three offshore case studies show how one size does not fit all
CGG’s global inversion scheme is the most rigorous approach as all available data are inverted simultaneously to find the global best-fit solution for every vintage (Lafet et al. 2009). Available production information can be used to impose realistic 4D rock physics constraints which reduce the inherent non-uniqueness of the inversion solution and produce results which are more accurate and consistent with the expected production effects.

The combination of global 4D inversion and Bayesian fluid classification (Lafet et al. 2009) can provide quantitative estimates of reservoir properties, such as fluid saturation, to map production-induced fluid movements and evaluate uncertainty in 4D fluid discrimination.

An additional degree of sophistication is achieved by Petrophysical Seismic Inversion (PetroSI) (Bornard et al. 2005) where a set of user-defined rock physics equations, called Petro Elastic Model (PEM), are used to predict the effects that several parameters, such as lithology, pore fluid types and saturation, stress and pore pressure, temperatures, etc., can have on elastic properties and their corresponding TWT and amplitude changes. In addition to connecting the inverted properties to the seismic response, the PEMs are used to maintain consistency between the times, depths and derived velocities throughout the inversion process. A consistent set of parameters can be jointly determined during the inversion, going from geometric parameters (depth, thickness) to static (porosity, shale content) and dynamic properties (pressure and saturations). Results can be delivered directly in depth.

It is therefore evident that insight and information from different disciplines, including petrophysics, geophysics, engineering and geology, must be wisely brought together to define the static properties of the reservoir and to characterize its dynamic behaviour.

**Case 1 - Deepwater MOHO-BILONDO field offshore Congo**

The 4D monitor survey was acquired two and a half years after first oil. The main objective was to track the movements of injected water inside complex turbiditic bodies and to follow the rise of the oil-water contact. Because of the limited vertical resolution of standard 4D attributes, such as envelope amplitude and RMS amplitude differences, difficulties were encountered to distinguish oil depletion from water injection.

Figure 1 shows how 4D seismic inversion has successfully identified the water pathway from injector to producer, as well as the OWC.

![Figure 1. MOHO-BILONDO field. Water pathway from an injector (Well 2) to a producer (Well 3) highlighted on Pseudo VClay and Acoustic Impedance variations derived from 4D simultaneous inversion of base and monitor seismic volumes.](image)

From B. Six et al., 2013. Data courtesy of Total E&P Congo and Société Nationale des Pétroles du Congo
**Case 2 - BRAGE field in the Norwegian North Sea**

In this case the aim was to identify undrained hydrocarbon sands. The prominent 4D signal in the monitor survey acquired after ten years of production is due to the large vertical movement of the oil-water contact which is interpreted to locate and quantify the volume of bypassed and remaining oil so that the life of the field can be extended with significant economic benefit. Following the combination of global 4D inversion and Bayesian fluid classification, the map of the oil-sand probability distribution close to the original OWC can be used in quantitative estimates of bypassed and remaining oil (Figure 2).

**Case 3 - TROLL WEST field offshore Norway**

In simple terms, we can state that the thin oil leg (13m) has to be produced prior to the start of significant gas production. The main drive mechanism is natural gas cap expansion due to depletion. The oil leg is produced by means of long horizontal drains penetrating the oil zone immediately above the oil-water contact to ensure the well stays within the oil leg as production goes on and the oil level decreases. Some residual oil, corresponding to a paleo-contact, is encountered immediately below the oil column. The reservoir consists mainly of alternating high-permeable clean sands, so-called C-sands, and less permeable micaceous sands, or M-sands. The large contrast in permeability gives a non-uniform drainage which is monitored by using time-lapse seismic measurements. The 4D seismic signal is strongly impacted by gas out of solution in the oil leg but also below the OWC, in the residual oil leg (paleo position of the oil leg), hiding the more subtle production-induced oil saturation changes.

Production efficiency is ensured by mapping and targeting C-sands as precisely as possible.

4D petrophysical seismic inversion (PetroSI-4D) was used to update an existing fine-scaled model defined in depth (geomodel) in order to make it compatible with the measured multi-vintage pre-stack seismic data. To reach this goal the following data were used:

- 50 km² of seismic data with five vintages
- 51 wells for quantitative QC purposes with detailed information
- a detailed geomodel with vertical resolution of the order of 1 m and horizontal resolution of the order of 50 m.

As only a limited and monotonous pressure drop occurred during production and the compaction simulation model predicted less than 0.5% in pore volume reduction in the reservoir, compaction due to pressure change since production started is assumed to be negligible. Consequently, porosity, depth and layer thickness are assumed not to vary across vintages (static variables). Dynamic properties, such as saturation and pressure, are expected to vary in time due to production. Therefore, a hybrid flow model is used with high resolution maintained only in the oil layer where dynamic properties, such as transmissibility and permeability, are defined, while outside the oil layer, only static properties are defined in a coarse model (100 m horizontal resolution, 10 m vertical resolution). Saturation variations are handled using a fluid contact model which is independent of the geomodel layering.
The resolution achieved by PetroSI-4D inversion of the Troll West data in positioning contacts in different vintages is around 1 m, significantly better than the expected seismic resolution. Figures 3, 4, and 5 show some of the results of the PetroSI-4D inversion:

- the very good match between the estimated porosity and the well log measurements (Figure 3);
- the predicted remaining oil column thickness for each vintage (Figure 4);
- the comparison between the original geomodel and the updated geomodel (Figure 5).

The TROLL WEST case is the result of a R&D collaboration program between Statoil and CGG.

For a more detailed description of the workflow and related references, please refer to the extended abstract presented at the Annual EAGE convention in 2013 (Th. Coléou et al., 2013).

Figure 3. TROLL WEST. Estimated porosity at the initial OWC position from PetroSI-4D inversion, together with porosity from well log measurements. As the properties from the inversion are delivered in depth, comparison with well data is straightforward. Note the good match between the inverted porosity and the drain branches. Drains can be located up to a few meters above the initial contact position.

Figure 4. TROLL WEST. Predicted remaining oil column thickness for each vintage from PetroSI-4D inversion. As there are no wells in the western part, we expect no change in the oil column (dark red).
REFERENCES


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