Long-Term Seismic Strategy for a Major Asset: Azeri-Chirag-Gunashli, South Caspian Sea, Azerbaijan
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Summary
At Azeri-Chirag-Gunashli (ACG), seismic activities have focused in three areas to insure critical risk reduction for appraisal and development drilling. Imaging and reservoir characterization constrain the “static” reservoir model, and 4D reservoir monitoring constrains the “dynamic” reservoir model. Over the last several years we have successfully implemented pre-stack depth migration, 4C-OBC acquisition and processing, and surface-tow 4D. Results from these technologies are being used to shape the long-term (20+ yrs) seismic strategy of the development. A long-term evaluation of 4D implementation, including permanent OBC, suggests substantial benefits may result from frequent time-lapse monitoring (> 1 survey/year) using permanent OBC. However, there remains much to be proven from this immature technology as clear case studies of benefits from frequent time-lapse, and early field-life 4D benefits need to be completed.

Introduction
The Azeri-Chirag-Gunashli (ACG) megastructure, located offshore 100km SE from Baku in the S. Caspian Sea, is a multi-billion barrel oil accumulation in the early stages of development. The Chirag field, with a single platform, has been on production since 1997. The first of three Azeri field production platforms is expected to begin production at the end of 2004. Finally, the Gunashli field is expected to be produced from a single platform beginning in 2007/2008. More than 400 reservoir penetrations are expected from these 5 platforms. With more than 20 years of production ahead, we are evaluating how best to apply seismic technology throughout the field life.

The ACG structure provides a variety of challenges to seismic imaging which include: steep dips (> 40°), structurally complex overburden, shallow gas, and mud volcanoes. Although the seismic data quality is variable, the seismic rock properties of the Pereriv and Balakhany reservoir sands are such that clear hydrocarbon fluid contacts and direct hydrocarbon indicators (DHI’s) are visible on a variety of seismic volumes.

Key Technology Elements of the Seismic Strategy
Within the asset subsurface teams we have developed an evolving strategy for application of seismic technology. Three critical areas are the focus of seismic activity:

• Imaging
• Reservoir Characterization
• 4D Reservoir Monitoring

Imaging and reservoir characterization provide constraints for the “static” reservoir model. Structural configuration and reservoir distribution are critical for appraisal and development well planning. 4D reservoir monitoring provides constraints for the “dynamic” reservoir model once production has begun.

Seismic Cycle Time versus Major Project Stages
Aligning seismic activities with the major field development decision points and stage gates is a constant challenge. In pre-sanction stages, funding is often defined in 9-12 month segments. The pre-sanction stages often include refinements to the static model, revised structural configuration, improved faults, and new reservoir distribution. The seismic cycle time typically ranges from 12-24 months depending whether the activity is reprocessing/remigration or new acquisition. The historical seismic time-lag, requires planning 2-3 years ahead to insure that seismic deliverables are ready when needed. Therefore funding of major seismic activities (acquisition in particular) often occurs outside the major project stage funding decisions. Post-sanction, the project stages are longer, usually 2-3 years in duration. However, the project development activities shift towards shorter-term, faster-paced activities focused on early development well drilling.
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Imaging

Since the acquisition of the first 3D surface-tow seismic over ACG in 1995, geophysical activity has focused on improving the overall data quality. Primary, structural imaging is fundamentally important for appraisal and development well planning on this high relief structure. Large areas of the reservoir in central Azeri and Gunashli have been masked by complex structure and gas in the overburden. Improvements in imaging have been derived from reprocessing with improved migration algorithms, and application of 4-component ocean-bottom-cable (4C OBC) acquisition. Major imaging steps have included:

- Post-stack time migration - original 1995
- V(z) pre-stack depth/V(xyz) post-stack depth-2000-01
- Kirchoff V(xyz) pre-stack depth – 2001
- 4C-OBC PZ anisotropic Kirchoff V(xyz) - 2003

In Chirag, implementation of the first V(z)/V(xyz) depth migration significantly changed the thrust fault geometry along the north flank of the structure. The changes in fault configuration transformed a large area that was unprospective because of structure, into a major production area for Chirag. There are now 3 producers and 1 injector in the area producing over 30,000 b/d.

In Azeri, the V(z)/V(xyz) migration brought major changes to the configuration and location of the structural culmination. The shape and location of potential gas caps was changed significantly. As a result, the first pre-drill development well was redirected to prove the existence of large gas caps in several of the primary reservoirs in Azeri.

Testing 4C-OBC – Reprocessing and improved migrations of the surface tow seismic, however, has not substantially changed the extent of large areas of poor data quality in the crest of central Azeri, and in Gunashli. We looked to 4C-OBC acquisition including PZ and PS imaging to further reduce the extent of poor data. The OBC acquisition was justified on the reduction to drilling hazards for the 40% of Azeri wells that would have to drill through the seismic no-data areas (Lyon, et al., 2004).

PZ results from the Azeri OBC (Lyon, et al.,2004; Bouska, et al., 2004) are demonstrating significant improvements in the image quality and a substantial reduction in the crestal poor data areas. Although dramatic PZ improvements were not necessarily expected, the combination of seabed coupling, P + Z summation, azimuthal variation, and higher fold (250 fold versus 40 fold for surface tow) is providing major improvement (Johnston, et al., 2004).

Reservoir Characterization

Surface-tow seismic data in ACG, historically has not been of high enough quality to allow successful quantitative use of seismically-derived reservoir properties. The hydrocarbon filled reservoir sands have a distinctive, and generally low impedance relative to the surrounding shales. However, there is enough variability in data quality, structural dip, and overburden that well-to-seismic correlations have been too low to be statistically useful for quantitative reservoir constraints.

The existing seismic data does however, seismically resolve the two major Pereriv B and D reservoir sands which average 50m and 30m respectively. There are also strong oil DHIs which are evident on full offset and partial-offset stacked volumes. These DHIs have been used with existing well control to map fluid contacts in several of the major reservoir sands.

Qualitative, soft-constraints from seismic have been provided for the more stratigraphically complex, and areally discontinuous Balakhany sands in the Balakhany VIII and X intervals. In the Chirag and Gunashli areas, sand body maps have been used to help guide reservoir descriptions used for reservoir simulation models of the Balakhany VIII and X (Sadigova, et al., 2004).

The potential of seismic for reservoir characterization in ACG will not be fully realized until another step improvement in data quality is achieved. We are beginning our evaluation of the PZ 4C-OBC data to determine if the well-to-seismic correlations have been significantly improved.

4D Reservoir Monitoring

In 2002, a 3D repeat surface-tow survey over Chirag and Gunashli was acquired to provide the first time lapse reservoir monitoring in the Caspian. Core and petrophysical log-based feasibility studies determined that a significant 4D response from fluid changes should be expected. Acoustic impedance (AI) changes of 4-8%, depending on the magnitude of the saturation change, were expected from water sweeping oil, or gas replacing oil. Pressure effects might also be detectable with a 1000 psi pressure drop causing about a 2% change in AI.

Processing Challenges – An iterative, parallel processing approach that included extensive testing and velocity analysis was applied to the 1995 and 2002 datasets. Fast-track 4D products were delivered in about 8 months and “final” volumes in 18 months. Although acquired with an identical line orientation, non-repeatable shooting direction changes in the 1995 acquisition caused spatial and timing shifts in relation to the 2002 data. As a result, there is significant acquisition-related amplitude striping in the difference products. Effective application of hi-res radon de-multiple was challenged by accurate discrimination of...
the multiple velocities. The steeply dipping primaries along the north flank (> 40°) were susceptible to attenuation by the radon de-multiple. To optimize positioning, a Kirchhoff V(xyz) pre-stack depth migration was applied to the final volumes.

4D Results – The 1995-2002 4D difference results show the movement of the waterflood along the south flank of Chirag. Independent patterns of water movement in the two primary reservoirs (Pereriv B and D), have a generally good correlation to behaviour expected from the reservoir simulation model. In detail, the shape of the water front does show differences to the simulation model and adjustments to the aquifer inputs are being tested. The 4D results indicate little or no aquifer movement on the north flank, again generally confirming results from the reservoir simulation model.

The 4D difference has not shown evidence of a secondary gas cap as expected from the reservoir simulator. Although crestal wells do produce with high GORs, the seismic data is not detecting a consolidated gas cap. This discrepancy is forcing a closer evaluation of both the seismic data quality and the expected gas behaviour and distribution in the reservoir.

Defining a Life of Field Seismic Strategy

The learnings applied from recent experience with depth migration, 4C-OBC, and surface-tow 4D are helping to define our seismic strategy as we look ahead. The asset needs to prepare itself for the massive development of Azeri field (nearly 300 penetrations, and peak oil rate of 800,000 bopd), ongoing drilling and production in Chirag, and the future Gunashli development (figure 2).

Evaluating long-term 4D benefits - The depletion plan and pace of development in each of the ACG fields dictates the appropriate level of 4D reservoir monitoring that may be required (figure 2). Our recent experience with image quality improvements from 4C-OBC acquisition is focusing interest on the benefits of permanent OBC implementation (Life of Field Seismic–LoFS). We have completed an economic evaluation for the Azeri field development of the potential benefits from a range of possible 4D options. The major elements of the evaluation include:

- repeat surface-tow versus LoFS
- comparison of 4D benefits for different time-lapse intervals – 2 yr, 1 yr, 3 month
- pace and timing of 4D implementation for a new field.

The benefit mechanisms that were evaluated fit into four general classifications – reserves increases, production acceleration, cost savings (capex, drillex, opex), and risk mitigation.

Two key assumptions were used to evaluate the possible benefits from different time-lapse sampling intervals. First, time-lapse seismic provides improved knowledge of fluid distribution and compartmentation that assists in improving development well positioning. The optimized well positioning potentially results in higher recovery (Marsh, et al., 2003), fewer sidetracks, and fewer overall development wells. And second, more frequent time-lapse reservoir monitoring should result in incremental improvement in overall recovery and reduction in number of sidetracks and total development wells. The challenge to the evaluation is to properly estimate the size of the incremental improvements.

We did not consider surface-tow acquisition more often than once a year because of the logistical and cost limitations of the method. LoFS potentially provides significantly greater acquisition flexibility since scheduling of a large seismic vessel is not required. “Seismic-on-demand” as needed in response to the reservoir behaviour should be possible with LoFS. Once the permanent cables are in place, acquisition cost per survey should be reduced by an order of magnitude compared to surface tow. Also, significant improvements in processing turnaround should be possible since the survey geometry is effectively fixed, survey repeatability improved, and data handling direct to the processor would be streamlined.

Our 4D benefits evaluation suggests that for frequent monitoring (> 1 survey/yr) the reserve increases contribute about two thirds of the value, while the other mechanisms (production acceleration, cost savings, risk mitigation)
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combined provide remaining one third (figure 3). For less frequent monitoring (2 yr time-lapse), the production acceleration, cost savings, and risk mitigation are reduced substantially, leaving the reserve increases as the only significant benefit.

Reservoir simulation models at both fullfield scale (coarse) and sector scale (fine) were used to help define the magnitude of potential benefits when applicable. In particular, potential reserve increases from peripheral well positioning, and possible acceleration and risk mitigation benefits were developed with constraints from reservoir simulations.

Challenges for Permanent OBC (LoFS) - There is interesting potential in ACG from LoFS for delivering significant value through improving 4D time-lapse seismic data quality and cycle time. However, there are several major issues with the technology that will have to be addressed both in ACG and the wider industry before large-scale implementation can occur. These include:
- large upfront initial investment for the technology
- early field-life 4D benefits not established
- differential benefits for short-interval 4D not established
- once installed – particular LoFS technology is locked-in (trenched in) with a loss of flexibility
- operational life of the LoFS cables not established
- data management and integration of large volumes of rapidly acquired seismic data

Widespread implementation of LoFS will not occur until these concerns are largely reduced or eliminated.

Conclusions

The ACG subsurface teams have implemented a seismic strategy that focuses on imaging, reservoir characterization, and 4D reservoir monitoring to assist in optimizing this major development. Progress in the last 3-5 years in implementing pre-stack depth migration, and 4C-OBC acquisition and processing has substantially reduced the structural uncertainties and risks associated with development drilling. Furthermore, a recent repeat surfacetow survey at Chirag has demonstrated that time-lapse reservoir monitoring is possible. Looking toward the next 20 years of the development, we are evaluating and comparing potential benefits from surface-tow 4D with permanent OBC. 4D reservoir monitoring from permanent OBC has large potential to increase value through optimized well positioning.

References


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