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Using conventional refraction travel time plot to establish the first breaks of refraction events, necessary for tomography inversion in regions with substantial complexity

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ABSTRACT

The structural complexity within the basement complex of Zaria batholith makes refraction survey and interpretation a very difficult task. Assignment of picked travel time into different layers which is critical for refraction tomography inversion is almost impossible, because it is very difficult to determine when the refraction event becomes the first break in a processed seismic data. Therefore, this research work is aimed at designing a technique that will help in establishing the time at which the refraction event becomes the first break in such situation. The procedure involves conventional travel time plots, identification of the time at which the refraction energy arrives with the aid of the conventional time plot, assignment of layers to the various travel time picks and the tomography inversion process. The results of the conventional travel time plots revealed that average time at which the refraction event becomes the first break was determined to be 33 ms. This was used to assign layers to the travel time picks that were used for tomography inversion that generated a tomography model that correlated very well with a borehole log sited at the centre of the profile. It was concluded that conventional refraction travel time plot will serve as a viable tool for estimating the time at which the refraction event becomes the first break necessary for refraction tomography inversion in regions of substantial complexity or for seismic refraction data that has very low signal to noise ratio.

Introduction

The subsurface structure obtainable within the basement complex is quite different from the layering structures obtainable in the sedimentary terrain. The subsurface structures in the basement complex are complicated by the intrusion and outcrops which occur abruptly over a very short distance of few meters. Most of the theory behind seismic refraction acquisition and processing are based on low velocity layer underlain by higher velocity layer with little or no undulation. To proffer a solution to this complexity, a technique has to be design to enable us estimated the actual time at which the refraction event in a seismic data become the first break. Hence the aim of this work is to make use of the conventional forward and reverse travel time plot to estimate the time at which refraction event become the first break, which is necessary for tomography inversion, for a survey carried out in the basement complex, where there are substantial complexity in the layering structure.

The seismic refraction method is based on the measurement of the travel time of seismic waves refracted at the interfaces between subsurface layers of different velocities. When the refractor is suspected to have a dip, the velocities of the beds and the dip of the interface can be obtained by shooting a second complementary profile in the opposite direction [5]. The refraction method is mainly used for mapping of the weathered layer, for determining depth to water table, for engineering purposes, and for applying correction to reflection data [8]. Tomography is define as an imaging techniques [9]. Tomography is an error-minimization process in which a model is computed that “best fits” the field data. The solution obtained from tomographic inversion processes generates the simplest representation of the subsurface; thus, regions with substantial complexity often will not be accurately imaged. However, when additional information is available such as outcrop or borehole data additional constraints can be placed on the inversion process to improve the inversion results [2]. Seismic refraction tomography can be used to image the subsurface to delineate the various strata within the subsurface [1]. The velocity distribution relates to the material within the subsurface, but those relationships are not always obvious on the final velocity model without additional information like borehole log [3]. Near-surface velocity anomalies produce severe distortions in seismic images [4]. It is suggested that waveform inversion with the tomographic results as the input model might be a viable option in imaging a paleovalley with complex architecture [7]. The instruments employed for this research (Fig. 1) includes: 24 channels Terraloc mark6 seismograph, vertical geophones, reels of cables with take-out points, trigger coil, base plate and sledge hammer as energy source.

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Figure 1. Seismic equipment used for the survey.

Location of the study area

The study area is bounded by latitude 11° 10' 28.24″ N to 11° 10' 24.64″ N and longitude 7° 40' 22.54″ E to 7° 40' 24.2″ E, with an average elevation of 672 m above sea level (Fig. 2).

Figure 2. Location map of the study area, profile line in white with red dotted ends, adapted from Google earth 2009.

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 older granite outcrops in the vicinity of Zaria are exposures of a syntectonics to late-tectonic granite batholiths which intruded a crystalline gneissic basement during the Pan-African Orogeny. This batholith is a north-south oriented body, about 90 x 22 km, extending from Zaria southward to the vicinity of Kaduna (Fig 3).

The Zaria granite batholith belong 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 [6]. These granites and granodiorites intruded into low grade meta-sediments and gneisses and were collectively called the "Older granites".

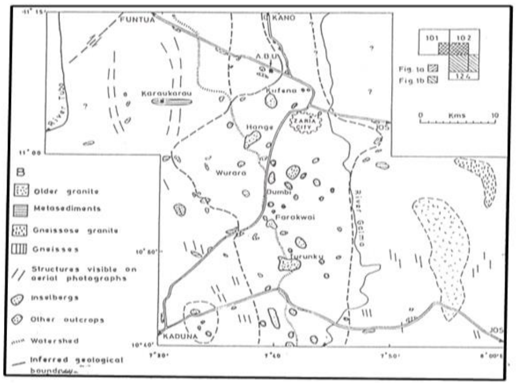

Figure 3 . Geological Map of Zaria, showing the geology of the area, after [6].

Data acquisition

The data acquisition started by laying out the geophone at intervals of 5 m on a straight profile. The reels of cable with take-outs were laid out, and the geophones were connected to the take-out points being mindful of the polarity. After all the connections were completed and the instrument were ready for recording, shots were fired at an offset distance of 5 m, and at each geophone point with a stack of five shots for each. The generated seismogram was recorded for onward processing. The raw seismic data which was generated with a sampling interval of 250µs and number of samples of 4096 is shown in figure 4. The record length is 1 s, which is a multiplication of the sampling interval with number of sample.

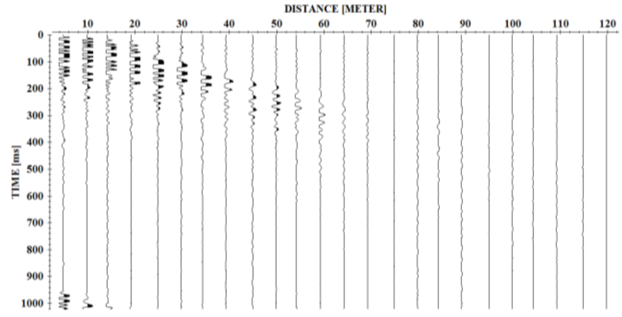

Figure 4. One of the raw seismic data generated during the survey.

Data Processing

The data processing started by importing the raw seismic data recorded in SEG2 format in the field into a dedicated software used for the processing. The next step on the processing flow was the inspection and editing of any wrong geometry mistakenly entered in the field. The Bandpass filter with "low cut-off" ("high-pass") of 5Hz and "high cut-off" ("low-pass") of 100Hz was applied to remove the effect of ground roll and improve the signal to noise ratio (S/N). The gain filter was applied to enhance the weak refraction events. The arrival times were picked from the processed data (Fig. 5) and saved. The picked arrival times shots at the first and last twenty fourth geophone and at the midpoint were extracted (Table 1 and 2) and used to plot a conventional travel time curve (Fig. 6 and 7). The two conventional travel time plots (graphs) were used to identify point at which the refraction event became the first break in both the forward and reversed travel time plots. This was used to assign layers to the various travel time picks (Fig. 8). The inversion process was carried out on the picks times (Fig. 9), to generate the initial model for the first and second layers (Fig. 10). Ray-tracing (Fig. 11) which is necessary to determine the ray-path that can be used to model the velocity profile was carried out. After which the initial generated model was iteratively inverted to generate tomography model by incorporating static correction information directly into the inversion routine.

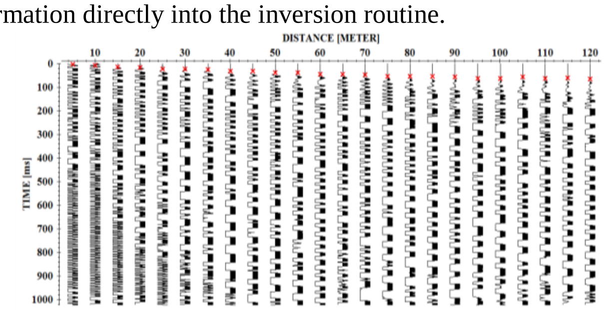

Figure 5. Processed seismic data showing the picked arrivals marked with "x".

Table 1.Picked arrival times for the forward and reversed travel time.

Distance (m)	Forward Times (ms)	Reversed Times (ms)
5	0	64
10	5.82	65.94
15	7.76	65.94
20	15.52	58.18
25	23.27	58.18
30	25.21	54.3
35	27.15	50.42
40	31.03	52.36
45	34.91	48.48
50	36.85	48.48
55	44.61	46.55
60	44.61	44.61
65	44.61	44.61
70	46.55	40.73
75	46.55	42.67
80	48.48	36.85
85	54.3	36.85
90	50.42	32.97
95	52.36	32.97
100	54.3	27.15
105	62.06	23.27
110	60.12	11.64
115	64	1.94
120	65.95	0

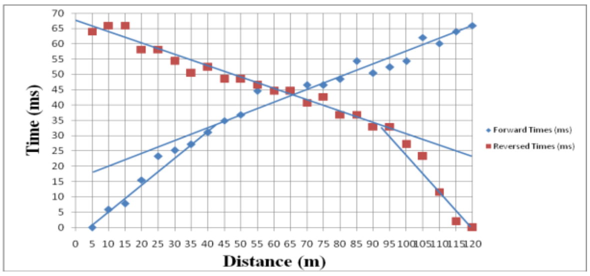

Figure 6. Forward and reversed travel time picks for shot fired at the first and last geophone.

Table 2. Picked arrival times for the forward and reversed travel time .

Distance (m)	Forward Times (ms)
5	44.61
10	42.67
15	44.61
20	38.79
25	38.79
30	34.91
35	32.97
40	29.09
45	25.21
50	19.39
55	19.39
60	5.82
65	0
70	9.7
75	17.45
80	19.39
85	29.09
90	34.91
95	38.79
100	40.73
105	40.73
110	42.67
115	46.55
120	44.61

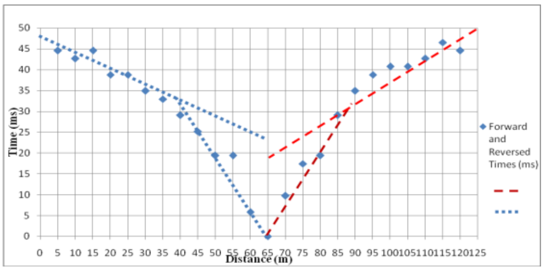

Figure 7.Forward and reversed travel time picks for shot fired at 65 m along the profile .

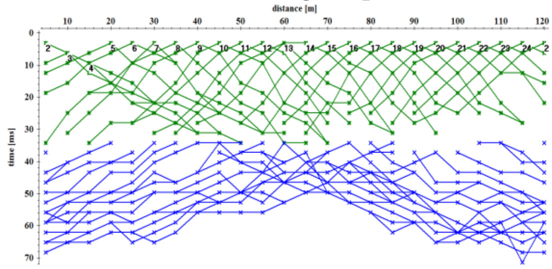

Figure 8. Assigned pick travel time into layers using result of figure 8 and 9.

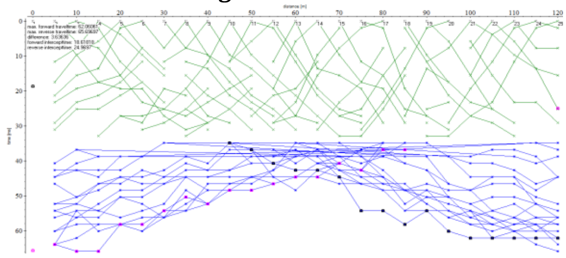

Figure 9. Assignment of layers to the different travel time picks, green for first layer and blue for second layer.

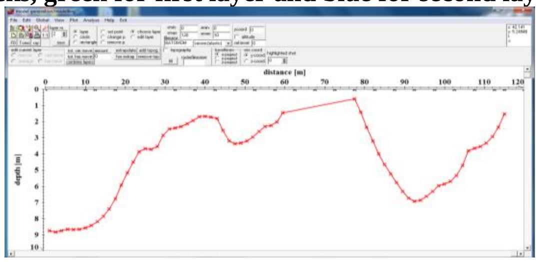

Figure 10 . Inversion process with Reflex software to generate initial first and second layers.

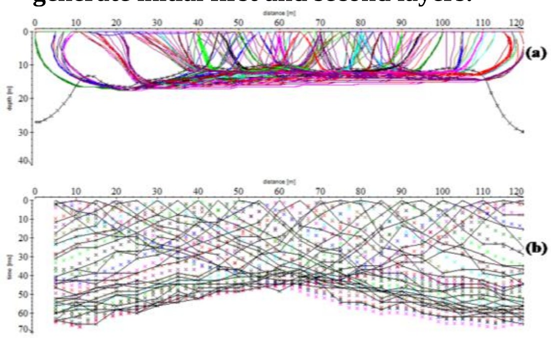

Figure 11. (a) Ray-tracing for each of the observed picked travel time (b) Observed and calculated time picks in colour.

Results and Discussion

From the conventional refraction travel time plot (Fig. 6), the time at which the refraction event becomes the first break which is the crux of this research was observed, and it was found to be about 33 ms for the forward and 33 ms for the reversed travel time plot. Another conventional refraction travel time plot for a shot fired midway at a distance of 65 m along the profile was extracted and plotted as shown in figure 7. The time at which the refraction event becomes the first break was also observed, and was determined to be 32 ms for the forward travel time and 34 ms for the reversed, which on the average boils down to 33 ms. Considering the complexity of the travel time picks displayed in figure 12, which were the travel time picks used for plotting of the convectional forward and reversed travel time plot in figure 6 and 7, it became obvious that it is almost impossible to assign layers to the travel time picks without it being a guess work, since it is very difficult to decipher the point at which the refraction events becomes the first break.

However, the assignment of layers to the travel time (Fig. 8) became possible as a result of the earlier results derived from the conventional travel time plot of figure 6 and 7. The first layer was assigned a green colour, while the second layer was assigned a blue colour. With this, it was possible to generate the initial model for the first and second layer (Fig. 10), which was iteratively used to generate the tomography model displayed in figure 13.

The intercept times on the time axis of the conventional travel time plot for the forward travel time were noted to be 18 ms, and that of the reversed travel time plot were noted to be 24 ms on both conventional travel time plot (Fig. 6 and 7). This was in conformity with what was generated by the interpretation software during the process of inversion (Fig. 9). The velocity of the forward and the reversed travel times shots for the refractor were determined to be 2500 m/s and 2750 m/s respectively. From the qualitative analysis of the travel time plot of figure 6, it was noticed that the reversed travel time has the highest intercept time, which signified that the subsurface was dipping toward the end of the profile, that is, toward the twenty fourth geophone where the reversed shot was taken. These results are also in conformity with the tomography model shown in figure 13.

The result of the tomography model was correlated with a borehole log (Table 3) sited at a distance of 65 m along the profile. To buttress the accuracy of the tomography model various layers identified by the tomography model correlated very well with the borehole log. The direction of dip of the subsurface structure in the tomography model was in conformity with that earlier identified in the conventional forward and reverse travel time plot of figure 6 and 7.

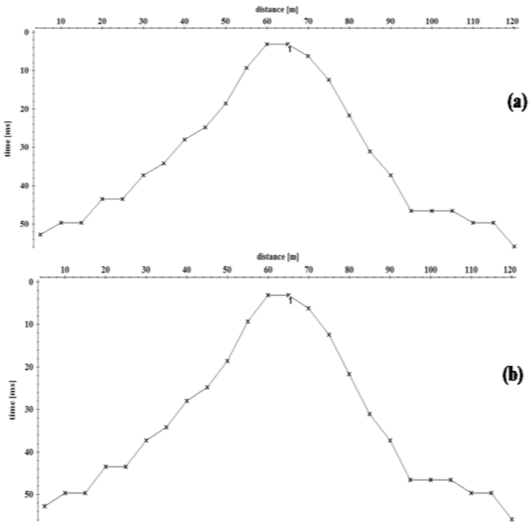

Figure 12 . Forward and reversed travel time picks used to plot the conventional travel time picks of figure 6 and 7 (a) At first and 24th Geophones (b) At midway 65 m along the profile.

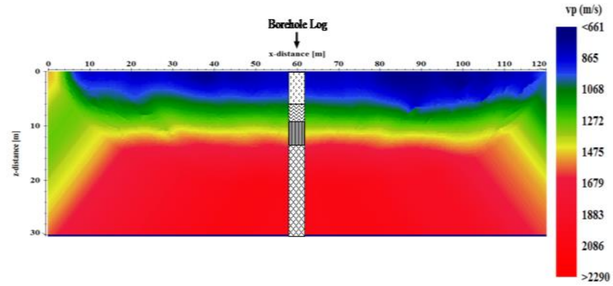

Figure 13 . Refraction tomography model generated from the travel time picks.

Table 3. Lithology and Aquifers Borehole Log.

Calibration (m)	Layers	Geologically interpreted lithology	Hydrological correlation	Key
0	Lateritic layer	Reddish brown silty clay with reddish brown ferruginous concretions	Lateritic layer is largely above saturated zone	
-4		Reddish brown sandy clay with ferruginous concretions	Water table about 4.30m	
-10	Weathered Basement	Grayish brown medium coarse sand containing gravels and pebbles	Aquifer	
-17	Fresh Basement complex	Quartzite probably also occurring with gneiss		
-30		Fresh crystalline rock		
-55				

Conclusion

This research work has actually brought out the fact that conventional forward and reversed travel time plot can be used to estimate the time at which refraction events becomes the first break in area of structural complexity or in the case of seismic refraction data with low signal to noise ratio. The “assignment of travel time to layers” which is critical for tomography inversion became possible for travel time picks that has slight observable pattern of refraction event. This will be a useful tool for refraction tomography survey in basement complex like that of Zaria, were the layering structure can change within a very short distance, also, in the vicinity of salt dome arc in the sedimentary terrain, or in the case of seismic refraction data with low signal to noise ratio.

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