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Improved Subsurface Imaging through Re-processing of Legacy 2D Seismic Data - A Case Study from a Deep South African Gold Mine

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Summary

Over the last few years, there has been a proliferation of seismic solutions, which employ specific combinations of equipment, acquisition, and processing techniques that can be applied in hard rock situations to improve the imaging resolution. The latest developments in seismic processing, in particular, make it worthwhile to re-process the legacy data to enhance the resolution of the data. This is particularly important in the mining regions where no new data are available or the acquisition of new data is expensive or not allowed due to new environmental regulations. In this work we demonstrate, through a case study from one of the world's deepest gold mines in South Africa, how revisiting, recovering and re-processing of the seismic data acquired decades ago can significantly improve the quality of the interpretations. The information can benefit future mine planning operations by providing a better estimation of the resources and inform in the siting of the sinking of future shafts. Thus, any future mineral exploration plans could take the information obtained from the re-processed legacy seismic data into account when planning either 2D or 3D seismic surveys.

Introduction

Over the last few years, there has been a proliferation of seismic solutions, which employ specific combinations of equipment, acquisition, and processing techniques that can be applied in hard rock situations to improve the imaging resolution (e.g., Malehmir et al., 2012 and references therein). In such a fast evolving technological era, legacy seismic data are often overlooked as inferior compared with the newly acquired data. However, if these data are properly retrieved and re-processed using advanced or even today's standard processing techniques, they can be of significant value, particularly in the mining regions where no other data are available or the acquisition of new data can be quite difficult and expensive. Furthermore, geological information from the re-processed legacy data can be used to identify areas of interest and optimize acquisition parameters for new advanced seismic surveys (Cheraghi et al., 2011).

In the 1980s and 1990s, Gold Division of Anglo American Corporation (now AngloGold Ashanti Ltd.) acquired a series of 2D seismic profiles (16,000 km in total length) in the Kaapvaal Craton for gold exploration in South Africa, with special focus in the Witwatersrand Basin. This is one of the most extensive hard rock seismic exploration programs in the history of mineral exploration. The details about these exploration programs, including the acquisition and processing of these data, are reported by Pretorius et al. (2003). The quality of some of the legacy seismic data from South Africa is poor where they have been published, and it is difficult to judge existing geological interpretations. Moreover, few of the original data have been irrecoverable due to tape deterioration. This work presents the preliminary results from the re-processing of one these legacy seismic profiles (Figure 1).

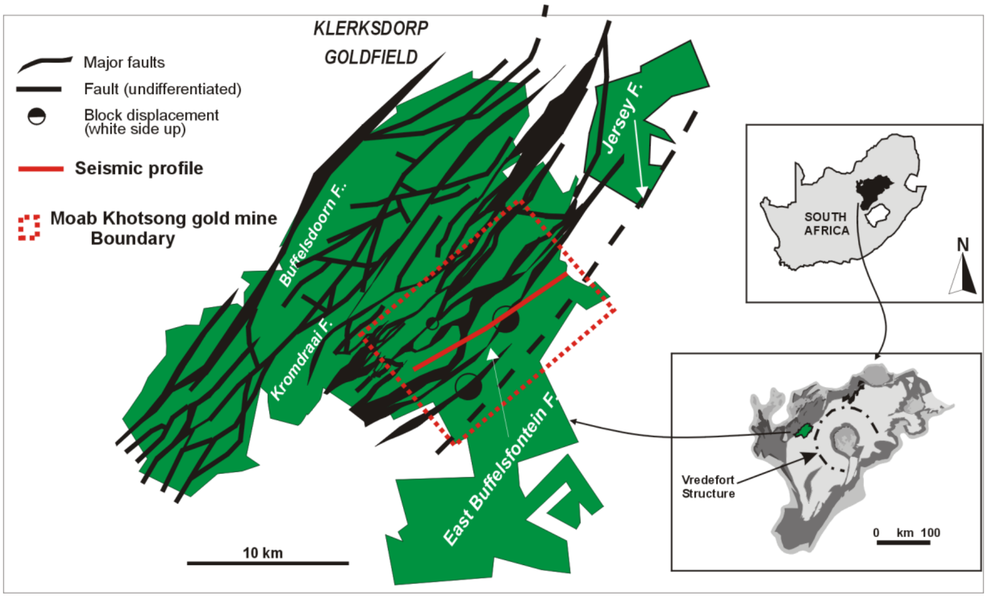

Figure 1 *Location map showing the location of the Moab Khotsong gold mine and seismic profile in the Klerksdorp goldfield, South Africa (after Pretorius et al., 2003).*

Gold deposits at Moab Khotsong gold mine

The structurally complex Moab Khotsong gold mine, located in the Klerksdorp goldfields (Figure 1), started its operations in 2003, making it the youngest of the South African deep level gold mines. The mine exploits the Vaal Reef orebody (VR, ca. 1 m thick) at depths between 2.5 and 3.8 km below the surface through vertical shaft systems (Pretorius et al., 2003). Due the complex geometry of the VR orebody at great depth, the mine is now assessing the feasibility of exploring and accessing ore resources at depths less than 3 km. The Black Reef Formation (BLR) gold deposit, located at ~ 1.5 km below surface, is one of the orebodies targeted by the company because it contains profitable concentrations of gold. This renewed interest in mapping the relatively shallow orebodies has triggered our interest to retrieve, re-process and interpret the seismic profile to evaluate the nature of the seismic reflectivity of the BLR orebody in the mining region with particular focus on imaging its continuity and faults that intersect it.

Re-processing of the legacy data

In this study, we have been able to recover and reconstruct coordinates, acquisition geometry and shot records of an 11-km-long north-northeast trending seismic profile across the Klerksdorp mining region (Figure 1). The navigation information was restored from the available field documentations, such as observer logs, recording sheets and location maps obtained from company's archives, forming the basis for an accurate re-processing. The data were acquired using a vibroseis source at 50 m source and receiver (10 Hz geophones) spacing. The record length and sampling interval were 6 s and 2 ms, respectively. The recording was made using a linear sweep: 24 s, 10-90 Hz, i.e., 3 octaves. Figure 2 shows selection of raw shot gathers (Figure 2a-d) versus re-processed ones to judge the quality of the data. The data exhibit excellent quality of the clear first breaks and reflections in raw shot gathers. However, the re-processed shot gathers using various filters (e.g., bandpass filtering and gapped deconvolution) show stronger reflections (at ~ 0.5 s and between 1.5 and 2.5 s, indicated by arrows) than the raw shot gathers.

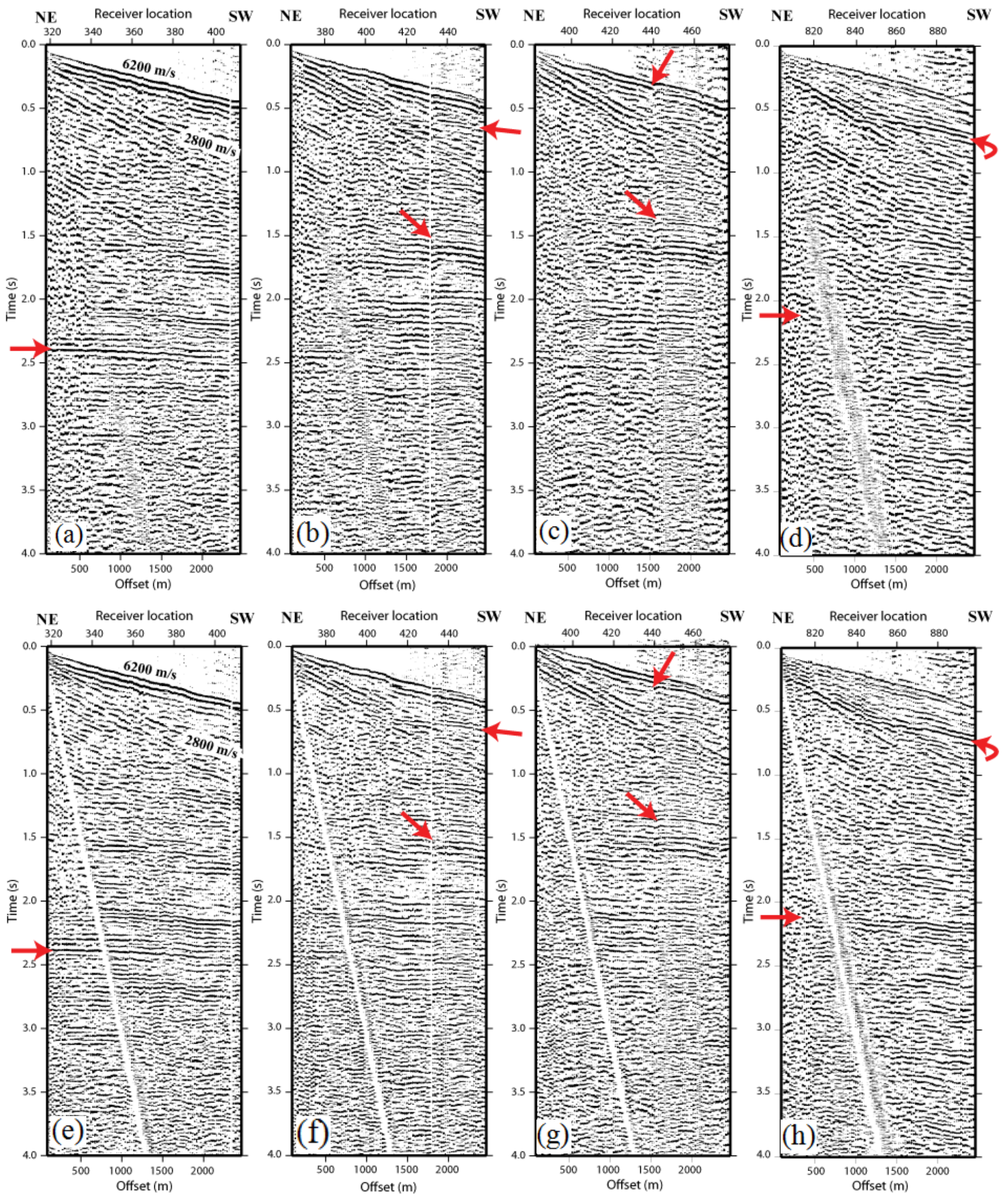

Figure 2 *Examples of (a-d) raw and (e-h) re-processed shot gathers showing a relatively good quality of the data. Strong reflections are more visible at 0.5 s and between 1.0 and 2.4 s (indicated by red arrows) in the processed shot gathers.*

First breaks were removed using a linear moveout (LMO) correction (with a constant velocity – 6200 m/s) linked to dip filtering. The LMO was later removed from the data prior to the stacking. Subsequently, a few filtering processes (mainly deconvolution) were applied to the stacked section to improve the signal-to-noise ratio and the frequency content of the data. Figure 3 compares the legacy stacked section processed in 1998 (Figure 3a) and stacked section from our re-processing work (Figure 3b).

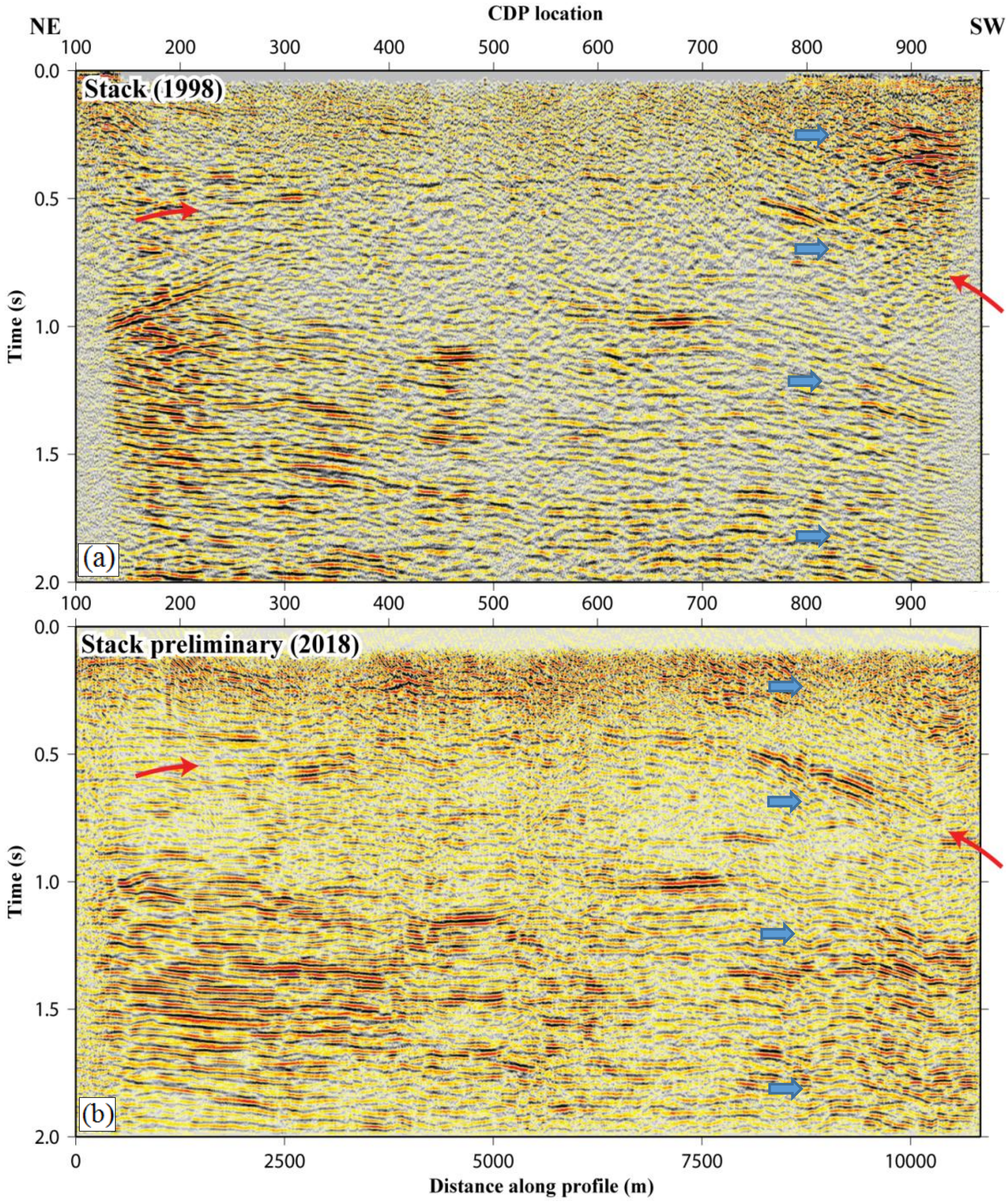

Figure 3 *Comparison between (a) legacy stacked section processed in 1998 and (b) re-processed (only preliminary at this stage) stacked section from the current study. Note that the re-processed section shows higher resolution, better continuity for the reflections relative to the legacy section. The new section also shows better imaging of the fault's offset (shown by blue arrows) of the Black Reef orebody (indicated by red arrows) located between 0.5 and 0.7 s.*

A general assessment of the two sections reveals that the re-processed section exhibits high signal-to-noise ratio (S/N) than the 1998 section. For example, the 1998 section exhibits a variable amount of noise in the upper portion of the sections (0-0.4 s), which may be related to source-generated noise or processing artifacts (Figure 3a). Data quality for the re-processed section is good at the target level (~ 0.5 s) across the section and moderate at great depths (1.0-2.0s) due to structural complexities (Figure 3b). Most importantly, the re-processed section emphasizes the seismic imaging of a steeply dipping structure (indicated by blue arrows) and continuity of a strong seismic reflection with a variable dips, located between 0.5 and 0.8 s (shown by red arrows in Figure 3b). We think the strong seismic reflection is from the Black Reef orebody (1.5 m thick). The strong reflection is caused by a significant acoustic impedance contrast between the overlying high-velocity (6700 m/s), high density (2900 kg/m^3) dolomites of the Chuniespoort Group and the underlying relatively low-velocity (6200 m/s), less dense (2700 kg/cm^3) basalts of the Ventersdorp Supergroup (Pretorius et al., 2003). Although there has been so much improvement in the quality of the data after re-processing, there are still significant limitations with data resolution related to data acquisition set-up (low fold), sparse receiver and source locations. Processing work will continue to further improve this image through additional prestack time and depth imaging algorithms.

Conclusions

We have shown through a case study from the Moab Khotsong mining region that revisiting, recovering and re-processing of the legacy seismic data acquired decades ago can significantly improve the quality of the interpretations. The case study demonstrates the value of re-processing the legacy seismic data using modern processing techniques. In areas that are closed due to stricter environmental regulations, re-processing of the data may be the only option to obtain improved images of the subsurface. What also made the re-processing of legacy seismic data remarkable was the ability to image the continuity of the Black Reef orebody and the geological features that intersect this. Establishment of the continuation of the orebody may assist the mine in improving and enhancing the resource calculation, financial valuation of the orebody and life-of-mine planning. Further processing on the data will be carried to improve the quality of the data and this will be constrained with underground exploration boreholes. Furthermore, the successful recovery of the legacy data from the company’s archives may pave the way for many mineral exploration and academic projects whereby legacy data can be re-processed using newly developed algorithms.

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