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Integration of Surface and Subsurface Data - From Satellites to Reservoir

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SUMMARY

Introduction

A study of a rift-bound petroleum system in the Gulf of Suez demonstrates how the integration of different technologies can unlock the complexity of the near surface and its correlation with the subsurface structure down to basement. The surface itself does not reveal any hints regarding the complex geology immediately below, nor do conventional seismic data provide access to these shallow layers.

Methodology

We have approached the geological challenges posed by the rift tectonics with a suite of geophysical methods, the integration of which allowed us to reveal the subsurface structural geology from the surface to the basement. The surface is studied with remote sensing technology (compare Laake et al. 2008). Satellite imagery processing and digital elevation models provide detailed lithology and fault outcrops. For the near surface we use seismic surface waves and shallow refractions to map lithological horizons and fault planes. In the deep part we use ant tracking and geobody extraction from the seismic prestack time migration (PSTM) cube to extend the fault planes to top basement and to extract reservoir sand bodies.

Figure 1 a – Digital elevation model, b – Radar back scatter intensity map, c – Lithology map from optical satellite imagery, d – Wadi map from visible and thermal infrared optical satellite imagery

The surface litho-structural characterization comprises the analysis of the surface elevation and radar back scatter as well as the interpretation for lithology and wadi courses (see figure 1). The elevation data show terrain edges related to subsurface tectonic movements, which are enhanced through erosion by water (figure 1a). High intensities of the radar back scattering show hard rocks and dense gravel at the surface. Sudden changes in the back scatter intensity may often be correlated with fracture zones reaching the surface. Low intensity radar data are correlated with high absorption in the

near-surface and reveal the pattern of recent and fossil wadis (Paillou et al. 2008, Robinson et al. 2006), which follow weak zones in the surface rock. These weak zones occur where fracture zones reach the surface (figure 1b). The interpretation of visible and infrared optical satellite images provides both the surface lithology and the lithological boundaries (figure 3c). Finally, the correlation of visible optical data with thermal optical data highlights the course of recent wadis, which in turn follow the outcrops of fracture zones (figure 1d). In this analysis we have distinguished between fractures running parallel to the rift faults (continuous lines running in NW-SE direction) from cross-rift faults (dashed lines running in NE-SW direction).

Point-receiver survey data provided the densely sampled data required for a robust Rayleigh wave velocity horizon mapping. From the resulting velocity-depth cube (compare Strobbia et al. 2009) we extracted the iso-velocity surface for 550 m/s Rayleigh wave velocity, which corresponds to the surface of a consolidated sandstone. Remarkably, this surface was far from flat; as close as 50 m below the surface we could map hills and valleys as deep as 100 m (see Figure 2 right).

Figure 2 Surface lithology imaging from satellite data (left) and near surface structural imaging using Rayleigh wave velocity maps

For the structural mapping of the deep strata we processed the P wave seismic data in two different ways. The amplitude heterogeneity mapping reveals structural edges in the elastic properties of the subsurface rocks. Lineaments are correlated with lines of elastic impedance contrast, which often occurs along normal faults (see figure 3a).

Figure 3 Litho-structural mapping from seismic P wave data : a – Fracture tracks from an amplitude heterogeneity map for a shallow horizon, b – palaeo wadi and delta contours from instantaneous frequency horizons

The cross-rift faults in our study did not reveal any elastic impedance contrast. However, we noticed from the satellite wadi map that the wadi courses were determined by the structural lineaments at the surface. Assuming that this process may have also occurred in the past, we ran a lithological analysis of the subsurface seismic P wave data in an instantaneous frequency cube. Lateral resonances are

observed when certain seismic waves of certain frequencies ring within a subsurface geobody and reveal anomalously high amplitudes. Using this method we could map palaeo-wadis and interpret their shape to delineate the cross-rift fault planes (figure 3b).

Results

The combination of satellite imagery, shallow and deep seismic data and respective processing provides a sequence of products

- High-discrimination lithology mapping provides insights into the geological structure and fault outcrops (Figure 4 top row)
- Near-offset refraction mapping and Rayleigh wave velocity mapping allows the generation of a realistic near surface geological model along with near surface faults (figure 4 middle row)
- Heterogeneity tracking for rift parallel faults and geobody extraction for cross-rift faults reveal the structural framework in the deeper section (figure 4 bottom row).

Figure 4 Summary of individual results from surface to basement

From the different datasets, maps are generated and gathered as georeferenced layers in a GIS database for correlation, QC and calibration with geological map data. 3D volume data are loaded and jointly interpreted in reservoir modelling software, which allows correlation of the results with geologic structure and fault planes. The workflow for this process is given in Figure 6.

Conclusions

The integration of the surface, near surface and subsurface data in GIS and reservoir modelling software demonstrates the importance of exchange of information between the different disciplines involved. Normal faults in the PSTM cube can be associated with transform faults detected on satellite imagery, which puts the subsurface fault system into the tectonic context.

For the first time surface and near surface lithology and structural geology have been imaged and mapped using a combination of remote sensing, surface wave and body wave seismic methods integrated in GIS and reservoir modelling software. This powerful combination improves the mapping of the reservoir tectonic structure from surface to basement. Cross-faults that are not clear on the PSTM cube can be interpreted from the delineation of wadi channels in connection with the cross-fault outcrops on satellite imagery by means of geologic analogs. The data integration is visualized

through the virtual merge of the surface photo with surface satellite imagery and near surface geology from Rayleigh waves and geobody extraction (see Figure 5).

The suite of near surface geological products – Rayleigh wave velocity mapping, near-offset rayparameter interferometry and shallow fault mapping – is enabled by the acquisition, processing and interpretation of point-receiver seismic data. For the first time detailed structural geology comprising faults and lithology changes was imaged in the near surface, a data regime that is conventionally contaminated by the seismic acquisition footprint.

Figure 5 Virtual merge of surface photo and subsurface geology for the study area viewed from the Gulf of Suez towards the basement of the Red Sea Mountains – Wadi Hawashia horst in the middle (light ridge) and paleo-wadi in bottom right corner (yellow).

Acknowledgements

The authors thank TransGlobe Energy, Dara Petroleum Company and WesternGeco for the permission to publish these results and WesternGeco Cairo for the PSTM cube data processing.

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