey color in dark sections, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock presents horizontal and vertical fractures. In some sections has a pumiced filling.



### 3.6 PERFORATION P-6

#### 3.6.1 Photography “Rock Samples” – Perforation P-6





### 3.6.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 1,20 | 1,20        | 0,40          | --- | ---  |
| 1,20        | 2,90 | 1,70        | 1,70          | 8   | 74%  |
| 2,90        | 4,60 | 1,70        | 1,35          | 2   | 79%  |
| 4,60        | 6,25 | 1,65        | 1,65          | 3   | 82%  |
| 6,25        | 7,85 | 1,60        | 1,60          | 0   | 100% |

### 3.6.3 Geological Description

|               |   |
|---------------|---|
| 0.00 – 1.20 m | Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.  |
| 1.20 – 1.40 m | Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.  |
| 1.40 – 7.85 m | Dacitic lava with an andesitic pattern; light grey color in dark sections, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock has a lot of fractures with a pumiced filling that is highly permeable |



### 3.7 PERFORATION P-7

#### 3.7.1 Photography “Rock Samples” – Perforation P-7





### 3.7.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 0,70 | 0,70        | 0,40          | --- | ---  |
| 0,70        | 1,10 | 0,40        | 0,30          | 6   | 75%  |
| 1,10        | 1,55 | 0,45        | 0,45          | 10  | 40%  |
| 1,55        | 3,00 | 1,45        | 1,45          | 2   | 100% |
| 3,00        | 4,60 | 1,60        | 1,60          | 0   | 100% |
| 4,60        | 6,20 | 1,60        | 1,60          | 0   | 100% |
| 6,20        | 7,85 | 1,65        | 1,65          | 1   | 100% |

### 3.7.3 Geological Description

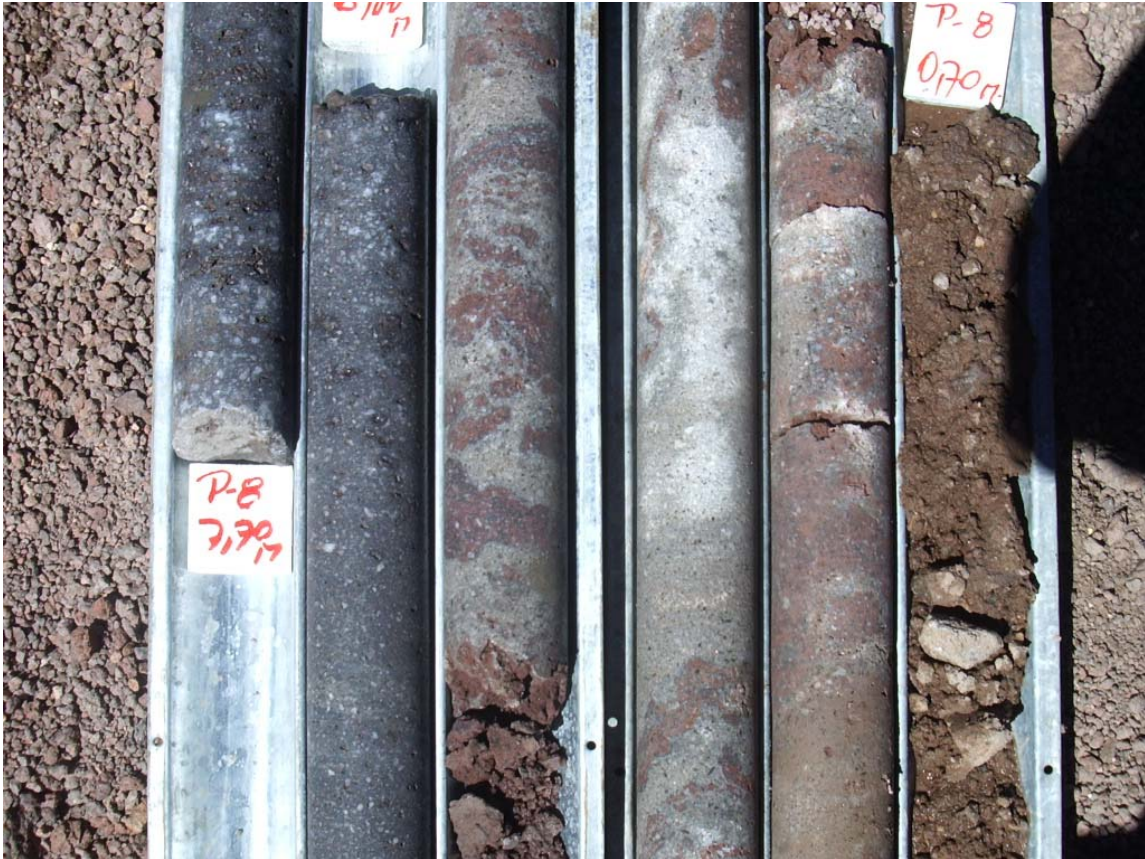
|               |  |
|---------------|--|
| 0.00 – 0.70 m | Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition.   |
| 0.70 – 1.55 m | Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.   |
| 1.55 – 7.85 m | Dacitic lava; light grey color with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock presents horizontal and vertical fractures. |





### 3.8 PERFORATION P-8

#### 3.8.1 Photography “Rock Samples” – Perforation P-8





### 3.8.2 Measurement

| Section (m) |      | Drilled (m) | Recovered (m) | FF  | RQD  |
|-------------|------|-------------|---------------|-----|------|
| From        | To   |             |               |     |      |
| 0,00        | 0,70 | 0,70        | 0,50          | --- | ---  |
| 0,70        | 1,70 | 1,00        | 0,70          | --- | ---  |
| 1,70        | 2,95 | 1,25        | 1,25          | 8   | 66%  |
| 2,95        | 4,55 | 1,60        | 1,60          | 1   | 100% |
| 4,55        | 6,00 | 1,45        | 1,45          | 2   | 86%  |
| 6,00        | 7,70 | 1,70        | 1,70          | 2   | 100% |

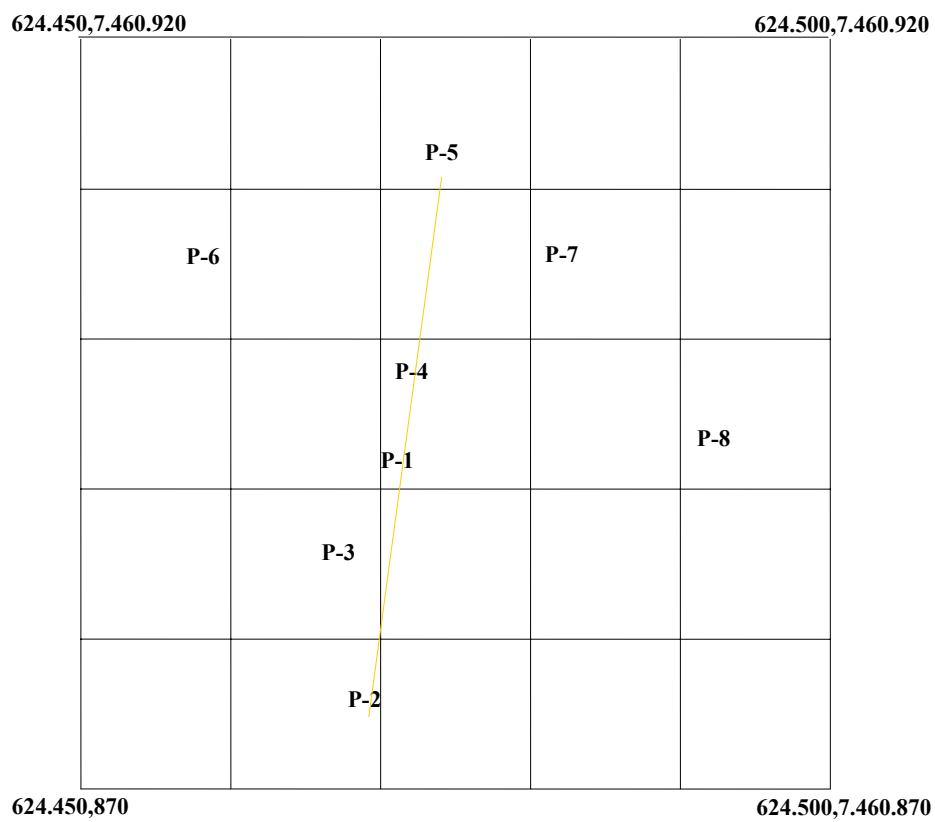
### 3.8.3 Geological Description

|               |   |
|---------------|---|
| 0,00 – 1,70 m | Level of overload and corresponds to fractured blocks filled with sand and gravel that is mostly of dacitic composition   |
| 1,70 – 2,40 m | Dacitic lava, rock with fractures, and has a light grey color; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline) and has a phaneritic texture and medium grain size.  |
| 2,40 – 7,70 m | Dacitic lava with an andesitic pattern; light grey color, with a reddish orientation; the degree of crystallinity corresponds to an effusive rock (Hipocrystalline), of phaneritic texture and with a medium grain size. The rock presents horizontal and vertical fractures. Some inferior sections have fractures with a pumiced filling. |



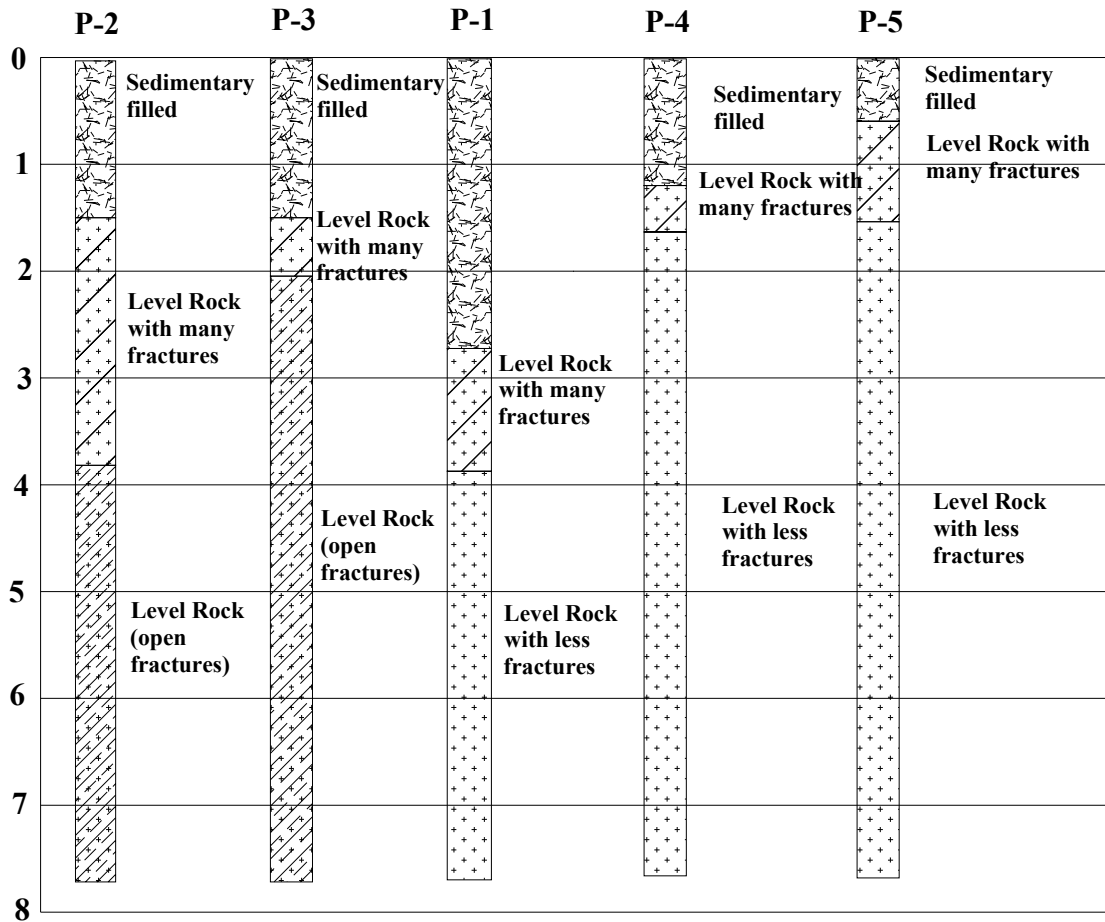
#### IV. PROFILE P-2 to P-5

## Geotechnical Perforations





# Geotechnical Perforations





## V. ANALYSIS

According to conceptual hypothesis formulated in relation to previous reports of Chajnantor and, comparing with new information analysed and obtain after drillings the following can be mentioned:

### - Preliminary main assumptions (AMEC):

- Level of overload (fractured rocks, gravel and sand) was found between 1.0 to 1.2 meters deep.
- Massive rock it is found approximately from 1.2 meters until 18 meters deep and correspond to the second level identified by ALMA (Igneus Composed Purico Superior Ignimbrite)
- Normal quality of massive rock in situ=70 (“good quality”; according to RQD (Rock Quality Designation)).

### - Obtained information after drilling work developed by GEOMINAS:

- Level of overload (fractures rocks, gravel and sand) it is found between 0.6 and 2.8 meters deep.
- Level of fractured rock:
  - P-1 Massive rock quality in situ = 0 (“Bad quality Rock”; from 2.80 to 3.92 m
  - P-2 Massive rock quality in situ = 20 (“Bad quality Rock”; from 1.45 to 1.95 m
  - P-3 Massive rock quality in situ = 10 (“Bad quality Rock”; from 1.40 to 2.05 m
  - P-4 Massive rock quality in situ = 30 (“Bad quality Rock”; from 1.20 to 1.60 m
  - P-5 Massive rock quality in situ = 30 (“Bad quality Rock”; from 0.60 to 1.40 m
  - P-6 Massive rock quality in situ = 10 (“Bad quality Rock”; from 1.20 to 1.40 m
  - P-7 Massive rock quality in situ = 0 (“Bad quality Rock”; from 0.70 to 1.00 m
  - P-8 Massive rock quality in situ = 30 (“Bad quality Rock”; from 1.70 to 2.40 m



- Massive rock it is found at a deep average of 1.4 meters (toward sector of perforations P-4, P-5, P-6 and P-7). Massive rock quality in situ =>80 (good quality rock)

For perforations P-1, P-2, P-3 and P-8, massive rock quality in situ is also good, but it is found deeper under 2.20 meters as an average.



## VI. CONCLUSIONS

- a) The present report determines as a main conclusion that the activities carried out in the area are located on top of dacitic lava. (Layer Volcanos of the Quaternary; according to leaf of Calama).
- b) The first level presents overload characteristics, blocks filled with gravel and sand; This characteristics are similar to the inform supply by AMEC (point 2).
- c) Under the overload a rock level is recognized fractured with different depths that goes from 0,60m to 2.0m; the zone of more homogenous rocks appears in the sector of the perforations P-4, P-5 and P-7.
- d) The rock level corresponds to layer volcanos of the Quaternary (according to Leaf of Calama). The information is similar to the information supply by AMEC from de ALMA study.
- e) Although perforations reached only 7,85 m deep, even a little more that was proposed initially (6,0 m), at this time was not possible to find out the "potencia" of the rock that cross the area with the drilling perforation equipment, but it is possible to validate the information given by the previous report wich stated that "Igneos Composed Purico Superior Ignimbrite" level rock reached 18 m deep.

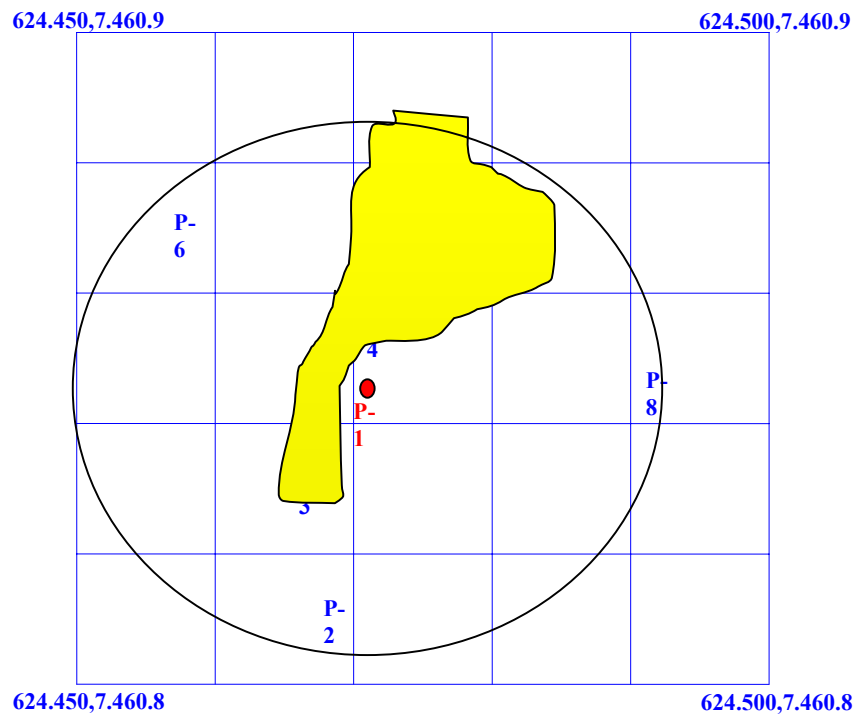


## VII. RECOMMENDATIONS

According to results of drillings and its deep (aprox 7,85m) it is clearly possible to state that rock layer with best quality conditions in terms of hardness and lack of fractures was found at line of perforations given by P-3; P-4; P-5 and P-7.

Considering this it is recommended the following:

- Plan any work in direction of the axes formed by perforations P-3; P-4; P-5 and P-7 as shown by the following scheme:



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