OIL & GAS
SUCCESS STORY - NIS NAFTAGAS (Serbia) and Gazpromneft NTC

Improving Seismic Images through EarthStudy 360
Full-Azimuth Depth Migration in the Pannonian Basin

RESULTS
• The study demonstrated the exceptional ability of EarthStudy 360™ to maximize information about the complex subsurface structural geological model and fine details required for identifying and characterizing small-scale fracture systems, which are essential for high productivity.
• Based on the results of the study, three new wells were drilled, all into fractured reservoirs. According to the latest test results, two wells are oil saturated and one is water saturated.

APPLICATIONS
EarthStudy 360 Full-Azimuth Angle Domain Imaging System

CUSTOMERS
NIS NAFTAGAS (Serbia) and Gazpromneft NTC

CHALLENGE
This oil field is one of the largest in Serbia, accounting for 14% of all annual national production. Industrial oil production began in 1991, with natural depletion taking place during the first five years. Reservoir pressure decreased by 50-60% and approached saturation pressure. Attempts to organize an in-situ waterflood did not bring the expected results due to the high heterogeneity of the reservoir and the block structure of the field. In recent years, hydraulic fracturing has been used, enabling increased production, possibly by involving previously untreated areas. The significant heterogeneity of the geological structure revealed during development of the field impacted not only well productivity, but also the success of the geological and technical measures applied.

SOLUTION
In order to improve the depth seismic images and zones of heterogeneity, an illumination study was performed with the initial velocity model. An initial background structural model was constructed, consisting of four major reference horizons/layers: pre-Neogene horizon base; reflecting (bottom) horizon of the clinoform formation, reflecting (top) horizon of the clinoform formation, and reflecting (bottom) horizon of the Pliocene sediment zone, which does not belong to the regional stratigraphic units.

3D ray tracing was then performed for the illumination study (Figure 1). The primary goal was to learn about the true relationship between the parameters of the LAD migration (sub-surface directional and reflection angles and azimuths) and the available seismic acquisition geometry (surface offsets and azimuths, and the extension of the migration

Figure 1. Ray tracing based on the background depth-velocity model in the submerged part of the pre-Neogene base.
Knowledge about available subsurface angles and azimuths plays a key role when deciding about the types of analysis that can be performed, in particular sensitivity to anisotropic effects. We realized that the target area located in the submerged part of the pre-Neogene base was illuminated up to an opening angle of 26-32°. This imposed certain restrictions on the entire subsequent processing workflow.

LAD migration was performed using the initial depth velocity model. The next stage of the migration involved estimating VTI (transverse isotropy with vertical axis of symmetry) parameters at the target sediment layers. Using the mis-ties between the depth of the interpreted horizons and the corresponding available well markers at those locations, we estimated the Thomsen $\delta$ parameters. The Thomsen $\epsilon$ parameters were estimated from the wide reflection angle seismic events along the full-azimuth reflection angle gathers. In some places this information was not available and the $\epsilon$ parameters were approximated by extrapolation from the known areas and as factors of the $\delta$ parameters.

LAD migration was then performed using the VTI model and iteratively refined through anisotropic tomography. As noted, due to the lack of wide opening angles we assume in many areas that $\epsilon = \delta$. The values of $\epsilon$ were later refined to improve the image focusing.

The next stage consisted of adding the existing faults automatically extracted from the migrated seismic cube. Figure 2 includes 31 traversed faults. Note that the creation of a structural model which includes tectonic disturbances is the most time-consuming task in the overall process.

As a result of the LAD migration using the refined VTI model, including the interpreted faults, there was a clear improvement in the quality of the LAD images over that of the Kirchhoff migration (Figures 3 and 4). The enhanced images with an improved signal-to-noise ratio improved both the quality of the depth image and the interpretation, enabling better tracking of structural continuities and geological boundaries. In addition, the LAD migration was able to suppress signal interferences (including internal multiples) during the migration process.

**Geological Interpretation**

The study resulted in a detailed structural-tectonic model based on a high-quality seismic image in which a key regional stress direction was established, and the main directions of the fracture/fractured network were determined. The detailed interpretation included a new high-resolution depth image, results of AVAz analysis, and field development data, such as hydro-survey materials, pressure measurements in wells, water salinity, and others.

This integrated analysis combined both kinematic (azimuth residual moveouts) and dynamic information (azimuth variations of the reflecting amplitudes). Figure 5 shows two examples where the azimuthal variations of the residual moveouts and the amplitudes are correlated with well measurements.

The next step was an ‘automatic fracture extraction’ procedure, which resulted in a diagram of the key identified directions (stereonet) (Figure 6). By testing various options and working with different designed filters, the diagram did not contradict the data in the azimuths indicated by the histograms.

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RESULTS
A quantitative assessment of the image quality in terms of the parameters: amplitude spectrum, vertical resolution, and signal-to-noise ratio in the target research area showed that in all parameters the results of LAD migration exceeded the image quality of traditional Kirchhoff migrations by 30-80%. It was also possible to identify new small faults, which could not be seen before.

Vector maps based on the results of AVAZ inversion showed the local orientation and intensity of the fracture systems. Testing of these interpreted shallow faults/fractures allowed them to be applied to a more complex study interval in the near-surface part of the Paleozoic deposits. Their azimuth direction of 110-120 degrees was confirmed by the results of automatic fault detection, which corresponded to the maximum on the anisotropic attribute histogram (azimuth of 30 degrees). Figure 7 shows the vector map along the lower horizon of a clinoform formation. Depending on the intensity and direction of anisotropy, various combinations of aligned vectors appeared.

BENEFITS
The full-azimuth directional and reflection angle image gathers provided unique information about the existence of small-scale fracture systems, which are essential for high productivity. Operating on the directional image gathers made it possible to explicitly enhance the low-amplitude signals diffracted from the aligned fractured objects, which are masked in conventional imaging methods by the high-amplitude signals of the reflection events. Thus, by designing dedicated diffraction-based weighted stack filters, we were able to see the signatures of the fracture systems for the first time. Additionally, the full-azimuth reflection angle gathers provided information about the orientation and intensity of the observed fractures.

The result of the full-azimuth studies was a substantiation of the criteria for the effective placement of production and exploratory wells, including optimization of the direction of the horizontal wells. This was positively evaluated by experts from NIS NAFTAGAS (Serbia) and received support for future replication. In addition, using the results of the LAD technology, three new wells were drilled in 2018. All of the wells were drilled into fractured reservoirs. According to the latest test results, two wells are oil saturated and one is water saturated.

* This Customer Story is taken from an article that originally appeared in First Break, October, 2019, authored by Tatiana Olneva, Gazpromneft NTC; Daniil Semin, Gazpromneft NTC; Alexander Inozemtsev, Emerson Automation Solutions; Ilya Bogatyrev, NTC NIS – Naftagas; Kirill Ezhov, NTC NIS – Naftagas; Elena Kharyba, NTC NIS – Naftagas and Zvi Koren, Emerson Automation Solutions. The authors of the article express their sincere gratitude to the management and specialists of NIS NAFTAGAS and NIS SEC (Serbia): A. Rodionov, M. Kuznetsov, and V. Jorovich, for their technical and programme support in the course of the project.

*Figure 6. Diagram obtained after the ‘automatic extraction of faults’ and visualization of extracted objects*  
*Figure 7. Fragment of the vector map in the time interval comparable to the productive interval combined with the Anisotropic Gradient attribute.*