7th International Conference & Exposition on Petroleum Geophysics

"HYDERABAD 2008"

P - 521

Application of High-Resolution 3D Seismic to Mine Planning in Shallow Platinum Mines

Gillot, E.[1], Gibson, M.[2], Verneau, D.[1], Laroche S.[1]

[1]CGG France, 1 rue Léon Migaux, F-91341 Massy cedex. E-mail: egillot@cgg.com

[2]GSD, Z-45060. E-mail: MGibson@angloamerican.co.za

Summary

Over the last decade 3D reflection seismic has been applied for platinum mining in South Africa. 3D seismic surveys have almost exclusively been conducted in the Western Bushveld where ore extraction depths range between 500 and 2000m. The ore is mined mainly via vertical shafts and also some decline shafts. In the Eastern Bushveld, the mining targets are at shallower depths of less than 400m. The challenge set by the mining companies is to obtain high-resolution seismic cubes with maximum vertical resolution at this depth of investigation. The cost of geophysics must also be more attractive than that of the "total drilling" alternative. Trials were therefore conducted at two mine sites in the Eastern Bushveld.

Exploitation of Existing Seismic Documents

A 2D test was performed by CGG over a mine in the Eastern Bushveld in 2001 with an explosive source and various vibrator sources. Although the results were encouraging, they did not meet the expectations of the mine operator. The explosive source was rejected due to its cost. The vibroseis source produced results of insufficient quality linked to the frequency content emitted by the vibrators used, such as the M18, and the difficulty in resolving static anomalies. It was therefore decided to change to the new generation Nomad 65 vibrator, which can emit up to 250 Hz, and focus specifically on resolving statics-related problems. As 2D acquisition proved not to meet client requirements to obtain a 3D image of his mine, it was also decided to move straight onto 3D projects.

1. The Proposed Project

A 3D survey test was therefore commissioned by the mine operator to find a solution for his mine planning challenges. The project had two main aims:
test the economic viability of the seismic method for mine planning via a gradual decimation of survey parameters, such as design, spread, sweep length etc., while retaining a financially attractive solution compared to the cost of the "total drilling" option, traditionally favoured by mining operators, obtain a result over a significant surface area of interest to the client, which could then be immediately used for mine planning.

The location chosen for the first project site lies in a valley crossed by a hydrographic network (*dongas*) encased in weathered strata, sometimes right up to the level of the hard norite substratum. Part of the challenge was therefore to provide a high-quality seismic image while resolving the difficult static corrections problem induced by this specific geological context in the first 50 meters.

The main ore body mined at this location is UG2 (<1m thick). It is a monoclinal structure with slight 2 m-amplitude undulations and a wavelength of 30m.

The survey was designed to image at a depth ranging between 100 m and 400 m at a 10° dip and track the disturbance of PGM (Platinum Group Metal) ore bodies (faults, flexures, potholes, etc.) to within 10 meters

Design

A 2.5 x 2.5m dimension was selected as the smallest bin size that could be technically possible at an economically viable cost. The distance between receiver lines and between vibrator lines was set at 20 m, as short offsets were important because of the shallow target depth.

2. The Acquisition

The acquisition of 3048 VPs was made with a patch of 16 lines of 140 traces. A single N65 vibrator was deployed using a sweep range of between 40 and 250 Hz with a 50% drive and an adapted sweep to compensate for the loss of groundforce observed between 100 and 150 Hz during individual VP tests made over the entire survey area.

3. Standard Processing

3.1 Statics solutions

The preliminary statics were computed with the general linear inversion (GLI) 3D refraction method, designed to pick and interpret first break data, and a two-layer near surface geological model was derived to compute our statics solution (figure 1). Surface-consistent long and short wavelength residual statics were performed with a small, shallow window due to the shallow geological context.

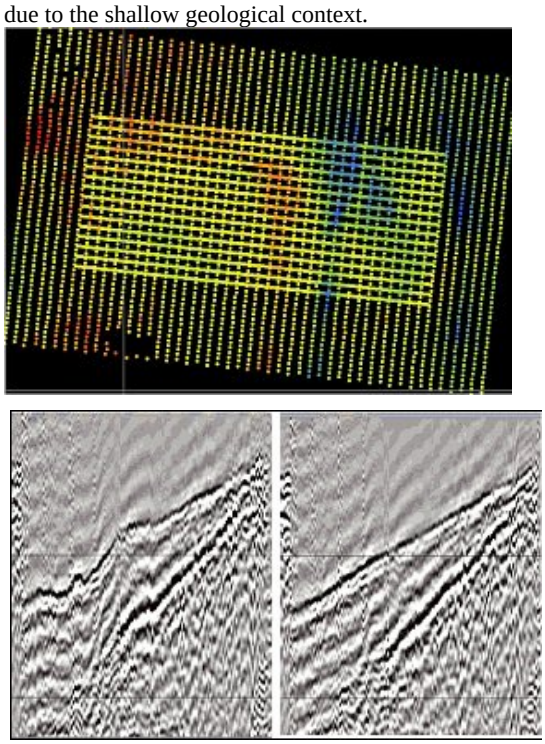

Figure 1 : Top :Static corrections derived from the GLI method (static values ranged from 2.6 to 35 ms) 5 Bottom : Raw VP without (left) and with application of the GLI statics (right).

3.2 FKx-Ky *filter*

A 3D filter was performed in the FKx-Ky domain. The process is conducted on cross-spread gathers after gain recovery and primary static corrections.

3.3 *Velocity analysis*

The stack image obtained at this stage is not very sensitive to velocity variations; it is therefore possible to deliver a correct stack image with a somewhat inaccurate velocity (approximately + or –5%).

An additional problem is posed by the thickness of the weathered layer (WZ), which can be up to 50 m. This is a significant thickness compared to the target depth (100-300 m) and the WZ velocity is therefore expected to have an impact on the RMS velocity.

3.4 Post stack time migration

Various post-stack processing techniques were tested prior to the migration and validated to increase the signal-to-noise ratio and the frequency content. These included linear noise attenuation, where a 3D FKx-Ky conical filter was applied in the inline/crossline domain, acquisition footprint attenuation and finally spectral equalization plus a band-pass filter of between 60 to 180 Hz.

3.5 Conclusions

To image such shallow targets, it is important to select the right offset ranges and mute functions to ensure a high-frequency content.

The ratio between the thickness of the WZ layer and the target depth ratio is high, implying that the WZ velocity will impact the stacking and migration RMS velocities.

A reasonably good signal-to-noise ratio was obtained. Figure 2 shows a NMO stack on a central line of the 3D polygon prior to the deconvolution stage together with its spectrum. The stack spectrum was compared to the noise spectrum and a good signal-to-noise ratio was noted up to 150 Hz.

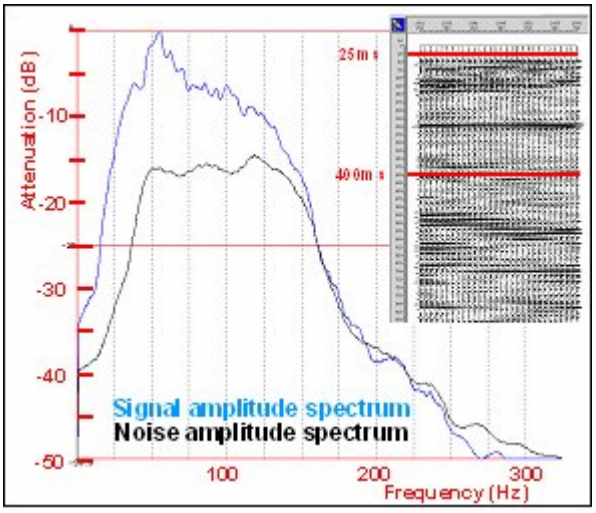

Figure 2 Signal and noise spectra on stack. The signal and noise spectra were computed on a 25-400ms time window.

This 3D HR survey was acquired as a feasibility study and the processing results prove that 3D seismic provides a reliable structural image for shallow targets (200 to 300 m below the surface at the first site and up to 50m at the second test site). The processing results therefore provided a positive geophysical response to the client's expectations.

4. Decimation And Prestack Time Migration

As the second challenge was to ensure the competitiveness of the seismic method, the data was decimated according to four designs (all with a 5m x 5m bin) and post-stack migrated. To further improve our processing effort, one of these decimated datasets was selected to run a Pre-Stack Time Migration test.

4.1 Decimation

The original survey was performed with a high-density of source points and receivers. The purpose of the decimation is to obtain final results of the same quality as the original survey in terms of resolution and structural image but with sparser acquisition parameters. Comparisons were made and, as can be seen in figure 3, the UG2 ore body at the relatively shallow depth of 230-330 m is adequately imaged up to decimation 2 while UG1 at a greater depth of 350 m is still satisfactorily imaged by decimation 3.

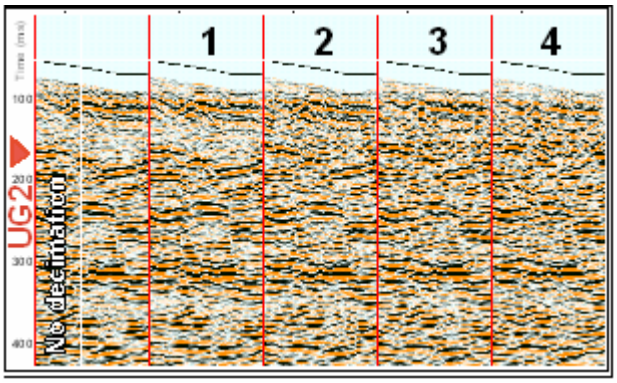

Figure 3 - Post-stack migration with post-processing for the full dataset (far left panel) and four decimations (1 to 4: the higher the decimation number, the stronger the impact of the decimation).

Decimation 2 was validated by interpreters for targets between 230 and 350 m and, as this depth is the most commonly encountered in the Eastern Bushveld, decimation 2 was chosen to perform the PSTM sequence. In addition, it was decided to reserve decimation 3 for targets at depths greater than 350m. Decimation 1 must be used for targets at shallower depths.

4.2 Kirchhoff time migration

CGG's Kirchhoff time migration (known as TIKIM) was performed on pre-stack data (figure 4).

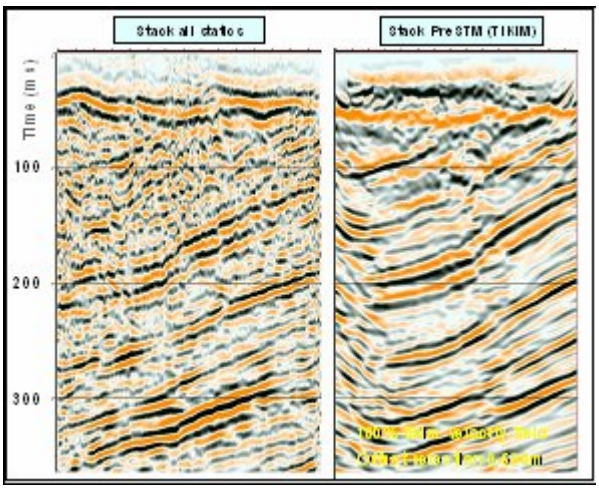

Figure 4 In-line Stack before (left) and after (right) full PreSTM (UG2 at a depth of less than 100ms).

4. Interpretation

Results from first-pass time migration (post stack) were structurally sound (figure 5). The post-stack time migration sequence preserved (figure 6) a high frequency content allowing the detection of 8-m fault throws, which corresponded to client specifications. However, it did not produce as good a structural image as the PreSTM cube as some fault diffractions are visible (see red circles in figure 6). Both processed cubes are therefore necessary for interpretation.

These 3D acquisition trials proved the economic (decimations 2 and 3) and geophysical effectiveness (decimations 1 to 3) of such surveys at very shallow depths and their competitiveness with extensive drilling campaigns down to 150m target depths. The use of a high-frequency Sercel N65 vibrator contributed greatly to the successful achievement of such a challenge and computation of the finest static model possible was also a key success factor.

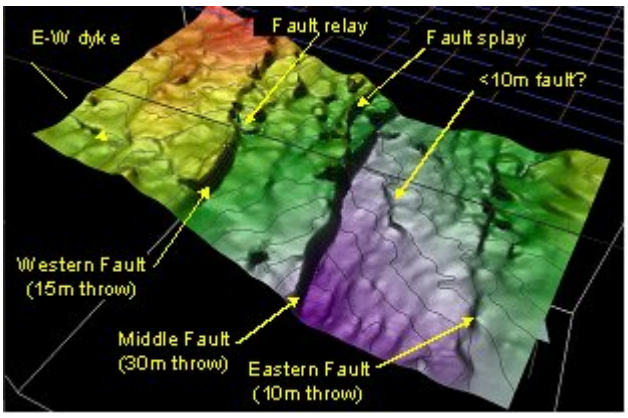

Figure 5 - Visualized UG2 surface with post-stack time migrated data.

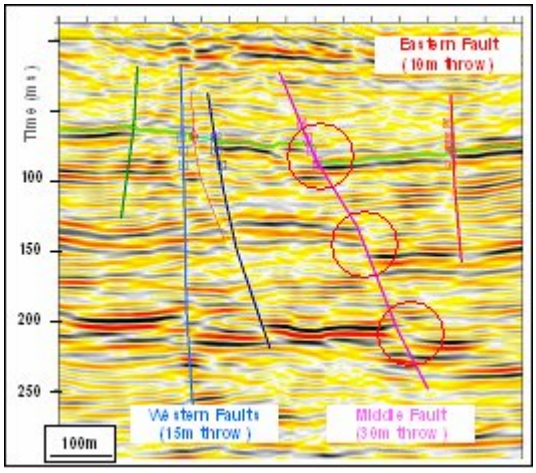

Figure 6 - Post stack time migration in-line.

CGG would like to thank Anglo Platinum and Impala for granting per mission to publish this data.