High resolution reflection seismic mapping of shallow coal seams

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ABSTRACT

Subsidence and collapse of unmapped shallow coal mine workings poses a risk to the public and hampers the development of valuable property. A high-resolution reflection seismic survey was conducted to determine whether it is possible to map the extent of the mine workings. Two 94 m profiles (tied to boreholes) were surveyed using a sledgehammer source. Processing was optimized to image the shallow reflections. The refraction seismic models and stacked time sections were compared and integrated with the borehole data to produce a 2-D geological model. It was concluded that high-resolution shallow reflection seismics could be successfully used to map the extent of the old mine workings provided adjustments are made to the acquisition and processing parameters.

Key words: reflection, seismic, shallow, cavities, processing, data acquisition.

INTRODUCTION

The development of an area north of Benoni (South Africa) is hampered by subsidence and collapse associated with century-old shallow coal mine workings (Figure 1). This was seen as an opportunity to gain experience in the use of the reflection seismic technique to map the near-surface, and a survey was conducted.

METHODOLOGY

Geotechnical investigation

A geotechnical study was conducted in early 2012 (Bear GeoConsultant, 2012). Surface mapping and several boreholes revealed that the mining was restricted to the east of the site and that the coal seam was about 10 m deep. The water table is only 1-2 m deep, filling several sinkholes that had formed above collapsed bords

Acquisition of seismic data

Two lines were surveyed to determine the optimum acquisition and processing parameters. In order to simplify the exercise, the lines were situated to the east of the undermined area. The initial acquisition parameters were based on published papers (Steeples and Miller, 1987, 1990; Knapp and Steeples, 1986) and discussions with the SEG Distinguished Lecturer, Professor Rick Miller (pers. comm., 2012). Each profile was 94 m long. The acquisition parameters are listed in Table 1.

Figure 1: M32 and Glen Glory road intersection, in Benoni. The yellow box indicates the survey area.

Table 1: Acquisition parameters

Source	5 kg sledgehammer striking a steel base plate
Receiver	14 Hz vertical component geophones
Source spacing	3 m
Receiver spacing	2 m
Seismograph	2x24 channel Geometrics Geode
Fold of stack	4
Recording length	250 ms
Sampling interval	0.5 ms

Data processing

First arrivals were picked and the travel-times of the direct and refracted waves interpreted using both delay-time and tomographic options in the SeisImager software package. Three layers were detected: dry sandy soil (300-500 m/s), weathered mudstone and sandstone (1,500-2,000 m/s), and high-velocity bedrock (2500 m/s). A borehole log and tomographic model is shown in Figure 3 (end of paper). The seismic velocities derived from this exercise were used to predict the likely arrival times of reflections from the coal seam or high velocity bed rock, and optimize the processing parameters.

The Reflex-W package was used to process the data. Many variations in processing parameters were considered in order to enhance shallow (ca. 10 m) reflections. In particular:

- It was deemed preferable to remove the coherent signal of refracted and surface waves by aggressive surgical mutes to avoid swamping the reflections.
- Attention was also given to bandpass filtering and deconvolution to improve the resolution.

A typical processing flowchart is shown in Figure 2.

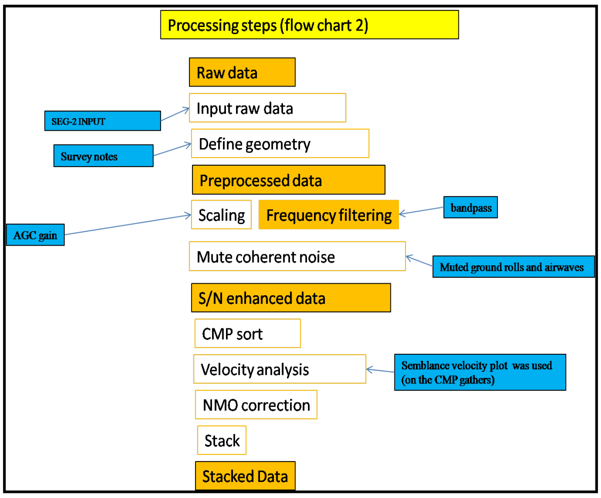

Figure 2: The flow chart shows the second processing flow which included the bandpass filter.

RESULTS

The seismic profile was tied to a borehole. The log suggested that there were significant changes in acoustic impedance at depths 10 m, 17 m and 21 m. We believe that we were able to map two undulating interfaces, at approximately 12 ms and 21 ms (Figure 4).

CONCLUSIONS

The shallow reflection seismic technique is a very useful technique for geotechnical studies. The depth of the deeper reflector was similar to the depth to bedrock determined by the refraction method. The refraction models complemented the reflection data, they revealed the groundwater level (~ 1 m), and the silty clay – sandy silt boundary (~ 10 m). The reflection method provides a higher resolution image of the subsurface than the refraction method, and would probably be able to detect the presence of old bord and pillar workings.

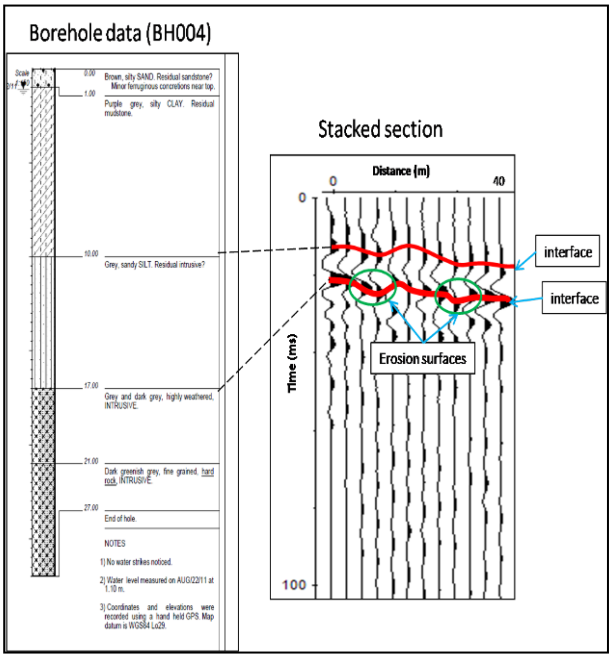

Figure 4: Stacked time section. The CMP increment was 10 with the first and last CMP selected using try and error.

RECOMMENDATIONS

The receiver spacing should be decreased to 0.4 m. This will increase the density of the data and the shallowest layers can be sampled efficiently (Schmelzbach et al, 2004; Steeples and Miller, 1990). The shot positions can be improved by making sure that there is not a shot next to the geophone that saturates the geophone and results in signal clipping. If the geophone spacing is 2 m, then, for maximum fold, the shot spacing should also be 2m with the off-end shot 1 m away from the first geophone. This design can improve the fold of the data and the density of the data. More time will be spent in the field, but better quality data will be acquired (Chaouch, 2012).

If available, high frequency sources, such as the rifle and the buffalo gun, and high frequency geophones (40 Hz or 100 Hz) will improve resolution (Pullan and MacAulay, 1987; Schmelzbach et al., 2004).

New processing technologies can also improve results, for example, seismic attributes (Chaouch, 2012).

The seismic methods can be supplemented with the microgravity and resistivity methods, which can easily detect underground cavities at shallow depths.

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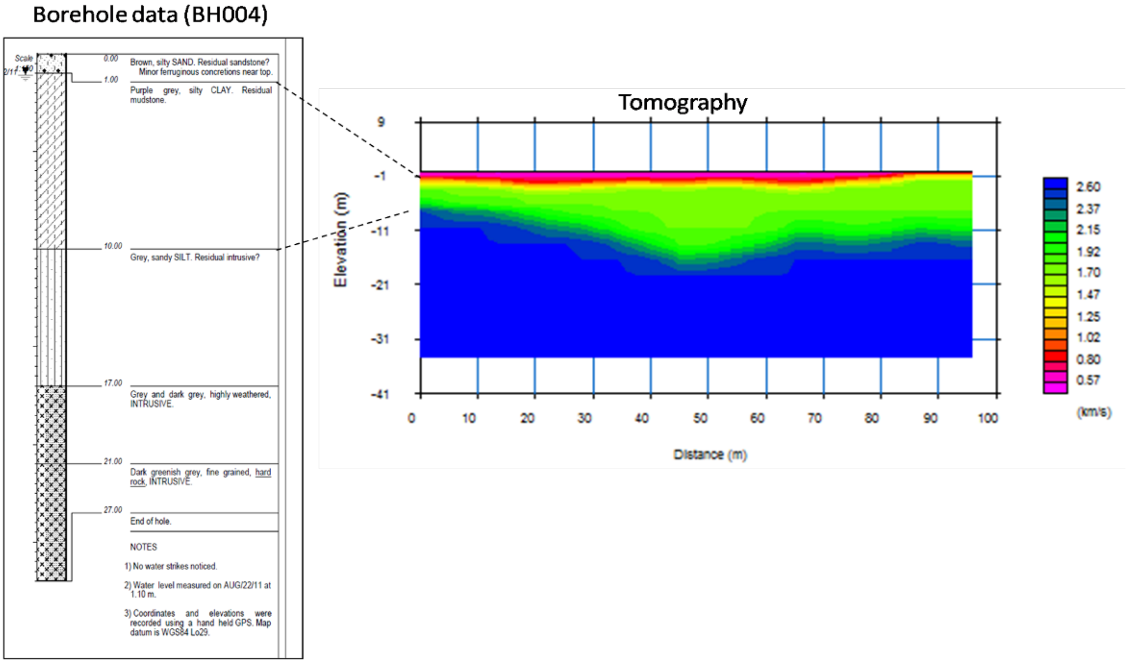

Figure 3. Tomographic model integrated with borehole log. The effect of the groundwater level on the seismic can be seen at approximately 1 m depth. The silty clay – sandy silt interface is likely marked by the transition from green to blue on the tomogram.