Reservoir Geophysics in Deep and Ultra-DeepWater Oil Fields Campos Basin, Brazil

Paulo Johann

Petrobras/E&P/GERER

Abstract

Petrobras has been developing oil production from over 400 fields located in many different geological settings along the eastern Brazilian margin. Turbidites are the most important petroleum reservoirs. These reservoirs vary in geometry, size and internal character. They contain an original oil-in-place volume of 52,3 billion bbl and total oil reserves of 9,8 billion bbl, 28% in deep waters (between 400 m and 1,000 m) and 45% in ultra deep waters (over 1,000 m). More than 160 turbidite oil fields have been discovered along the eastern Brazilian margin. Nowadays, technology and business in the petroleum industry demand more efficient and cost-effective particularly in reservoir management and development. Historically, most applications of geophysical technology have been focused on exploration. However, the increase of 1% in the recovery factor in a giant oil field may represent an economic impact greater than a new small sized discovery.

Reservoir geophysics can help recovery processes with more accurate reservoir characterization, in order to minimize capital investments and optimize oil recovery. 3-D seismic interpretation oriented to reservoir plays an important role in reservoir management and development planning.

In this paper, we describe the Petrobras experience in the development, management, and production strategy in the deep and ultra deepwater giant reservoirs in Campos basin with focus on reservoir geophysics technology.

Reservoir Geophysical Management

Petrobras started in 1995 a new strategy and management of reserves and reservoirs with the integration of different specialists in a new task-force group - Reserves and Reservoirs Department. The head office group is involved with Marlim complex, Barracuda/Caratinga/Espadarte fields, and Roncador field projects.

Petrobras acquired in 1997 its first time-lapse (4-D) seismic in Marlin field. In 1999, Petrobras started several 3-D, reservoir oriented seismic acquisition, covering former 3-D surveys: South Marlim, Barracuda/Caratinga, Espadarte, Marimbá, and Pampo-Linguado fields in Campos basin.

In terms of seismic processing, pre-stack time migration and 3-D AVO analysis are common routines. Post-stack inversion is systematically used in reservoir characterization to map internal characteristics of turbidites system and to reduce risk on reservoir presence and distribution during appraisal and production. Visualization techniques are applied in three-dimensional and stereoscope views of exploration and development projects.

The integrated reservoir studies are carried out in six main steps: 1) core description, petrophysics, log interpretation and well log facies analysis; 2) reservoir geophysics interpretation; 3) stratigraphic high-resolution modeling; 4) geostatistical kriging and simulation; 5) reservoir flow simulation and, 6) reservoir technical-economic studies and decisions. Figure 1 shows the location of Campos basin main fields and the strategic Petrobras areas linked to the integrated teamwork for reservoir development, management, and economic decision based in the head office.

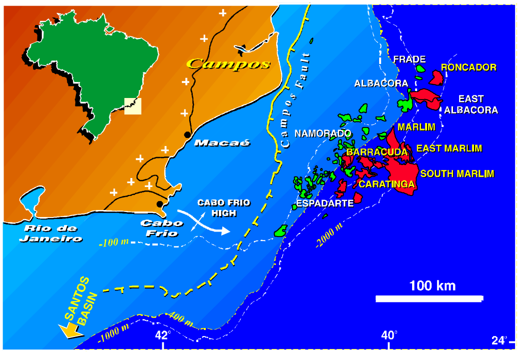

Figure 1. Location of oil fields in deep and ultra deepwater in Campos basin.

Petrophysics and reservoir geophysics

Some petrophysical properties used by engineers, geologists, and geophysicists to describe the reservoir can be related to acoustic impedance after seismic inversion. Seismic facies analysis can guide the stochastic simulation of petrophysical properties. Figure 2 shows images of the stochastic simulation for water saturation between 200 and 400 days constrained by seismic information. Petrobras R&D rock physics laboratory has developed analysis of acoustic and elastic properties of rock samples for reservoir studies.

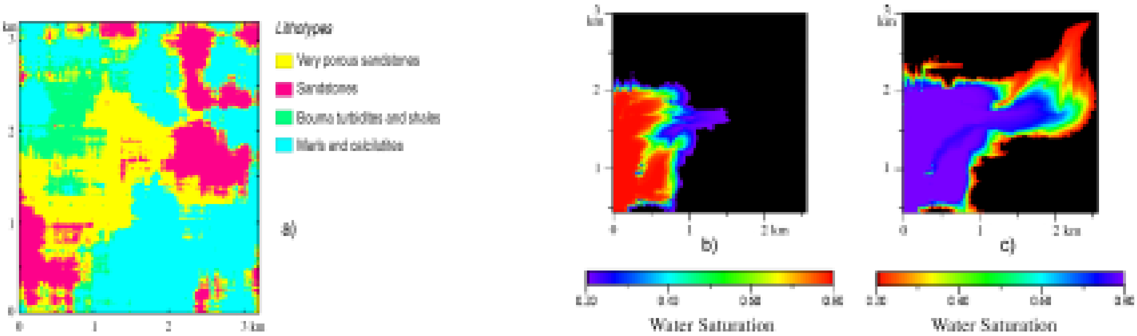

Figure 2. Stochastic model of water saturation in a turbidite reservoir constrained by seismic information: a) geological reservoir model; b) after 200 days; and c) after 400 days.

Reservoir geophysical acquisition trends

The challenge for the seismic contractors is to increase the quality and resolution of seismic data not only for exploration purposes but also for reservoir characterization. Figure 3 shows the Petrobras efforts in 3-D seismic acquisition since 1978, particularly regarding information density per area (traces/km^2). There was a remarkable increase in information density for the two seismic surveys oriented to reservoir geophysics (Marlim RR and Barracuda, Caratinga, Espadarte, and South Marlim RR surveys). The new acquisition and seismic processing parameters will improve the seismic quality and resolution. With this new data set, reservoir geophysicists could refine the description of the reservoir external geometry and better understand internal heterogeneity of turbidite reservoirs.

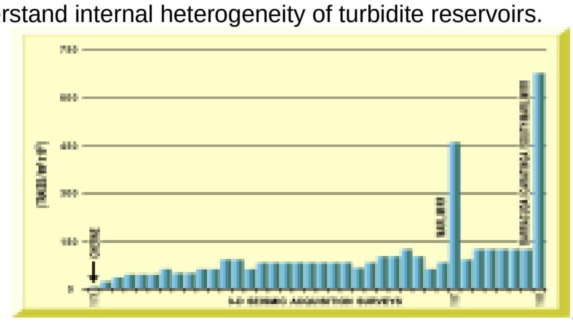

Figure 3. Petrobras historical density information in 3-D seismic surveys (traces/km^2 x10^3).

Processing trends in reservoir geophysics

Historically, reservoir geophysicists have been using the same sequential process normally used in exploration. However, Petrobras has recently applied new techniques such as 3-D AVO, pre-stack time migration, and a new flowchart adapted to reservoir needs. Figure 4 shows a line with three seismic processing flowcharts where the key steps were NMO/pos-stack seismic migration, pre-stack seismic time migration and seismic inversion, respectively.

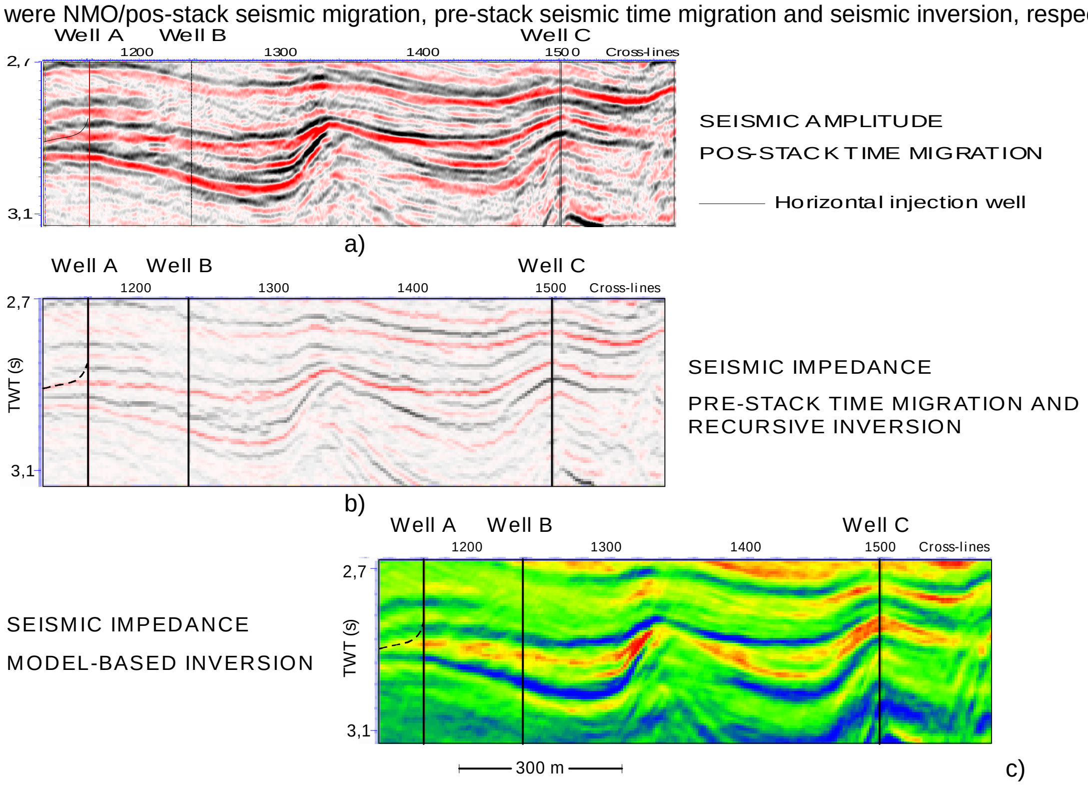

Figure 4. a)NMO/pos-stack; b) pre-stack seismic time migration/seismic inversion and c) pos-stack geoinversion.

Interpretation trends in reservoir geophysics

For seismic interpretation the Reserves and Reservoirs Department has been using: i) interactive interpretation between geophysical and geological models; ii) seismic inversion and/or stochastic simulations and; iii) 3-D visualization and voxel-based automatic interpretation. Such techniques allow a truly integrated approach in reservoir studies. For example, 3-D voxel pick interpretation of turbidites give an immediate image of the shape and connectivity of acoustic events (Figure 5).

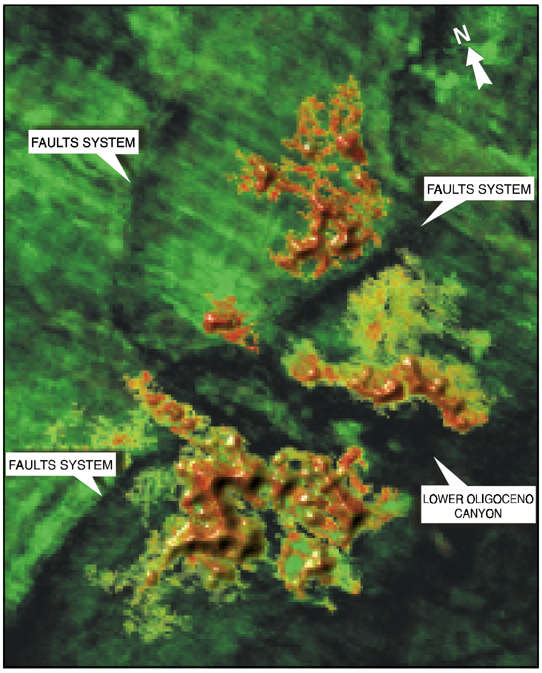

Figure 5. Automatic voxel pick interpretation of fan system in a giant turbidite oil field in deep and ultra deepwater in Campos basin.

Technology in reservoir geophysics

As Petrobras reserves are located mainly in deep and ultra deep waters, it is required a permanent search for new technological solutions to make feasible those reserves appropriation. Petrobras has two long-term corporate technological projects: a strategical project for advanced reservoir studies for geophysical characterization and a seismic monitoring project with the objective of surveillance of water injection in the deepwater reservoirs.

The main steps of geophysical reservoir technology applied to deep and ultra deepwater in giant turbidite oil fields are: a) revision and refinement of the interpreted horizons to map genetic sequences and better define the reservoir external geometry; b) integration of acoustic logs, seismic amplitudes and stratigraphic interpretation information in the geoinversion process; c) interpretation over acoustic impedance seismic and reflectivity associated to internal heterogeneity (sequence stratigraphy approach); d) seismic pattern recognition to capture spatial geological behavior (quantitative seismic facies analysis); e) derivation of reservoir properties from seismic data; f) stochastic simulation constrained by seismic derived information; g) integration of seismic facies in the pre-processing of flow simulation, and h) integration of reservoir properties derived from seismic information in the petrophysical volume model for flow simulation. Figures 6 to 7b display images of reservoir using different techniques in different phases of reservoir study.

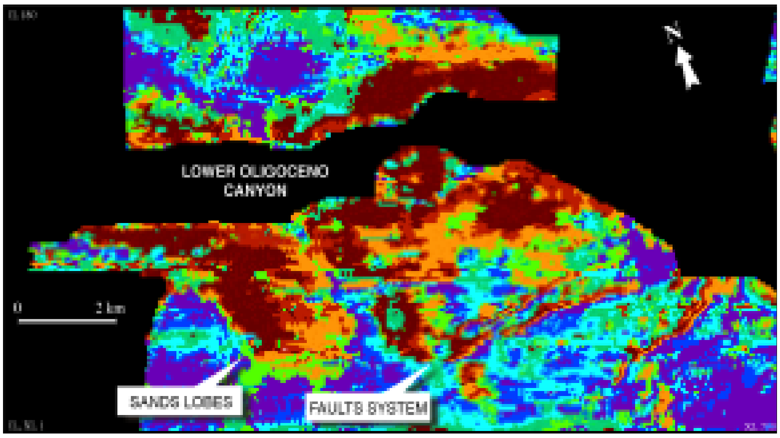

Figure 6. Automatic seismic facies analysis after seismic pattern recognition with neural network technique.

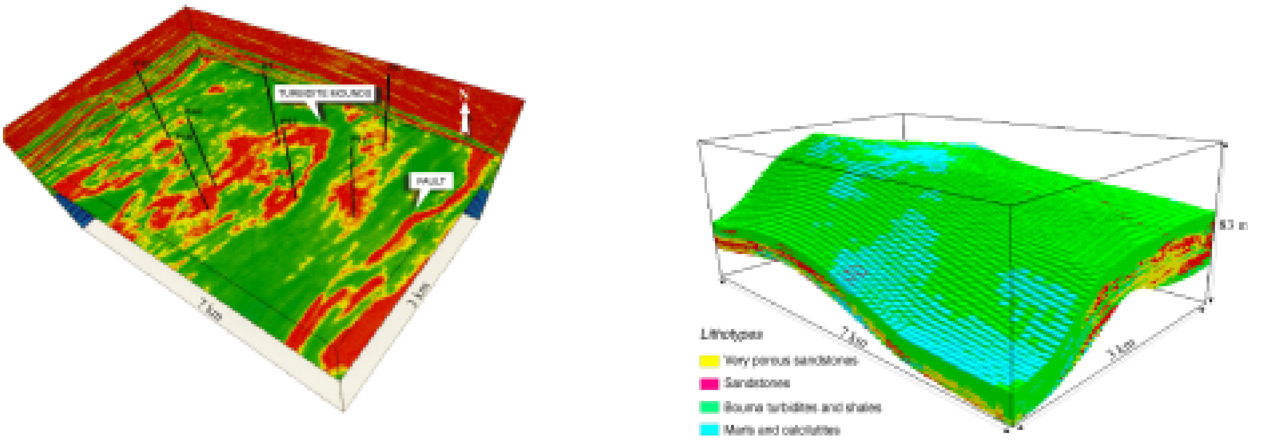

Figure 7. a) 3-D acoustic impedance from geoinversion (model-based inversion) of a turbidite field. b) 3-D stochastic simulation model constrained by seismic facies analysis of a turbidite reservoir.

Figure 8 shows a example of a horizontal well within a reservoir with thickness less than 15 m. For the correct positioning of the well is required a continuos improvement in seismic resolution integrated with high resolution stratigraphic modeling for reservoir description and prediction. The vertical and lateral distribution of turbidite sandstone within the surrounding no-reservoir facies is a critical factor that needs to be characterized before production or injection wells can be successfully drilled. The challenge is how to predict the exact location, spatial and stratigraphic, of drilling targets.

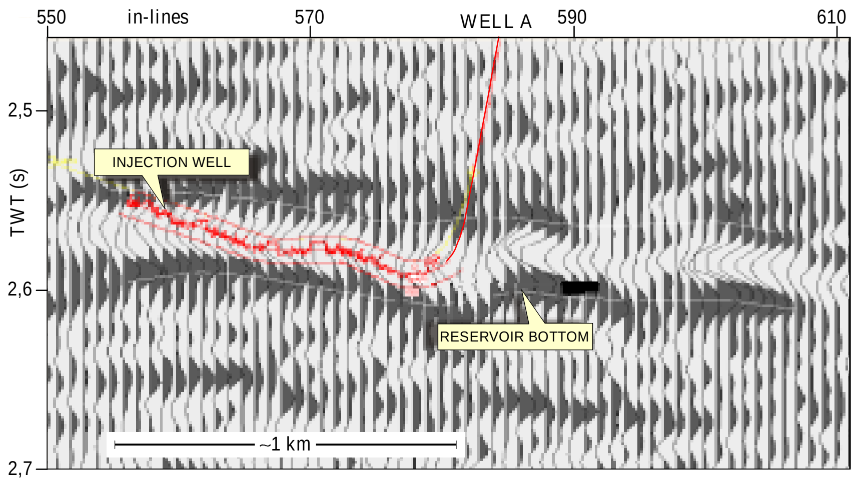

Figure 8. Monitoring a horizontal well in a turbidite field with seismic information. The radioactivity well log shows us different individual sandstones bodies with thickness less than 10 m interbedded by shales.

Economic evaluation and strategic decisions

Economic and financial analysis is performed after the establishment of the reservoir model and production curves. Different scenarios and strategies to develop the reservoir are analyzed. The evaluation of outcomes includes uncertainty (reserves distribution) and time value of money (present-worth concept). The main strategy consists in phasing the overall field development into modules. It starts with an "Early Production System" with pre-established procedures and check reservoir performance useful for future phases. The main advantages of this pilot strategy are: i) minimize risks; ii) distribute investments over a longer period; and iii) obtain production revenue from initial phases to finance future phases.

Conclusions

Reservoir oriented seismic acquisition, processing and interpretation have improved quality and reduced geological and engineering risks. Reservoir geophysics help to optimize and speed up decisions that must be taken based on expected reserves, well and platform locations and oil recovery strategy.

The use of advanced technology and the integration of all information available have a major impact in our geophysical reservoir studies. The challenge is the systematic use of these technologies in many Petrobras projects.

Technological and business requirements demand reservoir geophysics to be more efficient and cost-effective in order to aggregate results in the whole project. Geophysicists are important in reservoir management teams contributing to improving recovery factor, reduce cost, and optimize oil production.

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