AVO ANALYSIS USING COMMON MIDPOINT HIGH RESOLUTION 2D SEISMIC REFLECTION IMAGING DATA: A CASE STUDY OF ZARIA, NORTHERN NIGERIA.

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ABSTRACT: Zaria area forms part of the Precambrian basement complex of north central Nigeria, which comprises Precambrian rocks made up of granite, gneisses and low grade metasediment. High resolution seismic reflection survey was carried out in Zaria to determine the AVO characteristic of the granitic batholith and the country rocks into which the batholith intruded. The common midpoint data was analyzed for AVO, both qualitatively and quantitatively. The AVO analysis revealed three AVO types, Type -3, Type -4 and Type -5. The qualitative analysis indicates a general increase of amplitude with offset. The AVO analysis obtained between gneiss and granite, registered low positive reflection coefficient, which showed that the density and velocity contrasts between gneiss and granite is not much. The fractured zone showed negative reflection coefficient and a positive amplitude gradient. The high positive reflection coefficient and positive amplitude gradient observed from AVO analysis of the deeper structures confirm material with large density and high velocity, in relation to the surrounding rocks. It can be concluded that, Type -4 AVO indicates the possible type of seismic responses between granite and gneisses, Type -5 AVO confirmed the existence of fractured basement, and Type -3 AVO confirmed the presence of sill within the batholith.

INTRODUCTION

Amplitude variation with offset (AVO) comes from ‘energy partitioning’. When seismic waves hit a boundary, part of the energy is reflected while part is transmitted. If the angle of incidence is not zero, *p* wave energy is partitioned further into reflected and transmitted *p* and *s* components. The amplitudes of the reflected and transmitted energy depend on the contrast in physical properties across the boundary. For the purpose of seismic, the important physical properties in question are compressional wave velocity v_p, shear wave velocity v_s and density ρ. But reflection amplitudes also depend on the angle-of-incidence of the original ray. How amplitudes change with angle-of-incidence for elastic materials is described by the ‘Zoeppritz equations. But there are many different simplifications of these equations that make analysis of amplitudes with angle much easier. One thing to point out now is that ‘amplitude variation with offset’ is not always an appropriate term. For proper analysis, we need to examine ‘amplitude variation with angle’ “AVA”. (Michael et al, 2002). The different responses of these AVO attributes to changes in fluid type, saturation, and lithology allow us to more effectively distinguish hydrocarbon reservoirs from non-prospective zones (Andy, 2002).

Knott and Zoeppritz invoked continuity of displacement and stress at the reflecting interface as boundary conditions to solve for the reflection and transmission coefficients as a function of incident angle and the media elastic properties, in what is today known as Zoeppritz Equation, (Equation 1), (Castagna and Milo, 1999).

$$R(\theta) = A + B\sin^2\theta + C(\tan^2\theta - \sin^2\theta) \quad 1$$

Shuey (1985) came up with a simplification to the AVO Zoeppritz Equation. He used the Aki and Richards's approximation to Zoeppritz. Equation 1 has three terms, if we ignore the "C" part, we have a linear equation, (Equation 2). This equation does not handle high angles of incidence well, but it is simple to understand and much in use today. What is done is that the amplitudes at every time sample of a Normal Moveout (NMO) gather are plotted against the squared sine of the angle-of-incidence. The intercept describes the "normal-incidence *P*-reflectivity" (NIP), while the slope is the gradient (how the amplitude changes with angle).

$$R(\theta) = A + B\sin^2\theta \quad 2$$

The initial class I, II, III & IV classification of AVO represents Rutherford and Williams (1989) classification of gas sands. This classification is based only on the normal-incidence reflection coefficient (R_p = A) and the gradient (B).

Young and LoPiccolo expanded and partly redefined the currently used classifications. In order to distinguish among the schemes the term "Types," as opposed to "Classes," was proposed to name the different categories. The complete spectrum starts from Types 1 through Types –5. The new classification provides an unambiguous way of sorting the entire range of combinations of normal-incidence reflectivity and offset-dependent reflectivity, irrespective of the cause or the direction of change of the offset-dependent amplitude variations. It is further suggested that AVO effects are best described as being not just between shales and underlying sands, but between non-shale lithologies and the overlying rock (whether it be shale or not). The classification goes beyond gas sands in its intended application. Variation in AVO should be considered a physical phenomenon, the root cause of which requires interpretation. (Young and LoPiccolo, 2004).

This paper involved carrying out a high resolution seismic reflection survey in the basement complex, and subsequently conducting AVO analysis to determine the possible response and its characteristics.

LOCATION OF THE STUDY AREA

The study area is bounded by latitude 11^o 9' 11.81″N to 11^o 04' 40.74″N and longitude 7^o 39' 46.31″E to 7^o 43' 17.09″E, with an average elevation of 657 m above sea level, Figure 1.

GEOLOGY OF THE AREA

Zaria is underlain by Precambrian basement rocks which comprise of older granite, gneisses and low grade meta-sediment. It has been established that the Zaria batholiths intruded into the gneissic and meta-sediment complex which form the country rock. The granite batholith belongs to a suite of syn and late tectonic granites and granodiorites that marked the intrusive phase of the late Precambrian to early Palaeozoic Pan-African Orogeny in Nigeria. Complementary shear fault pervades the batholiths on consolidation. On a regional scale the dextrally displacive NE-SW shear faults are more important as a result of their large size. But on a local scale the sinistrally displacive NW-SE shear faults are statistically more numerous, although individual sizes are small and displacements minor. (McCurry, 1973)

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Figure 1: Location map of the study area showing profile lines.

METHODOLOGY

DATA ACQUISITION

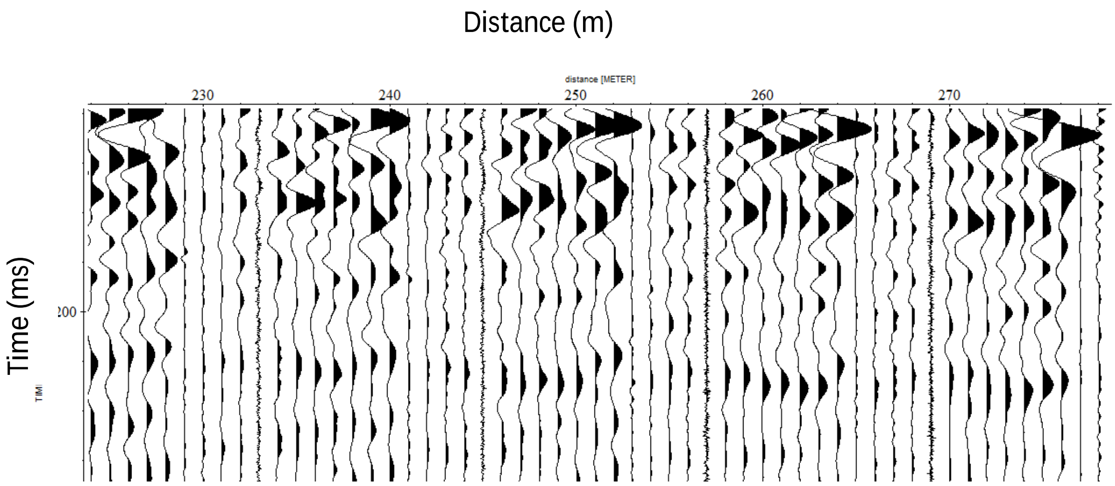
The high resolution seismic reflection data was acquired by putting the source and receivers on a straight line. The receivers were placed at 1 m interval, with a constant offset of 1 or 10 m used throughout the survey. After each shot, the first receiver was removed and placed 1 m beyond the last receiver. The connection to each of the "take out" where swapped in the direction of increasing profile. When all the connections were completed, the shot was fired in the previous position of the first receiver. The process was repeated until the end of the profile was reached. A stack of 5 shots was deployed for each shot location. Each of the points at the subsurface was sampled 12 times, resulting in twelve fold coverage for the 24 channel seismograph, with shot occupying positions of previous geophone. The generated seismogram with a record length of 1000 ms was stored for onward processing.

DATA PROCESSING

Preserved amplitude processing is a clear requirement for AVO studies, (Connolly, 1999). The processing of the AVO data started with the editing of the wrong geometry probably mistakenly enter during data acquisition, this is very important given that it is what is needed by the computer to sort the traces of the raw seismic data into common midpoint traces for AVO analysis. The gain filter was applied to enhance the amplitude of the weak signals. *fk* filter was then applied to remove ground roll and refraction event. 2D velocity model was generated which was used for normal moveout and to sort the data into CMP traces. To determine the actual depth where the AVO signal originated, the *fk* filtered data was isolated, stacked, migrated and converted into depth seismic section. Knowing the offset and the depth from which the AVO signal originated from, it was possible to estimate the various angle of incidence of the incident ray. The amplitude of the CMP trace was also measured and recorded. The recorded amplitude of the various trace was plotted against the “sin square of the angle of incidence”. The gradients and the intercepts of the various graph was determined and analyzed.

RESULTS

The seismic profile sorted into common midpoint traces for AVO analysis is shown in Figure 1. The AVO signature of Figure 1 labelled “A” was extracted from the CMP traces and displayed at a larger scale, (Fig. 2). Qualitative analysis of the AVO gather shows that, it has positive peak amplitude that became more positive with increasing offset. The tracing of the AVO signature back to its origin showed that it originated from a depth of 120 m. Hence the incident angles and the reflected angles were constructed based on the offset distance between the source and receivers, and the determined depth. The resulting angles was measured and tabulated with their corresponding amplitude (Table 1). The extracted amplitude was plotted against the sin square of the incidence angles (Fig 3), and the slope and the intercept was determined from the graph.



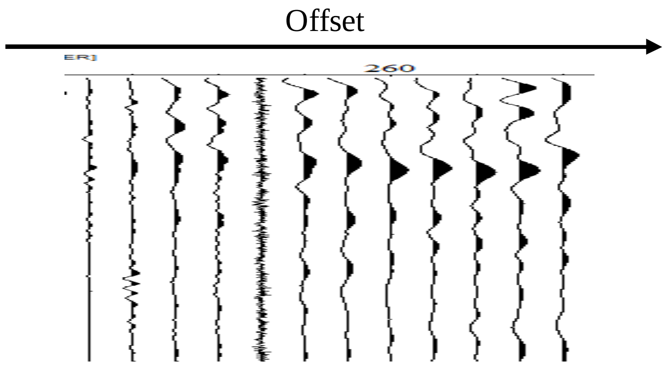


Figure 2: AVO Signature extracted from figure 1, sorted into CMP Traces

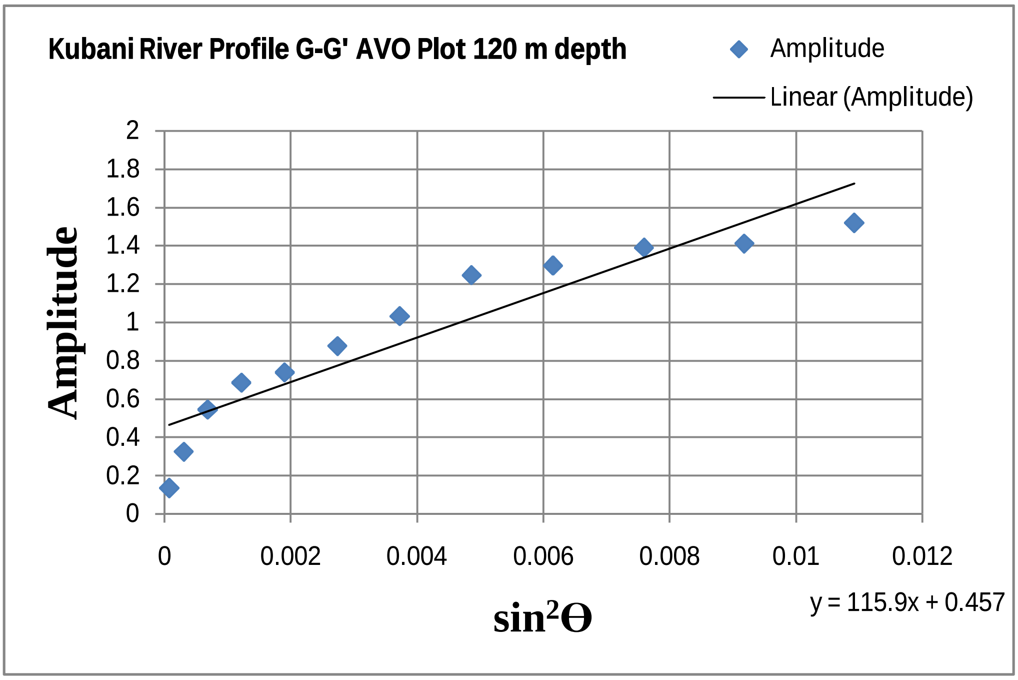


Figure 3: Amplitudes from each time sample of a gather A at 120 m depth, vs squared sine of the angle-of-incidence.

Table 1: *AVO amplitude and the incidence angles at 120 m depth*

Angle (θ) in degree	$Sin^2θ$	Amplitude
6	0.010926199	1.52049
5.5	0.009186408	1.4124
5	0.007596123	1.39165
4.5	0.006155829	1.29815
4	0.004865965	1.2482
3.5	0.003726924	1.0337
3	0.002739052	0.87806
2.5	0.00190265	0.74061
2	0.001217974	0.68707
1.5	0.000685232	0.54646
1	0.000304586	0.32682
0.5	0.000076152	0.1376

The graph shows a high positive intercept which signifies high reflection coefficient at normal incidence and a large gradient which indicates the rate at which the amplitude is increasing with offset. This class of AVO represents the Type -3, which has large positive peak that becomes more positive with increasing offset, which may have originated from the suspected sill within the batholith.

On another seismic profile but at different depth, AVO gather was extracted at the point labeled "B" (Fig. 4), and displayed at a larger scale (Fig. 5). The AVO gather was traced to have originated from a depth of 26 m, which was used to construct the various angles of incidence. The amplitude of the traces was plotted against the various sin square of the angles of incidence

(Fig. 6). Qualitative analysis of the traces shows that the amplitude was increasing with offset. However, the graph showed a negative intercept and a positive gradient. The negative reflection coefficient which the negative intercept detonate, may have resulted from fractured zone within the fractured basement. This can be classified as Type -5 AVO, which has a negative reflection coefficient but a positive gradient that indicates the rate at which amplitude is varying with offset.

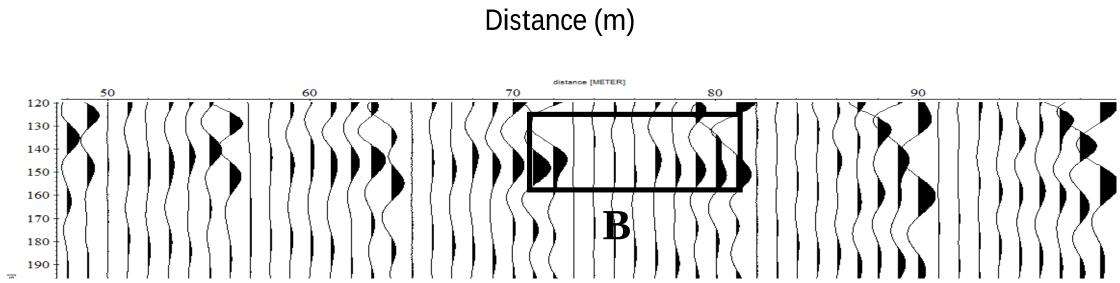


Figure 4: Seismic profile, sorted into CMP Traces for AVO analysis

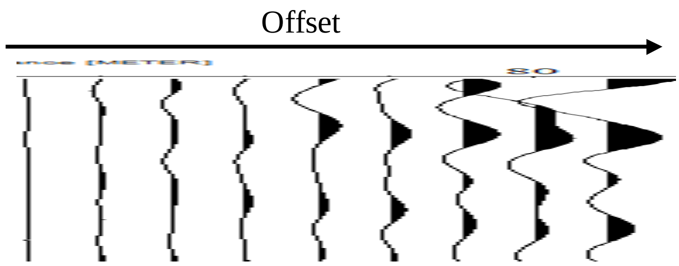


Figure 5: AVO Signature extracted from figure 4, sorted into CMP Traces

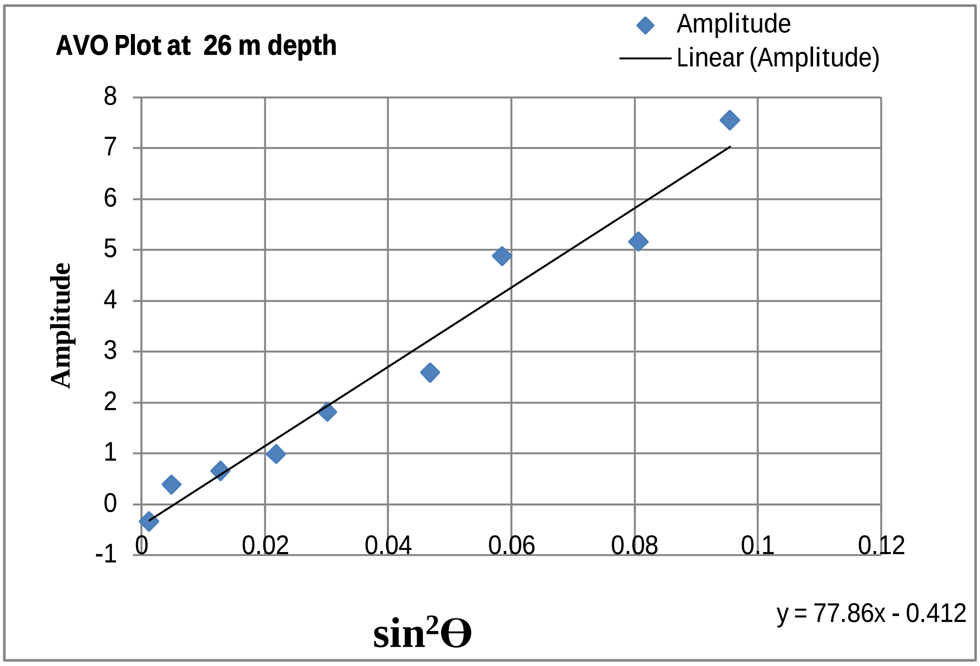


Figure 6: Amplitudes from each time sample of a gather B, figure 5 plotted against the squared sine of the angle-of-incidence.

The third seismic profile was sorted into CMP traces (Fig 7), from which the AVO gather was extracted, and displayed on a large scale (Fig. 8). The amplitude value of the traces was extracted (Tables 2 and 3) and plotted against the sin square of the angle of incidence (Fig. 9). Qualitative analysis of the seismic traces shows that it has a small peak that becomes more positive with offset. The graph has a small positive intercept but a large gradient, which is believed to have originated between gneisses and granite. The AVO signature can be classified as Type -4, which has low reflection coefficient but positive gradient.

Table 2: *AVO amplitude and the incidence angles at 26 m depth*

Angle (θ) in degree	$Sin^2θ$	Amplitude
18.5	0.095491502	7.55135
16.5	0.080664716	5.16511
15	0.058526203	4.88299
13	0.046846106	2.59554
10.5	0.030153689	1.82312
8.5	0.021847622	0.99197
7	0.012814967	0.6609
5	0.004865965	0.39229
2.5	0.001217974	-0.3313

Table 3: *AVO amplitude and the incidence angles at 30 m depth*

Angle (θ) in degree	$Sin^2θ$	Amplitude
4	0.095491502	9.60239
3.5	0.080664716	6.65001
3	0.058526203	7.4402
2.5	0.046846106	6.38916
2	0.030153689	3.03238
1.5	0.021847622	2.89515
1	0.012814967	0.70225
0.5	0.004865965	-0.3883

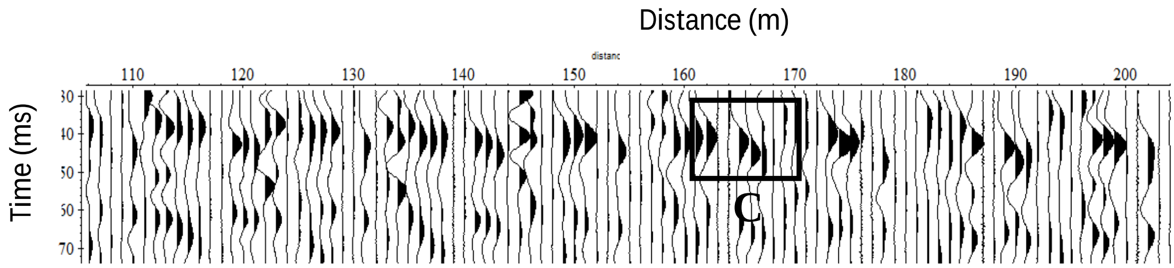


Figure 7: Seismic profile, sorted into CMP Traces for AVO analysis

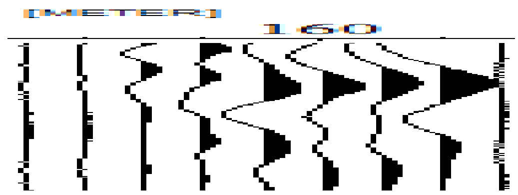


Figure 8: AVO Signature extracted from figure 7, sorted into CMP Traces

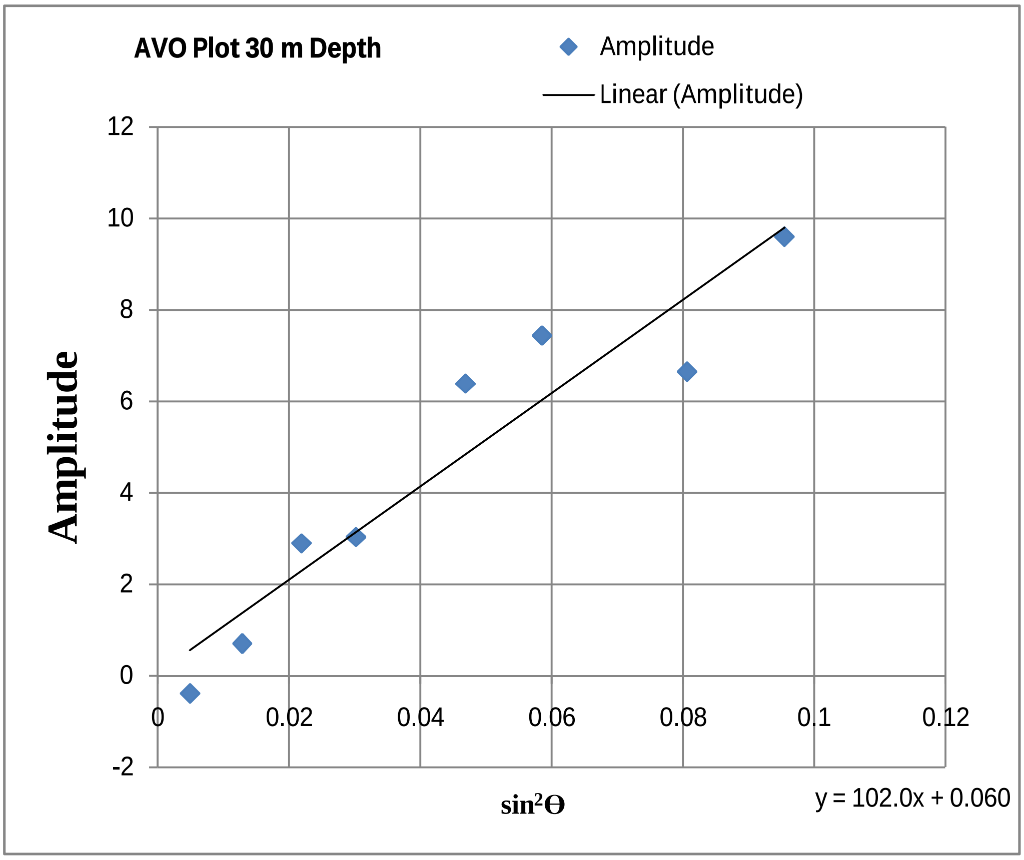


Figure 9: Amplitudes from each time sample of a gather C, figure 8 plotted against the squared sine of the angle-of-incidence.

CONCLUSION

Based on their response three AVO types were identified, which include Type 3, Type 4, and Type 5 which are typical of hard rock terrain with complex geology. The qualitative analysis of the various Ostrand gather (AVO signature) shows that the peak amplitude becomes more positive with increasing offset. The AVO signature from the respective profiles has shown that the reflection coefficient within the basement complex is almost always positive, except within the fractured basement. This work has shown that AVO analysis is not only limited to gas sand and shale lithologies but could be used as a useful tool to characterize the basement complex.

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