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Assesing the Degree of Fracturing and Weathered Layer Thickness Using Seismic and GPR Data

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SUMMARY

Granites in Portugal have been extensively exploited for dimension stone industry and aggregate exploration from the weathered zone. In order to study the fracturing and weathered granite thickness in the region of Nisa and Alpalhão (Portugal), seismic refraction surveys with P waves were acquired in several areas. In one of the places ground penetrating radar (GPR) data was also acquired. The objectives of this study were: 1) to determine qualitatively the degree of fracturing and the orientation of the principal fracturing systems, regarding ornamental rock exploration, close to Maceira Quarry and also to determine the weathered thickness; 2) establish the upper limit of the velocity of longitudinal seismic waves in the granites weathered zone that corresponds to zones of gravel exploration and from this information, 3) determine the alteration thickness of granites in the areas of Anta, Dam of Poio and Amieira and therefore estimate thickness of possible exploration of aggregates. In all places, information about the orientation of the principal fracturing systems was obtained as best as possible from nearby outcrops and compared with seismic data. A good match between geological and geophysical data was achieved and best locations for exploration of aggregates and ornamental granites were obtained.

1. Introduction

Granites in Portugal and through out the world have been extensively exploited for dimension stone industry and aggregate exploration from the weathered zone. In many places outcrops have been exploited to exhaustion, opening way to the use of geophysical methods to assess the quality of granite for both purposes. In order to study the fracturing and weathered granite thickness in the region of Nisa (district of Portalegre, Portugal), seismic refraction surveys with P waves were acquired in several distinct areas. In one of the places ground penetrating radar (GPR) data was also acquired (Maceira Quarry). The objectives of this study were: 1) to determine qualitatively the degree of fracturing and the orientation of the principal fracturing systems, regarding ornamental rock exploration, close to Maceira Quarry and also to determine the weathered thickness; 2) establish the upper limit of the velocity of longitudinal seismic waves in the granites weathered zone that corresponds to zones of gravel exploitation and from this information, 3) determine the alteration thickness of granites in the areas of Anta, Poio Dam and Amieira do Tejo and therefore estimate thickness of possible exploitation of aggregates. In all places, information about the orientation of the principal fracturing systems was obtained as best as possible from nearby outcrops.

2. Geological Setting

The granites of the study area are part of the Nisa Eruptive Complex (NEC) (Ribeiro et al., 1995) located in the Hesperic massif in the southern sector of Central Iberian Zone (Lotze, 1945; Julivert et al., 1974). In the north, the batholith intruded metasediments of the Beiras Group (Neoproterozoic–Cambrian) and produced a contact metamorphic aureole (Campos & Pereira, 1991; Fig. 1). The NEC has been reported to be a post-tectonic (post-D3) intrusion (Ferreira et al., 1987). Based on tectonic studies, Pereira *et al.* (1998) suggested that the complex was emplaced by a pull-apart mechanism related to the late Variscan regional deformation (late-D3). Main fracture systems observed are NNE-SSW to NNW-SSE.

The Nisa Granite occupies most of the NEC outcrop area and consists of a coarse-grained porphyritic, two-mica monzogranite to syenogranite (Solá *et al.*, 2009). In the core, there are finer-grained granitoids that clearly contrast with the host granite, forming a discontinuous alignment with the same arcuate shape as the NEC (Moreira, 1994; Fig. 1). In the study area these granitoids are: Alpalhão Granite, a fine-grained biotite granodiorite to monzogranite with a grey-bluish colour and, Gafete Granite, a medium- to fine-grained muscovite>biotite syenogranite. Both granites, specially the former, are subject to exploitation for ornamental and aggregate purposes.

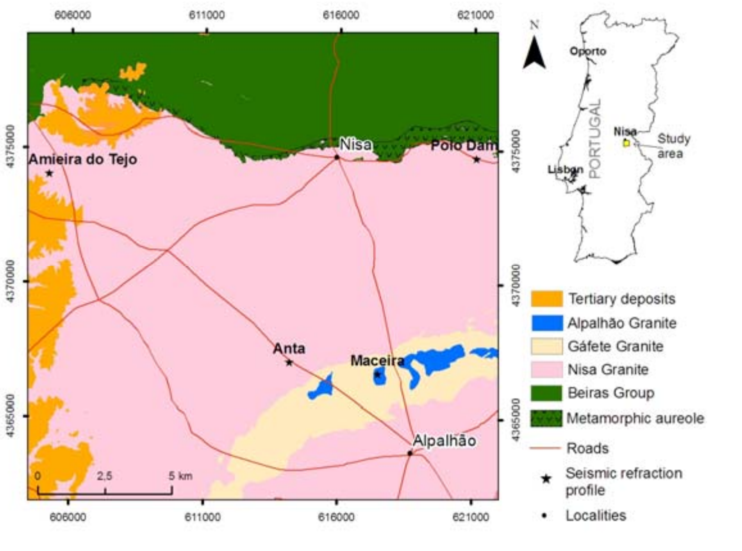

Figure 1 *Location and geological mapof the study area, with the location of the seismic refraction profiles overlaid.*

3. Methodology, data processing and interpretation

The geometry used in the refraction profiles was two end shots and a third shot in the middle of the receiver layout, in order to ensure a better control of the parameters of the surface layer. The spacing of the geophones was 2.5 m and source-nearest receiver offset was 1.25 m. Since 24 geophones were used, the length of each profile was 60 m. The seismic source used and the source-receiver offsets determined that the maximum depths reached do not exceed 25-30 m, which according to previous geological information would allow to reach the targets of the work.

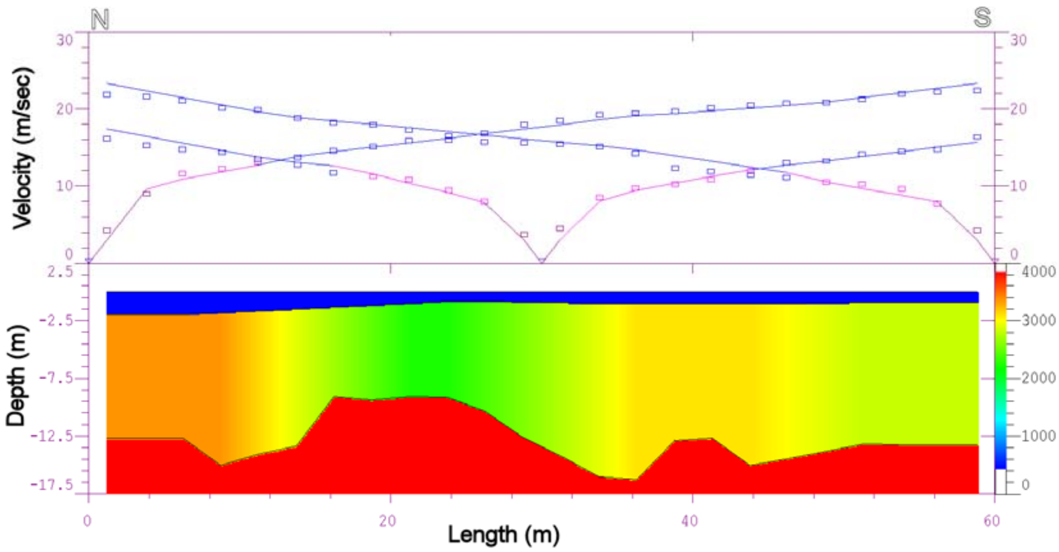

Figure 2 *Example of model obtained by seismic refraction interpretation at Maceira. Top: observed (squares) and calculated (line) time-distance curves, Bottom: obtained P-wave velocity model from GRM and slope-intercept interpretations.*

The interpretation was made using commercial software IXRefraX. The application builds a velocity model using the generalized reciprocal (GRM, Palmer 1980, 1981) and the slope-intercept (in Cox, 1999) methods. The processing chain can be briefly described as: introduction of the geometry of the profile for each shot and the topography; gain adjustments, frequency filtering and zooming of the records in order to identify the first arrivals; picking of the first arrivals; interpretation of first arrival curves by assigning the different segments of the time-distance curves to distinct layers of the subsurface, inversion of the initial model and finally interpretation by the GRM. For receivers which reciprocal times were not available, the depths of layers are estimated using the slope-intercept method. At last, the refinement of the final model is made based on the joint interpretation of the various profiles at each site and also using geological information where available.

The weathering degree and fracturing in granite or other rocks is reflected in a change of the propagation velocity of the longitudinal seismic waves. As the weathering degree and fracturing increases, P-wave velocity decreases. Previous work carried out in a different type of granite using seismic refraction and attenuation studies (Carvalho et al., 2000) showed that the geophysical parameter that best correlates with data from direct observation of fracturing is the P-wave velocity (95 % correlation). Therefore, we have used this parameter in this study to determine the degree of fracturing. It is not possible to determine whether the decrease in velocity is due to change of fracturing or weathering without other geophysical or geological evidences. However, it has been observed in previous works in granites, that for velocities higher than 3 km/s the degree of alteration it is very low, and it is due almost exclusively to fracturing.

To determine the direction of the principal systems of fracturing, following the methodology of Carvalho et al. (2000), three crossing profiles were acquired at Maceira and directions of fracturing were estimated by analysing velocity variations from profile to profile. At Maceira Quarry three GPR profiles coincident with the seismic profiles using 200 MHz antenna were also acquired, processed and results compared with geological data collected at different levels of the quarry, located at about 100m from the survey site. The degree of fracturing was estimated by the number of scatterers present in each profile.

At the other sites, the main target was to estimate the thickness of the weathered layer and due to economical reasons, only two profiles per site were acquired. At the aggregate quarry of Anta, an L shaped profile was acquired to supply the upper limit of the P-wave velocity of material of economic interest by observing the depth of the exploited layer and comparing it with the velocity model. The other transversal part of the L shaped profile was used to detect if anisotropy (other then produced by fracturing) was present in the granite.

4. Results and conclusions

The velocities and depths of the model interfaces obtained for all profiles are shown in Table 1. Table 2 shows the observed geological data obtained in nearby outcrops. From the interpretation of the profiles at the Anta aggregate quarry, an upper limit velocity of 1200 m/s for the commercial material was obtained. Typical velocities of the exploited material range 400-550 m/s. More profiles should be acquired to obtain a more accurate limit velocity. Results form other unpublished works suggest that velocities up to 800-900 m/s could be used.

Profile	V1 (m/s)			P2 (m)			V2 (m/s)			P3 (m)			V3 (m/s)			Strike
	A	max.	min.	A	max.	min.	A	max.	min.	A	max.	min.	A	max.	min.	
ANTA	575	607	560	1,8	2,1	1,2	1553	1617	1508	14,6	11,7	17,3	2764	3450	2421	N40W
ANTB	658	702	594	2,5	1,3	3,6	1303	1468	998	10,6	14,6	8,3	2504	2947	2131	N32E
TANTA	488	537	439	1,9	2,3	0,7	1326	1515	1206	8,4	6,6	10,5	3391	4273	2842	N40E
TANTB	456	457	453	1,1	2,0	0,8	1537	1730	1199	10,0	7,5	12,2	4463	5069	4273	N30W
POIA	450	450	450	1,2	2,1	0,8	1389	1502	1156	7,3	4,7	9,7	2233	2365	1940	N25W
POIB	464	467	460	1,8	3,0	0,9	1562	1741	1410	15,7	11,1	19,4	2940	3485	2535	E-W
AMA	561	594	519	7,5	15,0	3,1	780	806	728	na	na	na	na	na	na	N45W
AMB	317	326	315	1,2	2,2	0,6	756	796	729	28,5	26,6	29,9	1910	1910	1910	N73E
MACA	438	438	438	1,2	2,0	0,8	2874	3343	2227	12,9	9,1	16,3	4235	4640	3847	N-S
MACB	393	411	369	1,6	2,0	0,6	2675	3970	1596	7,7	4,6	12,1	5117	5905	4707	E-W
MACC	331	331	331	0,9	1,0	0,6	2521	3343	1885	6,0	3,3	11,2	4989	5615	4497	N60E

Table 1 *Velocities and depth of interfaces of the models obtained by refraction interpretation in all sampled sites. Na- not detected. A- average; Vi- velocity of the ith layer; Pi- depth of the ith layer; Strike- orientation of the seismic profile.*

Velocities obtained in the part of the profile with the receivers oriented perpendicularly to the seismic wave propagation showed very small difference in arrivals times and therefore of anisotropy in the directions sampled (about 45 degrees).

Taking into consideration the previous results, average exploitation thicknesses at Anta de São Gens, Poio Dam and Amieira are respectively 2.2 m, 1.5 m and 20 m (minimum). In spite of having only two profiles at these sites, the results concerning the orientation of the main fracturing systems were compatible with direct observation at nearby outcrops.

At Maceira, the penetration of the GPR was quite limited compared to the seismic refraction data but the degree of fracturing estimated in the above mentioned qualitatively way, produced similar

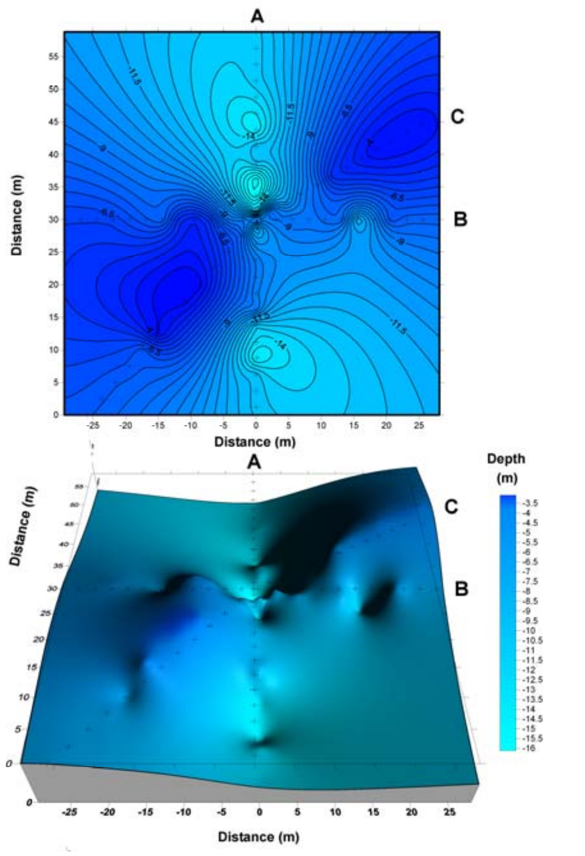

Figure 3 *Model of the relief of unweathered granite at the Maceira Quarry obtained from seismic and GPR data. Letters indicate the location of the three profiles acquired.*

results to the seismic data. From seismic data we were able to obtain the orientation of the principal and secondary systems of fracturing at the three different levels of the quarry (that coincide with seismic layers) and also to determine the areas where the degree of fracturing is less or more intense.

Location	Fracturing System Orientation	
	Principal	Less frequent
Anta	50º-80º	150º-160º
Poio Dam	20º-30º	60º
Amieira	150º-160º	20º-30º
Maceira	330º	60º and 90º

Table 2 *Fracturing orientation data obtained by direct observation of geological granite outcrops located close to the seismic and GPR profiles.*

The depth of unweathered granite varied from 3 m to 16 m. A map of the depth of the unweathered granite was produced (figure 3) and from the analysis of velocity variations along the three profiles, the location of the most superficial and less fractured granite was established, in order to obtain samples of good quality granite from the point of view of dimension stone exploitation. The site will be drilled to confirm our results at Maceira and assess possibility of using this methodology for ornamental rock exploration.

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