Imagine platinum targets using 3D reflection seismics

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Since it was first patented in 1917, the seismic reflection method has steadily established itself as the most important tool for detailed imaging of sub-horizontal layering within the Earth. Together with wireline logging, the three-dimensional application of the technique forms the backbone of present-day oil and gas exploration. In the appropriate environment, the technique yields results that are the closest of any geophysical technique to a conventional geological section or volume.

Due to its strength in imaging layered stratigraphy as well as geological structure that disturbs layer continuity, the South African platinum mining geophysicists became very interested in applying the technique to the layered Bushveld Igneous Complex. Specific objectives included imaging the Merensky Reef and the UG2 Chromitite Reef, as well as highlighting any major strike changes, faults, folds or potholes that typically disturb these reefs. Although the three-dimensional application of the technique was fairly well established in the South African Witwatersrand gold mining industry in the late 1980s and early 1990s, it was only applied in the Bushveld in 1998 for the first time, as the platinum market demand began to rise after a decade of relatively low prices.

The first 3D survey was undertaken by Impala Platinum in 1998 and the following winter, Lonmin conducted its first 3D survey that spanned their Karee Mine project area. Due to the success of these surveys, a second, far larger survey was conducted by Impala Platinum in 2000, which spanned the major proportion of their lease area in the Western Bushveld. Anglo Platinum then commenced an intensive programme of 3D seismic surveying in 2001, also in the Western Bushveld. Although 3D seismic surveys are generally far more expensive than other geophysical exploration techniques, it is currently the only technique capable of providing a true 3D volume of the subsurface from surface to depths of ±4.0 to 4.5 km with the data resolutions required for mine planning and development. The technique is particularly useful when applied in the first stages of orebody evaluation as it enables the optimum siting of exploration boreholes, thereby substantially reducing drilling budgets. As a guideline, the cost of a 3D seismic survey in the Bushveld will typically comprise less than 1% of the total direct mine development costs (Trickett and Düweke, 2005). Due to the consistently favourable platinum economic climate, most of the major Bushveld Complex mines are currently in the process of planning additional 3D surveys that are due to take place in the forthcoming three years.

The seismic reflection methodology

In essence, seismic reflection is a form of “echo-sounding”, whereby seismic energy is introduced into the ground and the portion of energy that is reflected back to the surface is recorded by a grid of geophones (or hydrophones). For a seismic wave to be reflected back to the surface there has to be a rock interface (reflector) across which there is a contrast in acoustic impedance, Z, which is the product of the seismic velocity (V) and the density (ρ) of each layer. Each reflection from a geological interface is recorded as a “wiggle” so that a series of interfaces forms a “wiggle-trace” and is recorded on each geophone in the recording grid.

Data acquisition

All of the 3D surface seismic surveys in the Bushveld have been undertaken by Compagnie Generale de Geophysique (CGG) a company based in France with seismic acquisition expertise in both the hard- and soft-rock environments. (CGG and Schlumberger are the largest global seismic acquisition and processing companies). Typically, crews of approximately 100 people are deployed to work on a 24-hour basis and equipped with a range of acquisition equipment and high-end technologies designed to obtain the highest frequency signal possible from the target area (www.cgg.com; 27 November 2006). These systems include:

- Geoland information management software
- Conventional, inertial and global positioning system surveying
- Large vibrator sources (known as vibroseis sources) engineered for real-time monitoring and broad band-width source signals
- Real-time vibrator positioning systems
- Sercel’s SN 388/408UL industry-standard 24-bit recorders. Currently, CGG operate 1000 channels simultaneously with a sample interval of 1 millisecond (i.e. data is acquired at a rate of 1-million 24-bit numbers per second). These numbers are

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1 Compagnie Generale de Geophysique (CGG): 1 rue Leon Migaux, 91341, Massy Cedex, France. www.cgg.com
2 Sercel – France: www.sercel.com

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Fig. 1: Instantaneous dip attribute showing major faulting on the UG2 Chromitite Reef (image supplied by Impala Platinum Ltd).
checked and displayed on the control screen for each vibroseis shot. Approximately 400 vibroseis shots are acquired per day.

- Geovecteur Plus for in-field quality control and processing of seismic data

Data processing

The purpose of data processing is to convert the digital signal into an image that best represents the geological subsurface in reality. Before commencing with full data processing at one of their dedicated centres, CGG typically conducts preliminary pre-processing in the field, which involves demultiplexing of the data and the conversion of data from time-domain storage to space-domain storage.

Due to the extraordinarily large volumes of data collected in a typical seismic survey, data processing demands the highest-end computing power currently available. CGG has developed specialised techniques for processing data targeted at thin mineralized layers at depths of up to approximately 5 km and these techniques are incorporated in the software package known as Geovecteur Plus. Data processing involves the following core steps:

- **Data reduction**: corrections are applied to correct for changes in surface elevation and the near-surface low velocity layer.
- **Data sorting**: data is sorted into appropriate common depth-point "bins" (discrete areas into which a survey is divided). For example, all traces (say, 70) belonging to one bin are collected for a total of (say) 50 000 bins.
- **Velocity analysis**: accounts for the offset in seismic travel-time variations between the seismic source and the depth point on the subsurface reflector interface.
- **Stacking**: required to improve the signal-to-noise ratio and involves the adding of all traces in one bin (for each individual survey bin).
- **Post-stack processing**: data frequency filtering to further improve the signal-to-noise ratio.
- **Migration**: an inversion operation that uses the wave equation to rearrange data so that reflections and diffractions are plotted at their true locations. The need for this arises since variable velocities and dipping horizons cause reflections to be recorded at surface positions different from the actual subsurface positions.

Data interpretation

The processed seismic volume can give a very direct picture of the subsurface structure, but is not a true vertical depth section as it is measured in time and not depth. It is therefore the seismic interpreter’s task to provide the vital link between a seismic volume and the target geology.

**Impulse Geophysical Consulting Services (Impulse) – South Africa** has undertaken the interpretations of the Impala Platinum 3D seismic datasets in the Western and Eastern Bushveld as well as the Lonmin Karee Mine dataset. In the case of the Impala 2000 survey, a total area of ± 138 km² (and a strike length of ± 26 km) was surveyed at 1 ms intervals and a record length of 1,099 s (Fig. 1). Prior to post-processing, the original seismic data file was ± 5 GB in size.

Interpretation is essentially the fine art of "pattern-recognition", involving the correlation of a seismic reflection package with the target reef horizons, using a priori depth information derived from borehole logs. Impulse uses a seismic interpretation software package developed by Seismic-Micro Technology (Houston) known as the Kingdom Suite. This software is PC-based and offers a wide variety of interpretation and post-processing functions. The Kingdom Suite is a very effective platform for the integration of classical geological data, topographical and geophysical data. The software demands high-end computer specifications, particularly in support of its sophisticated 3D visualisation capabilities.

- Initially, synthetic seismograms are generated in order to predict the seismic response given known input seismic source parameters. These seismograms provide a guideline in correlating seismic reflection patterns with geology.
- The interpreter typically calculates a variety of physical and mathematical attributes of the seismic volume in order to highlight the reef geometry and the structure affecting reef continuity. Different attributes will highlight different aspects of this structure, for example, the instantaneous dip of a reef horizon is an excellent tool for highlighting major fault systems, while the relative acoustic impedance attribute may highlight potholes or zones of reef depression.
- The target horizons are then "picked" interactively by the interpreter on a line by line basis. Once a control grid is established, the software can automate the picking process based on a number of user-defined control parameters. Picking can be performed on 2D vertical seismic sections, 2D horizontal time slices and on the 3D volume.
- The interpreted time horizon is then converted to a depth horizon by means of a predefined velocity surface. The velocity surface is calculated in the Kingdom Suite using a variety of different techniques.
- The resulting target depth surfaces as well as the fault surfaces can be exported in any typical GIS format and can be viewed (together with all other existing geological and geophysical project data) within Kingdom as a 3D geological model. These data are then typically imported into the client’s mine planning project(s). Fig. 2 illustrates a typical example of a 3D seismic model of a pothole.

Conclusions

Three-dimensional reflection seismics has proven itself as the most successful geophysical method to date in imaging the target platinum reefs and their host lithologies in the Bushveld Igneous Complex. Its capabilities in highlighting

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reef geometry including major fault networks, strike and dip changes and to some degree, potholes, has resulted in the major South African platinum mines insisting on 3D seismic data as mandatory for any future mine planning and development.

From survey design and data acquisition through to the final interpreted model, the seismic method is heavily reliant on high-end hardware and software computing technology. The South African platinum industry has reaped the benefits of the rapid advances in this technology due to the high and sustained level of funding provided by the global oil industry.

References

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