IOP Conf. Series: Earth and Environmental Science 221 (2019) 012062 doi:10.1088/1755-1315/221/1/012062

Application of Refraction Seismic On the Vulnerability of Underground Aquifers

Julio Cesar Gall Pires [1,2], Daniela G. Sotelo [1,2], Adolpho H. Augustin [1], Vanessa C. Osório [1], Tales F. de Paula [3], Cassio S. Moura [1,3]

[1] Pontifical University of Rio Grande do Sul (PUCRS), Institute of Petroleum and Natural Resources, Av. Ipiranga, 6681, Porto Alegre/RS, CEP 90619-900, Brazil
[2] Postgraduate Program in Materials Engineering and Technology – PUCRS
[3] School of Sciences– PUCRS

gallpires@hotmail.com

Abstract. The multichannel seismic survey consists of a geophysical technique of indirect quantification, whose principles are based on the acoustic properties of the seismic waves produced locally. The current study deals with seismic refraction, whose main advantages are avoidance of any environmental impact during the exploration, low cost and a fast way to present the results. The objective of the technique is to show acoustic characteristics of the geological environment, such as the propagation velocity of the P wave allowing the estimation of the type of rock that constitutes the subsoil. The layers depths determination depends on velocities estimated in the data analysis. The information provided by the seismic survey is used to determine the degree of vulnerability of local groundwater reserves. The region of interest of this study is the central depression of the State of Rio Grande do Sul, Brazil. This region consists of one of the recharge areas of the Guarani Aquifer System. This system consists of a set of geological formations rich in sand and poor in clay, which results in a kind of compartmentalized sponge with potential to accumulate groundwater, covered by impermeable rock. Profiles analyzed, in the region of the municipality of Santa Cruz do Sul suggest the presence of basalt, argillite and sandstone at approximately 10 meters depth. These conditions indicate a vulnerability of the aquifer which varies laterally. Therefore, some regions showed to be less protected than others, requiring more attention on the possibility of propagation of some contaminant.

1. Introduction

A practical way to investigate different stratigraphic layers, which may reveal geological structures with potential for water storage, is to drill wells in the region of interest. However, this technique, besides being economically unfavorable, creates open pathways doors for contaminants since the confining layers can be broken.

Seismic waves are mechanical vibrations that are propagated in geological layers [1]. These waves can be natural or artificial. Seismic wave propagation obeys the Snell-Descartes law, which states that when a seismic wave encounters an interface that separates two layers with different acoustic impedances, two different waves are created: a reflected and a refracted wave.

In this work, we performed an assessment of local vulnerability on groundwater reserves using the geophysical technique of multi-channel terrestrial seismic. In order to do that, it was necessary to determine the propagation velocity of the primary waves and correlate it to the local acoustic characteristics of the subsurface rock type.

A seismic survey is based on the analysis of seismograms, which is a graphical representation of the receiver's positions and the transit time of the artificial wave from the seismic source to the reflecting underground surface and its way back to the receivers. With this graph it is possible to draw lines, which represent the transit (or travel) times of the seismic wave in the geological environment. In the current work, the ABC reciprocal method was applied, whose processing depends on 5 shooting points [2]. In general, the reciprocal ABC method is used to create the seismic profiles, which makes it possible to estimate the thicknesses of the lithological layers.

2. Materials and methods

2.1. Seismograph

The equipment used was a RAS-24 Seistronix™ multi-channel seismograph. It includes accessories such as: trigger, extension of the trigger, data cable for connection with notebook, geophones, batteries and the connection cable to the geophones. This cable allows the use of arrangements up to 120m with up to 12 geophones. The parameters used for acquisition were sampling period equal to 0.125ms with recording time of 1s and pre-amplification of 24dB. The natural frequency of the geophones is 10Hz. The artificial seismic source consists of an 8kg sledgehammer accompanied by a 20x20cm aluminum plate for the coupling of the shot with the ground, as show Figure 1.

Figure 1. a) Extension of the trigger, b) RAS-24, c) 12v battery, d) trigger e) serial cable, f) 12 geophones, g) connection cable of 120m for the geophones, h) 8kg hammer and aluminum plate 20x20 cm.

2.2. Processing method

The determination of the seismic waves transit times allows the creation of graphic maps of the refractors in subsurface. It is of fundamental importance to set the geometry for the data acquisition during the survey. As a seismic source we mechanical percussion with an 8 kg sledgehammer which was sufficient to investigate depths down to 60 m. Such a procedure ensures that the arrivals of the refracted wave fronts are detected by the same segment of the array on the surface.

The reciprocal ABC method [2] was applied using 5 trigger points distanced by 30m. 12 geophones were arranged in a straight line distanced 5m from each other totalling an arrangement of 60m, as depicted in Figure 2-I. Three acquisitions were made at each trigger point and 5 seismograms were obtained in each row and superimposed for analysis. **Chyba! Nenašiel sa žiaden zdroj odkazov.**-II shows a representation of the real data presented on Figure 2-III.

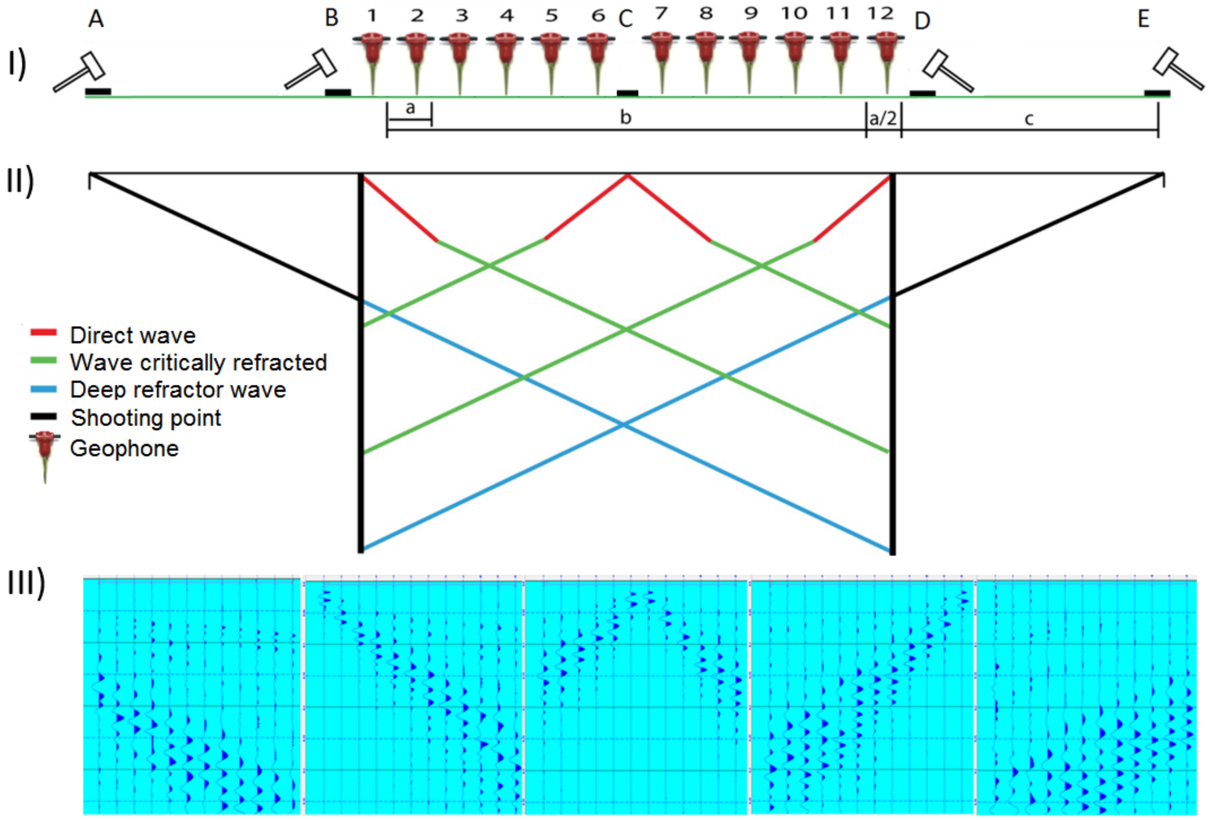

Figure 2. I) Illustration of the arrangement with the shooting points at A, B, C, D and E; II) Illustration of the respective wave transit times; III) Seismograms acquired at shooting points.

After the acquisition of the seismic data were made, the best records were chosen out of a triplicate shooting. The visualization and marking of the first arrivals of the wave in the seismogram, the calculation of velocities and the depth of each layer are also fundamental for compiling the profile. To generate the travel time chart of the survey, the marking of the first wave arrival on each geophone for each record was made using WinsSism™ Version 10.15 processing software.

In the processing step, information such as refractor speed, definition of the number of adopted layers, velocities and characteristics such as inclination and thickness of the refractors can be obtained through the travel time chart with the use of tools accessible in the software. The final result is the generation of a velocity profile, in which the geological strata are differentiated by the seismic velocity on each stratified layer. The Phantom Arrival method [3] was used to determine the layers depths.

2.3. Location of the seismic survey

The region investigated is located on the municipality of Santa Cruz do Sul, where there is a strong human development process due to the agricultural and urban exploitation. In addition, in this region, the weathering mantle is thin layer made of regolith and can be easily damaged, compromising the local groundwater reservoirs.

The municipality, as shown in Fig. 3, is located in the transition between the Basaltic Plateau and the Central Depression of Rio Grande do Sul. Consequently, a slope is observed in the north-south direction, going from approximately 600 m down to 80 m above sea level [4]. The site shows the presence of escarpments in the transition zone. Figure 3, shows the geographical position of the acquisition site.

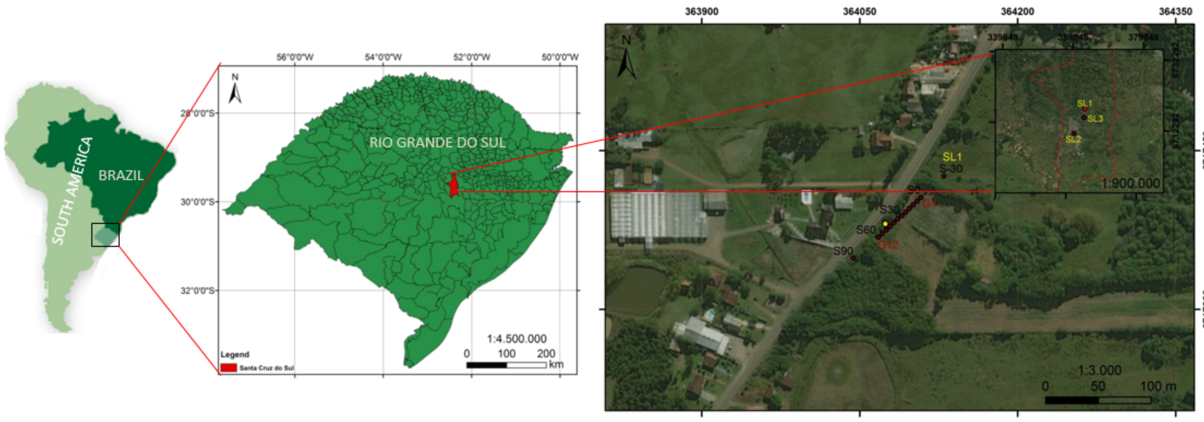

Figure 3. Location of seismic survey sites in Santa Cruz do Sul.

It is possible to find outcrops in the region: the Serra Geral formation, the Botucatu formation and the Santa Maria formation, as well as some recent sedimentary deposits. Such formations may have characteristics adequate to groundwater storage.

The Serra Geral formation belongs to the Cretaceous period. It represents a colossal volcanic activity that preceded the fragmentation of the supercontinent Gondwana and contains predominantly basaltic acid rocks [5]. Such types of rocks present reasonable porosity due to fractures and consequently can hold groundwater [6]. The large number of fractures observed in the outcrops of such formation results in a strong alteration process which generates clayey soils. The Serra Geral formation can be divided in the Gramado and Caxias formations. Attention will be given to Gramado formation.

The Gramado formation represents the first magmatic spills on the Botucatu desert. Such formation occurs along the transition zone, on the cliffs, intercalating with the Botucatu formation in the interface region. With a maximum thickness of 300 m, this first manifestation was confined by the Botucatu desert, forming valleys and dunes. By the end of the contribution of the Botucatu formation, the later magmatic manifestations dominated and covered the desert, conditioning the local topography [7]. The rocks of these facies are massive basaltic, with microfiber texture, gray to black colour and thicknesses between 15 and 35 m [7], age of 132 million years and fine to medium granulation [8].

The Botucatu formation preceding the Gramado formation corresponds to the immense desert environment on the Jurassic period (203 to 135 million years ago). This formation consists mainly of sandstone sedimentary rocks of fine to medium granulometry. There is also occurrence of feldspar sandstones as well as quartzites and conglomerates, although only in specific regions. The predominant sedimentary structure of this formation is cross-stratification of tabular type (of variable thickness from small to large), but there is also occurrence of plane-parallel laminations [6]. The sediments that formed these rocks were continuously worked by wind and, eventually, fluvial action, in a variable climate from semi-arid to arid - desert environment [9]. In contact with the Serra Geral formation, intercalations of such formations occur, resulting in sandstone intertraps also known as sandstone lenses.

3. Results and discussions

Figure 3 showed the three acquisition sites we have studies. They are identified as SL1, SL, 2 and SL3. The processed seismic data is shown in Figure 4.

In site SL1 (Figure 4a) the propagation velocities of the seismic waves presented three typical values from top to bottom: 350, 3000 and 6000 m/s. The topmost layer has a thickness of 2.5 m and is probably made of weathered rocks. In the second layer, the velocity increases and makes it possible to relate it to a transition to the sandstone, which descends to 10 m, where it encounters basalt, the third layer that we were able to identify. The deepest layer suggests the presence of basalt, argillite and sandstone at approximately 10 meters' depth. Such a structure can bear a shallow water reservoir.

In site SL2 (Figure 4b), the following velocities were detected: 350, 1200 and 2500 m/s. Therefore, it is possible to suggest that the first layer is 2.5m thick and consists of rocks altered by weathering. The second layer presents a transition possibly to clay, reaching down to approximately 6 m.

In site SL3 (Figure 4 c), it is possible to differentiate three layers based on the propagation velocities of the P waves: 350, 500 and 3000 m/s). In the first and second layers the low velocities are due probably to weathered rocks that form the weathering mantle with thicknesses varying from 2.5m to approximately 11m. In the third layer it was possible to find speeds higher than sandstone´s velocities. The Botucatu formation is mainly responsible for this geology.

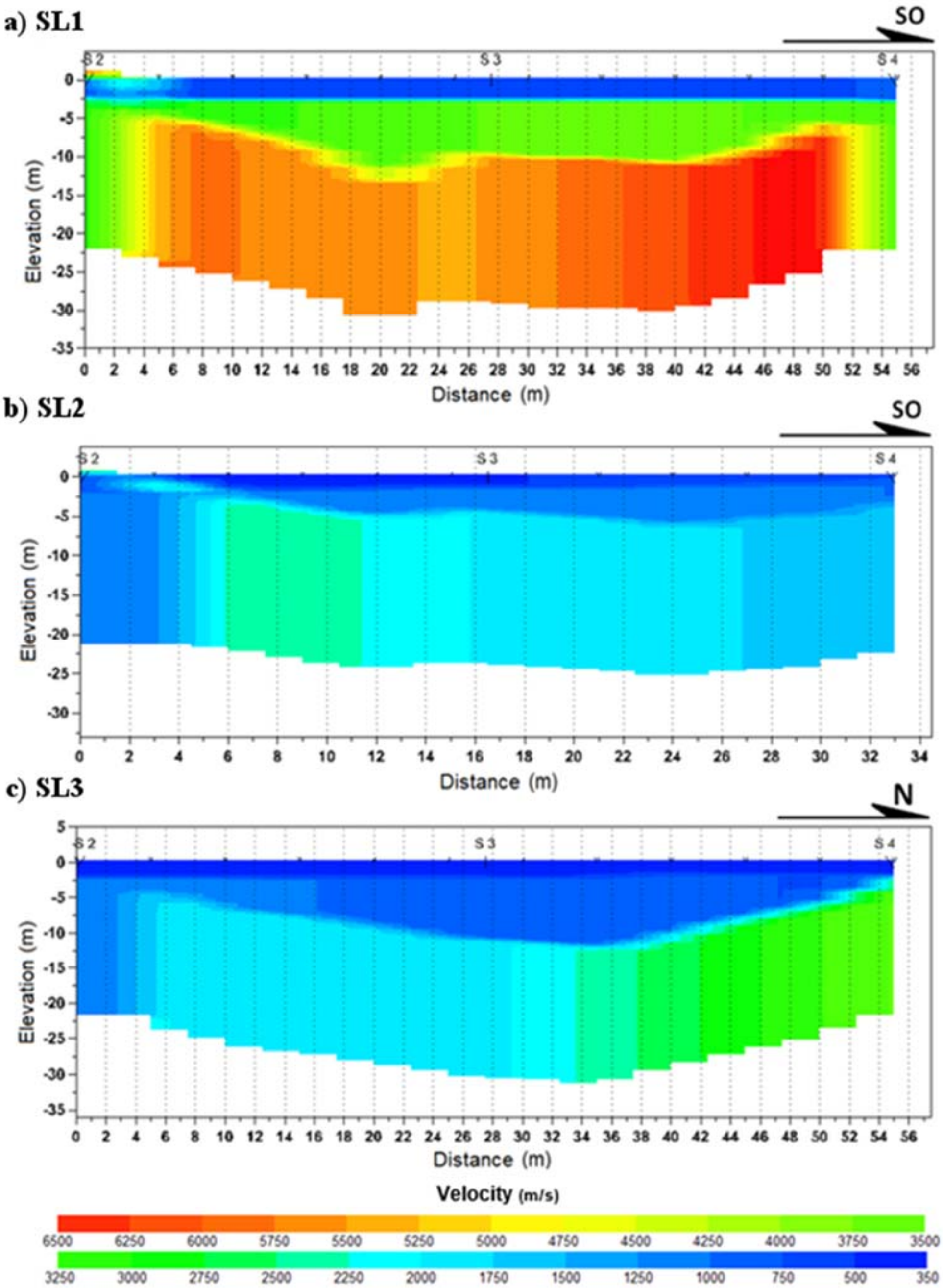

Figure 4. Mapping of the three survey sites in Santa Cruz do Sul

4. Conclusions

The results suggest the presence of geological formations with potential for water storage at 10 m depth. In this case, the fragility of the probable open aquifers of the region is evidenced by the proximity of these formations to the surface.

The seismic method used allowed us to analyze three different stratigraphies, so it was possible to infer the local variability in the issue of vulnerability of groundwater from geological characteristics. Thus, SL1 and SL2 sites are more vulnerable due to the billing of their geological formation. Sites such as SL3 are more protected since the Botucatu formation consists of sandstone sedimentary rocks of fine to medium granulometry and presents low porosity. Its superior contact with the basalts of the Serra Geral Formation is evidenced by a non-conforming surface, where the sandstones become much silicified, hardened and with reduced porosity [10].

Acknowledgments

Authors thank the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES) for the financial support, EMATER, CORSAN and the local municipality for their operational support.

References

[1] Anomohanran, O. Seismic Refraction Method: a Technique for Determining the Thickness of Stratified Substratum. American Journal of Applied Sciences 10, 857–862. 2013
[2] Hawkins, L. V. The reciprocal method of routine shallow seismic refractions. Geophysics, 6, 806-19. 1961
[3] Hagedoorn, J. G. The plus-minus method of interpreting seismic refraction sections. Geophysical prospecting,7, 2, 158-182. 1959.
[4] Hasenack, H.; Weber, E.(org.) Base cartográfica vetorial contínua do Rio Grande do Sul - escala 1:50.000. Porto Alegre: UFRGS, Centro de Ecologia. 2010.
[5] Rossetti, L. M. M. Arquitetura de Fácies Vulcânicas da Formação Serra Geral na Região de Feliz – Caxias do Sul. Porto Alegre: UFRGS, Geociências. 2011.
[6] Machado, J. L. F. Compartimentação Espacial e Arcabouço Hidroestratigráfico do Sistema Aquífero Guarani no Rio Grande do Sul. Porto Alegre: UNISINOS. 2005.
[7] Wildner, W.; Filho, V. O.; Giffoni, L. E. Excursão Virtual aos Aparados da Serra – RS/SC. CPRM. Porto Alegre, 2004.
[8] Modena, R. C. C.; Hoff, R.; Farias, A.R.; Viel, J. A. Diferenciação de Rochas Vulcânicas da Formação Serra Geral Utilizando Gamaespectrometria Terrestre na Região Vitivinícola Serra Gaúcha, RS – Brasil. 47° Congresso Brasileiro de Geologia. Salvador. 2014.
[9] Manieri, D. D. Comportamento Morfoestrutural e Dinâmica das Formas do Relevo da Bacia Hidrográfica do Rio São Pedro – Faxinal – PR. Maringá: UEM, Centro de Ciências Humanas, Letras e Artes, Departamento de Geografia. 2010.
[10] Noronha, F. L; Bressani, L. A; Mizusaki, A. M. P. Mapeamento geotécnico da área urbana de santa cruz do sul. In: V Seminário de Engenharia Geotécnica do Rio Grande do Sul, Pelotas, RS. 2009