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Geophysical Near-surface Characterization for Static Corrections: Multi-physics Survey in Reggane Field, Algeria

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SUMMARY

We are presenting a new methodology for building near-surface static corrections models consisting on multi-physics measurements integration. The methodology was applied in two geological contexts: presence of a complex, multi-layered sandy overburden on Kahlouche area and important weathered zone fluctuations due to shallow complex geology on Reggane. Electric and electromagnetic methods were chosen to characterize near-surface geology and improve the existing up-holes velocity models. Seismic / resistivity cross-correlations provide detailed transit time maps fully integrable in the seismic static-corrections processing workflow.

Introduction

Reggane and Kahlouche blocks are located in the south west of Algeria, in Adrar region, with an approximated extension of 922 km² and 530 km² respectively. The area is well known for its deserted planes of gravel and the presence of sand dunes reaching up to 60 meters high.

Despite the continuous improving of seismic acquisition and processing technologies, such environments characterized by complex geological weathered layers lead to dramatic deterioration of land seismic data quality (Marsden, 1993). Long / medium wavelength static phenomena remains a major issue in land seismic processing, and most common approach for compensating the problem caused by the near-surface consists on building up-hole models. Up-holes usually provide accurate but punctual information and their acquisition is associated with high costs. Additionally, up-hole drilling cannot be performed in some areas (sabkha) or could imply a wider exposure to drilling shallow hazards. During previous campaigns, 45 up-holes were drilled, 28 in Reggane and 17 in Kahlouche. However, considering the size of the prospect, the distances between up-holes are too broad (in the range of kilometres) providing interpolated models excessively smooth and simple.

Being aware that precise static corrections are essential for the accurate seismic imaging, needed for Reggane field development phase, geophysicists from Groupement Reggane (GRN) explored the possibility of using multi-physics methods to improve the spatial resolution of the near-surface velocity model.

Regardless the proximity of these two blocks, the challenges concerning the static solutions are significantly different (*Fig. 1*): the Kahlouche block is placed in the dunes zone and the sandy overburden thickness is the major unknown, while in the Reggane block the main problem is to structurally characterize the complex weathered zone (WZ) due to strong lateral velocity variations. Electric and electromagnetic techniques were tested during a preliminary phase in order to assess their sensitivity and suitability. Based on the test results and given that in Kahlouche area there is a clear distinction between the high resistive sandy overburden and the conductive substratum, Frequency Domain Electromagnetics (FDEM) plus Ground Penetrating Radar (GPR) surveys were proposed.

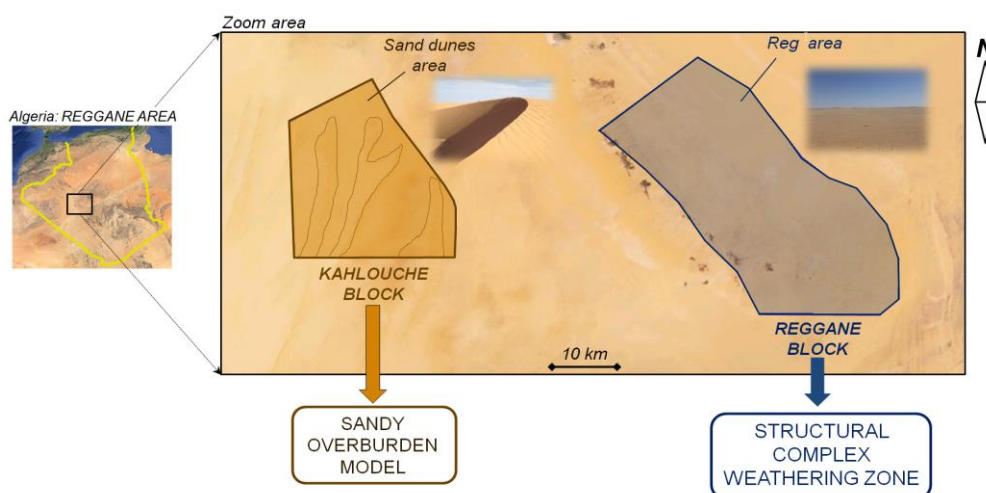
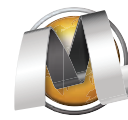


Figure 1: General overview of the survey areas with associated near-surface context.

A vertical electrical sounding in direct current (DC VES) survey was proposed for the Reggane area, assuming that the method would allow a detailed delineation of resistivity variations among heterogeneous weathering zone (WZ).

The EM results have been further employed, in both blocks, to improve the resolution of velocity models estimated based on seismic information from up-holes and weathering reflection surveys (WRS, Youssef et al. 2011), leading to a complete multi-physics data integration process.



Methodology

In Kahlouche, the land FDEM data has been acquired with ten frequencies and two different spacing of 20m and 50m between transmitters and receivers, for a theoretical investigation of 20 different depth layers. This EM method is particularly important because it accurately identifies the top of the conductive / clayey layer below highly resistive / sandy overburden (basement of the dry sand).

The GPR long profiles have been acquired along previous seismic lines. Additionally, few small GPR sections have been acquired close to existing up-holes for calibrating EM wave velocities with up-holes transit times. GPR is fully complementary to EM; the method is very well fitted to accurately characterize highly resistive dunes structure / sedimentary cross-stratification (Bristow et al, 2000; Adetunji et al. 2008; Francke and Utsi 2009) associated with velocity variations inside dunes (**Fig. 2**).

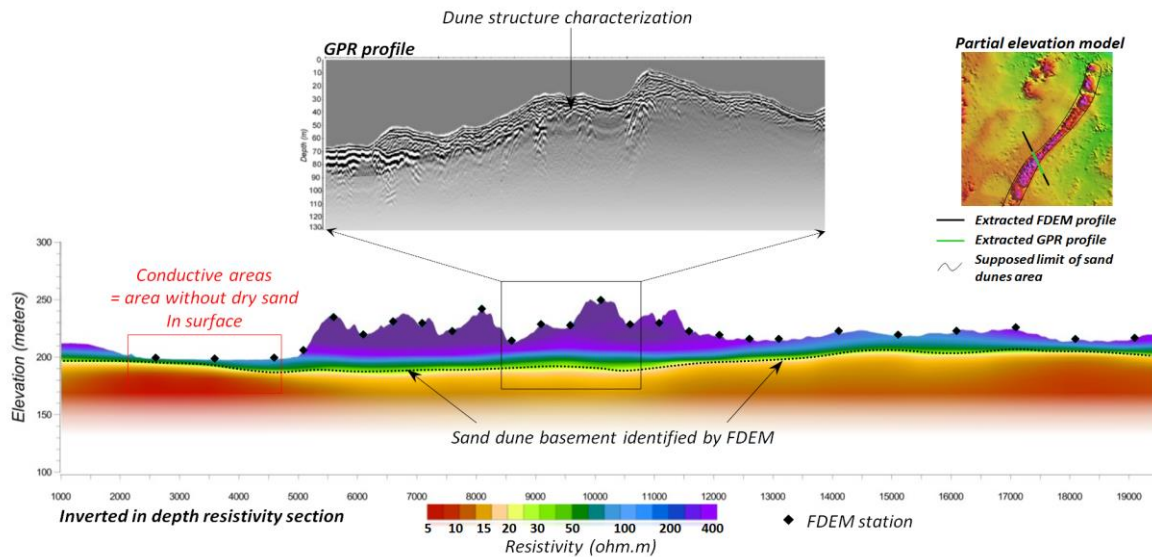


Figure 2: Examples of integrated geophysical results on Kahlouche. Bottom: 2D depth resistivity section from FDEM measurements - Top: GPR profile.

Regarding the Reggane block, DC VES data has been recorded in SW-NE lines, following as much as possible the surface geology layer's direction. Maximum horizontal separation between electrodes reached 3000 m in a geometrically linear configuration. Several soundings have been acquired at up-holes locations for calibration purposes, using resistivity and transit time. Preliminary tests showed that DC resistivity measurements confirmed the vertical limits highlighted by up-holes, clearly imaging structurally complex WZ and characterizing strong lateral variations of resistivity associated to facies / velocity variations. The near-surface model on Reggane was to be determined down to the top Palaeozoic sediments, which corresponds to the first clearly identified seismic reflector on seismic section, the Hercynian Unconformity (HUC) at about 300 meters deep (**Fig.3**).

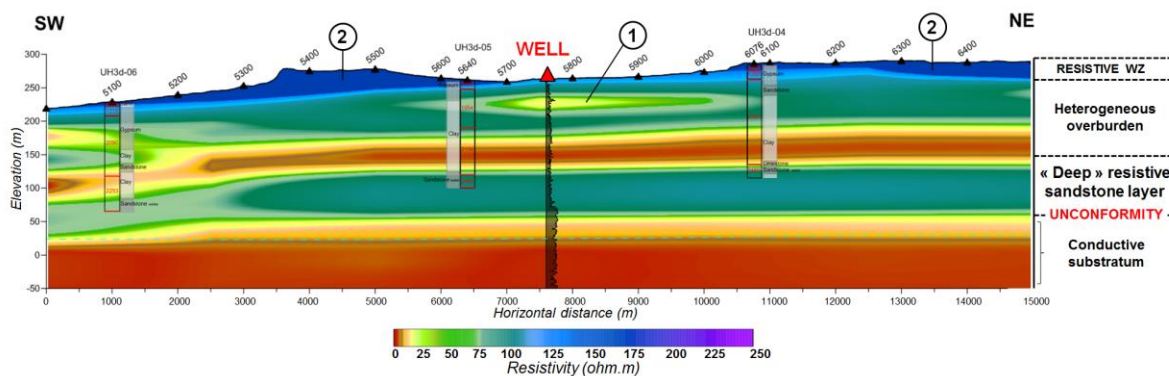


Figure 3: Example of geophysical results on Reggane: DC resistivity section inverted in depth. Main lateral variations are observed 1) Conductive values at the center of the profile, 2) High resistive values at the relief's position.

Independently on area or prospecting technique, both near-surface model building workflows have been similar: 1) initial geological model building, 2) EM data /resistivity constrained inversion in depth, 3) EM waves / resistivity to velocity conversion, 4) velocity model building.

Firstly, all existing datasets (up-holes information, wells logs, WRS data and seismic horizons) have been gathered for building the initial geological model. Following integration of lithology and velocity data analysis allowed the identification of near-surface main geological entities. Reggane model consists on a shallower model, subdivided in an outcropping WZ and an interval of heterogeneous layers, and a deeper model, composed by a more homogeneous sandstone. Model bottom corresponds to Hercynian Unconformity horizon. Kahlouche model focused on sandy layers, overlying a conductive / clayey substratum.

In the next stage, the initial geological model has been integrated in the depth inversion process, guided by geological horizons. Additionally, in Kahlouche, the GPR data has been converted to depth and used as a constraint for the FDEM inversions along the profiles. An iterative algorithm improves the geological layers during the resistivity inversion process. The outcome was the 3D resistivity data cube.

Calibration measurements performed at up-holes locations allow generating regressions between EM data / DC VES resistivity attributes and transit times from up-holes. In Reggane, calibration DC VES provided values for transverse resistance that can be correlated with up-hole transit time. Similarly, in Kahlouche, sandy overburden transit time was obtained thanks to regression law between up-holes seismic velocities and GPR sections performed at up-hole locations.

Finally, these empirical resistivity – velocity regression laws of the area have been used to transform resistivity 3D cubes into velocity cubes for characterizing near-surface geology and refining seismic statics.

Results

Fig. 4 shows a comparison between cross-sections in Reggane for the simple up-holes interpolation model and for the resistivity model, including the transit time variations curve. The resistivity model has significant higher resolution, highlighting the geological complexity of the area and featuring a detailed transit time variation curve.

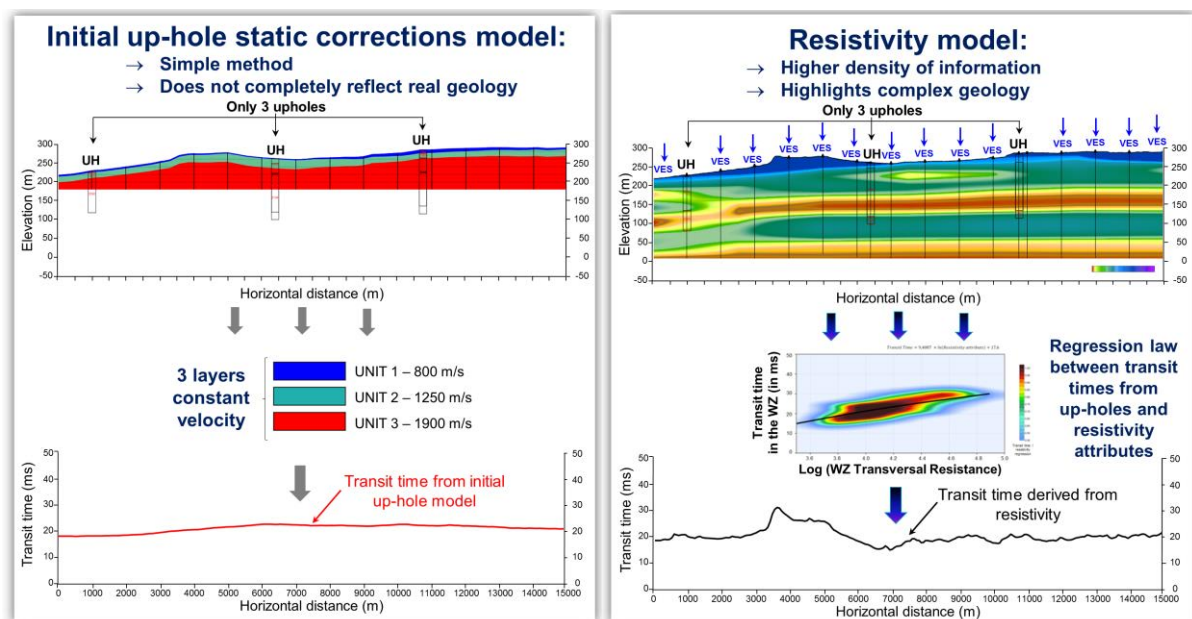
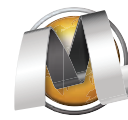


Figure 4: Comparison between transit time from initial up-holes model (left) and transit time derived from resistivity (right).



The multi-physics data integration led to rigorous transit time maps at the prospect scale for each geological unit. The final transit time maps are presented in *Fig. 5*.

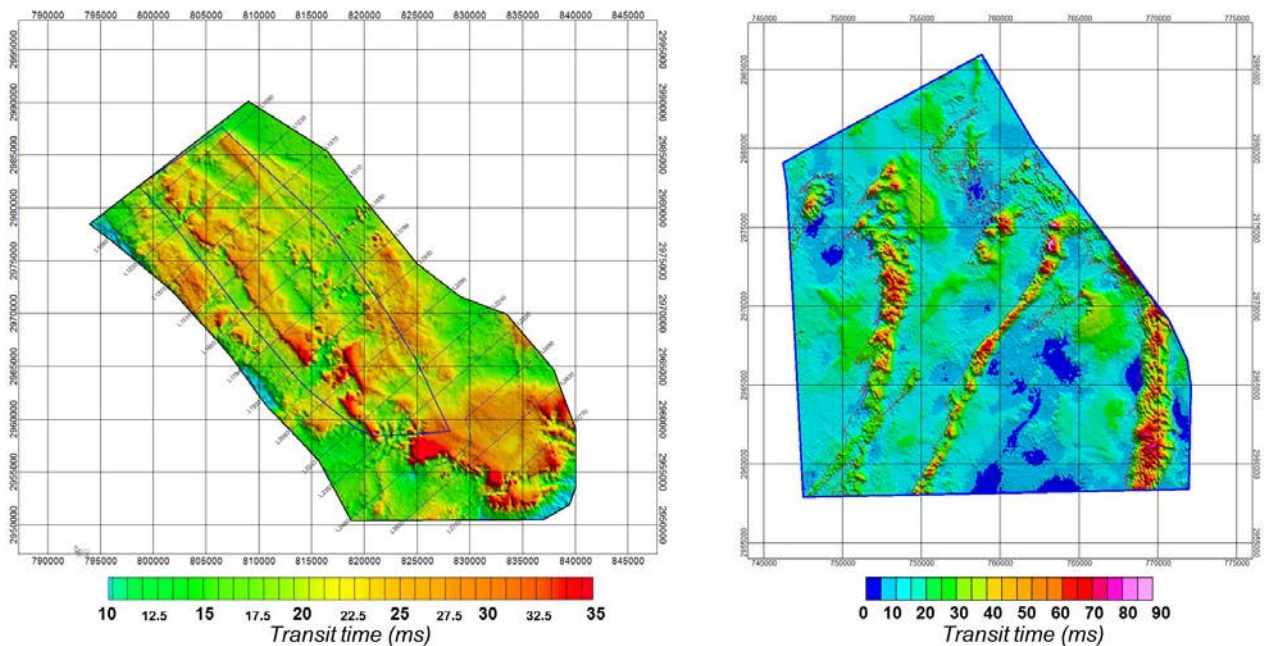


Figure 5: Transit times maps derived from multi-physics data integration: final transit time map down to Hercynian Unconformity in Reggane (left) and final transit time inside sandy overburden for Kahlouche (right).

Conclusions

We are presenting a new methodology for building near-surface static corrections models consisting on multi-physics data integration. Electric, electromagnetic and up-hole velocity data, provides seismic / resistivity cross-correlations in two environmentally different areas. The final improved transit time maps of weathered zone in Reggane and sandy overburden in Kahlouche are currently being incorporated in processing workflows for the proper estimation of static corrections.

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