The 4D Experience in TOTAL

E. Brechet, S. Maultzsch,
A. Grandi, O. Rahmanov, C. Hubans
Total

Born nearly thirty years ago, time lapse (4D) seismic monitoring technology has been developed in such a way that it has finally proven to monitor fluid movement and to distinguish between drained and undrained portions of a reservoir. Its ultimate aim is to quantitatively improve reservoir models, particularly their predictive capability. Indeed, the benefits of time-lapse seismic for reservoir characterisation depend on the quality of 4D acquisition and processing, but they also greatly depend on the particular 4D inversion and interpretation schemes used; finally, a decisive aspect is certainly also the capability of integrating results from different disciplines in an effective way. In fact, the 4D success comes through close interaction between Geophysicists, Geologists, Rock Physicists, Geomechanicists, Reservoir Engineers and Drillers. Timing is also crucial: results delivered in a few months can have a direct operational impact such as optimising well locations.

For the last ten years, Total has recognised the importance of time lapse seismic and has therefore conducted 4D seismic monitoring in different geological environments. Examples of 4D experiences range from monitoring of water injection and production for reservoir management and field development in the Gulf of Guinea (Angola Block 17, and Nigeria); monitoring of geomechanical effects in HPHT fields (Elgin-Franklin, UK), in compacting reservoirs in Norway (Ekofisk and Valhall) and in the Gulf of Mexico (Matterhorn, US); monitoring of steam chamber in tar sands (Surmont, Canada) and monitoring of compaction and water rise in carbonates (South-East Asia).

To illustrate capabilities of time lapse seismic monitoring two cases are presented. The first case is a deep offshore field in Angola with turbiditic stacked channel reservoirs with a good 4D response. The main 4D effect is given by fluid substitution and in particular by gas both injected and generated by a small depletion, the initial pressure being close to bubble-point; in this case the seismic quality and repeatability are outstanding and in fact the fluid change in the reservoir is very well resolved. The second example pertains to an HPHT field in the UK where the seismic quality is degraded due to the extreme depth of reservoir burial (>5000m) as well as the vicinity of the platform. It shows 4D effects due to a dramatic pressure drop; it is a significant result because it shows that appropriate tools enable achieving reliable results even in critical conditions.

Block 17, Angola, the Dalia Field

Geological & field development context

The deep offshore fields operated in Angola (Block 17) are composed of confined and unconfined unconsolidated turbidite sands aged from Miocene and Oligocene at an average depth ranging from 2,200 to 2,800m subsea with an average water depth of 1,300m. Three fields, named Girassol, Dalia, and Rosa were discovered in the Mid 90's and started producing in 2001 for Girassol, 2006 for Dalia and 2007 for Rosa. These turbidite fields are known for their strong heterogeneities, which imply complex fluid communications and dynamic behaviour which must be fully understood before drilling the significant number of development and infill wells required.

Geophysical context

On Block 17, seismic data are of very good quality with a dominant frequency between 50 - 60Hz and a vertical resolution from 7 to 10m. After one year of production a 4D seismic was shot on these fields in order to monitor development wells (water injection efficiency, depleted areas), understand reservoir communications (vertical communications, fault behaviours), but also prepare the next development and infill wells. Owing to positives results obtained from the first 4D survey, a two year periodicity between monitor surveys was planned.

Due to the field environment (unconsolidated sands and shallow burial), 4D effects are very strong and time shifts due to fluid changes larger than 10ms have been observed on the Dalia Field. Post-stack processing and interpretation techniques were optimized in order to fully interpret 4D effects and integrate them into the reservoir model.

For all three fields, three production mechanisms are present: water injection, gas injection and depletion. As reservoir pressures of these fields are close to the bubble point, migration of dissolved gas occurred with depletion.

In order to generate a reliable 4D signal, an in-house warping inversion was used to retrieve the relative velocity changes (dV/V) due to production between the two seismic acquisitions (Fig. 2). In areas adjacent to producers, depletion of around -10 to -40 bars associated with the appearance of dissolved gas is observed. This induces a decrease of P-velocity (Gassmann's theory) whereas fluid pressure decrease (increase of effective pressure) induces an increase of P-velocity according to laboratory measurements. In the case of Dalia, the pressure effect is negligible, and the main effect is a P-wave velocity decrease. Around water injectors two effects are observed: when injecting water in the oil pool, one observes an increase of P-velocity, whereas injecting water in the water pool yields a decrease of P-wave velocity due to salinity differences between injected water and aquifer.

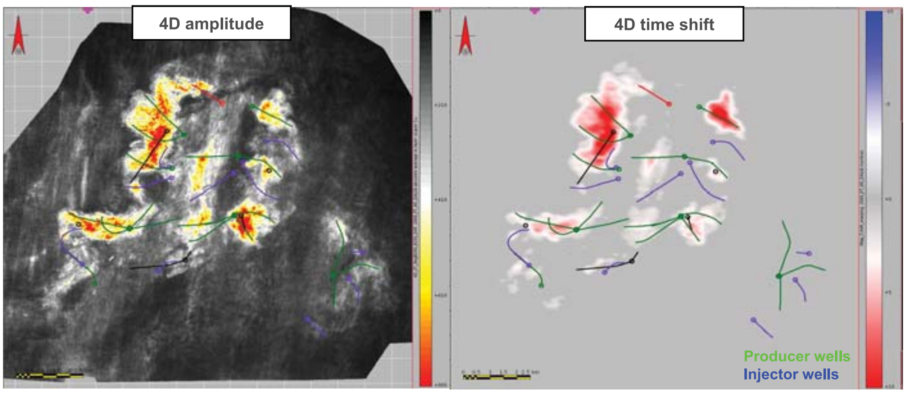

Fig. 1. *Fast track amplitude differences over the reservoir interval of Dalia (left) and associated time shift of the reservoir in ms (right)*

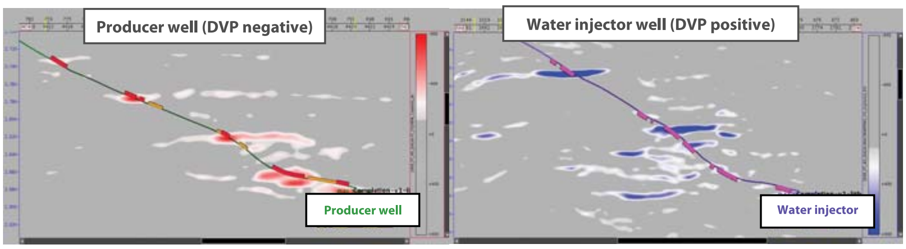

Fig. 2. *Warping results: time re-alignment of monitor seismic data. Illustration of a depleted area around a producer which induces a strong pull down*

4D results

4D results on the Dalia Field improved the understanding of geological heterogeneities, fluid pathways and therefore helped the reservoir management. Here are short-listed the domains where 4D brings useful information:

+ Reservoir management by understanding well injection and production efficiency coming from the interpretation of 4D anomalies. This has an impact on the understanding of water breakthroughs at producers.

+ Identification of depleted areas and impact on the positioning of development wells.

+ Understanding of the vertical dynamic communication through erosion and degraded facies inside turbiditic channels and lateral communication between turbidite deposit systems.

+ Fault behaviour with connecting faults and partially sealing faults.

+ Rise of the oil-water contact within several turbiditic lobes, which were not predicted by reservoir models.

Fig. 3 shows an important contribution given by 4D in understanding water breakthroughs of four producers. Without 4D results it would have been impossible to know the origin of the produced water (aquifer or a specific water injector well), and the role of faults in inhibiting or allowing fluid flow would not have been known.

Fig. 4 shows how 4D attributes helped understanding the vertical communication in stacked channels and inter-system communication. 4D anomalies were confronted with geological and dynamic knowledge of the field: The vertical dynamic communication, seen on MDT pressure measurements, occurs in areas where sand channels erode each other for example.

Another important issue is the role of faults in the dynamic flow. On one of the systems, which is heavily faulted, several

4D anomalies (anomalies of depleted areas) terminate along fault directions and some other anomalies (water injection) seem spread out along fault directions. 4D seismic data correlated to dynamic information and structural knowledge proved a useful resource in understanding the dynamic role of faults. The Dalia Field contains two fault families N45 and N160. The first family of N45 faults show fault relays and very large water injections anomalies around them. These faults behave as non sealing faults and as drains for water injectors. The second fault family (N160) delimits many depleted areas and seems to reduce the fluid transmissibility.

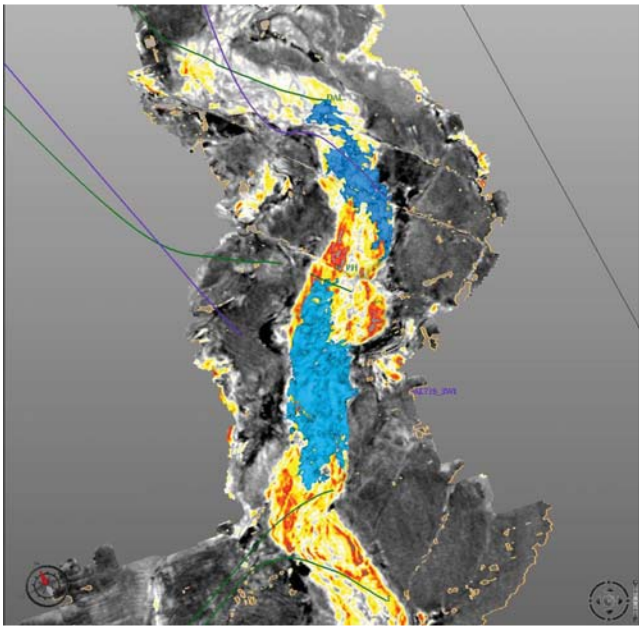

Fig. 3. Water injection efficiency of two water injectors: Water is reaching producers. Some faults reduce water injection efficiency in the North

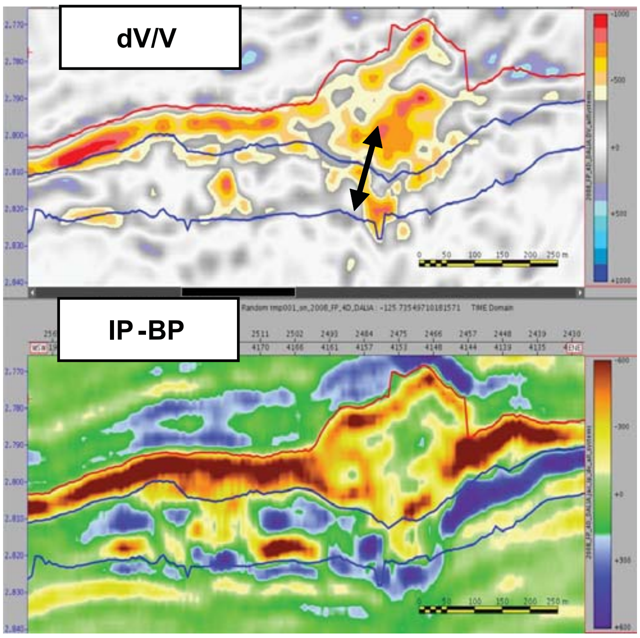

Fig. 4. Example of vertical communication between lobes

For unconfined turbidites (lobe types), we observed water front movements on some lobes (Fig. 5), which help to locate future producers up-dip of aquifers. Thus the 4D assists in preventing early water breakthroughs and helps for reservoir model history matching.

North Sea Central Graben, UK, Elgin Field

Geological & field development context

The Elgin Field, located in the UK North Sea Central Graben, is an extreme HPHT field. The initial reservoir pressure is in the region of 1,100 bars and the bottom hole temperature around 200°C. The Jurassic sandstone reservoirs, buried some 5,300m below sea level exhibit permeabilities ranging from a few tens of mDarcy to 1 Darcy. Three main reservoir units are identified, from top to base: Fulmar C sands, of moderate reservoir quality; Fulmar B sands which have the best reservoir properties and are the main contributor to production; and Fulmar A sands, which are generally of poor quality. The overall Fulmar sand pay thickness is about 170m with an average porosity of about 19%. The cap rock is formed by Upper Jurassic shales of the Heather and Kimmeridge formations.

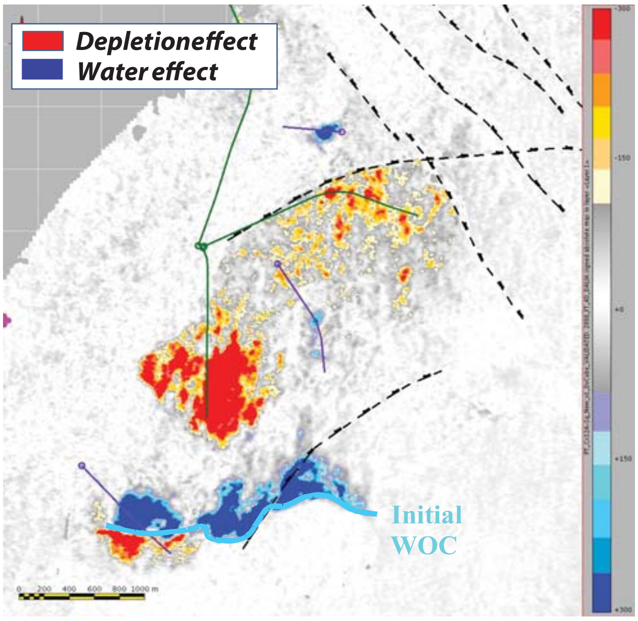

Fig. 5. dV/V attribute extracted on a lobe showing in the South the water front movement and water injection efficiency of the South injector in oil pool (positive dV/V) and in water pool (negative dV/V)

The Elgin Field was discovered in 1991 and brought on stream in 2001. Typical of most HPHT fields, reservoir pressure dropped rapidly in the first few years of production. The early rate of pressure depletion on Elgin was about 100 bars every six months. The initial development plan did not consider re-entering highly depleted areas technically feasible and hence all the development wells were drilled before start of production.

Geophysical Context

In order to monitor the pressure drop across the field and investigate the stress redistribution in the overburden induced by reservoir compaction (with a corresponding measurable effect on seismic velocities and travel times), a 4D seismic survey was acquired in 2005. The two expected main benefits of the 4D seismic survey were identification of un-depleted fault compartments, and the calibration of the geomechanical model. Indeed, although not part of the business case, another important aspect is the identification of areas where well integrity was at risk (casing/liner deformation or rupture).

4D results

Time-lapse seismic monitoring has improved the understanding of the Elgin HPHT field. It helped assisting infill drilling by minimising risks of well failure. It improved understanding of compartmentalisation, flow connectivity and reservoir quality away from control wells.

The most important results were:

Identification of un-depleted panels: The 4D inversion, performed in the overburden and within the reservoir, shows the relaxation of the overburden associated to the reservoir compaction and associated relaxation of the overburden. Within this time strain attribute, a delineation of depleted panels versus un-depleted was performed, showing un-depleted panel in the South-East (Fig. 6).

- Calibration of the geomechanical model: 4D attributes show positive time shifts in the overburden, indicating the relaxation of the overburden and negative time shifts in the reservoir associated to compaction. This geomechanical effect is not only seen on Elgin but also on nearby fields such as Franklin and Shearwater. 4D time shifts where used to calibrate the geomechanical model and reservoir simulation models.

- Assistance in infilling well: geomechanical model calibrated by time lapse seismic results in the overburden (Fig. 7) provided accurate mud weight windows during infill drilling operations enabling to re-enter highly depleted reservoirs. Moreover 4D results helped understanding and predicting geo-hazards related to high pressure gas intervals in the overburden.

- Reservoir model update: the reservoir model was updated and reserves were secured.

- Reservoir quality far from control wells: 4D results highlighted possible facies degradation in the eastern panel of Elgin.

Conclusion

Today, a number not too far from one hundred fields are covered by 4D seismic and this number is growing fast. In Total, 4D acquisition has proven to be an excellent enabler for improved reservoir management and hence an important source for value creation in the petroleum industry. 4D has always been positively used with direct impact on the field development (well planning, reservoir management, well integrity). Total's experience in this technology lies mainly in clastic or chalk offshore oil reservoirs as well as in tar sands.

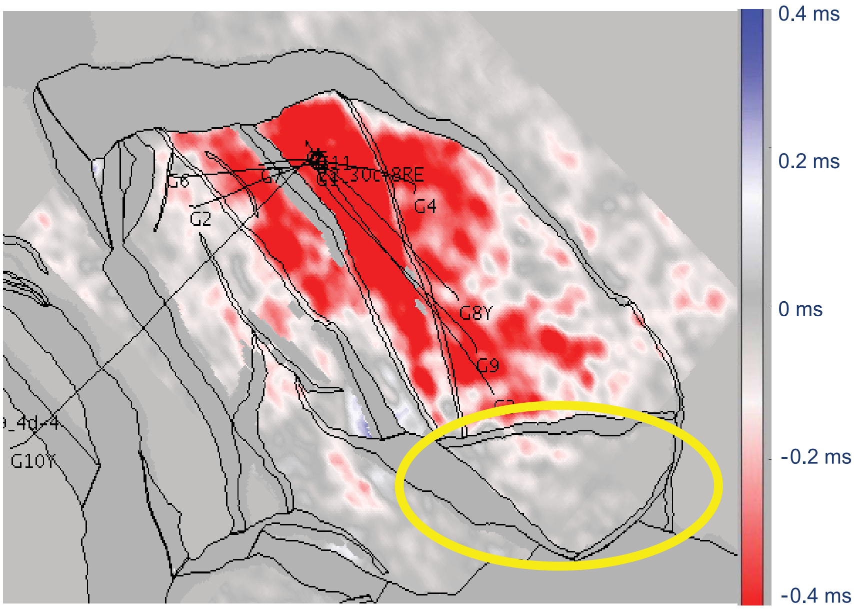

Fig. 6. *Time-Shift cumulated within the B sands layer*

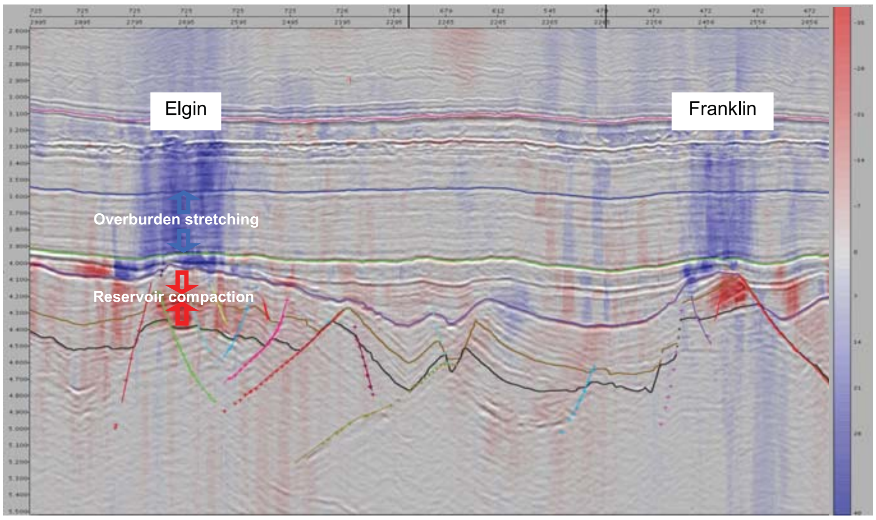

Fig. 7. *Time strain (4D attribute given by the sum of compaction and relative velocity change) on a line across Elgin and Franklin fields*

A Business Case approach prior to sanctioning a 4D project is a good way for evaluating the stakes and issues of the field. It gathers all disciplines in order to put in perspective the different issues and possible actions for the field management/development. In many cases the benefits initially expected were fully confirmed. However, very often there have been additional benefits which were not foreseen or evaluated prior to interpretation. These unanticipated benefits sometimes appear to be the major value of some 4D surveys.

We have learned that 4D projects must be anticipated in the Field Development Plan, since the global 4D process can be long, as acquisition, processing, inversion and interpretation request significant time and have to be successfully timed. 4D feasibility studies have proven to be essential in generating questions and anticipating possible problems. A crucial part of its feasibility is represented by rock physics, which enables to identify 4D seismic effects by studying fluids, pressure, temperature and salinity parameters depending on the production process.

The two examples discussed in this paper show practical applications on improved understanding of the fields and therefore on field development. In Total 4D seismic is considered a fundamental tool for reservoir monitoring and, thanks to in-house inversion techniques and interpretation, its impact on reservoir management, infill and development wells as well as reservoir dynamic communications understanding is dramatic. A number of patents were filed to protect our know-how on 4D inversion and demonstrate that Total has pushed technology to anticipate future trends.

Although an extensive use of time-lapse seismic has been made mainly in a qualitative sense, we expect a usage in a more quantitative way where reservoir flow simulation and 4D seismic are merged in an attempt to provide largely improved forecasts of reservoir behaviour. Such a progress would have a major impact on the future of 4D seismic in the Industry.

The 4D workflow (planning, Business Case study, feasibility, acquisition, processing, interpretation and integration) adopted by TOTAL appears well appropriate. This process is being improved continuously. Amongst all the key factors, the most important aspect in making a time-lapse project successful are:

- Integration of both expertise and data anlalysis/management between different disciplines: Geology, Geophysics, Geomechanics, Reservoir Engineering, Rock Physics and Drilling,

- Anticipation and effective 4D feasibility study,

- Quick turnaround time,

- Inversion and interpretation techniques adapted to the specific challenges of every given field case.

Acknowledgments

The authors wish to thank TOTAL and co-venturers for permission to publish this work:

- TOTAL Angola and the Block 17 concessionaire Sonangol and its partners Statoil, ExxonMobil and BP

- The Elgin Franklin co-venturers: TOTAL E&P UK Ltd, ENI UK Ltd, BG Group, GDF SUEZ, E.ON, Ruhrgas UK E&P Ltd, Esso E&P UK Ltd, Chevron, Dyas, and Summit Petroleum.

Thanks also to the many assets, specialists and advisors who have helped and advised on the paper.