Passive Seismic Tomography a complementary geophysical method: successful case study.

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Abstract

Passive Seismic Tomographic Inversion a method that used P and S-wave travel times from natural micro-earthquakes to accurately estimate 3D Vp (structural) and Vp/Vs (lithologic) information of the subsurface and its potential is presented here. The objective of the project was to use this complementary geophysical technique to aide in the imaging of the sub-surface volume in the region, in terms of hydrocarbon exploration and/or delineation. The results of this case study will show the very good agreement between the predicted estimates of passive versus the exploration well outcome.

Introduction

Passive Seismic Tomograhy has been used in the past for seismological reasons on a different and certainly larger scale than that of hydrocarbon exploration and delineation. The application and modifications of such an operation to fit the standards of petroleum investigations was pioneering in the region of Epirus in NW Greece. The quality of the results and the advantages over conventional seismic clearly indicate the benefits of the method in oil exploration, delineation and even production.
The key advantages of Passive Seismic Tomography are the low cost and relatively easy operation in relation to conventional seismic, especially in difficult (mountainous) terrains. Another very positive issue is that the application of the method is environmentally friendly, an issue of considerable importance to the global oil company activity today.
The 3-D seismic velocity and Poisson ratio model of the upper few Km of the crust can be used for:

- **Improvement of Structural and**
- **Lithologic interpretation**
- **Better understanding of the geology in the area**
- **Reprocessing and improvement of existing seismic**
- **Definition of any upside potential and help design future seismic acquisition.**

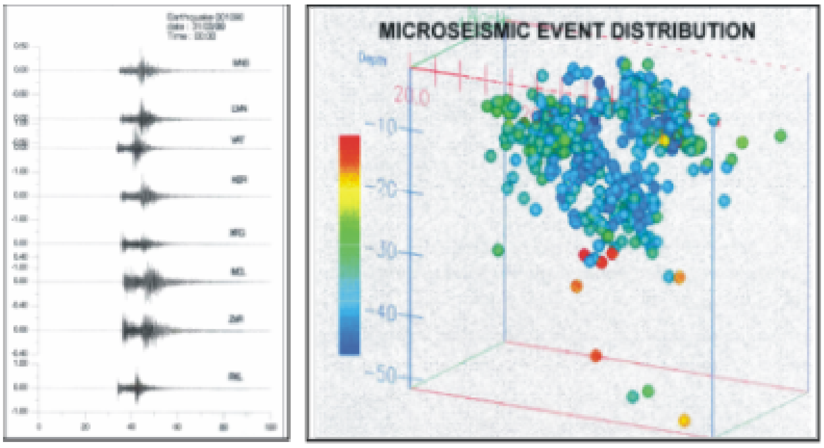
and lead to:

- **Risk reduction**
- **Better well placement and**
- **Better reserve estimates.**

Data

The Passive Network (code name PATOS) was installed in Epirus and operated by LandTech in collaboration with the Seismological Laboratory of Patras University, Greece. The network design took into consideration a uniform spatial coverage of the area, high sampling resolution and frequency content. The PATOS network consisted of forty 3-component high resolution 24 bit seismometers, buried in order to improve signal-to-noise ratio. It covered an area of approximately 3300 km^2, where there is strong attenuation in conventional seismic reflection energy due to high velocity and/or karstified carbonate outcrop. PATOS recorded micro-earthquakes continuously for eleven months. In total more than 900 events were accurately located and used within or close to the network area.

<u>Natural Seismicity</u> down to 0.1R can be used as passive source



Data selection is one of the most critical and important steps to be undertaken before an inversion, where we solve simultaneously for earthquake location and velocity model adjustments. It is therefore important to use earthquake locations well constrained by the data. The earthquakes used in the tomographic inversion satisfied the following criteria: a) must lie within the network and in the inversion grid b) have at least 15 P & S phases c) the upper limit of the RMS residual is 0.20 sec and the horizontal and vertical error are less than 0.8 km.

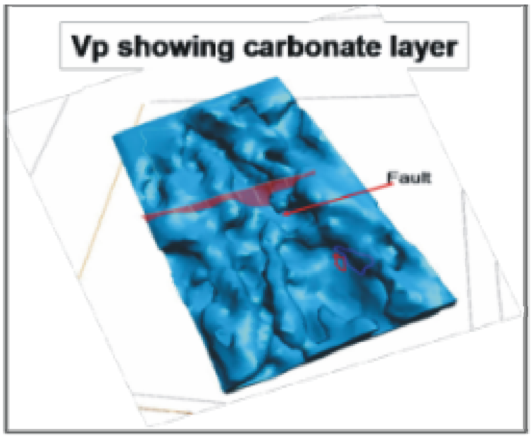
Methodology

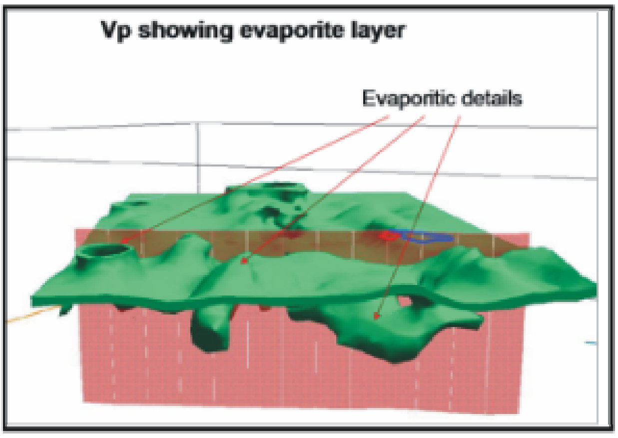
The tomographic procedure is carried out in basic steps. The first one is the selection of the optimal 1-D velocity model that will be used as initial in the 3-D inversion step (Kissling et al, 1994).

The results of the 1-D inversion used in the second step where we performed the 3-D joint hypocenter-velocity inversion in order to obtain the optimal 3-D Vp and Vp/Vs models and the most accurate hypocenter locations.

In a passive seismic tomography problem the only known parameters are the receiver coordinates and the observed arrival times with the latter suffering from uncertainty. The unknowns are the hypocenter coordinates and the slowness field. The target is to improve model parameter estimation (hypocenter and velocity) by perturbing them in order to minimize some measure of the misfit to the data. In the tomography experiment in Epirus we followed the above methodology, which resulted an accurate 3-D model for Vp and Vp/Vs. The results converged after five iterations and the decrease of the total RMS misfit was 32% (the RMS value after 1-D inversion was 0.1119s while after 3-D inversion reduced to 0.076s).

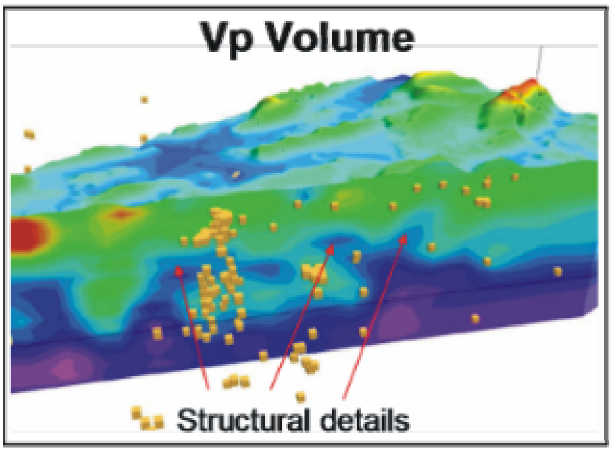
The third basic step in solving a tomography problem is the *quality check* of the results (Thurber et al, 1993). In this particular project we performed the most common quality tests such as resolution or with synthetic models tests. In addition we compared our results to pre-existing geological observations, to those of other geophysical methods and later on with the VSP data after drilling in the study area.

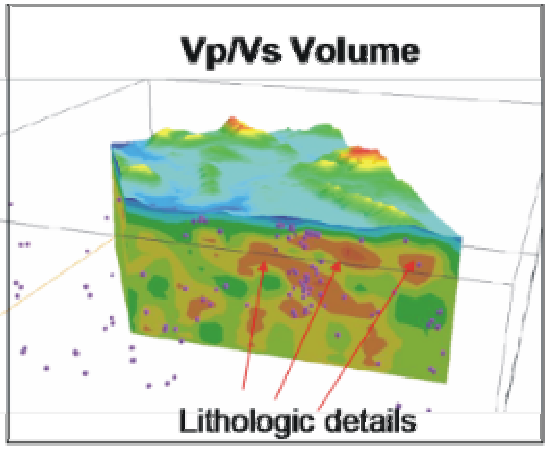




Results – Comparison

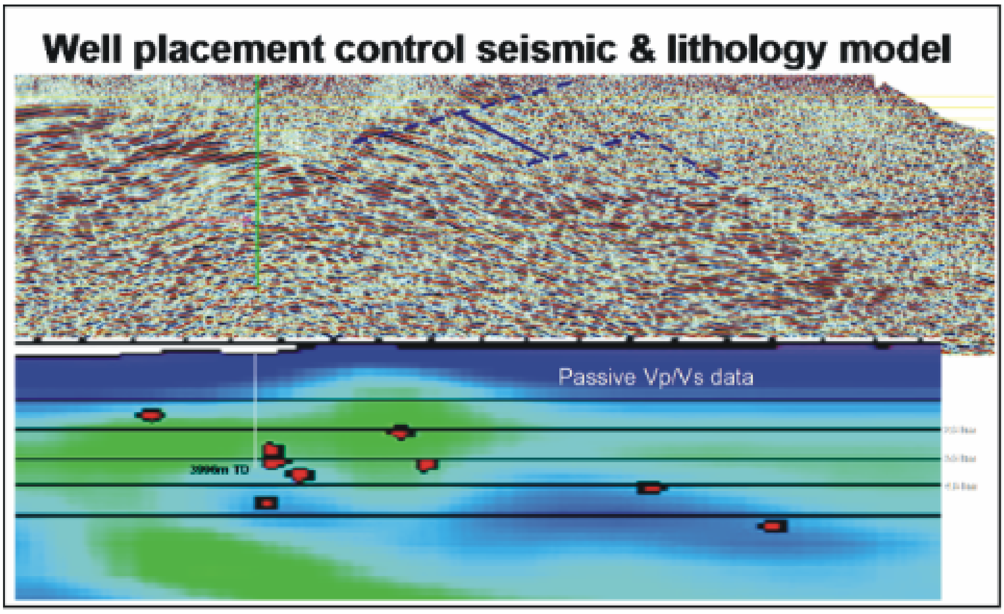
The resulted velocity structure images were taken at specified vertical cross-sections and at horizontal depth slices (0-10km depths). The depth slices at 0 (mean sea level) and 1km (for Vp and Vp/Vs) showed a very close correlation with the surface geology. The Vp velocity values range between 4.5 and 5.6 km/sec and fit very well to the carbonate (higher) and flysch (lower) typical velocities, which form the major part of the surface of the study area. They also correspond very well to the existence of evaporite outcrops (4.9-5.4 km/sec) that has been observed in the area. Additionally, the Vp/Vs values ($\geq$ 1.85) at 0 km depth are in a good agreement with the high porosity and saturation of the geological formations and the karstification of carbonates. The evaporite existence mentioned above at 1km depth is justified from the 1.70-175 Vp/Vs calculated values.





At depths from 2-6 km the Vp and Vp/Vs values (4.9-6.0 km/sec and 1.70-1.83 respectively) correspond very well to carbonates and evaporites structure defined by other geophysical and geological modeling in the area. The results are also confirmed by those of the well, from the surface to 4 km depth.
According to the passive method, the Vp velocities ranged between 5.1-5.4 km/second and Vp/Vs between 1.90-1.80 from the surface to 1900m depth, correlating very well to karstified/saturated carbonates. The same conclusion comes out based on the VSP method, with Vp velocities.

It must be understood that the passive outcome played a very important role in well location and placement as shown below.



The comparison of the passive and VSP results confirm, above all, the reliability of the Passive procedure. Although the results have a maximum divergence of about 5-10% in Vp velocities, the imaging of the structure and the lithological distribution in the well area is quite similar. Complete comparisons will be shown in our presentation.

Conclusions

The application of passive tomography in Epirus and the comparison of the results to other geological and geophysical data and at the end the post well data, proved the importance of the method in hydrocarbon exploration and delineation. It is also very important to mention that the resulting model was used in re-processing and re-interpretation of poor -quality seismic data, due to karstification of carbonates and helped to control the drilling process.
According to the aforementioned reasons and considering that the application of the method is environmentally friendly and cost-effective, it is clear to us now that the Passive Seismic Tomography technique could be a very useful imaging and interpretation tool not only in tectonically active regions but also in regions with similar problems were minor natural seismicity could occur.

Acknowledgments

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