E-ELT project: Geotechnical investigation at Cerro Armazones.

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ABSTRACT

The design and construction of large telescopes include significant geotechnical challenges. In order to guarantee reliable and stable operations, a giant telescope like the European – Extremely Large Telescope (E-ELT) requires a foundation performance according to the level of accuracy of the other telescope's components. This paper describes the main geological and geotechnical activities conducted on site along with the studies completed in specialized geotechnical laboratories with the objective to achieve a thorough characterization of the ground conditions. This study shows that, the properties of the foundation materials are appropriate to guarantee a good performance of the E-ELT.

1. INTRODUCTION

The geotechnical and geological ground characterization is an imperative task to ensure good design and performance of any building. This is particularly true for highly sensitive structures such as telescopes, as their high-precision components cannot be affected by foundation settlement and/or angular deformations. This is even more critical in highly seismic environments such as in Chile. This paper presents the description of the investigation conducted for the evaluation of the foundation conditions of the European – Extremely Large Telescope (E-ELT), with the objective to obtain the geotechnical and geological properties for design. The E-ELT will be built over a platform on the top of Cerro Armazones, at an elevation of 3.046 m.a.s.l. located in the Second Region of Antofagasta, Chile, at the Coastal Cordillera (*Cordillera de la Costa*).

2. FIELD WORK AND LABORATORY TEST

A thorough field work program was completed for the geological and geotechnical characterization of the E-ELT foundation, including:

- Eight boreholes (vertical and inclined) with lengths between 19 m and 75 m, with continuous sample recovery and core logging and mapping. The selection of the lengths and inclination of boreholes was made considering the elevation of the foundation platform, dip direction of the structures observed in the field and the placement of the foundation of the telescope (see Figure 2-1). The drilling was made almost entirely in rock (soils were found on the surface with less than 2 m of thickness). No water level was encountered during the drilling of any borehole.
- Geophysical survey was completed during and after the boreholes drilling, to supplement the information provided by these. The geophysical tests conducted were:

- Refraction Seismic and Multichannel Analysis of Surface Waves (MASW) profiles were completed obtaining the compressional (Vp) and shear (Vs) wave velocities,
- Optical Televiewer technique was also used to obtain orientation of geological structures,
- Down Hole wave velocity measurements were performed within all the boreholes, obtaining compressive and shear velocity values.

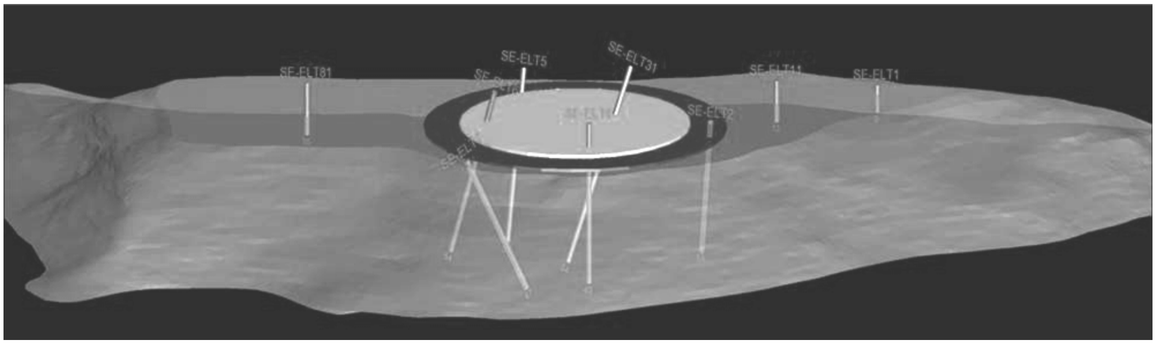


Figure 2-1: Boreholes location on E-ELT Platform

- Laboratory testing were conducted on rock samples taken from drill cores and on soils samples obtained from the ground surface. Rock test as Density, Porosity, Vs¬Vp Velocity, UCS, Triaxial and direct shear were developed. Soil laboratory testing were only chemical test (Ph, Organic matter, Total soluble salts, chloride, sulphats and coal-lignite) to establish possible aggressiveness of the ground and its adequacy to be used as rock material for the access road or concrete aggregates. All laboratory testing were performed according to European standards or equivalent.

3. GEOLOGY

3.1 REGIONAL GEOLOGIC AND GEOMORPHOLOGIC INFORMATION

The area under study is located in the Second Region of Antofagasta, Chile, at the Coastal Cordillera (*Cordillera de la Costa*) ant it is constituted by a basement of Mesozoic intrusive rocks dissected by North-South faults and barely covered by Cenozoic sediments and volcanic rocks.

The Cerro Armazones is a residual relief remnant originated by a Jurassic and Cretaceous granitoid basement. It has a relatively circular shape with moderately steep side slopes. The base elevation is approximately 2.850 m.a.s.l. and it´s slopes show significant erosion channels that transport the colluvial material from the summit towards the surrounding plains, where they come to rest and form a continuous piedmont around the Cerro Armazones, very typical in the area.

The Cerro Armazones is located inside the Atacama Fault Zone formed by series of very long faults trending N-S, close to the East limit defined by the Quebrada Grande Fault located 3 km to the East of the area being studied. Even though, out of the study area, diverse authors have indicated the existence of very recent fault movements in the Atacama Fault area, these evidences are only observed to the west of the Paposo Fault, while to the east between no evidences have reported (see Figure 3-1).

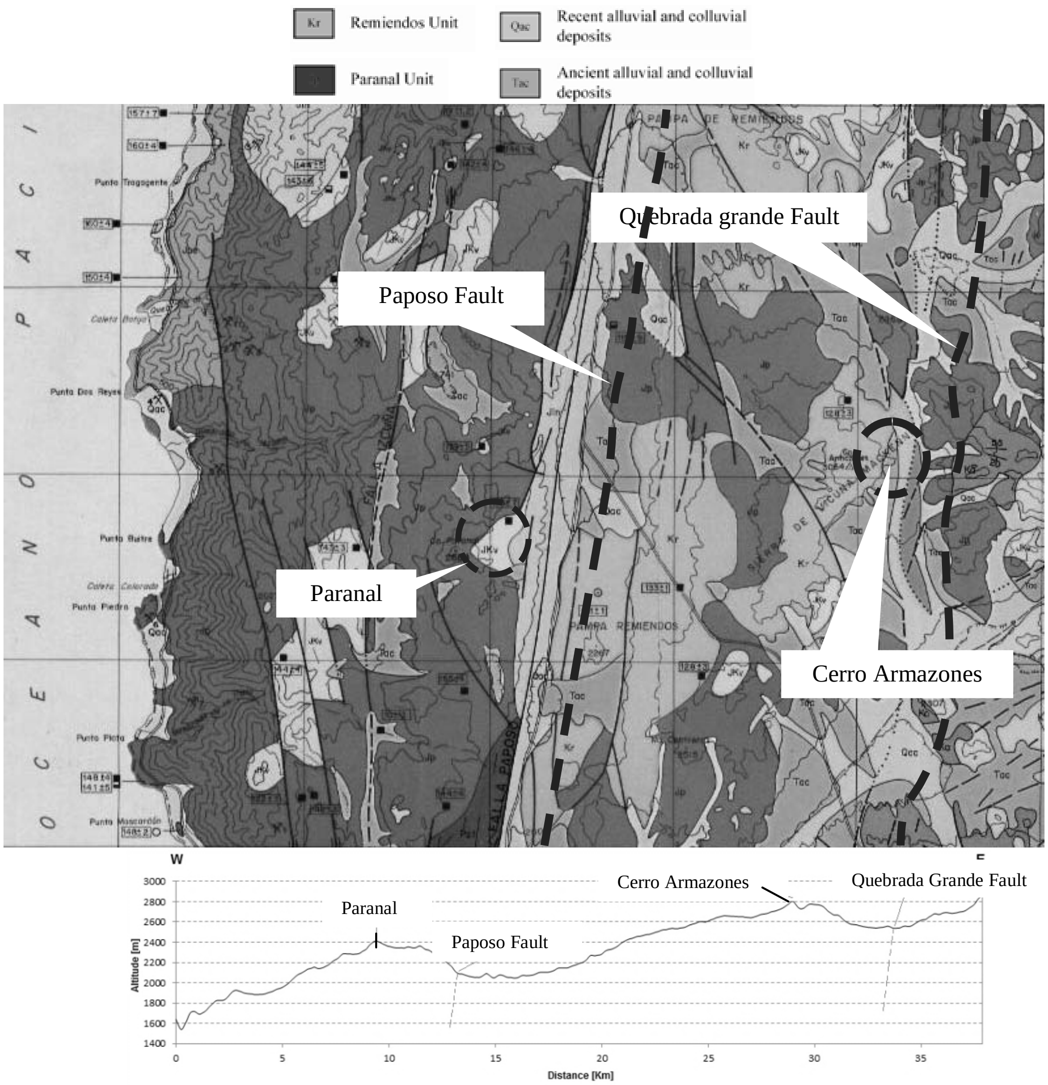


Figure 3-1: Regional geology

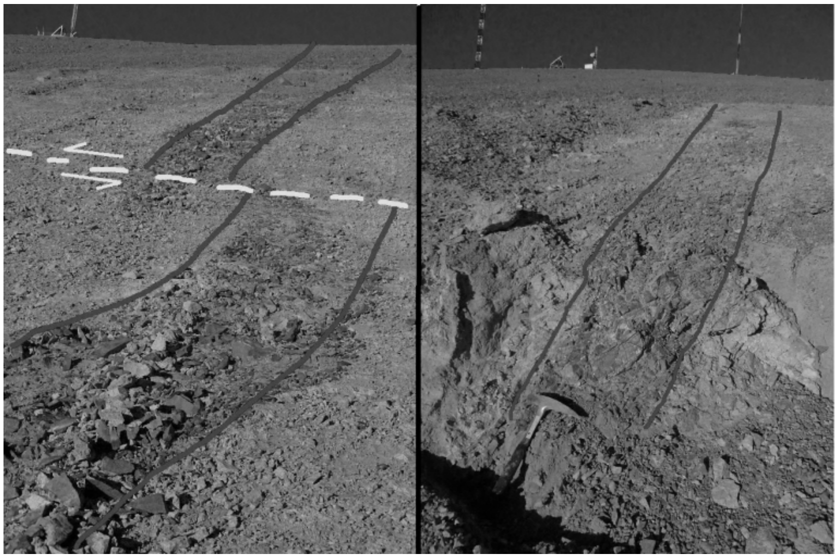
3.2 DISTRICT GEOLOGY

The rocks in Cerro Armazones were classified into three units according to the process which originated them: an intrusive plutonic unit and two dykes of a different composition.

- Granitoids: Found across the entire area under study making up the largest part of Cerro Armazones. A great part of the hill surface is highly fragmented and weathered. (See Picture 3-2)
- Andesitic dykes: Intrusions formed from volcanic rocks of an intermediate chemical composition and 1 m to 5 m width. The unit corresponds to a high strength rock, with medium weathering affecting both the rock and the discontinuities surfaces. These dykes cut across the unit formed by the plutonic rocks described above. (See Picture 3-2)

- Aplitic dykes: This unit is formed from volcanic rocks of an acid composition. The rock color varies from pink to white. The unit corresponds to a strong to very strong rock. It is fractured with low-medium weathering principally affecting the discontinuities' surfaces. The width of these intrusions does not exceed 6 to 7 m.
- Soil units: The soil layer found at the Cerro Armazones is less than 10 cm thick and corresponds to a mixture of sand and gravel with limited fines content. This layer results from the weathering of the underlying rock units caused by physical and chemical processes, with little or no transport, generating an oxidized cover in situ which is, very often, difficult to distinguish from the rock (See Picture 3-4) Colluvial deposits are found near the hillside borders close to the valley floor level, with a maximum thickness of 5 m.

Picture 3-2 Photograph of a granitoid outcrop, showing slightly weathered discontinuity surfaces.



Picture 3-3: On the left side, surface trace of an andesitic dyke displaced by faulting. The right side picture shows another andesitic dyke outcrop

Picture 3-4: Example of the reduced soil cover on the rocks found at the hillside.
The white line shows the contact between both materials.

4. GEOLOGICAL-GEOTECHNICAL MODEL

As a part of the geological-geotechnical characterization of Cerro Armazones for E-ELT placement, a tridimensional geologic model was developed representing the main lithologies in order to associate them with the geomechanical classification (See Figure 4-1).

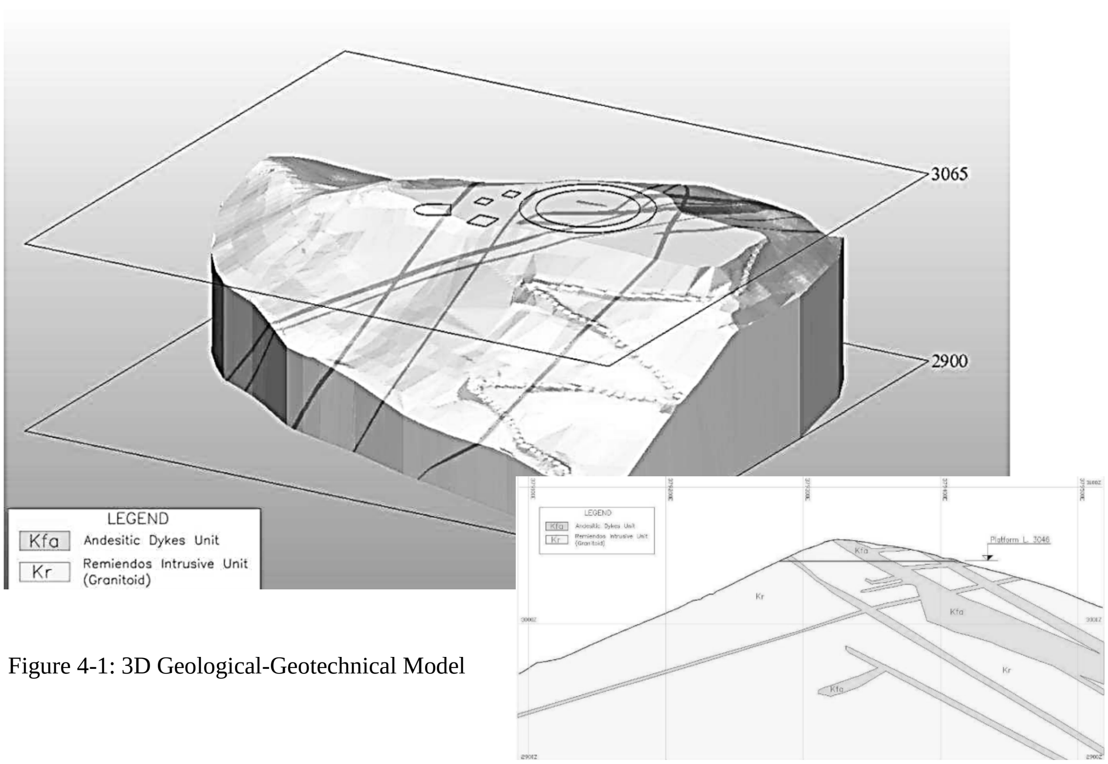
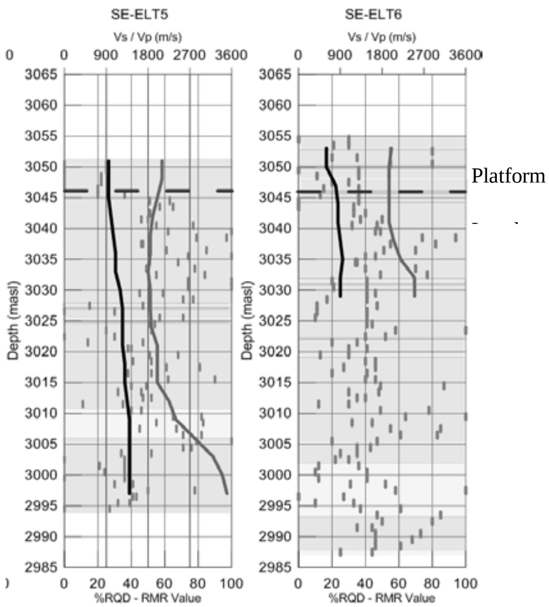


Figure 4-1: 3D Geological-Geotechnical Model

5. GEOMECHANICAL CLASSIFICATION

From the 3 lithologies described above, those that define the geomechanical quality of the rock mass at Armazones are granitoids and dykes with an andesitic composition, which represent approximately 80% of the materials found in the area. Geomechanical classification systems were used to characterize the rock mass. Figure 5-1 presents the distribution of RQD and RMR, compression (Vp) and shear (Vs) velocities for each lithology with depth on two of the boreholes excavated.



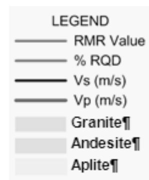


Figure 5-1: Variability of RQD-RMR percentages and Vs-Vp with depth on Boreholes

Rock Quality Designation (RQD): Parameter based on the recovery of rock borings, as the core percentage recovered in whole fragments with a length equal or greater than 100 mm, from the entire drill length.

Rock Mass Rating (RMR): System used to characterize the rock mass corresponds to Bieniawski classification (1976) from the following parameters:

- Uniaxial compressive strength of rock material
- Rock quality designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation of discontinuities

The analysis of Televiewer, REMI and Downhole tests, as RQD and RMR results, indicate that there is not an increase of geotechnical quality of the rock mass under the platform level.

6. GEOMECHANICAL PROPERTIES AND FOUNDATION DESIGN BASES

In order to obtain the rock mass strength parameters, the intact rock properties obtained from laboratory tests on rock where scaled to rock mass level, which was made through the application of a failure criteria. For highly fractured hard rock, as is the case of the rock mass where the telescope will be founded, the bearing capacity of the rock used for foundation design was estimated using the Hoek and Brown failure criterion.

Rock mass strength, Elastic and Dynamic Modulus, were obtained for each lithology, and Winkler modulus and settlements estimation where obtained also as an equivalent value for the telescope foundations, according to the 3D Model. (See Figure 6-1)

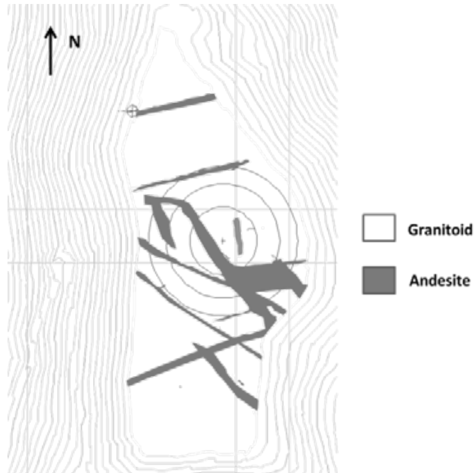


Figure 6-1: Granitoid and intrusive partial areas Rock Formations at Foundation Level

7. RIPPABILITY

The construction of the platform for the foundation of the telescope will required cutting about 190.000 m^3 of the hill, between 3.046 m.a.s.l and 3.064 m.a.s.l.

The propagation velocity of longitudinal waves (Vp), correlated with the rock type is the most widely used parameter to determine the depths to which the material it is excavated, rippable or requires blasting. In the case of study it is estimated that for igneous rocks the rock can be considered rippable with compression speeds until the order of 2.000 m/s. According to the result of the geophysical survey developed, the compression velocities above the elevation of the platform at 3.046 m.a.s.l. are less than 2.000 m/s, so most of the material should be excavable, and only specific areas will require the use of explosives.

As a reference, Figure 7-1 have the results of one of the Profiles developed, including Down hole test, with the platform level.

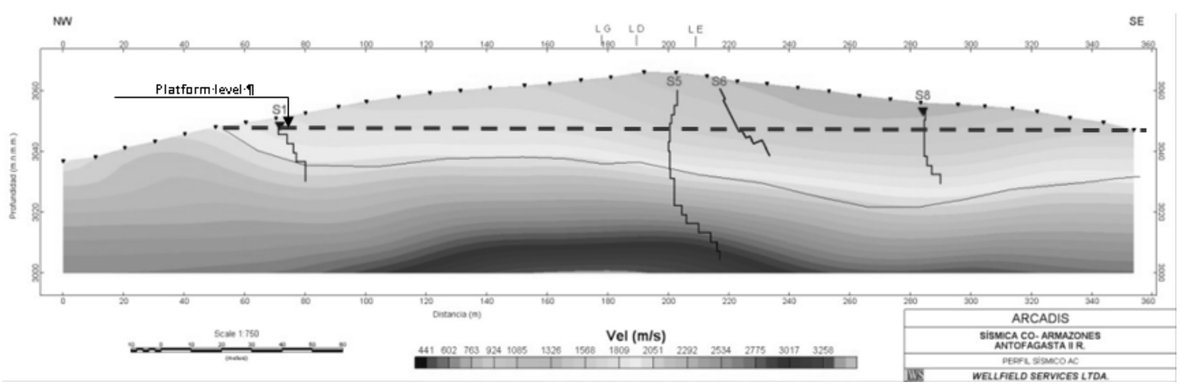
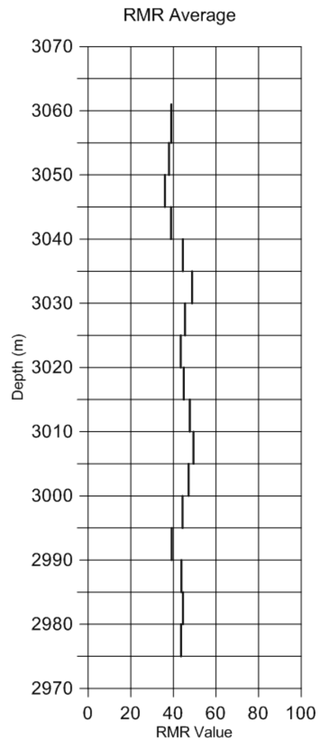


Figure 7-1: Compression velocities obtained from Seismic Refraction Profile and Down Hole Tests results

8. CONCLUSIONS



- The E-ELT will be founded on a rock mass, consist in three lithologies; Granitoids, Andesitic dykes and aplitic dykes.

- Geological and geotechnical information generated in this stage of the study was considered sufficient to determine the geological and geotechnical model of the E-ELT, and the estimation of parameters for the design of foundations.

- The rock mechanical properties vary with depth; however, at greater depths not necessarily better conditions have been observed. Due to alternating occurrences of the lithologies with depth the rock mechanical properties also vary.
- Figure 9-1 presents the RMR_{76} average considering all the boreholes as function of depth, in which it is observed that the variation of the elevation of the platform will not involve a substantial improvement in the geotechnical characteristics of the massif.

Figure 9-1: RMR Average of Boreholes as depth function

9. REFERENCES

The available data reviewed for this report are:

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