Geophysical methods in shallow coastal aquifers explotation Ovar Dunes (NW Portugal)

Geophysical methods in shallow coastal aquifers exploration -Ovar Dunes (NW Portugal)

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RESUMEN

Portugal dispone de gran longitud de costas y una parte importante de la población, agricultura e industria se sitúa a lo largo de las mismas. Ello origina que la explotación de acuíferos costeros provoque problemas muy particulares, derivados de varios factores asociados. Los fenómenos de contaminación suelen tener causas diversas, como la intrusión marina, efluentes domésticos e industriales, derivados de la actividad agrícola, ascenso progresivo del nivel del mar, etc. La gestión de acuíferos costeros deberia incluir una planificación hidráulica previa, el conocimiento detallado de los parámetros geométricos, hidrogeológicos e hidro- químicos de esas unidades y el control riguroso de la interfaz agua dulce-agua salada, además de otros parámetros hidráulicos y de calidad del agua.

La región de Ovar, NW de Portugal, está emplazada sobre formaciones de dunas que cubren un importante acuífero cuaternario en contacto con el mar, donde se explota toda el agua necesaria para el abastecimiento doméstico e industrial del área. Esta explotación puede provocar una sustancial y peligrosa modificación de las relaciones agua dulce-agua salada y sus consecuencias en las reservas hídricas del área. Se han realizado trabajos de Geofísica con el objetivo de detectar la cuña salina y, también, mejorar el conocimiento de la geometria del acuífero. Se ha empezado por aplicar métodos eléctricos inductivos (perfiles y mapas electromagnéticos) para definir la cuña salina en las áreas más sensibles donde se verifica intensa extracción de agua subterránea. A continuación se ha llevado a cabo una campaña de sísmica de refracción para detectar la profundidad del zócalo y del nivel freático. Posteriormente, y con la finalidad de emplazar nuevos pozos a construir, se han hecho pseudo-secciones de resistividad, al Norte y Sur de los pozos existentes, las cuales se han revelado con características distintas. Con un perfil sísmico de reflexión, realizado con el “optimum offset window”, se ha mejorado la interpretación de la pseudo-sección al Sur de los pozos existentes. Por fin, y de acuerdo con la aportación proporcionada por la Geofísica, se han ejecutado y ensayado nuevos pozos.

ABSTRACT

The Ovar Dunes region, NW Portugal, bears a shallow coastal Quaternary aquifer that has been used both for domestic and industry uses. Increasing water demand and pollution can jeopardize local aquifers resources and thus a Geophysical survey was designed to detect the saline intrusion and to assist in the delineation of shallow aquifers boundaries so that proper exploitation strategies could follow.

Electromagnetic profiling and mapping were first applied to detect saline intrusion extension. Afterwards, a seismic refraction survey was planned to investigate bedrock attitude in the East- West direction as well as to detect freatic levels. Then, in order to assist new water exploitation boreholes location, resistivity pseudo sections were done to the North and South of existing boreholes. These data showed distinct characteristics and a further shallow seismic reflection survey, using the “Optimum offset window” concept, was undertaken to clarify the interpretation of the resistivity pseudo section South of the existing boreholes. Finally, and according with the results and interpretation of Geophysics data some exploration boreholes were drilled.

INTRODUCTION

Exploration Geophysics has been used widely in Hydrogeological studies, Chapellier et al, 1991. In fact, Geophysical Exploration Methods are fast, economic and non-invasive techniques suitable to study most of the problems related with water resources exploration, contamination and investigating geometric characteristics of water bearing formations. It is good practice to combine different geophysical methods, so that interpretation ambiguity can be reduced and a better overall geophysical model can be proposed.

Recently, in the Ovar Dunes region (40º 55’ N, 8º 40’W), 30 Km south of Oporto, NW Portugal the existing water exploitation boreholes proved to be insufficient to satisfy water demand in the area. These wells exploit a shallow aquifer installed in Quaternary deposits not far from the Atlantic Ocean, Fig. 1. Thus there is a strong risk of saline water invasion to balance shallow aquifers overexploitation.

In order to investigate saline intrusion several electromagnetic profiles, using a Geonics EM34 equipment, with horizontal coils 20 metres apart were conducted, Fig. 1.

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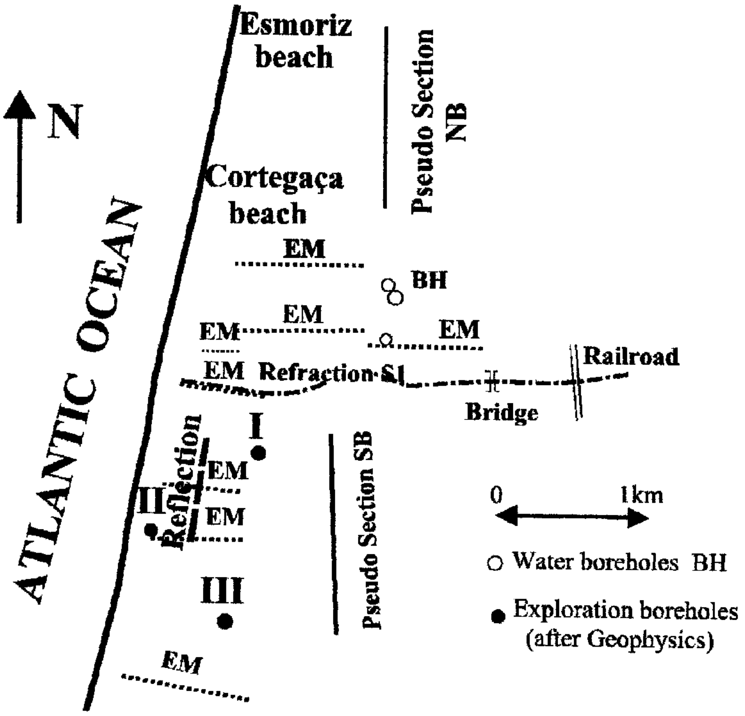

Fig. 1 Location of Geophysical Works and of local boreholes

Bearing in mind the expected local geology it was proposed to investigate bedrock attitude and sediments thickness in a East-West direction by using a long seismic refraction profile, S1 on Fig. 1. With these results it was decided that any future wells should not be drilled to the East of the existing ones as sediments thickness decreases rapidly. Thus two resistivity pseudo sections were planned to the North and South of the existent wells, NB and SB on Fig. 1.

Pseudo sections interpretation indicated different geological settings in the area. Owing both to the depths and resistivity values expected it was decided to carry out a further seismic reflection survey to clarify data interpretation to the South of the boreholes. Finally data from new boreholes, drilled in accordance with geophysical results, are presented.

GEOLOGY HYDROGEOLOGY OF THE AREA

Ovar dunes region is located in the Portuguese Western Mesocenozoic Margin in an area where Quaternary Deposits lay over eroded Cretaceous formations and can be divided into two sequences. The lower sequence shows normal graded bedding, and it is composed of gravel horizons at its bottom, passing into course, medium and fine sand deposits. At the top argillaceous layers can be found. The upper sequence is composed of fine sands, followed by a continuous layer of organic mud and clayey sands. On its top there are well sorted eolic sand dunes up to 15 m thick. A Holocene age is generally accepted for these deposits. Finally, eroded Cretaceous formations lay over the Ante-Ordovician "Schist - Greywacke Complex". The bedrock topography and depth of burial as well as eventual tectonic accidents in the area are unknown, Teixeira et al.,1976. Between the Lower and the Upper Quaternary sequence occurs one, occasionally more, organic mud layer that behaves as an aquitard. Therefore from the Hydrogeological point of view two subsystems can be considered:

(i) the Lower Quaternary Aquifer is bounded, at the top, by the mud layer which prevents hydraulic communication with the upper system. This unity is developed in the gravel horizons mainly, and its lower limits are the Cretaceous formations or the Schist basement. The lower aquifer is often considered as a confined one but it can behave as a leaky aquifer if the organic mud layer, on its top, is sufficiently thin or sandy. Then the aquifer recharge occurs by vertical drainage through the organic mud layer discontinuities. This subsystem has been exploited for domestic and industry uses by using boreholes 30 to 40 m deep.

(ii) the Upper Quaternary Aquifer is limited at the bottom by the organic mud layer and occurs in sand dunes. It behaves as a freatic aquifer and has been exploited by local traditional wells for domestic and agriculture proposes. This subsystem is heavily dependent on rainfall and is extremely vulnerable to industrial, domestic and agricultural contamination.

According to rainfall and evapotranspiration values for the region, the calculated water balance, Mendes et al., 1980, indicates a clear deficit of water during the summer.

SALINE WATER INTRUSION INVESTIGATION

Several EM profiles, perpendicular to the coast, Fig. 1, were carried out to investigate the possible saline intrusion. Measurements were taken every 20 m on each profile, with a Geonics EM34 (20 m vertical dipole separation). With this particular configuration and according to Ogilvy et al., 1991 it is expected a penetration depth of 25.3 metres in homogeneous ground. Since local boreholes reach the schists at a depth of about 30 m, it is reasonable to use the above described configuration.

The map on Fig. 2 shows the conductivity contours for the area. As it can be seen, conductivity rises considerably west of the boreholes and this higher conductivity area is larger in the boreholes region. Furthermore, it must be noticed a small higher conductivity area in the close vicinity of the boreholes.

With these results it was decided to drill boreholes I and II. Borehole II reveals saline water at a depth of about 6 metres and no fresh water was encountered. On the other hand borehole I has fresh water at a depth of 10 metres. Therefore the electromagnetic map on Fig. 2 is a good indicator of the saline intrusion extension.

EAST WEST REFRACTION PROFILE

In order investigate the depth of the bedrock in the boreholes area a seismic refraction profile was carried out with an approximate East-West direction, S1 on Fig. 1. Good data coverage was obtained by using multiple shot geometry, that is, far-end, off-end and central shots, with a 6 m geophone spacing. Interpretation was done using the Generalized Reciprocal Method, Palmer, 1980, in conjunction with information from local wells.

Data interpretation is summarized in Fig. 3. The third layer is interpreted as the crystalline basement and, as it can be seen, Upper Sedimentary formations thickness increases to the West gradually. Bedrock depth can change abruptly as is the vicinity of the bridge, where there is a sudden 10 m increase in bedrock depth over an horizontal distance less than 50 m.

The profile also shows a faster second layer West of the bridge. Considering the information from local boreholes the boundary between the first and the second layer should correspond to the freatic level (between 5 and 7 metres in the boreholes) and thus, to the east of the bridge, there appears to be no water resources. Therefore it is not advisable to drill new exploitation boreholes to the East of the present ones.

RESISTIVITY PSEUDO SECTIONS

To investigate the areas North and South of the boreholes two resistivity pseudo sections were carried out, NB and SB on Fig. 1. A Wenner array was used with a 6 points per decade sampling rate and pseudo sections were constructed by plotting field data according to sounding location and Wenner array “a” spacing. To the North of the boreholes the pseudo section NB, left of Fig. 4, shows consistent horizontal contour lines giving a clear evidence a horizontal layering. Thus each sounding was interpreted, using an interactive computer program, and the proposed model was obtained using borehole information and geoelectric equivalence analysis. Interpretation for each sounding was accepted only when the departure between theoretical data and field data was less than 5%.

The 1D interpretation, right of Fig. 4, reveals a model corresponding to horizontal layering with depths of

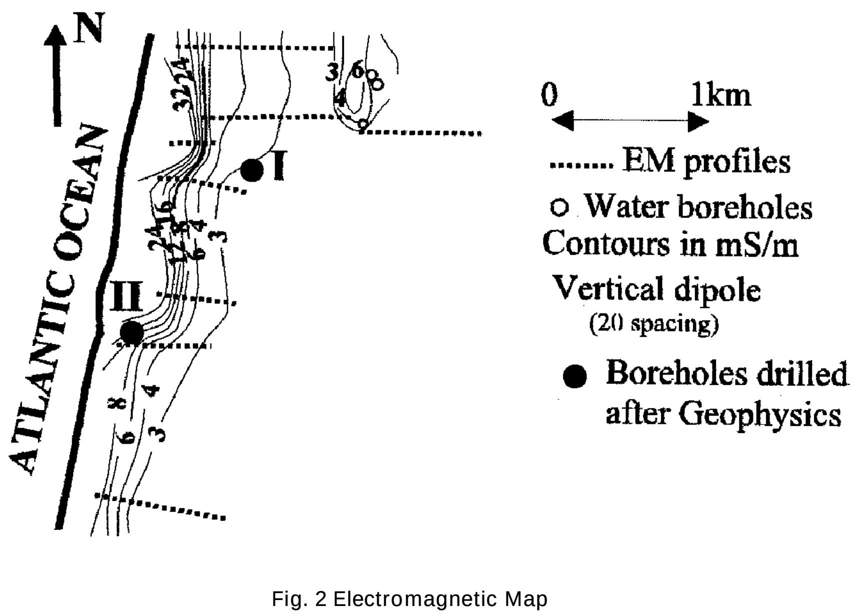

Fig. 2 Electromagnetic Map

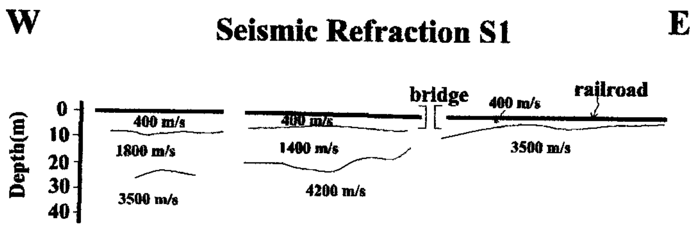

Fig. 3 Seismic Refraction Interpretation

bedrock between 30 and 35 metres, thus similar to that of the boreholes. However, owing to the electrical conductivities on the electromagnetic map of Fig. 2, it is not advisable to drill new boreholes in this region.

Using the same field configuration the pseudo section SB was obtained south of the boreholes.The data are shown on the left of Fig. 5. As it can be seen horizontal layering is not clear owing to the behavior of the contour lines.Thus a 2D interpretation was attempted Loke et al, 1996.The interpretation proposed is shown on the right of Fig. 5.

As it can be seen, to the South of third sounding the model proposes a more conductive ground that should not be justified by saline intrusion as it is reasonable to expect from the electromagnetic map on Fig. 2.Thus there is the possibility of a deeper bedrock or of a lateral variation in the sediments in this area.

SEISMIC REFLECTION SURVEY

To clarify the previous interpretation and taking into consideration the expected depths and resistivity values it was proposed to carry out a shallow seismic reflection profile, Fig. 1, to detect stratigraphy, bedrock topography and depth. However, this survey, had some difficulties such as varying topography due to the presence of Quaternary fossil dunes, high attenuating thick surface media and some degree of lateral variation in ground coupling conditions throughout the profile.
Walkaway noise tests were conducted along the profile that provided vital information on the presence of reflections and at what offsets and times they would occur, Fig 6. From this analysis an ideal offset of 68 metres was chosen, which is in accordance with general practice, that is, the use of offset values of the same order of the reflection depths, King, 1992. The profile was then carried out, from North to South, with a shot interval of 5 meters using a standard 12 gauge shot pipe in a 60-cm hole.

The signal was recorded with a signal enhancement seismograph,using 14 and 100 Hz geophones. Field analogue filtering was done by means of a 25 to 1000 Hz bandpass for the 14Hz geophones and a 100 to 1000 Hz bandpass for the 100 Hz geophones. High frequency low-cut filters were not used because of the high attenuating coupling media and of previous filter tests. It was assumed that the dynamic range of the used 15 bit seismograph is good enough to prevent low frequency high amplitude signal from dominating the record, Knapp et al, 1986. Thus signal bandwidth was the main concern for maximum resolution and for later digital processing.

Processing was performed using a commercial PC software package and particular attention was paid to static corrections,consisting of first break alignment due to the knowledge of the refraction from the top of the water table (5 –7m below surface). This stage improved greatly the alignment of the reflection events, Pugin et al, 1998, and allowed the compensation for velocity and thickness variations along the profile. Trace shifts are due to varying conditions of the low velocity layer (thickness and velocity) as sur-

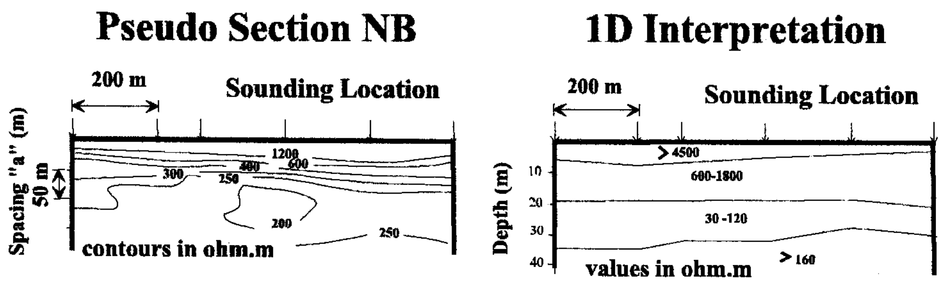

Fig. 4 Pseudo Section NB and 1D Interpretation

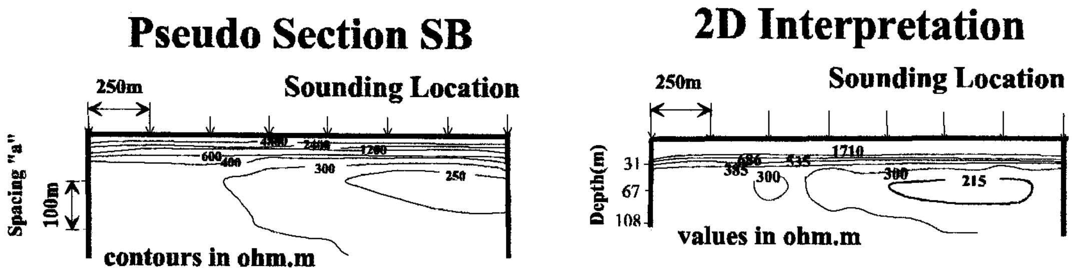

Fig. 5 Pseudo Section SB and 2D interpretation (5.3% error)

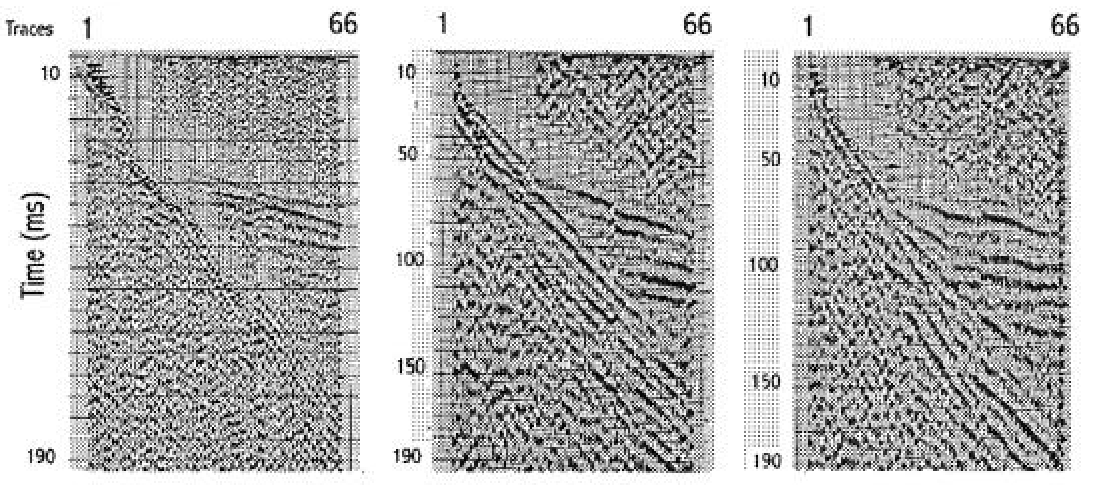

Fig. 6 Walkaway noise tests performed at the beginning middle and end of the seismic profile. Trace spacing is 1.1m (66 channels). Notice, from 1 to 3, reflections appearing at later times.

face layer velocity variations are peculiar to shallow reflection data since velocity contrasts in saturated/unsaturated ratios can be as much as 1:5, Pugin et. al., 1998. Thus time shifts can be greater than the period of the reflection events resulting in incoherent raw sections. Therefore optimum offset technique has to be carefully used in order to avoid pitfalls of interpretation. In the processing stages mutes are placed in order to remove the refraction wave group as well as the groundroll and airblast, Steeples et al.,1986. The alignment of these events can easily be mistaken for reflectors on the final section so careful observation of the complementary tests and refraction data is important. On the other hand these mutes also enhance reflections since the high amplitudes from groundroll no longer dominate the seismic section.

The depth scale is based on the velocity determinations obtained from refraction data and hyperbolae fitting of field tests. Reflectors were used to determine average velocity above them. From these, interval velocities were calculated and the effects of the unsaturated zone removed. The average velocity for the saturated material was found to be approximately 1200 m/s. Finally a depth scale was calculated based on the formula in Slaine et al, 1990, Fig. 7.

Based on these results the new borehole III was drilled and reached the schists bedrock at a depth of 45 metres thus proving a significant deeper bedrock in this region. Therefore future water wells should be drilled in this area, bearing in mind the control of an eventual saline intrusion that should always be checked.

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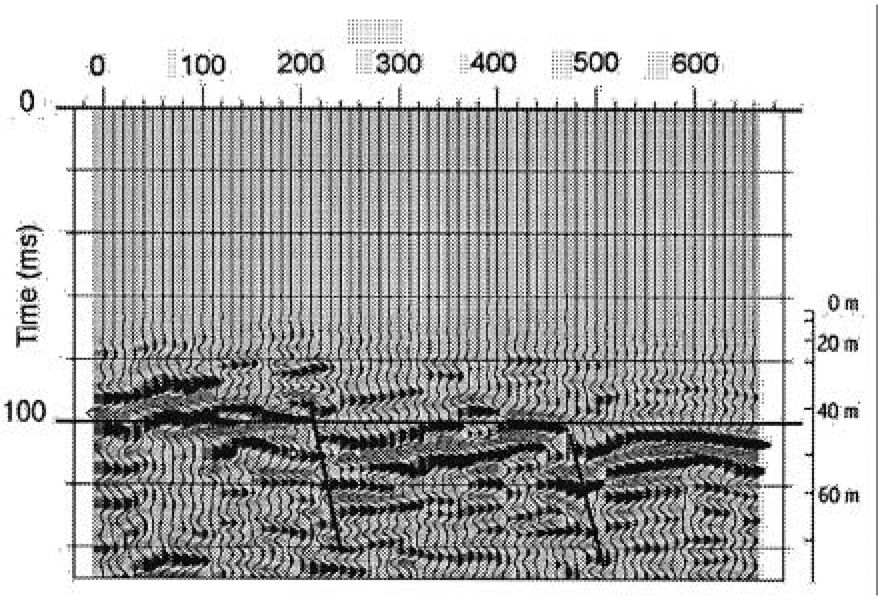

Fig. 7 Reflection processed final section in Optimum offset mode (14Hz Geophones)

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