AVO Analysis in Gold Exploration: A South African Case Study

C. P. van den Berg, P. M. Gidlow, Soekor (Pty) Ltd., South Africa; W. A. Duweke, General Mining, Metals, and Minerals Ltd., South Africa; and B. Müller and G. C. Smith, Soekoer Ltd.

SUMMARY

A modification of the Geostack method of AVO analysis as described by Smith and Gidlow (1987) is used in a hard-rock mining environment as an aid to distinguishing between volcanic and sedimentary successions on a seismic section.

Poisson's ratios derived from laboratory measurements on sediments and volcanics in the Witwatersrand Basin in South Africa are used to set up "sediment" and "volcanic" lines, equivalent to the "mud-rock" line of Catagna (1985) for clastic silicates. It is demonstrated that these sediment and volcanic lines are sufficiently different to allow the Geostack method to distinguish between the sediments and volcanics on both synthetic and real seismic data.

INTRODUCTION

In their paper of 1987 Smith and Gidlow develope a method of AVO inversion ,which they call the GEOSTACK method, based on weighted stacking. This method uses weighted stacking on conventionally processed seismic data as an aid to gas detection and lithologic mapping. Central to their method is the concept of the "mud-rock" line as described by Castagna (1985). This mud-rock line predicts the compressional wave velocity versus shear wave velocity (Vp vs. Vs) relationship for seismic waves in a specific lithology. Smith and Gidlow use the concept of a mud-rock line in such a way that those reflections originating from an interface whose properties deviate from the postulated mud-rock line are emphasized relative to reflections from interfaces whose properties fall on the mud-rock line.

In this paper we extend this concept from the oilpatch to a hard-rock mining environment, and use a modified implementation of Smith and Gidlow's method to produce stacks which distinguish between sediments and volcanics.

In this paper the terms "sediment line" and "volcanic line" are used to represent the Vp vs Vs relationship for sediments and volcanics respectively and the term "lithologic line" is used generically for mud-rock,sediment or volcanic line.

We determine Vp vs. Vs relationships for the volcanics and metamorphosed sediments of the Witwatersrand Basin in South Africa and show that these relationships are sufficiently different to allow AVO techniques to distinguish between these lithologies. We test the method on synthetic data and extend the investigation to real data.

GEOLOGICAL SETTING

The study area lies in a section of the Witwatersrand Basin of South Africa in which the gold-bearing ,generally argillaceous,sediments of the Central Rand Group (age approximately 2300 my) are generally overlain by mainly volcanic rocks of the Ventersdorp Supergroup (age approx 2200 my). These volcanics can vary in thickness from zero up to 3000m. The younger Karoo sediments (age approximately 180-300 my) form a cover of approximately 500m thickness in this area.

A problem often encountered in surface seismic interpretation in this area is the determination of the thickness and base of the Ventersdorp lavas, and thus the depth to possible gold-bearing sediments. The extent of the lavas and their lower contact is not always readily interpretable from conventional seismic data.

SYNTHETIC STUDIES

An initial phase of synthetic study was undertaken to determine what AVO effects could be expected in a section consisting of quartzites,shales and volcanics as found in a typical Witwatersrand basin environment.

For this stage of the investigation a set of geophysical logs from a typical borehole (BH1) in the Witwatersrand Basin was used. Unfortunately no shear wave velocity log was available so shear wave velocities were calculated from the p-wave velocity log using published Poisson's ratios,where available, for the different lithologies intersected (Gay and Jager 1986). Figure 1 shows the crossplot of Vp vs. derived Vs for BH1.

The sediment and volcanic points fall into separate clusters,thus allowing the AVO technique to distinguish between Volcanics and sediments.

The data for the crossplot is very sparse and does not uniquely define Vp vs. Vs lines for volcanics and sediments. A volcanic line was calculated using 1500 M/Sec as Vp intercept and passing through the volcanic Vp vs. Vs cluster. The same assumption was used to calculate a sediment line. As the volcanics in this area appear to have a fairly constant p-wave velocity any error introduced by assuming an incorrect intercept value should not be significant. The sediments however show a considerable range in P-wave velocity and any sediment line calculated could not be considered reliable at this stage.

Figure 2a shows the synthetic CMP gather derived by raytracing the model defined by the logs at BH1. The full Zoeppritz equations were use to determine AVO effects for this gather. Significant AVO effects are visible at some of the reflectors within this gather. Even though the sediment Vp vs. Vs relationship was not considered to be reliable it was all that was available for the creation of this synthetic data set.

Because of the low signal to noise ratio of surface seismics acquired in the Witwatersrand Basin it is almost impossible to gain an insight into possible AVO effects by inspection of individual real CMP gathers.

For this reason a statistical means of examining the AVO effects was deemed necessary. The weighted stacking scheme, as described by Smith and Gidlow (1987), is geometry dependent and the presence of large structural effects together with the need to be able to take crooked line geometry into account meant that this method would not be practically implementable in this environment.

A reformulation of the Geostack method using Walden's (1991) statistical fit and using an approximation to the angle of incidence rather than raytracing was implemented. Also it was found that using a velocity model derived from the stacking velocities gave sufficiently accurate angles for the AVO calculations.

The statistical fit decribed by Walden (1991) is more robust in the presence of noise than weighted stacking and is thus more suited to data from the Witwatersrand Basin.

The formulation of the equation is based on approximation of the Zoeppritz equations, ignoring higher order terms (Aki and Richards 1979). Further simplification, assuming small density contrasts and small angles of incidence leads to:

$$R \approx \frac{1}{2}\frac{\Delta V}{V} + \left(\frac{1}{2}\frac{\Delta V}{V} - 4\frac{W^2}{V^2}\frac{\Delta W}{W}\right)\sin^2\theta$$

Where R = reflection amplitude
$\Delta V/V$ = zero offset P-wave reflectivity
$\Delta W/W$ = zero offset S-wave reflectivity
V = average P-wave velocity across interface
W = average S-wave velocity across interface

This is the equation of a straight line when plotting amplitude versus $\sin^2\theta$ with intercept given by :

$$A = \frac{1}{2}\frac{\Delta V}{V}$$

and slope term given by:

$$B = \frac{1}{2}\frac{\Delta V}{V} - 4\frac{W^2}{V^2}\frac{\Delta W}{W}$$

The assumption of a straight line AVO response is valid for angle of incidence less than about 25 degrees (Walden 1991).

The term θ in equation 2 above is calculated using velocities from the regional velocity field derived from the stacking velocities and using Walden's (1991) approximation:

$$\sin^2\theta = \frac{X^2 V_i^2}{V_a^2\left(V_a^2 t^2 + X^2\right)}$$

X = offset
V_a = average velocity to interface
V_i = interval velocity above interface
t = two way time to interface

The ΔF-stack (lithology stack, called the "fluid factor" in Smith and Gidlow, 1987) is calculated from the equation:

$$\Delta F = \frac{\Delta V}{V} - S\frac{W}{V}\frac{\Delta W}{W}$$

S = slope of lithologic line

This ensures that in the regions where the assumption of Vp vs. Vs relationship is true (ie the data falls on the assumed lithologic line) the calculated ΔF-stack will have small amplitudes relative to regions where the assumption is violated. At interfaces between sediments and volcanics the assumption will be grossly violated with the true line moving between the sediment and the volcanic lines. These effects are illustrated in figure 2b.

The results show that the Vp vs. Vs differences between the sediments and volcanics are sufficiently large to theoretically allow AVO techniques to distinguish between the two lithologies.

REAL DATA EXAMPLE

The method was tested on seismic line SL1 which passes through two boreholes. The acquisition parameters for this line are shown in Table 1.

Figure 3 shows the conventionally processed results from line SL1, together with a broad scale litholog from BH1.

The AVO preprocessing of line SL1 was designed to preserve amplitudes as much as possible while at the same time eliminating as much coherent noise (ground roll and air wave) as possible. The pre-stack processing route for line SL1 is described in Table 2.

The modified Geostack technique was then applied to the gathers to produce a stack in which the volcanic part of the section is suppressed (Figure 4). The interpretation of line SL1 based on the Geostack section is shown in Figure 5.

Because of the paucity of Vp vs. Vs data for the sediments no reliable sediment line could be derived and a stack showing suppression of the sediments was not created.

CONCLUSION

The Geostack method of AVO inversion has found application in the hard rock environment for distinguishing volcanics from sediments.

With more accurate measurements of Vp vs. Vs from logging measurements the method could be more rigorously applied and better discrimination between lithologies attained.

ACKNOWLEDGEMENTS

The authors would like to thank the managements of Soekor (Pty) Ltd. and Genmin Ltd. for their permission to publish these data.

Special thanks to Miss J. Moffett of Soekor for her aid in coding up the statistical subroutines for the project and to Dr J.L. Fatti of Soekor for helpfull discussions and critically reading this abstract.

REFERENCES

Aki, K. and Richards ,P.G.,1979, Quantitative Seismology,W.H. Freeman and Co.

Castagna, J.P.,Batzle, M.L, and Eastwood, R.L.,1985, Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks:Geophysics 50,571-581.

Gay, N.C., and Jager A.J.,1986,The influence of geological features on problems of rock mechanics in Witwatersrand mines, in Anhaeusser,C.R.,and Maske,S.,Eds.,Mineral Deposits of Southern Africa:Geological Society of South Africa,753-772.

Smith, G.C., and Gidlow, P.M.,1987, Weighted stacking for rock property estimation and detection of gas:,Geophysical Prospecting 35,993-1014.

Walden, A.T.,1991, Making AVO sections more robust:Geophysical Prospecting 39,915-942.

Instrument	Sercel SN368+FPCS
Sampling interval	2ms.
No. of channels	240
Near offset	62.5m
Group interval	25m
VP interval	100m
Stack Multiplicity	30-fold
Source	5*Failing Y2700 vibrators
Sweep length	16 Sec
Sweep range	25-139 Hz.

TABLE 1: Acquisition parameters used for seismic line SL1

Sampling interval	2 ms.
Spherical divergence correction	
Field static correction	
F-K filter	
Surface consistent deconvolution	
CMP gather sort	
Velocity analysis	(X 2)
Surface consistent residual static correction (X 2)	
NMO correction	
Surface consistent scaling	

TABLE 2: Pre-stack processing route for seismic line SL1.

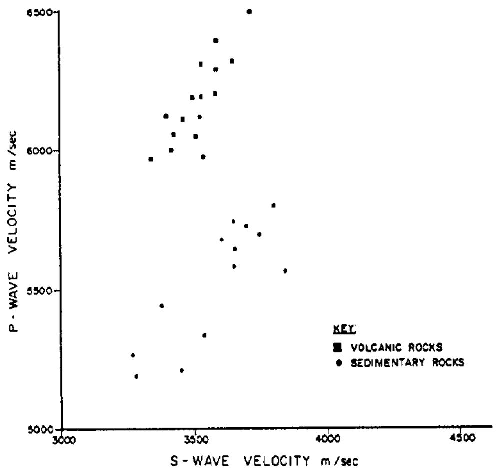

FIGURE 1.

Vp vs. derived Vs crossplot showing the separation of volcanic and sediment points in this domain.

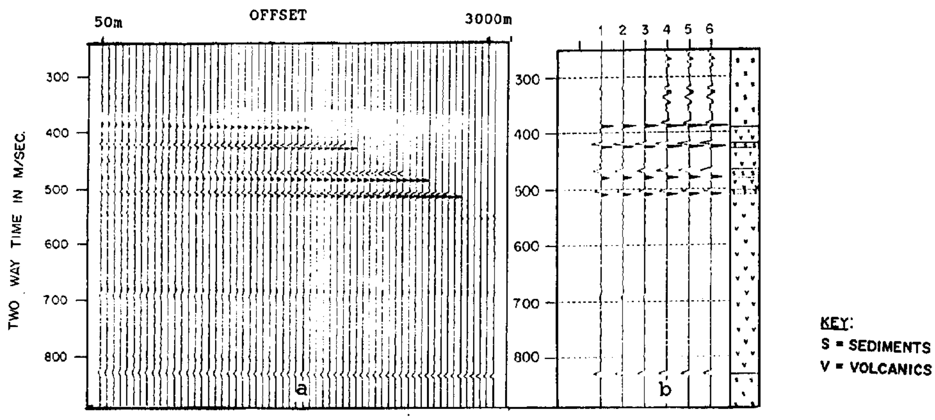

FIGURE 2. (a) Synthetic CMP gather derived at borehole BH1. (b) F-stack traces derived from (a). Traces 1 to 3 show the lithology stack derived using the sediment line and traces 4 to 6 show the lithology stack derived using the volcanic line

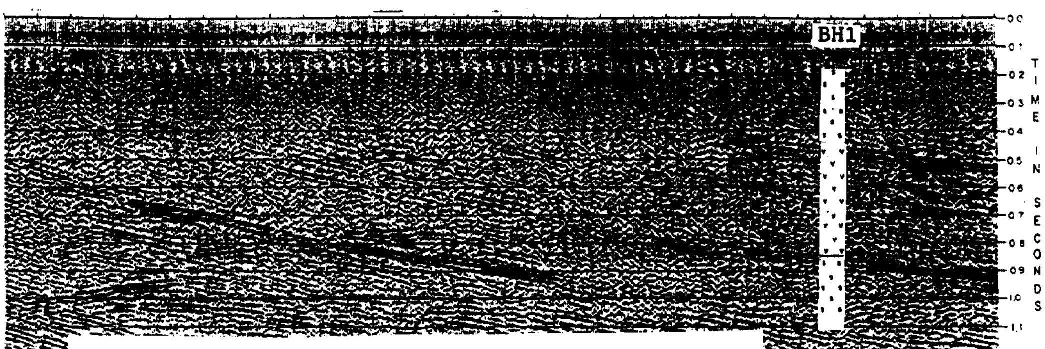

FIGURE 3. Conventionally processed data for seismic line SL1.

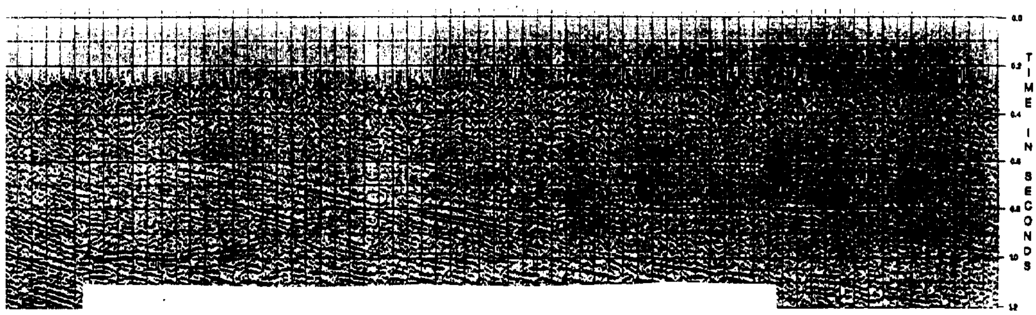

FIGURE 4. Lithology stack for line SL1 with volcanic suppressed.

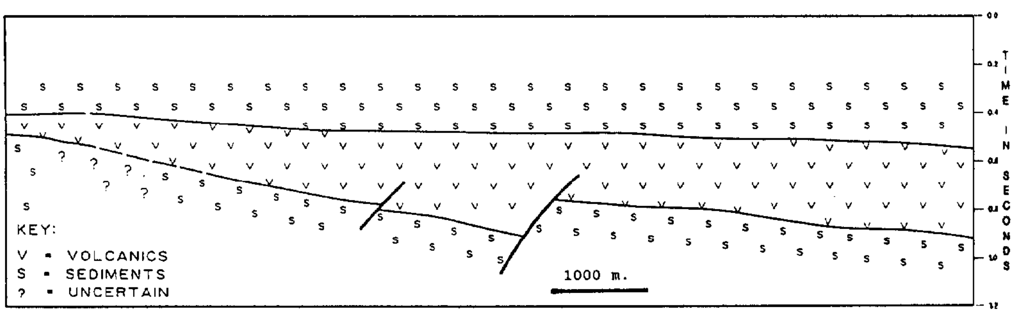

FIGURE 5. Geological interpretation from the lithology stack of Figure 4.