A Successful Example of a Shallow Ore-Body Imaged by Surface 3D Seismic*

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Abstract

Surface 3D is now a widely used imaging tool in the Western Bushveld in South Africa to derive continuous structural images for ore bodies with a depth ranging from 600 m to 1700 m below the surface. The cost of such surveys is directly linked to the source and receiver surface sampling. Such a structural model was requested for the Modikwa Platinum mine, in the Eastern Bushveld, with an ore body whose depth ranges from 200 m to 450 m. In order to balance the costs versus the expectations, a trial was conducted in 2004 whose main focus was to determine the most optimum surface sampling scenario and also benchmark the results of surface seismic versus the initial model derived from boreholes. This test has delivered as expected an acquisition model for shallow UG2 surveys in Eastern Bushveld and also a structural model with reliable small features such as fault throws down to 12 m due to the achieved vertical resolution. In 2006 the main survey took place and the expected structural image was achieved after processing. The fault network, when compared to the initial model, had its accuracy and reliability pushed down to fault throws around 12 m for a cost balancing the current density of boreholes.

Introduction

For a long time, boreholes were considered to be the main tool to derive a 3D structural images of an ore body in South Africa. Boreholes will always be required to directly sample the grade of the target ore-body, but have two significant drawbacks:

1) The time taken to drill with respect to the size of the target, and
2) The density of boreholes required for adequate structural sampling is often many times that required for facies and grade sampling.

Surface 3D seismic was introduced for the deep gold reefs imaging in the early 1990's and in early 2000 only for the platinum reefs in Western Bushveld (MR and UG2). The depths investigated were shallower than oil exploration by an order 2 to 3. The shallowest platinum reef imaged was around 800 m to 1000 m deep.

The need to image shallower ore bodies arose in 2003 at the Modikwa platinum mine. The structural model from boreholes was inadequate as far as small faults were concerned and small faults were known to exist but had not been imaged. Overall, the depth range to investigate was the interval 200 m to 450 m. The validity of surface seismic as a cost effective and reliable shallow ore-body imaging tool needed to be demonstrated on a feasibility test prior a full scale survey. The key element to investigate was the density of source and receiver surface sampling.

Feasibility Study

A dense surface patch was designed in 2004. The goals were to study the surface sampling density and also as a by-study, the size of the sampling cell (subsurface bin). The main surface patch parameters were:

Receiver sampling: 5 m
Source sampling: 10 m
Receiver lines interval: 20 m
Source line interval: 20 m
Number of receiver lines: 16 lines of 140 receiver points
Number of source lines: 48 lines of 64 source points

With this setup the minimum bin size is 2.5 m by 5 m, and by decimation 5 m by 5 m bins or even larger sampling can be tested. The same philosophy can be applied for the receiver and source line interval, one of every two can be discarded, leading to a 40 m by 40 m elementary pattern size and the process can be repeated. Another important issue is the vertical resolution achieved, which is a function of the dominant wavelength. The more high frequencies passed into the ground the smaller the vertical resolution achieved.

After intensive testing, a 30 Hz to 250 Hz signal was sent into the ground with an emphasis around 150 Hz. The expected vertical resolution could resolve fault throws down to 10 m. Data has been processed using the standard “Bushveld platinum imaging sequence” applied in all previous Western Bushveld 3D surveys for deeper targets. Then the data was decimated in order to compare the following combinations: Bin 2.5 m x 5 m versus bin 5 m x 5 m. The 5 m square bin was delivering nearly the same structural accuracy than the smaller bin. All subsequent combinations were done with 5 m bin sizes. The main Middle Fault was known but not included in the initial mine planning and the other faults were only detected by this survey (Figure 1).

These combinations were:

Elementary pattern 20 m by 20 m: Decimation 1
Elementary pattern 40 m by 40 m: Decimation 2
Elementary pattern 40 m by 80 m: Decimation 3

The interpretation of the results over the varying depths of the UG2 leads to the following surface sampling rules:

Depth UG2	Decimation
100 m to 230 m	1
230 m to 350 m	2
350 m to 450 m	3

The acquisition sampling rate was tested for its potential effect on the model resolution. The data set was recorded with 0.5 ms sampling against the usual 1 ms sampling rate of all previous surveys. An extra CPU effort for processing the smaller sampling rate has not brought any additional information.

Main Survey

Using the conclusions of the pilot survey, a wider area was surveyed in 2006 on the same mine. The full fold area was 1.43 km^2 and the UG2 depths were in the 200 m to 450 m range. The decimation rules were applied in order to optimize the density of surface points and consequently meet the mine budget, giving this project an economical viability. Furthermore, as the portion theoretically requiring decimation 1 was quite small, it was decided to use only decimation 2 for the shallowest part of the survey. With this optimum surface sampling the cost of imaging 1.4 km^2 was quite balanced when compared to a continuous borehole imaging over the same area. The data was processed on site, leading to a fast track interpretation and then further processed abroad leading to a later final interpretation. The data was migrated twice, on PSTM Kirchhkoff migration in order to output the most reliable structural image and also a Poststack migration to preserve the highest frequencies above 130 Hz required to resolve vertical features around 10 m. The fast track structural image confirmed the features already highlighted by the pilot survey, namely the Middle Fault and Western Fault. The vertical resolution helped to resolve fault throws of 10 m, a small pothole on the east of the survey and a series of small faults, mainly north-south, but one east-west on the west side of the Middle Fault. The main Middle Fault generated a small antithetic fault in the northern half of the survey, and this fault also was never previously integrated in any model. Figure 2 displays the final structural depth map of UG2 related to MSL, with all the small faults detected by the seismic.

Conclusions

By a careful planning through a feasibility study it was possible to derive a cost effective surface sampling required for the shallow target depth (200 m-450 m). The application of this sampling delivered an accurate and high frequency structural image with a resolution of 10 m for fault throws and other seismic objects. Variations in dip and strike of the target UG2 are also imaged. These facilitate accurate mine planning and allow future exploration to be accurately targeted. Current technology enables the imaging of any ore body as shallow as 100 m deep for costs balancing the same image through boreholes. The only requirement is a good acoustic impedance contrast at the ore body level.

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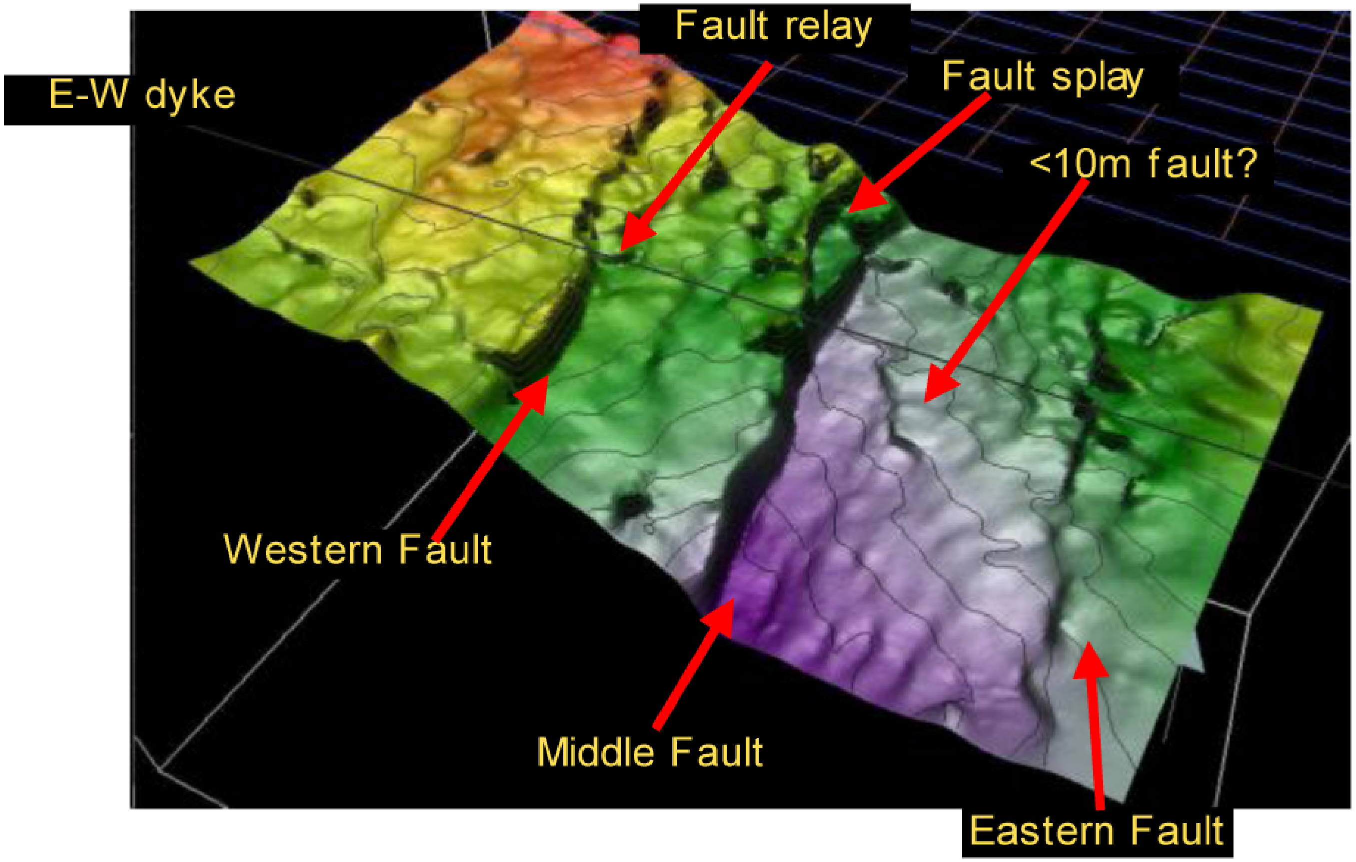

Figure 1. Structural image achieved by 5m bins and Decimation 1.

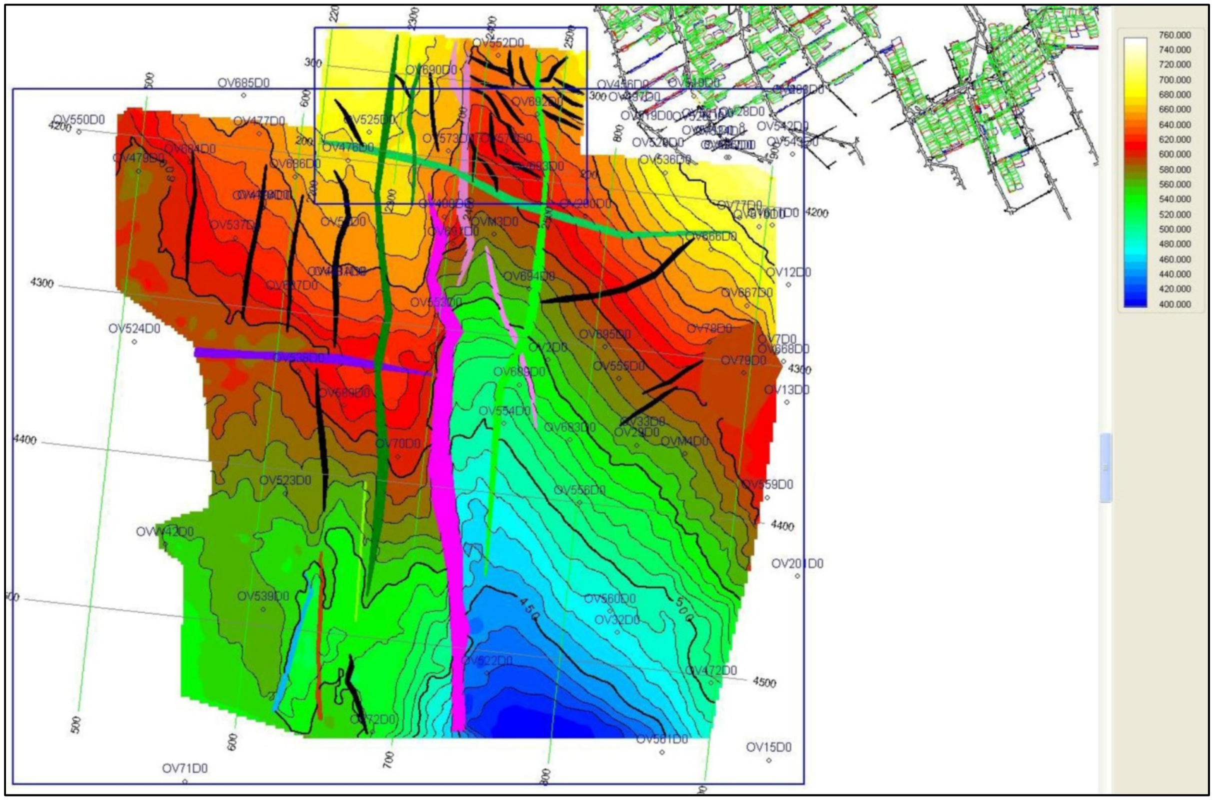

Figure 2. Final structural image of UG2 with depths related to MSL.