



## Field Comparison of the Vertical Resolution of Two Geophone Types for Near-Surface Seismic Reflection Investigation of Dolerite Sill Intrusion in Coal Mines

Ahmed I. Isiaka<sup>1</sup>, R.J. Durrheim<sup>2</sup> and M.S.D. Manzi<sup>3</sup>

<sup>1</sup>Ahmadu Bello University Zaria, Nigeria

<sup>2</sup>University of the Witwatersrand, South Africa

<sup>3</sup>University of the Witwatersrand, South Africa

### ABSTRACT

A preliminary geophysical investigation involving high-resolution shallow seismic reflection was conducted at an abandoned coal mine site located in the outskirt of Johannesburg. The main objective of the study was to compare the vertical resolution of two vertical geophone types, in order to choose the appropriate geophone type that will be suitable for subsurface delineation of dolerite sills that are commonly associated with coal deposits in South Africa. Two vertical geophones with different resonant frequencies of 48 Hz and 100 Hz were compared during the investigation. The acquisition geometry and the data processing sequence were the same for the data acquired with the two geophone types along with a profile where a borehole had confirmed the presence of an intrusive dolerite sill. The results of the investigation show that both geophone types have a similar vertical resolution as they are both able to resolve the intrusive dolerite sill which is about 13 m in thickness.

**Keywords:** reflection seismic; dolerite sill; coal; geophones

### INTRODUCTION

Geophones are an essential part of seismic exploration, because of their primary functions as detectors of ground motion. They are capable of detecting the amplitude of ground motion as low as 0.0025 mm/s and can measure the frequency of seismic data up to 500 Hz (Alcudia et al., 2008), depending on their resonant and spurious frequency. The resonant frequency (also referred to as natural frequency) of a geophone determines the limit of the recordable seismic frequency, as well as the amount of seismic information that is obtainable in a seismic data. This parameter makes the choice of geophone considerably important in seismic exploration, especially in the near-surface investigation, where detailed information of shallow sub-surface (< 30 m) is usually required. However, besides the resonant frequency of geophones, other site-dependent factors (e.g. heterogeneity of the overburden layer, thickness of the weathered layer, and water table conditions) that are related to sub-surface geological conditions could also affect the resolution of near-surface seismic data (Kalweit and Wood, 1982; Widess, 1982; Singh, 1984; Palmer, 1987; Maxwell et al., 1994; Feroci et al., 2000; Yilmaz, 2001; Burger et al., 2006; Isiaka et al., 2018). Therefore, it is of importance that preliminary test investigations are carried out to determine the most appropriate acquisition parameters to be employed in a particular geological condition.

Doleritic intrusions are common in most South African coal fields with some of them exhibiting complex morphology (de Oliveira and Cawthorn, 1999). These intrusions and their characteristic complex morphology sometimes pose risk to coal mining and also affect the quality of the coal. Hence, delineating or predicting zones where dolerite intrusions exist ahead of mining can assist in coal

mine planning and safety. This study is a preliminary investigation conducted at an abandoned coal mine site using a high resolution shallow seismic reflection method. The main objective of the study is to compare the vertical resolution of two geophone types of different resonant frequencies, in order to choose the appropriate survey parameters for future seismic investigation of near-surface doleritic intrusions in the area.

### Location and geology of the study area

The study area is an abandoned coal mine site that is being proposed for commercial and industrial development. The site is located within Benoni Agricultural Holdings, Johannesburg, South Africa (Fig. 1a). History of coal workings and sand mining were reported to have taken place within the vicinity of this area in the early 1930s. The subsurface geology of the study area is well known to, at least, depth of 40 m, based on the information available from the shallow boreholes that were drilled for preliminary geotechnical assessment (Fig. 1b). The underlying geology consists of sand, clay, coal (which is about 7 m thick), and dolomite of the Transvaal Supergroup. One of the boreholes, BH004, encountered an intrusive dolerite sill of up to 10 m in thickness. Although, it is difficult to establish the exact thickness of the dolerite sill due to the limited depth penetrated by this borehole.

### Data Acquisition

High-resolution reflection seismic data were acquired with the aid of a Geometric Geode digital seismograph along with profile LN1 (Fig. 1a), where the dolerite intrusion was encountered in borehole BH004. Two vertical geophones having resonant frequencies of 48 Hz and 100 Hz were utilized for the data acquisition along with this profile, with the objective of comparing their vertical resolution. The

acquisition geometry was the same for the two geophone types along with the profile, with 24 geophones per spread, and minimum and maximum offsets of 8 and 54 m respectively. The energy source was provided by a 10 kg sledgehammer striking an aluminium plate, while shots were fired at 2 m

interval within the offsets and the geophone spread. The total recording time of 500 ms was employed in the data acquisition at a sampling rate of 0.25 ms. Summary of the parameters employed in the seismic data acquisition is presented in Table 1.

**Table 1:** Seismic data acquisition parameters

Acquisition Parameters	Description
Energy source type	Sledgehammer
Source weight	10 kg
Geophone types	Vertical geophones (100 Hz, 48 Hz),
Seismograph	Geometric Geode 24-channel
Geophone spacing	2 m
Shot spacing	2 m
No of shots stacked per station	4
Minimum offset	8 m
Maximum offset	54 m
Sampling rate	0.25 ms
Record length	500 ms
Record format	SEG-2

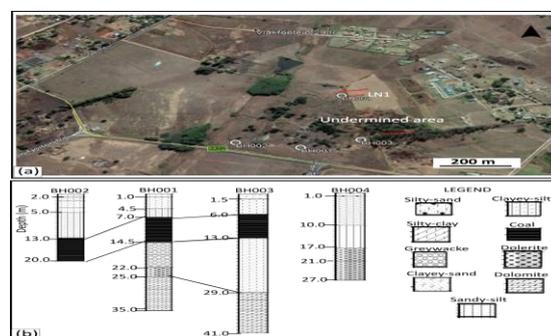
8	Velocity analysis using constant velocity stacking method (CVS)
9	NMO analysis
10	NMO correction
11	Stacking
12	Post-stack bandpass frequency filtering
13	Migration (Kirchhoff's migration at a maximum dip of 3.5 ms/trace and RMS velocity of 2000 m/s)
14	AGC at 50 ms window length
15	Time-to-depth conversion

**Table 2:** Seismic data processing sequence

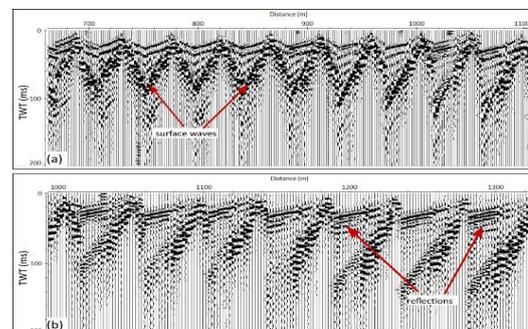
Processing Sequence	Description
1	Reformat from SEG-2 to ReflexW format
2	Trace editing (polarity check, removal of noisy and dead traces)
3	Butterworth bandpass filter (85-250 Hz) to suppress the ground-roll
4	Surgical bottom mute at 330 m/s apparent velocity (to eliminate air-waves)
5	Refraction static analysis
6	Refraction static correction
7	CMP sorting

**Seismic Data Processing**

Similar processing sequence, as presented in Table 2, was employed for the seismic datasets acquired with both geophone types. The frequency spectrum of the datasets acquired with both geophone types generally shows similar predominant frequency of approximately 100 Hz. Preliminary processing, including trace editing, reverse polarity correction and frequency filtering, was applied to the seismic datasets. Prior to filtering, spectral analysis, using the Fourier Transform, was conducted on some selected traces to determine the frequency components of the different seismic events observed in the raw data. Subsequently, a Butterworth bandpass filter of 85-250 Hz was applied to the data to suppress the surface waves and the high-frequency random noise (Fig. 2). This was followed by the application of surgical bottom muting at an apparent velocity of 330 m/s to eliminate the airwaves (Fig. 3a, b). Since the study area is flat with no significant undulation in topography, the delay time due to the weathered layer was the only static correction applied to the datasets.



**Figure 1:** (a) Satellite image of Benoni study area showing the location of the boreholes, the seismic lines acquired in the area and the (b) The stratigraphic correlation of the geology encountered in the boreholes drilled in the study



**Figure 2:** Pre-stack shot gathers from profile LNI (a) before and (b) after applying a Butterworth bandpass filter of 85-250 Hz. Note the suppression of the surface waves and the enhancement of the reflection events.

The static correction was subsequently followed by the normal moveout (NMO) correction and the stacking of the datasets, which were simultaneously carried out in the common mid-point (CMP) domain. The seismic datasets acquired with the two geophone types were stacked at root mean square velocity (RMS) range of 1800-2400 m/s, while the quality of the stacked sections was further improved by applying a bandpass frequency filter of 85-95-140-160 Hz. Migration of the data was carried out using the Kirchhoff migration method (Sheriff and Geldart, 1995) at a constant RMS velocity of 2000 m/s and a maximum dip angle of 3.5 ms per trace. The data were later time-to-depth converted after the application of automatic gain control (AGC) at 50 ms window length.

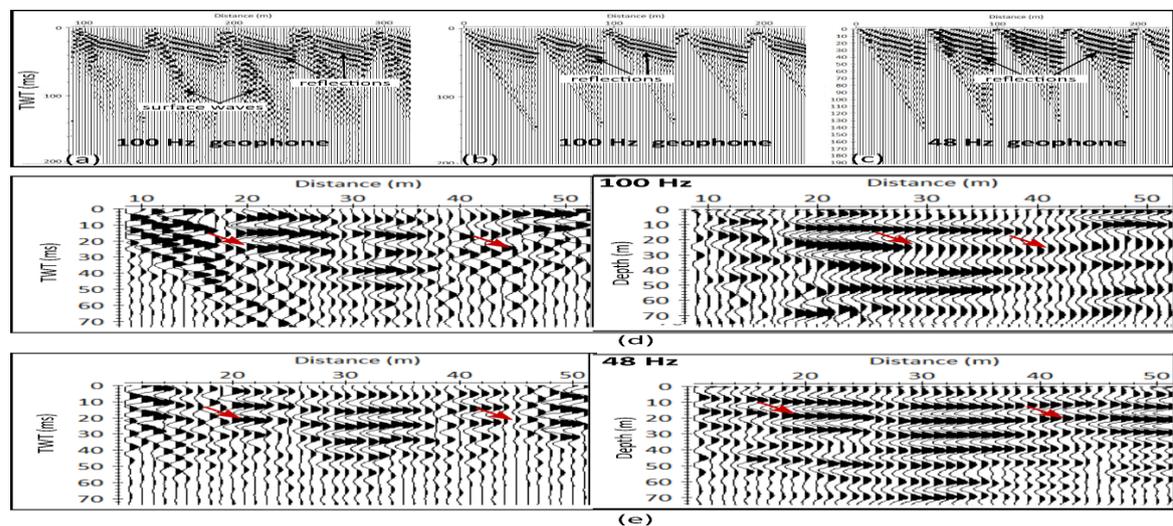
## RESULTS AND DISCUSSION

The seismic data acquired in the study area with the two geophone types generally show high signal-to-noise ratio, as reflection and first break refraction events are visible in the pre-stack shot gathers (Fig. 3a, b, c). To verify some of the reflection events observed in the stacked sections, 2-D synthetic, zero

offset stacked models were generated with the model parameters presented in Table 3, as derived from the geological information encountered in borehole BH004. The simulation of the synthetic stacked sections was carried out using the finite difference method, with the assumption of a horizontal layer model and an exploding reflector as the energy source. According to the prediction by the synthetic models, the dolerite layer occurs at 21 ms two-way-time (TWT). Similarly, the objective to resolve the dolerite layer in the study area depends on the layer medium velocity and the dominant frequency recorded in the datasets. The seismic datasets obtained for the two geophone types generally show the same dominant signal frequency of approximately 100 Hz, while the RMS velocity within the region occupied by the dolerite layer, as obtained from the NMO analysis, is approximately 2800 m/s. If the Widess' minimum resolution criteria of a quarter wavelength (Widess, 1973) is considered, the minimum thickness of dolerite layer that can be resolved by the two geophone types based on the dominant frequency of 100 Hz is 7 m. Hence, the dolerite layer encountered in the borehole BH004 is within the seismic resolution limit of the datasets acquired by the two geophone types.

**Table 3:** Model parameters for borehole BH004

Layers	Depth (m)	P-wave (m/s)	Density (g/cm <sup>3</sup> )
Silty-sand	0-3	900	1.9
Silty-clay	3-10	1650	2.1
Sandy-silt	10-17	2200	2.3
Weathered dolerite	17-21	2700	2.7
Fresh dolerite	21- ~	3200	2.9



**Figure 1:** Pre-stack and stacked sections obtained for the two geophone types along LN1. (a) Shot gathers from the 100 Hz geophone showing visible reflection events after applying a bandpass Butterworth filter, with trace normalized gain applied for display. (b) The same shot gathers from the 100 Hz geophone after applying a surgical bottom mute at 330 m/s (c) Shot gathers from the 48 Hz geophone showing visible reflection events after applying a bandpass Butterworth filter and a surgical bottom mute, with trace normalized gain applied for display, (d) Stacked section (without AGC) and the corresponding time-to-depth converted migrated section (with AGC) obtained along LN1 with the 100 Hz geophone type, and (e) Stacked section (without AGC) and the corresponding time-to-depth converted migrated section (with AGC) obtained along LN1 with the 48 Hz geophone type. The top of the dolerite layer is indicated by the red arrow.

The seismic sections obtained for the two geophone types (100 Hz and 48 Hz) along with this line display similar reflection events. Both geophone types are able to resolve the dolerite layer which appears as a strong continuous reflector at approximately 21 ms TWT on the seismic sections obtained for the two geophone types (Fig. 3d, e). The two geophone types also show another continuous reflector immediately below the dolerite sill at approximately 31 ms TWT, corresponding to about 30 m in the depth migrated section (Fig. 3d, e). This reflector is interpreted as the top of the underlying dolomite layer in the area, since dolomite is expected to be the dominant lithology at this depth, based on the stratigraphy encountered in the boreholes. This also implies that the dolerite layer encountered in the borehole BH004 may reach up to about 13 m in thickness.

## CONCLUSIONS

This preliminary investigation has shown that both geophone types have a similar vertical resolution, as the seismic sections obtained for the two geophone types (100 Hz and 48 Hz) display similar reflection events. In addition, both geophone types are able to resolve the dolerite layer which is about 13 m thick. Therefore, any of the geophone types will be suitable for future subsurface delineation of dolerite sill intrusions in the study area.

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