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Improving Near Surface Characterization by Combining Reprocessed Vintage Seismic and Geophysical Passive Datasets

B. Benjumea* (ICGC- Institut Cartogràfic i Geologic de Catalunya), A. Macau (ICGC), A. Gabàs (ICGC), M. Esquerda (ICGC) & S. Figueras (ICGC)

SUMMARY

This study reveals the importance of reprocessing vintage seismic data, originally focused on deep targets, in order to retrieve near-surface velocity model and structure. This information can be verified and complemented using cost-effective geophysical methods (passive seismic and audio-magnetotelluric - AMT data technique). This methodology has been applied to the Empordà Neogene basin (NE of Spain) where oil reflection datasets are available. 41 H/V stations were deployed along one seismic reflection profile to detect seismic impedance contrast between Quaternary/Neogene sediments and basement (Palaeozoic and Mesozoic). In order to calculate this contrast depth, shear-wave velocity profile has been obtained using seismic noise array technique. The final model obtained from the different seismic datasets show a basin shape with a gentle dip at the SW end of profile and an abrupt dip at the NE side interpreted as the Roses Fault. Bedrock depth reaches 660 m at the center of the profile according to H/V results. Finally, an AMT survey was undertaken at 10 sites to report a detailed 2D geoelectrical image across the Roses fault. The electrical resistivity model allows to characterize both structure and fluid properties associated with fractures network within the fault.

Introduction

Empordà Basin is located in NE Catalonia (Spain) between the Pyrenees, the Catalan Coastal Range and the Mediterranean Sea (Figure 1). The Oligo-Aquitanian extension episode corresponds to the opening of this sedimentary basin along major normal faults (Albanyà and Roses faults). The fault system is characterized by NW-SE direction (Saula et al., 1996).The sediments deposited in the area during and subsequent to the tectonic extension are of Neogene and Quaternary age. Bedrock in the study area is composed of Palaeozoic metamorphic and plutonic rocks and Mesozoic limestones.

This basin has been the target of different geophysical studies. During the 80s, several oil companies carried out seismic reflection surveys to characterize the main deep geological structures for exploration purposes. Rivero et al. (2001) showed a 2D gravity model of the basin. From a hydrogeological point view, different field surveys have focused in the shallow aquifers using mainly VES and ERT for saline intrusion characterization (Zarroca et al., 2011).

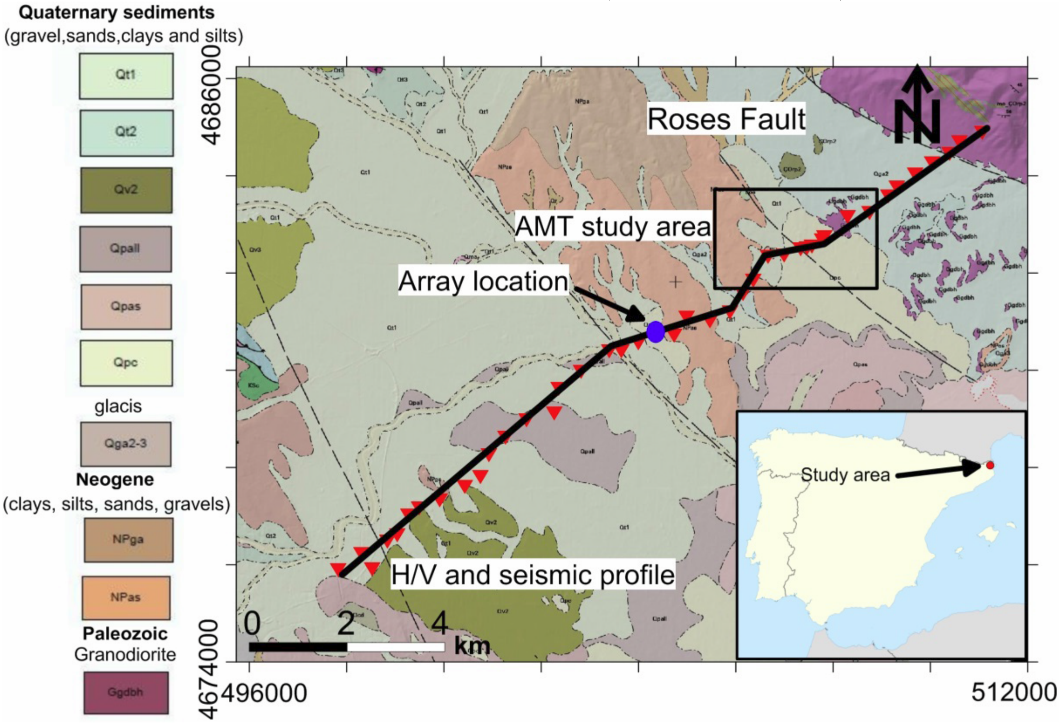

Figure 1 Geological map of the studied area with location of the Empordà Basin and fault system. Solid black line indicates the surface trace of the seismic model. Red triangles denote H/V sites. Array location is marked with a blue circle. Black rectangle shows the area crossing the Roses fault studied with AMT method.

The objectives of this work are: to characterize Neogene sediments and underlain bedrock, to obtain bedrock geometry and to image one of main faults (Roses Fault). The methodology includes:

- Reprocessing of vintage seismic data. First arrival data have been obtained and inverted to obtain a P-wave velocity model. This model allows characterizing lateral variations of near-surface filling the gap between surface and reflection image. Seismic reflection data has been analysed in order to obtain Neogene sediment thickness.
- New geophysical data have been acquired. First H/V seismic noise technique has been used to detect seismic impedance contrasts (mainly Quaternary/Neogene sediment-bedrock contact). Second, array measurements allow to obtain the depth for these contrasts. On the other hand, AMT data have been obtained and processed to characterize sediments and bedrock from an electrical point view as well as imaging the Roses fault. This methodology has been shown in previous works as suitable for Neogene basins (Gabàs et al., 2013; Macau et al., 2013).
- Combination of the results. P-wave velocity model and H/V results allow to define bedrock geometry in the shallow zones. Reflection data, H/V and array data contributes to delineate bedrock in the deepest part of the transect. And finally, both P-wave velocity and resistivity

model from AMT can be used to image the Roses fault. AMT result allows to characterize both rock and fluid properties.

We will focus on a profile NE-SW crossing four mapped faults (Figure 1) with both active and passive seismic techniques and on the Roses fault sector combining seismic and electrical models.

Data acquisition and processing

Seismic reflection vintage data was acquired during 1981 using dynamite detonated in boreholes at 20-30 m depth. In this study, we will use 110 shot gathers acquire with 48 channels with split configuration. The geophone group for channel was located every 60 m and the shot point interval was 120 m. Sampling rate was 2 ms with a total record length of 5 s. A total of 5280 P-wave arrivals were picked using Promax. A flow based on Matlab code was developed to pass geometry, travel-time information to the tomographic traveltime inversion step. Rayfract software (by Intelligent Resources Inc.) was used to perform the inversion. The final model shows a normalized RMS error of 2.6 %. Seismic dataset has low-fair reflection quality as shown in the stacked section. In addition, acquisition and processing were setup for deeper targets making difficult obtaining near-surface information from the seismic image. Since we focus in reflections corresponding to the Neogene sequence and base, a first analysis of shot gathers has been carried out to identify these targets. Figure 2 shows three shot gathers depicting how the Neogene base reflection deepen towards SW.

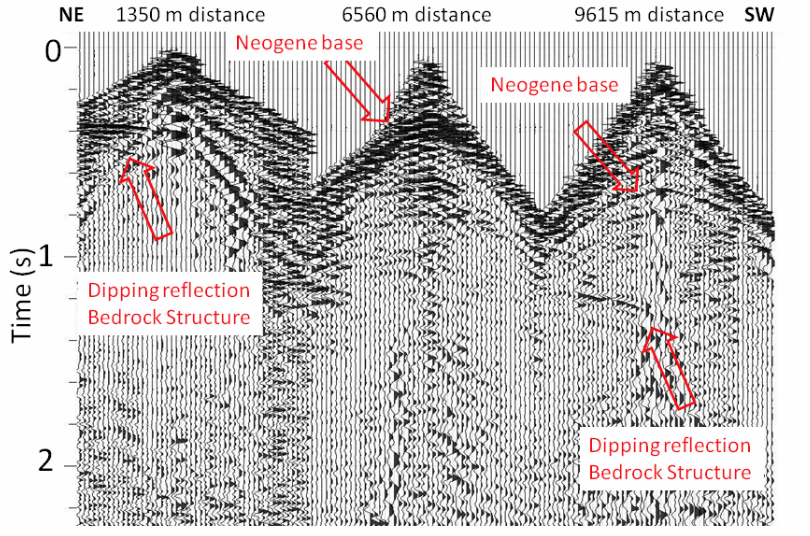

***Figure 2** Example of shot gathers along the profile and interpretation of Neogene base reflection.*

Seismic noise was recorded in 41 single stations along the profile shown in Figure 1. The seismic noise vibrations were recorded using a SARA SL06 datalogger connected to one Lennartz LE-3D, 0.2 or 0.05 Hz, triaxial sensor. H/V spectral ratios were computed by dividing the noise recordings into 60 to 120 s-long windows. The resulting 41 H/V spectral ratios were analysed considering the recommendations proposed by SESAME (Bard et al., 2004). Most of H/V curves show clear peaks which frequency is related to the soil fundamental resonance frequency at each site. Stations located on bedrock are characterized by flat curves, without significant peaks. In addition, in order to check whether a site is 1D, H/V spectral ratio is computed with an horizontal component spanning different azimuths. The H/V ratios were calculated using the Geopsy software (http://www.geopsy.org).

One 2D seismic noise array was deployed at the sector with the lowest H/V frequencies where the deepest part of the basin is expected (Figure 1). Array equipment consisted of 7 Lennartz LE-3D 0.2 Hz triaxial sensors and 7 SARA SL06 seismic recorders. The sampling rate was fixed to 200 samples per second. This wireless equipment with GPS time allows recording ground motion simultaneously. The procedure for the array consisted in recording simultaneous seismic noise at six stations forming two equilateral triangles with two different radii to a common centre where a seventh sensor was located. The radii ranged from 25 to 750 m. Record length was setup depending on the array radii, the larger the array aperture, the longer the record length. Records of each seismic noise array measurement were analysed with the Frequency – wave number (FK) and Spatial Autocorrelation (SPAC) methods to obtain dispersion or autocorrelation curves. An unique dispersion curve (DC) built from the DC of each configuration has been inverted using the neighbourhood algorithm. As in H/V method, the processing of seismic noise array data has been carried out using Geopsy package (Whatalet, 2005).

AMT soundings have been made at ten locations, separated 100 m approximately, along 1.5 km profile crossing the Roses Fault in order to fully describe the structure of this zone. In performing the survey, we used the AMT equipment developed and manufactured by Metronix, ADU07e working in a frequency range from 1 second to 50.000 Hz. Only the horizontal components of the electromagnetic field were used to process the electromagnetic data. We examine the dimensionality analyses using the MT phase tensor (Caldwell et al., 2004). A small value of phase tensor dimensionality indicator (β) could indicate a strong two dimensionality of regional conductivity structure in Empordà basin. This preferential direction was applied to decoupling the impedance tensor into transversal electric (TE) and transverse magnetic (TM) modes and both modes were considered for the 2D inversion process. An average value of 20 Ω·m for the first 50 m obtained from old VES studies was considered to correct the static shift. 2D models have been constructed inverting the apparent resistivity and phases of both modes, TE and TM, with the algorithm of RLM2DI (Rodie and Mackie, 2001).

Results and Interpretation

Figure 3 displays a spectrogram with the relationship between the H/V spectral ratio amplitude (colour coded) and location along the profile. The H/V amplitude maxima (purple colours) correspond to a frequency range between 0.3 to 15 Hz. An abrupt decrease in frequency values of the maxima (from 15 to 1 Hz) can be seen between 4000 and 5000 m distance indicating a steep slope for the impedance contrast (sediments/bedrock contact). Frequencies have been transformed into depth using the relationship by Gabàs et al. (2013).

Figure 4 shows the combination of the P-wave velocity model obtained with refraction tomography and the bedrock depth using H/V technique. Velocity model shows a sharp lateral velocity contrast around 4 km distance that correlates with the bedrock geometry delineates with H/V technique. This feature would correspond to the Roses Fault. Velocities in the NE side ranges between 2400 m/s and 5000 m/s. These high velocity values are interpreted as shallow igneous rocks. The velocity model at the SW side of the fault is characterized by low velocity values with a maximum of 2500 m/s. These materials are interpreted as Quaternary/Neogene sediments. H/V bedrock values delineate the basin with a maximum depth of 660 m and a gentle dip at the SW end compared to the NE side. In addition, the electrical resistivity model obtained across the Roses fault helps to characterize not only the structure features but also the fluid that fills porous and cracks in the fracture zone.

Conclusions

The combination of vintage seismic and passive seismic data along a transect NE-SW crossing the Empordà Basin marks the position and dip of the Rosas Fault. In addition, high resolution AMT survey helps to map subsurface features and to increase understanding of the fluid and rock properties of this fracture zone. This study reveals the advantage of using vintage reflection data to characterize near surface using tomographic approaches. The shallow velocity model gives information of the near-surface that cannot be retrieved from reflection data. Analysis of the active seismic data set (both refraction and reflection arrivals) combined with low-cost passive geophysical data results (H/V and AMT) in a suitable methodology to characterize an extensive Neogene basin.

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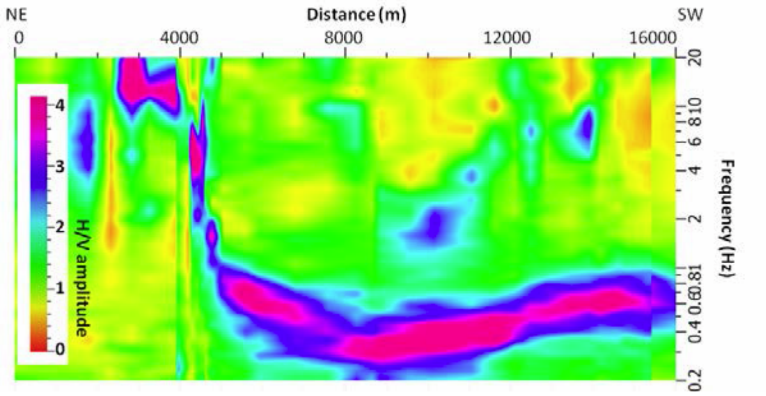

Figure 3. *H/V spectral ratio amplitude (colour coded) as a function of distance along the profile and frequency.*

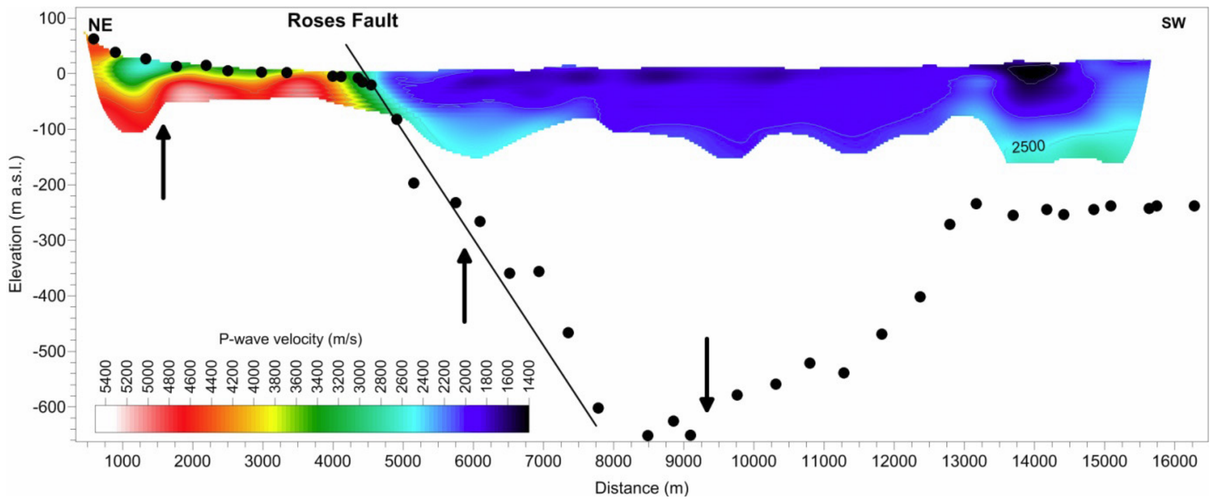

Figure 4*. P-wave velocity model from refraction tomography and calculated bedrock depth obtained from H/V technique (black dots). The rows indicate the location of the shot gathers shown in Figure 2.*

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