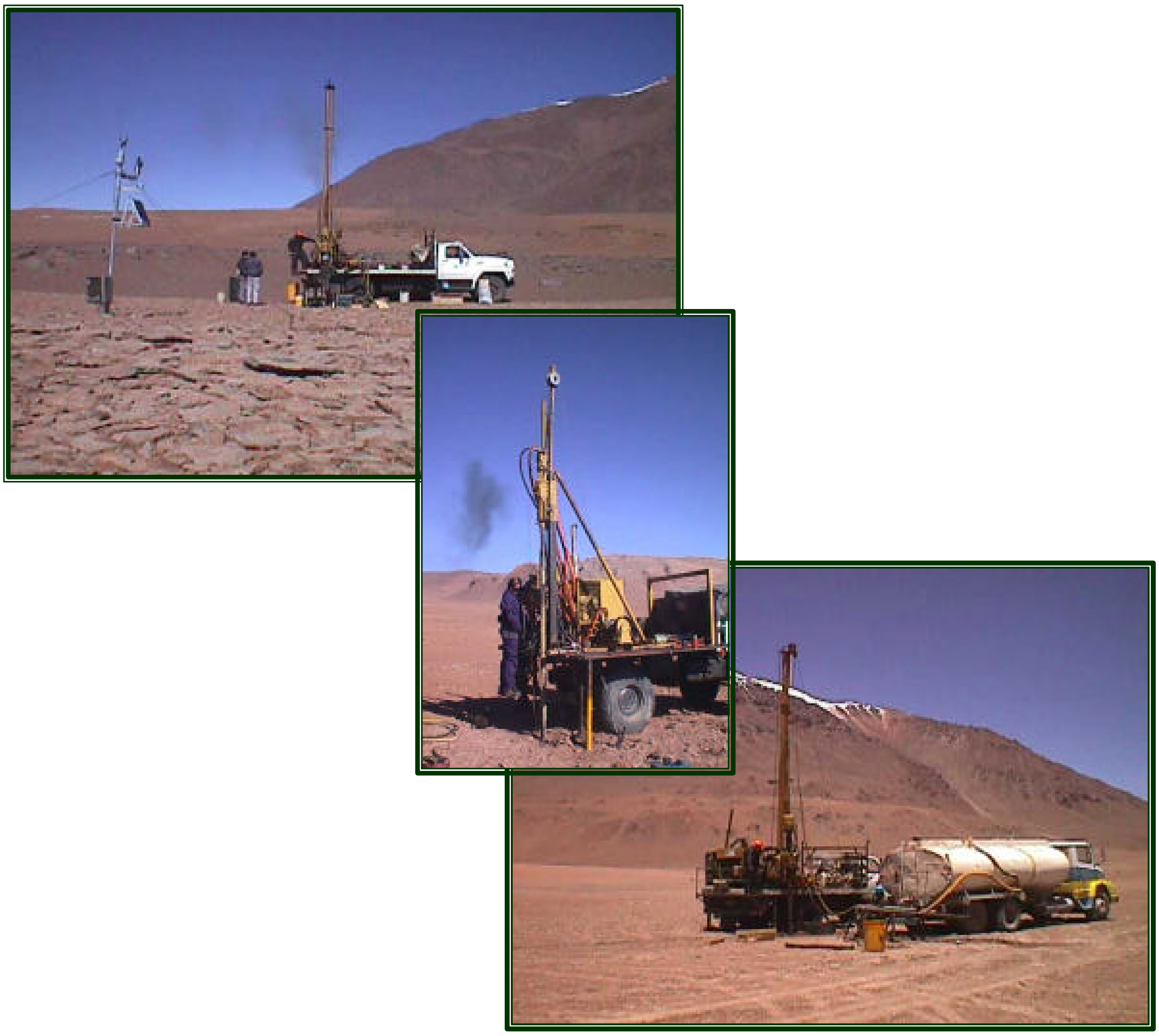
REPORT GEO 99/37 (REV. A)
GEOTECHNICAL STUDY

CHAJNANTOR SITE, II REGION
NOBEYAMA RADIO OBSERVATORY
NRO - NRAO



MARCH, 2000

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CHAJNANTOR SITE, II REGION, CHILE
NOBEYAMA RADIO OBSERVATORY

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TABLE OF CONTENTS

SECTION

TABLE

FIGURE

APPENDIX

GEOTECHNICAL STUDY
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1. INTRODUCTION

The present Report is written by ***Geo Ambiental Consultores Ltda***. and summarizes the geotechnical study of the **Nobeyama Radio Observatory Authority** Chajnantor Site in the II Region, Chile.

The site is a fairly flat area (pampa) at high altitude (approximately 5,000 m above sea level), located at the foot of the Chajnantor and Chascón Mountains, not far from The Jama Pass International Road, about 80 km from the town of San Pedro de Atacama.

The Nobeyama Radio Observatory Authority plans to install an array of large parabolic antennas at the site. Thus, the foundation engineers require the geotechnical characteristics of the subsurface for their design work. The NRO representatives indicated a total of six locations to drill and investigate.

The following Sections summarize the field and laboratory work developed for the project, give a geological description for the area and indicate the design parameters requiered for the development of the infrastructure for the antennas at the six locations. Finally, the Consultant makes recommendations for future developments in the area of the study. Boring logs and photographs of the rock cores are presented in the Appendix.

2. SITE DESCRIPTION

The site considered for the NRO project is within the CONICYT Science Preserve and sorrounds the Chascón Mountain which has an elevation slightly higher than 5,700 meter above sea level.

The area is fairly flat and most of its extention slopes gently to the South. It´s mean elevation is 5,000 meters above sea level and it has a number of depressions and other topographic features that make it uneven in many areas. Some of these depressions have been formed by incipient water flows which occur with rainfall mostly during the summer months (January and February). The surface shows a thin layer of gravel and pebbles followed by a few centimeters of sand, although rock outcrops are notorious at the site. Vegetation is almost non-existing due to its high altitude and the very little rainfall experienced in the region.

To the South-West of the Chascón Mountain the landscape shows the Agua Amarga Hill within the site, with an elevation a little over 5,050 meter above sea level.

A gas pipeline recently constructed crosses the area in a North-West to South-East direction from Argentina to the South of the Chajnantor and Agua Amarga, cutting it at a 30° angle from an East-West imaginary line.

A few dirt roads are present. Also two other scientific camps and small facilities are already installed in the area.

The NRO actual camp site is located at Pampa La Bola, a flat area, North of the Chascón Mountain and close to the International Road.

3. GEOLOGIC SETTING

Several stratified units, ranging from Paleozoic to Quaternary, and groups of plutonic rocks, have been distinguished in the overall region. The precordillera and Andean cordillera domain morphostructure contains upper Cenozoic volcanic rocks separated into two major groups, the ignimbrites and the volcanoes.

The ignimbrite is defined as a silicic volcanic rock forming thick, massive, compact, lavalike sheets covering wide areas. The rock is chiefly a finegrained rhyolitic tuff composed mainly of glass particles, firmly welded. The deposits are believed to have been formed by the eruption of dense clouds of incandescent volcanic glass in a semimolten or viscous state from groups of fissures.

The ignimbrites in the region are divided into three groups according to their ages, that is: Miocene, Pliocene and Pleistocene. They are constituted by pyroclastic flows, mainly dacitic and andesitic; the Cajón ignimbrite, present at the site, is dated from the Pleistocene-Holocene with 0,8 Million years. Its outcrop covers approximately 450 km^2 in the Calama sheet, extending another 530 km^2 to the South. Its thickness ranges from 250 m to a few meters, thinning to the West.

To the North-East of the Purico volcano (zone of interest), the unit is composed by tuff moderately to weakly welded with phenocristals of plagioclase, quartz, biotite and hornblend. Its matrix is composed of pieces of glass. Typically, the flows contain a large number of pumice. From a chemical point of view they are classified as chalcoalcalines.

It is proposed that the Cajón ignimbrite was formed by the emission through concentric fractures around the Purico volcano.

The volcanoes are divided into three groups: Miocene, Pliocene-lower Pleistocene and upper Pleistocene-Holocene, with the Chajnantor and Purico being strato-volcanoes from the later group.

The Purico volcanic group is believed to have evolved around an old strato-volcano (the Purico) with andesitic composition, with a later emission of very viscous lava flows (North-East and South-East of the Purico and on the South-East flank of the Chajnantor). The emission of ignimbritic flows would have come later in the superior Pleistocene. The last stage would be the occurance of the Toco, La Torta, Chajnantor, and Chascón volcanoes around the Purico.

The tectonic structure shows very little disturbance by recent activity. The only structures known correspond to normal faults and fractures of little magnitude with three main system: N-S, NW-SE, NE-SW.

The N-S system in line with the N-S volcanic chain, affect the Cajón ignimbrite West of the Purico, but has not produced vertical movement on the rock. It seems that they have been inactive prior to the ignimbrite flows.

The NW-SE and NE-SW systems affect various volcanic units in the area. They are minor structures with local development. These systems appear controlled by the local volcanic activity. They would be the result of E-W extension movements.

4. FIELD EXPLORATION AND LABORATORY PROGRAM

4.1. Field Exploration

The field exploration consisted of drilling six borings with HQ tools in combination with a wireline double wall sampler. No additives were used during the drilling operation and only fresh water was applied as a coolant to the cutting tool at the bottom of the drilling rod.

The location for the borings is indicated in Table 1.

Table 1

Location of Borings

Boring N°	Identification	Coordinates (*)	
		East	North
1	Pampa La Bola	0.633.650	7.460.200
2	ASTE Candidate Site	0.632.940	7.459.040
3	Chajnantor North	0.627.410	7.454.050
4	Chajnantor South	0.627.610	7.452.850
5	Saddle Point	0.631.250	7.455.850
6	Chascón East	0.637.710	7.457.280

Note : (*) GPS positions (UTM/UPS WG S84) provided by NRO

The drilling was done during a period of 10 days, between February 1st and February 10th, 2000. A coordination meeting with the representatives of NRO in San Pedro de Atacama was conducted on January 31 and a site visit was acomplished that afternoon.

The corresponding boring longs and photographs for the six sites are presented in the Appendix. The logs indicate depth, percent of sample recovery, determination of Rock Quality Designation (as a percent of the sum of the samples having length greater than 10 cm over the coring length) and observations made for each core run.

The subsurface in general is characterized by a thin top layer of residual soil over very broken to broken rock. The depth to massive rock (very few discontinuities, cracks or fissures) is indicated in Table 2. The rock, as described by the Consultant´s geologist is ignimbrite (welded tuff), reolithic with quartz and some fragments of volcanic rocks. The rock is medium hard, abrassive and stable. It shows weakness planes coincident with deposition planes in which the rock is weakly welded or indicates different events. The geologist description is in agrement with the general geologic setting.

Table 2

Depth To Massive Rock

Boring N°	**Total Depth (m)**	**Depth To Massive Rock (m)**
1	15.2	1.6
2	15.3	3.6
3	15.2	2.0
4	15.0	2.0
5	16.6	15.0
6	15.0	7.0

In addition to the six borings a 1.50 m deep trench was excavated at the site of Boring N°5 where sand was found to a depth of 15 m. Samples were taken from the bottom of it and two in-situ unit weight measurements were performed.

4.2. Laboratory Testing and Test Results

The laboratory testing of the rock samples from the borings consisted of unconfined compression tests. Due to the homogeneity of the rock encountered at the site, only a total of eight test were performed. Each sample was chosen at a depth to be representative for the foundations to be designed.

The samples tested under unconfined compression conditions were prepared in the laboratory so that the length to diameter ratio was equal or slightly greater to two. The ultimate load for the eight tests is presented in Table 3.

Table 3

Unconfined Compression Tests on Selected Rock Specimens

Boring N°	**Specimen Depth (m)**	**Unit Weight (Kg/m^3)**	**Ultimate Axial Resistance (Kg/cm^2) (1)**
1	2.0-2.2	2,189	279
1	1.4-1.6	2,057	226
2	3.5-3.75	2,174	406
3	3.9-4.1	2,128	202
3	3.2-3.4	1,998	113
4	2.3-2.5	2,089	124
4	2.0-2.4	1,993	216
6	7.4-7.6	1,931	161
$\bar{\chi}$	---------	2,070	216
s	---------	0.086	88

Note (1): 1 Kg/cm^2 = 98.07 kPa

The tests were conducted at the Laboratory of the Technical University Federico Santa María in Valparaíso.

The testing of the sand samples obtained from the trench consisted of index properties such as moisture content determination, grain size distribution and specific weight of mineral particles determination.

The two in-situ unit weight tests performed at the bottom of the trench show an average wet unit weight of 1.75 Ton/m^3, with a natural moisture content of 7% which implies a dry unit weight of 1.6 Ton/m^3.

The specific gravity of the mineral particles was measured to be 2.5, whereas the grain size distribution obtained for the samples taken to the laboratory is presented in Figure N°1.

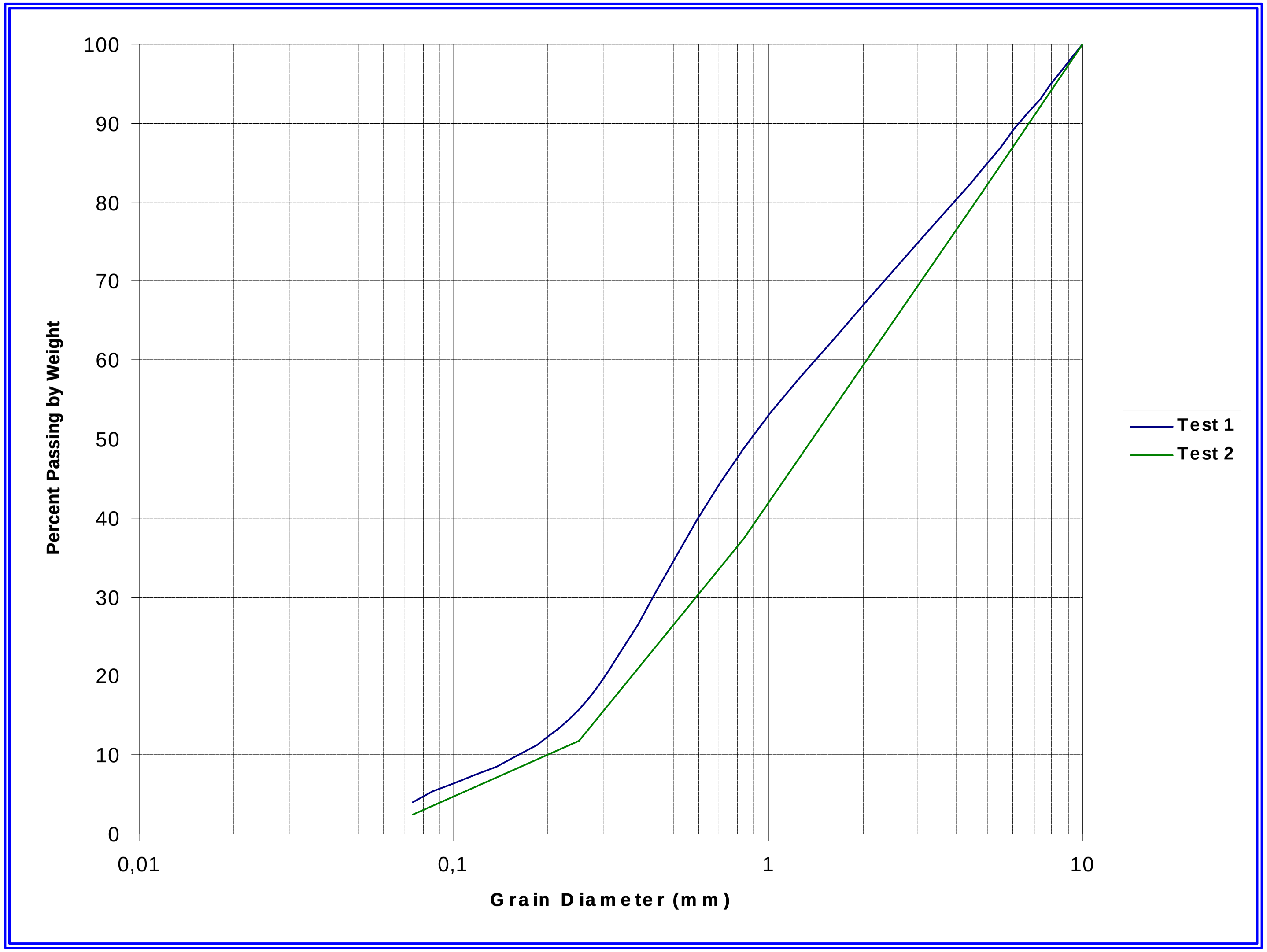

Figure 1. Trench at Boring Nº5 Site. Grain Size Distribution of Sand

5. GEOTECHNICAL CHARACTERISTICS OF THE SUBSURFACE

As previously indicated, the subsurface at the site is characterized by a thin layer of residual soil over vey broken rock. This horizon was found to be of varying depth (see Table 2) and is believed to have formed by action of frost-defrost cycles of the water infiltrated in the crevices and cracks over may years.

A previous investigation performed by this Consultant by excavating trenches showed the nature and morphology of the broken rock horizon. Figure 2 shows two photographs of typical walls in the trenches. Figure 3 has two photographs of rock outcrop at the site also showing the "layering" morphology of the meteorized rock at the surface.

Due to the stringent conditions imposed by the equipment to the foundations, this Consultant considers necessary to locate the foundations at a depth below the broken rock horizon or at least 2 m below the surface. This is a requisite to isolate the foundation from the uplifting forces of frost heave effect.

The statement above implies that (but for Boring Nº5 location), the horizon of most interest to characterize is the massive ignimbritic rock. To do this, the rock has been classifies according to the Rock Mass Rating (RMR) system proposed by Bieniawski, which is presented in Table 4.

Figure 2. Photographs of Broken Rock in Trenches

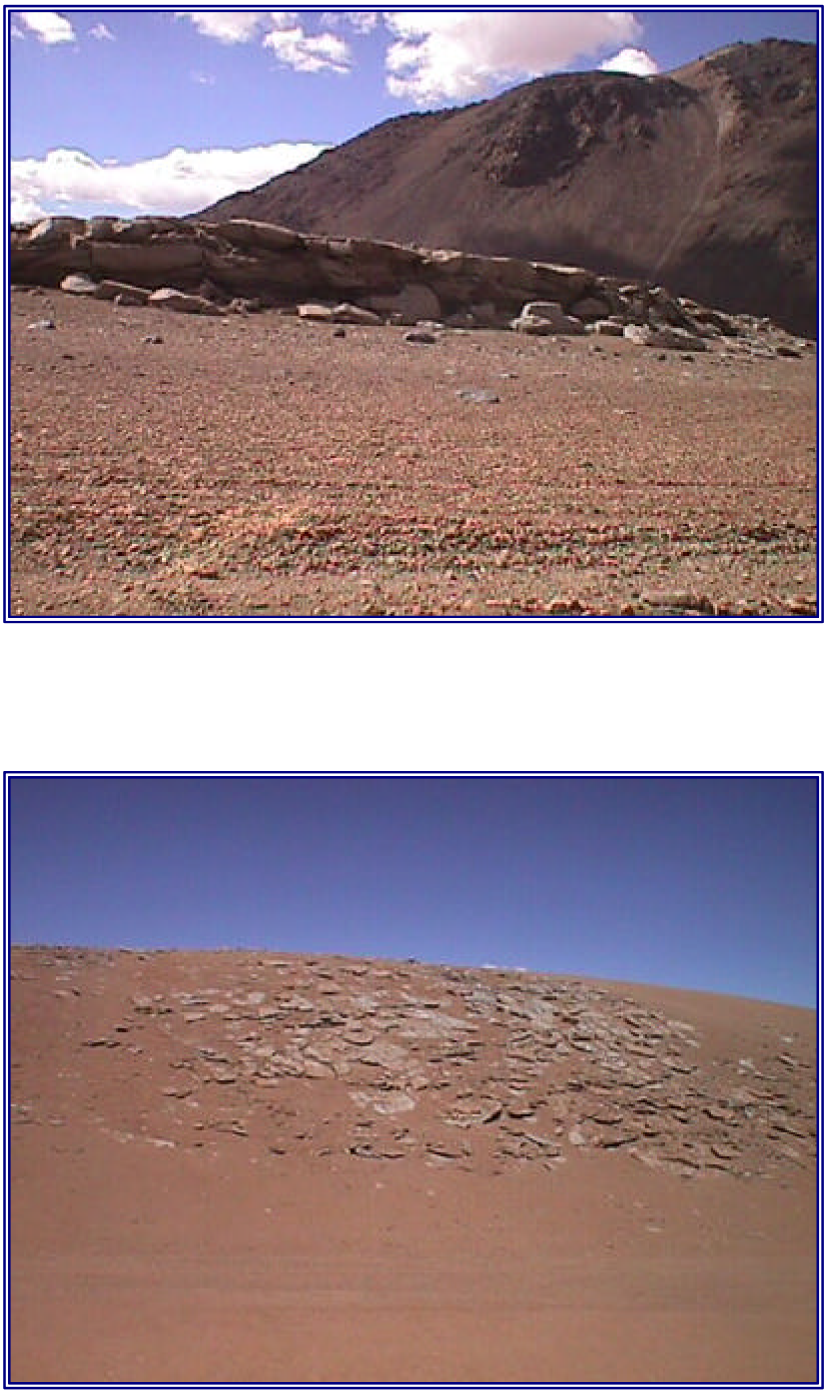

Figure 3. Photographs of Typical Rock Outcrop at Site

Table 4

Rock Mass Rating System For Jointed Rock Masses (Bieniawski)

A. Classification Parameters and Their Ratings

PARAMETER			RANGES OF VALUES						
1	Strength of intact roack material	Point-load strength index	> 10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range -uniaxial compressive- test is prefered		
		Uniaxial compressive strength	>250 MPa	100-250 MPa	50-100 MPa	25 - 50 MPa	5-25 MPa	1-5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0,6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces. Not continuous No separation Unweathered wall rock	Slightly rough surfaces. Separation < 1 mm Slightly weathered walls	Slightly rough surfaces. Separation < 1 mm Highly weathered walls	Slickensided surfaces OR Gouge < 5 mm thick OR Separation 1-5 mm. continuous	Soft gouge > 5 mm thick OR Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length	None	< 10 litres/min	10 - 25 litres/min	25 - 125 litres/min	> 125		
			OR	OR	OR	OR	OR		
		Joint water pressure / mayor principal stress Ratio	0	0,0 – 0,1	0,1 – 0,2	0,2 – 0,5	> 0,5		
			OR	OR	OR	OR	OR		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. Rating Adjustment for Joint Orientations

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. Rock Mass Classes Determined from Total Ratings

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 20
Class N°	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. Meaning of Rock Mass Classes

Class N°	I	II	III	IV	V
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2,5 m span	30 minutes for 1 m span
Cohesion of the rock mass	> 400 kPa	300 - 400 kPa	200 – 300 kPa	100 – 200 kPa	< 100 kPa
Friction angle of the rock mass	> 45°	35° - 45°	25° - 35°	15° - 25°	< 15°

Under the RMR system the designer can also apply the following correlations:

Table 5

Geotechnical Parameter Correlations

(Hoeck and Brown)

RMR	Friction Angle (º)	c-Intercept (kPa)
20	30	96
40	35	144
60	40	201
80	45	306

$E_i = 0.564\ \text{RMR}^{1.958}$ (ksi) (RMR ≤ 60)

$E_i = 290$ RMR - 14,500 (ksi) (RMR > 60)

(1ksi = 6.9 MPa)

This Consultant has classified the upper broken rock and the lower massive rock as shown in Table 6, characterizing the materials with the values of the geotechnical parameters indicated in this Table.

Table 6

Geotechnical Parameters For the Site

Total Unit Weigth = 2 Ton/m^3

Poisson Ration = 0.2

Parameter	Broken Rock	Massive Rock
RMR	35	70
Friction Angle (°)	35	42
c-Intercept (Kpa)	134	250
Ei (MPa)	10,000	40,000

The values of the friction angle and the c-Intercept correspond to applying the Mohr-Coulomb strength model with a straight failure envelope.

It should be note that the cyclic loading of the foundation will come from the wind and thus, it will produce little deformation in the massive rock. Under these circunstances the material will have an elastic behavior with very little hysteretical effect. The dinamic modulus will be at least 10 times higher than that indicated for Ei and the damping ratio will probably be less than that for dry sands and gravel, that is < 0.03.

In the case of location at boring Nº5 and should a need to install a foundation on sand or residual arise, the designer will be forced to use soild geotechnical parameters. Considering the conditions found at the site, the following geotechnical parameters are suggested.

Table 7

Geotechnical Parameters for Sand at Location of Boring Nº5

Index Properties			
Total Unit Weight	=	1.75	Ton/m^3
Natural Moisture Content	=	7	%
Dry Unit Weight	=	1.6	Ton/m^3
Specific Gravity	=	2.5	
Grain Size Distribution as Show in Figure 1			
Strenght and Deformation Properties			
Friction Angle (º)	=	30	
c-Intercept	=	0	
Elastic Module	=	7-10	kPa

6. RECOMMENDATIONS

As presented in this Report, a total of six sites were investigated. The results show that the upper horizon of broken to very broken changes in deph with location, thus making difficult to extrapolate the data to locations not explored. None-the-less the depth to massive rock is not high, varying from 1.6 m at Boring Nº1 to 7.0 m at Boring Nº6 (Boring Nº5 not included). Considering that it has been suggested that a minimum excavation of 2 m be developed for the projected foundations, in most places the bottom of the foundations will occur close to or at the massive rock horizon.

This Consultant understands that the antenna arrays have not been defined yet. Thus, a number of other foundation locations will need to be investigated. An efficient mean to define the depth to the massive rock at locations other than the boring ones is using geophysical methods such as seismic refraction in combination with the results from this and previous studies. A low energy refraction method is recommended since the background noise in the area is very low and investigations being conducted by various research entities would require to produce the least interference possible.

With the results from the geophysical investigation, trouble spots can be detected and a new drilling campaing can be defined, if neccesary. Also, other geotechnical methods, such as plate loading test, can be applied at difficult locations if the defined array so requires.

7. REFERENCES

The following documents have been considered when developing this Report:

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APPENDIX

BORING LOGS AND CORE PHOTOGRAPHS

NRO GEOTECHNICAL INVESTIGATION

BORING Nº1

COORDINATES : N: 0633650
E: 7460200

IDENTIFICATION : Pampa La Bola

LOCATION : Pampa La Bola, closest to international road

MATERIAL : Ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 1.6	92.5	29	20 cm of soil on top
1.6 - 2.4	96	79	
2.4 - 4.0	97.5	97	One piece
4.0 - 5.6	97.5	87	Three pieces
5.6 - 7.2	96	89	Hard rock @ 6.4 (length is 10 cm). Very fractured 6.40-6.45 m
7.2 - 8.8	89	89	One piece
8.8 - 10.4	96	91	One piece
10.4 - 12.0	96	96	One piece
12.0 - 13.6	95	95	One piece
13.6 - 15.2	99	99	One piece

0.0

3.0

Boring Nº1
Box Nº1
Depth 0.0 – 3.0 m

3.0

6.0

Boring Nº1
Box Nº2
Depth 3.0 – 6.0 m

6.0

9.0

Boring Nº1
Box Nº3
Depth 6.0 – 9.0 m

9.0

12.0

Boring Nº1
Box Nº4
Depth 9.0 – 12.0 m

12.0

15.0

Boring Nº1
Box Nº5
Depth 9.0 – 12.0 m

NRO GEOTECHNICAL INVESTIGATION

BORING Nº2

COORDINATES : N: 0632940
E: 7459040

IDENTIFICATION : Pampa La Bola

LOCATION : Pampa La Bola, closest to international road

MATERIAL : Ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 0.15	-	-	Soil
0.15 - 2.4	35	0	Very fractured
2.4 - 3.6	-	-	Silty-like material. Fault?
3.6 - 4.1	100	100	
4.1 - 5.5	96	36	
5.5 - 7.0	90	53	
7.0 - 8.6	100	31	
8.6 - 10.1	93	77	
10.1 - 11.6	87	53	
11.6 - 13.1	100	100	
13.1 - 14.7	100	94	
14.7 - 15.3	100	83	

0.0

3.0

Boring Nº2
Box Nº1
Depth : 0.0 – 3.0 m

3.0

6.0

Boring Nº2
Box Nº2
Depth : 3.0 – 6.0 m

6.0

8.8

Boring Nº2
Box Nº3
Depth : 6.0 – 8.8 m

8.8

12.0

Boring Nº2
Box Nº4
Depth : 8.8 – 12.0 m

12.0

14.6

Boring Nº2
Box Nº5
Depth : 12.0 – 14.6 m

14.6

15.2

Boring Nº2
Box Nº6
Depth : 14.6 – 15.2 m

NRO GEOTECHNICAL INVESTIGATION

BORING Nº3

COORDINATES : N: 7454050
E: 0627410

IDENTIFICATION : Chajnantor North

LOCATION : Pampa Agua Amarga, closest to Eso camp

MATERIAL : Ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 2.0	43	0	Very fractured
2.0 - 3.0	76	76	One piece
3.0 - 4.6	99	95	One piece
4.6 - 6.2	99	99	One piece
6.2 - 7.8	99	98	One piece
7.8 - 9.4	95	89	One piece
9.4 - 11.0	100	100	One piece
11.0 - 12.6	91	82	Longitudinal fracture (50 cm)
12.6 - 14.2	100	89	
14.2 - 15.2	100	100	One piece

0.0

4.6

Depth : 0.0 – 4.6 m

4.6

7.8

Boring Nº3
Box Nº2
Depth : 4.6 – 7.8 m

7.8

10.0

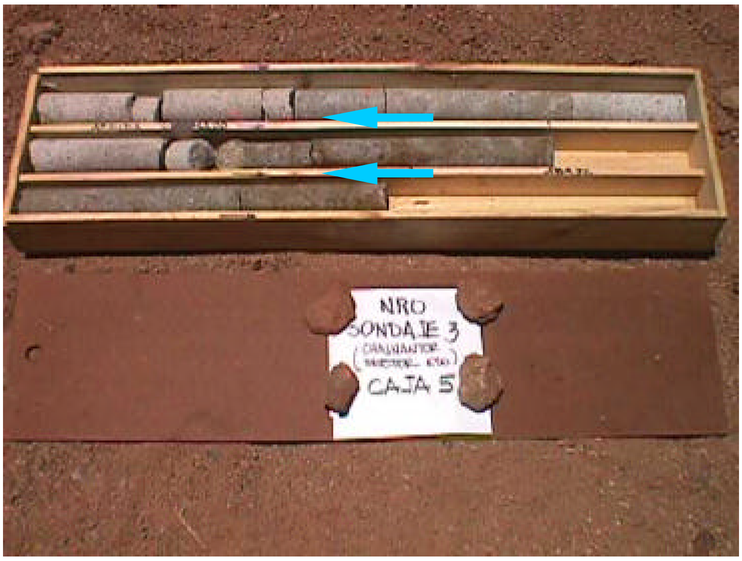
Boring Nº3
Box Nº3
Depth : 7.8 – 10.0 m

10.0

13.1

Boring Nº3
Box Nº4
Depth : 10.0 – 13.1 m

13.1



15.3

Boring Nº3
Box Nº5
Depth : 13.1 – 15.3 m

NRO GEOTECHNICAL INVESTIGATION

BORING Nº4

COORDINATES : N: 7452850
E: 0627610

IDENTIFICATION : Chajnantor South

LOCATION : Pampa Agua Amarga, across road from Caltech camp

MATERIAL : Ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 1.5	70	0	Very fractured
1.5 - 3.0	97.5	81	Long lower piece (1 m)
3.0 - 4.0	70	67	
4.0 - 5.5	86	79	
5.5 - 7.5	-	-	Lost sample in hole
7.5 - 8.05	89	42	Overall value for 5.5 to 8.05
8.05 - 9.55	91	91	
9.55 - 11.0	100	100	One piece
11.0 - 12.5	97	97	One piece
12.5 - 14.0	100	100	One piece
14.0 - 15.0	100	100	One piece

0.0

3.5

Boring Nº4
Box Nº1
Depth : 0.0 – 3.5 m

3.5

6.0

Depth : 3.5 – 6.0 m

6.0

9.0

Boring Nº4
Box Nº3
Depth : 6.0 – 9.0 m

9.0

13.0

Boring Nº4
Box Nº4
Depth : 9.0 – 13.0 m

13.0

15.0

Boring Nº4
Box Nº5
Depth : 13.0 – 15.0 m

NRO GEOTECHNICAL INVESTIGATION

BORING Nº5

COORDINATES : N: 7455850

E: 0631250

IDENTIFICATION : Saddle Point

LOCATION : Next to meteorological station

MATERIAL : Sand (product of ignimbrite meteorization) over ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 13.5	-	-	Sand. Casing needed
13.5 - 15.0	43	0	Very broken
15.0 - 16.6	69	63	Pieces up to 40 cm long

Note: A trench was excavated to depth 1.50 m and unit weight tests performed. Also, grain size distribution and specific gravity tests were performed in the laboratory. The sand is loose to medium density.

0.0

3.0

Boring Nº5
Box Nº1
Depth : 0.0 – 3.0 m

3.0

6.0

Boring Nº5
Box Nº2
Depth : 3.0 –6.0 m

6.0

9.0

Depth : 6.0 – 9.0 m

9.0

12.0

Boring Nº5
Box Nº4
Depth : 9.0 – 12.0 m

12.0

15.0

Boring Nº5
Box Nº5
Depth : 12.0 – 15.0 m

NRO GEOTECHNICAL INVESTIGATION

BORING Nº6

COORDINATES : N: 7457280
E: 0637710

IDENTIFICATION : Chascón East

LOCATION : Next to meteorological station on far North-East side of site

MATERIAL : Ignimbrite

DEPTH (m)	RECOVERY (%)	RQD (%)	OBSERVATIONS
0.0 - 1.5	-	-	Sand
1.5 - 3.0	-	-	Sand
3.0 - 4.5	-	-	Sand
4.5 - 6.0	-	-	20 cm of rock at bottom. Very fractured
6.0 - 7.5	53	27	
7.5 - 9.0	93	53	
9.0 - 10.5	93	60	
10.5 - 12.0	100	80	
12.0 - 13.5	100	93	
13.5 - 15.0	100	100	One piece

0.0

7.5

Depth : 0.0 – 7.5 m

7.5

10.1

Depth : 7.5 – 10.1 m

10.1

13.0

Boring Nº6
Box Nº3
Depth : 10.1 – 13.0 m

13.0

15.0

Boring Nº6
Box Nº4
Depth : 13.0 – 15.0 m