Natural Gas Leakage Occurrence on a Shallow Groundwater Reservoir

Roberto Heemann\textsuperscript{1}, Adolpho Herbert Augustin\textsuperscript{1}, Julio Cesar Gall Pires\textsuperscript{1}, Daniela Govoni Sotelo\textsuperscript{1}, Cassio Stein Moura\textsuperscript{1}

\textsuperscript{1}Institute of Petroleum and Natural Research, Av. Ipiranga, 6681, Porto Alegre, RS, Brazil, CEP 90619-900

cassio.moura@pucrs.br

\textbf{Abstract.} The present study was carried out at the coastal region of Santa Catarina State, near the banks of the Tubarão River (Laguna/SC). The occurrence of natural gas leakage on the surface was investigated with the execution of geophysical surveys (resistivity and refraction seismic) to identify the gas saturate zone. The leaked gas is mainly composed of methane of biogenic origin, according to the isotopic studies. The gas origin is probably related to the burial of ancient Tubarão River branches enriched with the organic matter. The geophysical surveys identified that the gas concentration in the subsurface has an inverted mushroom shape with the base occurring at 15 meters depth. The natural leakage probably should originate from the fractures that occur in overlying seal rock.

\section{Introduction}

Natural gas can be found in geological reservoirs from shallow structures down to profound depths. If the sealing rocks on top of the reservoir present fractures or high porosity, the gas may reach the surface. From the economical point of view, if large amounts of gas are available, it can be commercially exploited. On the other hand, for sub-commercial situations, the gas may simply leak to the atmosphere, contributing as a greenhouse gas to global warming. In this work, we investigated a reported natural gas leakage in the coastal region of Laguna near the banks of the Tubarão River, in the state of Santa Catarina. The location is shown in figure 1 and pictures taken at vent point are shown in figure 2. The water bed is very close to the soil surface and gas bubbles are easily observed permeating water and reaching the atmosphere. This investigation aimed at estimating contrasts of lithologies and saturated zones in the subsurface (water/gas) using geophysical tools (electroresistivity and refraction seismic). The studied region has been considered for real estate investments and therefore it is very important to acquire a better knowledge of the subsurface gas reservoir prior to any decision on establishing a construction area.
2. Methodology
Several methods can be applied to investigate the presence of underground fluids [1]. We chose to use electrical resistivity imaging (ERI) and refraction seismic surveys on the leakage area. The resistivity survey identified the probable plume of subsurface water/gas saturated formation and the seismic survey verified the continuity of the subsurface layers and the occurrence of anisotropies. Data processing of the geophysical survey enabled the construction of geological profiles showing the subsurface structure.

2.1 Resistivity survey
The different types of geological materials found in the subsurface can be imaged through mapping their physical properties such as the electrical resistivity, which can vary within an extensive range.
Igneous rocks, for example, present higher resistivity values, while sedimentary rocks and soils formed mainly by clay and sand are more conductive. Metamorphic rocks present intermediate resistivity values.

ERI is a geophysical method used to determine the subsurface electrical resistivity allowing to lithologically identify the weathering mantle, soils and rocks, as well as water/sediment/air (or gas) interfaces. An electric current is injected in the subsoil through a pair of electrodes, while another pair is used to measure the electrical potential difference generated as a result of the current flow. Several electrodes settings on the field can be employed and offer great versatility to the method. The dipole-dipole array is considered one of the most traditional, important and accurate ways of geoelectrical investigations. It presents a good horizontal resolution as the main advantage, which makes the array useful to map vertical structures.

Electrical measurements have been applied around the world to identify the relationship between the amount of gas and water inside pores found in subsoil [2], to detect water and gas displacements within underground reservoirs [3], to enhance the estimation of greenhouse gas emissions on surface [4], to follow the movement of the injected gas inside complex geological formations and analyze leakage risks [5].

In order to investigate the methane plume in subsurface around the well where the vent gas appears, we used a dipole-dipole array on two investigation lines, 100 m long each one, according to figure 3. The electrode spacing was set to 5 m.

![Figure 3](image_url)  
**Figure 3.** Investigated area showing the position of the two investigation lines: LINE_1 (NW-SE) and LINE_2 (NE-SW). Each line was 100 m long and had a unit electrode spacing of 5 m

Processing and inversion of the acquired data were performed with Res2Dinv software. The resulting sections for each profile are shown in figures 4 and 5 for lines 1 and 2, respectively. In a general way, for shallow depths, low resistivity values were observed indicating the presence of high conductivity saline water. This should be expected due to the proximity to the ocean shore. Line 1 shown in figure 4 presents a low resistivity zone between 6 and 12 m depth, possibly corresponding to the accumulation of water in the sediment pores with different levels of salinity. In the near surface region, medium resistivity values are found, indicating sand-clayey soil saturated with water. Below a 13 m depth, there is a higher resistivity zone, which may indicate the presence of the sandy soil, with gas saturation.
2.2 Seismic survey

Acoustic waves when traveling in Earth are called seismic waves. Seismic investigation is possible because when propagating in different geological media the seismic wave also changes the speed of propagation. This is due to the interaction of the wave with the boundary between two geological media with different acoustic impedances. Propagation velocities are obtained from the transient times needed for the wave-front travel from the seismic source to an arrangement of geophones distributed along a line with known distances. This allows determining the distribution of propagation velocity and depths of the underground interfaces where the waves modify their speed.

The method in question is largely applied to geological structure studies because it is an indirect quantification method that does not harm the environment. Other advantages of its use are associated with low cost and relative ease of processing. Its applications are related to geotechnical and environmental studies such as the location of the water table, the mapping of fractured regions with water and the identification of faults.

The seismic refraction method is based on the horizontal propagation of the wave by a certain distance, after it reaches a geological discontinuity at a critical angle. Such a critical angle obeys Snell's Law and demands that the wave velocity increases at deeper layers. After propagating for some distance along the layers interface the wave returns to the surface and is detected. Visual analysis requires a graphical representation of the transit times of the seismic waves as a function of the distance of the geophones along the seismic line. This representation is known by the name of the seismogram.
The wave amplitude as a function of depth depends on the strength of the source and the extent of the seismic line. In our investigation, the waves were created by percussion of a mallet on a metal plate coupled to the sedimentary bed. One of the characteristics of the terrain under study is to be flat, so the chosen acquisition method was the one called plus-minus.

In this reciprocal method, the Snell-Descartes Law is considered with trigonometric relationships applied to a flat-layer model. It allows calculating the variation of propagation velocity along the seismic line. To do so, two shots are taken at the ends of the line and one at the center. In this way, it is possible to estimate the velocities of the seismic waves as well as the thickness of each layer below the receivers. It is common in this method to use two shots apart. The shots are positioned at half the length of the line and are called direct shot (beginning of the line) and reverse shot (end of the line).

The seismograph used was a RAS 24 (Seistronix) with 12 channels and cables of 120 m. The source used was an 8 kg sledgehammer. The array was set to a length of 60 m and a geophone spacing of 5 m as shown in figure 6. Seismic data processing was performed using the travel time obtained from the refracted waves and allowed determination of the sediment layers on site. More details on data processing can be found in reference [6].

![Figure 6](image6.png)

**Figure 6.** Representation of the seismic array with 12 receivers, where a is the geophone spacing, b is the line size, a/2 is the near shooting distance, and c is the distant shooting distance.

Figure 7 shows the seismic profile obtained for line 1. It can be observed three sediment layers with propagation speeds of 150, 200 and 350 m/s. Comparing figures 4 and 7, we observe a clear layer distinction at around 10 m depth. Probably, this interface corresponds to the water bed. The low wave velocities agree with the speed of sound in gases at a pressure near the atmospheric which indicates the possible presence of gas accumulation in the investigated area.

![Figure 7](image7.png)

**Figure 7.** Seismic profile of line 1

Figure 8 shows the seismic profile of line 2 and should be compared to figure 5. The three layers with propagation speeds of 150, 200 and 300 m/s are present as in the perpendicular direction shown in figure 7.
Comparing figures 7 and 8, the presence of three sediment layers is revealed, corroborating the electrical survey. The seismic results showed a certain prevalence of values with a low velocity at the shallow region down to 2 m depth. Such values suggest a sandy sediment formation.

In the middle layer, higher velocities were observed. Taking into account that the water table was roughly 1 m below the surface, it is possible to infer that the increase in the medium velocity is due to the saturation of the terrain. Either way, the velocity of around 200 m/s may be coming from soft clay sediment. As seismic cannot differentiate small changes in the acoustic characteristics of two media, it is possible that the sediment may also consist of sand and clay. The third layer, with a velocity of around 300 m/s is probably due to a higher compaction substrate.

3. Conclusions
Geophysical surveys indicated the presence of methane gas that was generated in lenses of organic matter associated to the depositional system of old ramifications of the drainage system, which were buried during the process of geological/sedimentary evolution of the investigated area. The water/gas saturation plume is restricted to the zone adjacent to the leakage point, with little lateral continuity (<10 m), although relatively persistent at depth (16 m). Considering the geological and hydrogeological conditions of the area (open sediment aquifer) and the restricted lateral continuity of the gas plume, the gas reserve presents a sub-economic extension. On the other hand, plans of constructions on the region should be avoided due to the risk of explosion if the gas accumulation happens above the surface.

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