Introduction

During the last years, Passive Seismic Tomography has been extensively used as an exploration methodology, mainly in the case of large onshore exploration blocks, characterized by difficult topographies, complex geological settings and/or environmental restrictions.

Due to the methodology’s nature itself, it has a minimum environmental impact, since the sources involved are low-magnitude naturally-occurring microseismic events, it is not affected by rough topographies, since the recording stations are stand-alone seismological stations and, last but not least, it does not suffer from seismic energy penetration issues, since it exploits one-way travel-times, in opposition to the two-way travel-times involved in most active methods.

Moreover, Passive Seismic Tomography has been applied for exploration at various scales, ranging from a reconnaissance tool to a reservoir level. An example of its broad range of applications is the Delvina Passive Seismic Tomography project, a two-phase study that has been completed in the Delvina Gas Field area, SW Albania. The study area is a mountainous thrust-belt zone and the productive structure is located underneath an evaporitic layer.

The scope of the work was double. On one hand, it aimed in delineating the extent and geometry of the productive structure of this particularly complex reservoir and, on the other hand, the ambition was to locate possible target areas within the broader exploration area. The project was considered highly successful, since Passive Seismic Tomography managed to provide coherent answers to both questions.

The Delvina Gas Field

The Delvina Gas Field is a marginally producing gas condensate field, located in SW Albania. Its discovery dates back in 1989 and was based mainly on geological studies and intensive drilling. It is a Cretaceous/Eocene Carbonate reservoir, located at depths that range from 2800-3400m.

Since its discovery, a number of wells have been drilled around the main productive structure, in the scope of delineating its extent. However, they only achieved to confirm its complexity, since nearby wells gave different – and in some cases even confusing – results.

Figure 1 The microseismic network installed in the context of the Delvina Gas Field Passive Seismic Tomography project. Green triangles correspond to microseismic stations of both phases, while blue dots represent the location of existing wells.
More particularly, five wells have been drilled in total on the area that is believed to be overlaying the productive structure, based on superficial geological observations (figure 1). These are the wells D4, D9, D10, D12 and D14. However, only three of them were successful (D4, D9 and D12) in reaching the carbonate reservoir and only two of them are producing up to date, since D9 exploded at some point due to high pressures. The other two wells were dry (D10 and D14). Well stratigraphy is presented in figure 2.

![Figure 2 Well stratigraphy below M.S.L. The sequence in all four wells (top to bottom) consists of Triassic Dolomite, Triassic Evaporite, Paleogene flysch, followed by Eocene/Cretaceous carbonates, which constitute the reservoir rock.](image)

It has to be noted here that, even though in the case of D14, this was expected, since drilling was terminated before reaching the target depth, the case of D10 could not be explained. Moreover, the two remaining productive wells (D4 and D12) are producing gas condensate of different quality. These facts led to the assumption that the Delvina gas field consists of a highly compartmentalized reservoir. However, this assumption had not been positively confirmed in the past by any scientific study, despite the fact that a number of seismic lines had been shot in the area. These lines did not manage to clarify the image, mainly due to the sub-evaporitic location of the reservoir.

### Passive Seismic Tomography Results

In that scope, a two-phase Passive Seismic Tomography project has been completed around the Delvina Gas Field, focusing both on delineating the extent of the reservoir and on spotting possible new targets within the broader Exploration area.

The first phase consisted of a 50-station network, covering a 900km² area around the Delvina Gas Field. After 11 months of recording, this phase resulted in a 2500 microseismic events dataset, 1860 of which were used for tomographic inversion. During the second phase, a 70-station network was deployed in a much smaller area, covering approximately 400km², enriching the previously acquired dataset by more than 1000 microseismic events. The total dataset deriving from both phases consisted of approximately 2900 events that were finally exploited for modelling, providing 3D p-wave velocity and Vp/Vs distributions of the entire study area.

The results acquired were particularly encouraging, since passive seismic one-way travel-times, in opposition to reflection data that seemed to be characterized by seismic energy penetration issues, managed to provide a coarser, but clearer image of the area of interest (Martakis et al., 2013).

This is confirmed by figure 3, where the tomographic results were superimposed on a geological cross-section created using geological observations and well data. The cross-section is passing across the wells D4, D9 and D10 and visualizes the remarkable coincidence of the tomographic velocity
model with the major structures of the study area. Observing figure 3, it becomes obvious that the western part of the model is in better accordance with the geological cross-section than the eastern part. This is due to the fact that the available well data were limited to the area west of the well D10, while the rest of the geological cross-section (eastern part) was based solely on surface geology.

**Figure 3** P-wave velocity distribution along a 12km line passing through the wells D4, D9 and D10. The velocity model resulting from tomographic inversion of PST data is superimposed on a geological cross-section, which was created based on geological observations and well data.

In order to get a clearer image of the velocity distribution around the productive wells, an area of 8x8km was isolated from the 3D cube of PST results and depth slices every 100m are presented in figure 4. The velocity values confirm the deepening of the productive structure, which is met by the well D12 at a depth of 2800m, towards the area where the wells D4 and D9 are located.

**Figure 4** P-wave velocity distribution along depth slices, at an area of 8x8km around the productive wells. A depth slice is extracted every 100m between 2900m and 3600m.

Trying to explain the fact that the two productive wells (D4 and D12) are producing gas condensate of different quality, as well as to locate possible areas of interest, an attempt was made to isolate the characteristics of the reservoir, in terms of Vp and Vp/Vs values, at the producing depth of D12. These values (Vp values ranging from 5.1 to 5.4km/s and Vp/Vs values ranging from 1.78 to 1.80) were then used as evaluation criteria, in the scope of “scanning” the 3D cube of the tomographic
results and delineating areas with similar characteristics. The results of this multi-parameter filtering procedure are presented in figure 5, which clearly indicates that the productive zone is interrupted between the wells D12 and D10. It becomes obvious that the wells D4 and D9 seem to be producing from an adjacent, smaller reservoir, located deeper that the main productive structure. This fact is in complete accordance with the scenario of a compartmentalized reservoir.

Moreover, the same evaluation indicated the existence of another possible target area, located at approximately 4km SE of D12 (Kardhikaqi area). This area is characterized by the same Vp and Vp/Vs values dominating the productive zone of D12, at slightly shallower depths. Consequently, this area could be a possible zone of interest for further investigation, in terms of hydrocarbon potential.

Conclusions

Passive Seismic Tomography, as applied in the Delvina Gas Field, provided useful information, concerning a particularly complex reservoir. Even though the gas field has been producing for 25 years and despite all the geophysical studies that have been realized in the area, the geometry of the reservoir had never been positively delineated. In that scope, contribution of Passive Seismic Tomography results was important in providing a well-constrained scenario concerning the productive structure, being at the same time in accordance with all available data. Besides, those results played a critical role in well-placement decisions. Last, but not least, the fact that Passive Seismic Tomography provided information both on p-wave and on s-wave velocities resulted in a multi-parameter 3D space, the evaluation of which indicated the existence of possible target areas for further exploration.

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References