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Delineation of aquiferous layers within the basement complex using joint inversion of seismic refraction tomography and high resolution 3D seismic reflection survey

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ABSTRACT

Zaria, where this Survey was carried out is located in the basement complex of North Central Nigeria. It consists of Precambrian rocks types made up of granite, gneisses and low grade metasediment. The gneiss and the low grade metasediment forms the country rock into which the granitic batholith intruded. This work is meant to examine the effectiveness of joint inversion of refraction tomography and high resolution 3D seismic reflection survey in locating the best point of aquifer within the basement complex. The result of the seismic refraction tomography showed the distribution of seismic velocity within the subsurface with a general increase of velocity with depth. The overburden has an average velocity distribution of 994 m/s. The weathered basement has a velocity range of 1446 to 2912 m/s .The average thickness of the overburden and the weathered basement was found to be 20 m and 9 m respectively. The depth to the fresh was 29 m. 3D surface for both the weathered basement and the fresh basement were generated making use of the X, Y, and Z co-ordinates picked from the reflected seismic events on the individual 2D seismic profiles. The result showed that 3D reflection seismic was able to map-out the structural complexity within the subsurface that change over very little distance, thereby providing a better view of the structural settings within the subsurface. A joint inversion of both methods has proved to be better in the location of the best point for aquifer, than a single method used alone.

INTRODUCTION

The shallow-reflection technique is mainly used in mapping bedrock profile beneath alluvium in the vicinity of hazardous waste sites, detection of abandoned coal mines, following the top of the saturated zone during a pump test in an alluvial aquifer, and in mapping shallow faults. (Steeples and Miller, 1987).

Hydro-geological conditions, such as aquifer thicknesses, sediments and structure of alluvium, are important factors in determining the available intake of water by riverbank filtration (RBF). The high-resolution seismic survey, combined with (common midpoint) CMP refraction and Pbeam methods, is a powerful tool to obtain subsurface information and evaluate potential RBF sites (Hyoung and Jung, 2008).

The remediation of contaminated aquifers is important to the long-term health of water supplies. The design of appropriate remediation strategies (such as bioremediation or pump-and-treat) requires an understanding of aquifer properties and of the subsurface structure that may affect those properties (Thomas et al, 2004).

High-resolution surface seismic, acquired at a south Florida aquifer, delineated flow units associated with permeability between 1- 4 Darcy and porosity between 30 to 45 percent which shows that Seismic is the more practical method to use in south Florida for mapping flow units (Jorge and Chris, 2003).

The aim of this research work is to examine the effectiveness of joint inversion of refraction tomography and high resolution 3D seismic reflection survey in locating the best point of aquifer within the basement. The instruments used for this survey include 24 channels Terraloc Mark6 digital seismograph, vertical geophone, reels of cables and sledge hammer strike on base plate.

Location of the study area

The study area is bounded by latitude 11^o 08.870' N, 11^o 08.876' N and longitude 007^o 38.085' E, 007^o 38.093' E with an average elevation of 659 m above sea level (Fig. 1).

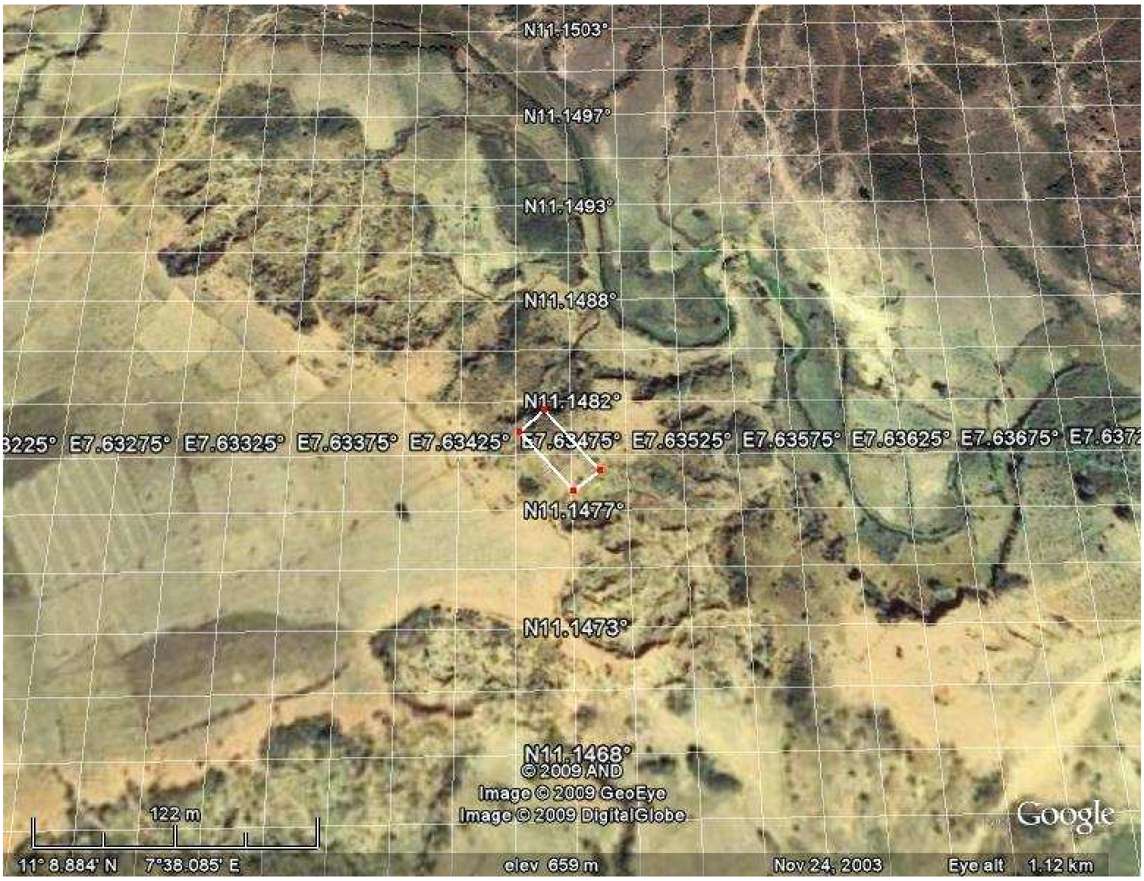

Figure 1: Location map of the study area, the red out line and the blue arrow represent the position of the 3D seismic reflection survey and the refraction tomography profile. Map adopted from Google earth.

Geology of the area

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. These rocks have been variably metamorphosed and granitized through at least two tectono-metamorphic cycles and folded during the Pan African Orogeny where exposure is good, contact of the batholiths with country rocks is sharp and often exhibits a phenomenal interbanding of granite injections with sheets of pre-existing schists and gneisses McCurry (1970).

Data acquisition

During the acquisition of data for refraction tomography, the receivers where placed at 5 m interval. An offset distance 30 m was used on both ends of the profile. The shots where fire at intervals of 2.5 m (to improve resolution), 30 m before the first receiver, at each receivers point, between the receivers and 30 m after the last receivers. The generated data was recorded for onward processing.

Individual parallel 2D profiles where acquired for the 3D seismic reflection survey. During the data acquisition the receivers where placed at 1 m interval, with a constant offset distance of 10 m. After each shot the first receiver close to the shot point was taken and inserted 1 m from the last receivers. The connections to each of the take-out were swapped in the direction of increasing profile. When all the connection was made, the instrument was "Armed", and the shots were repeated with a stack of 5 shots for each point, to improve the recorded data quality. The generated seismogram was recorded with the seismograph. The same processing flow was used for all the individual 2D seismic profile lines that constitute the entire 3D seismic reflection survey.

Data processing

The data processing for the refraction tomography started with importation of the raw seismic data and the edition of the wrong geometry. The next step on the processing flow was the application of the Bandpass filter. 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). Gain filter was applied to improve the amplitude of the weak refracted signals. The first arrival signal was picked by making use of the "pick" option in the interpretative software. The picked travel time was inverted to produce an initial model, which was used in conjunction with the observed travel time to iteratively generate a tomographic model of the subsurface.

The processing of the reflection data started with the importation of the raw seismic data and the edition of the wrong geometry. Gain filter was applied to enhance the amplitude of the weak reflection traces. fk filter was applied to remove refraction events and surface wave. The processed data was subjected to semblance analysis to produce a 2D velocity model, which was used for normal moveout correction and the stacking of the common midpoint traces. The stacked section was migrated in time using Kirchhoff migration. The migrated seismic section was converted into a depth section by making use of the earlier generated 2D velocity model. The reflection events for the different layers were correlated and "picked" by making use of the "pick" option by marking "x", as shown in figure2.

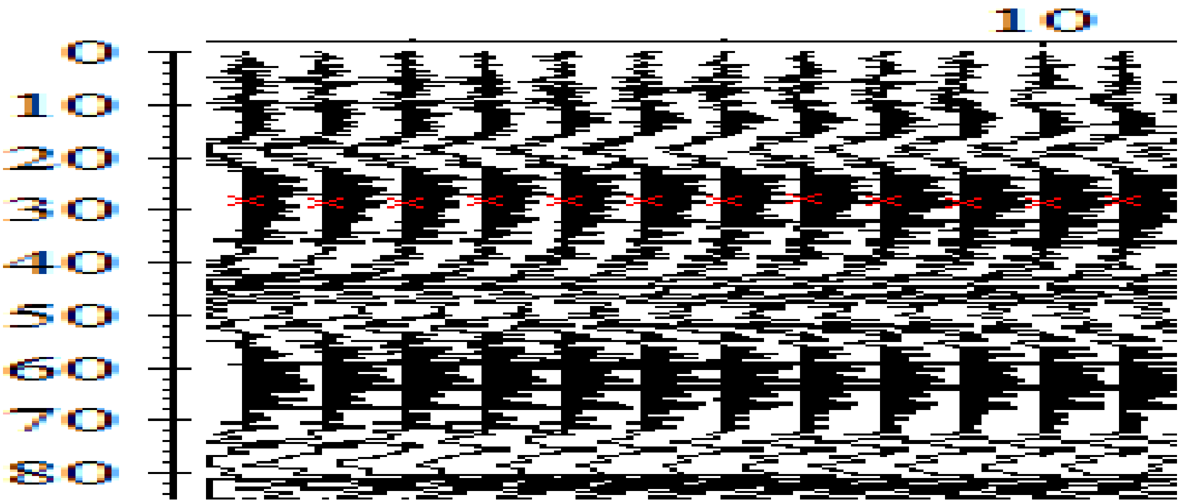

Figure 2: Part of the depth migrated seismic section Picked layer Mark with cross "x".

Each of the picked values generated the three Cartesian components X, Y and Z values of the reflection events. X direction along the profile, Y direction along the profile offset from other individual 2D profile lines, Z direction, which represent the depth to the reflector. The picked values were analysed with "Surfer" programme to produce 3D surface of each layer.

RESULTS AND DISCUSSION

The refraction tomography model of the subsurface is shown in figure 3. The distance along the profile displayed by the refraction tomography was the same distance covered by 3D seismic reflection survey for ease of comparison. The model actually depicts a general increase of velocities with depth, with an average overburden thickness of 20 m and an average overburden velocity of 994 m/s. The weathered basement has a velocity range of 1446 to 2912 m/s, with an average thickness of 9 m. The depth to the fresh basement is about 29 m, with an average velocity of 4400 m/s, starting from 3000 m/s. The top velocity of the weathered basement corresponds with the velocity of the water table of 1400 m/s (Keary et al, 2002). Indicating that the aquifer thickness could be about 9 m.

The 3D surfaces generated from the X, Y and Z co-ordinates of the reflection events, picked from the 5 parallel individual 2D seismic reflection profiles are shown in figure 4 and 5. Figure 4 depict the surface of the weathered basement, while figure 5 illustrates the 3D surface of the fresh basement. The shallowest part of the 3D surface of the weathered basement lays at the beginning of the survey when considered along Y direction, while the deepest part lays at the end of the profile lines when considered in Y direction. The 3D surface showed relative undulation along both X and Y direction, with a slight depression toward the end of the profile. The 3D surface slopes from the beginning of the profile toward the end. The surface of the fresh basement exhibit a wave like undulation, with the shallowest point at the centre of the profiles, and the deepest point at the end of the profiles when considered along the Y direction. It should be noted that despite the refraction tomography model was able to delineate the various layers within the subsurface and the water table, but in terms of the subsurface structure it was obvious that it was sited on a crest, considering the structural surface of the 3D surfaces. Making use of only the tomography model to determine the best point of aquifer within the subsurface would be very misleading, considering the level of undulation exhibited by the subsurface structure along

Y direction. In general the co-ordinate point of 30 m along the X direction and 3 m along the Y direction indicate the best point of the subsurface aquifer and the best point to sink a borehole, since it will constantly receive recharge from all direction.

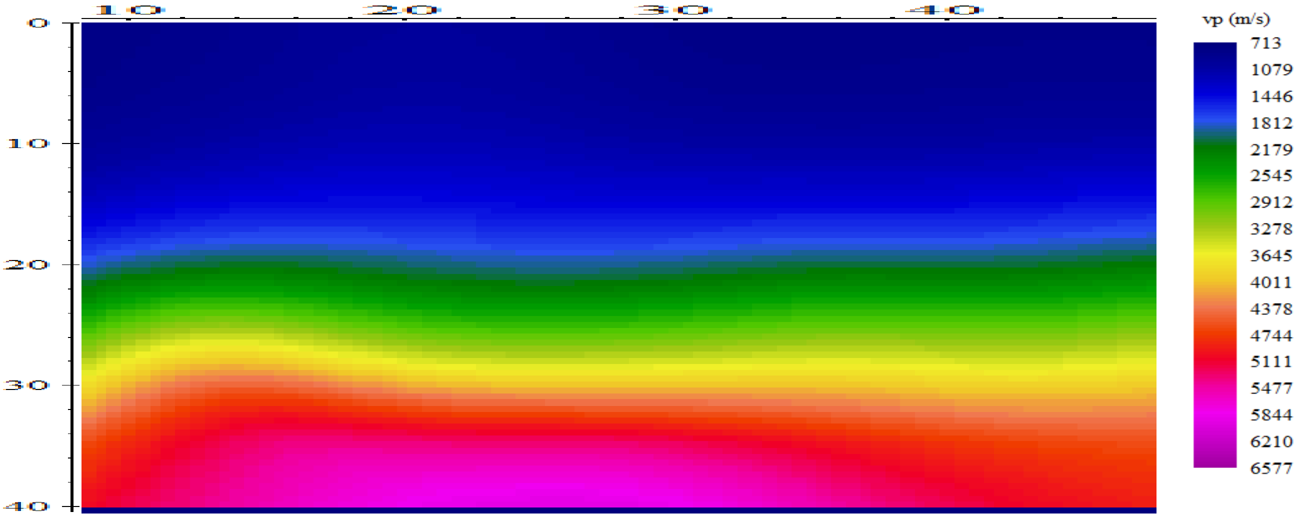

Figure 3: Seismic refraction tomography, showing the distribution of velocities within the subsurface

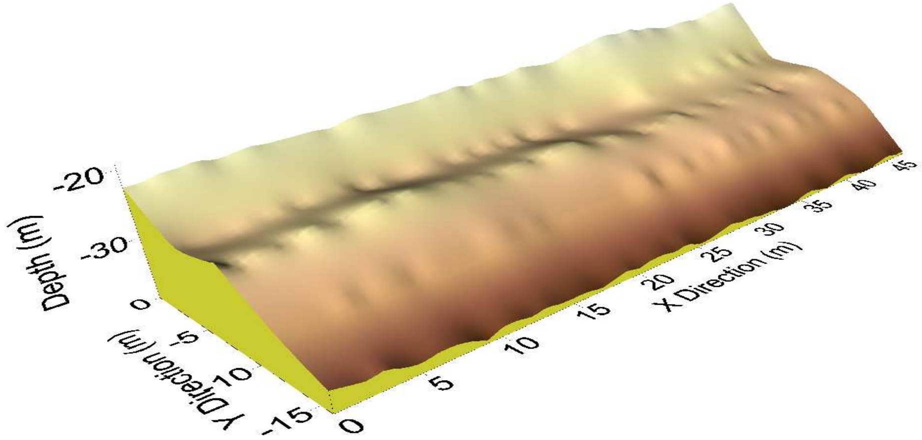

Figure 4: Generated 3D surface of the weathered basement

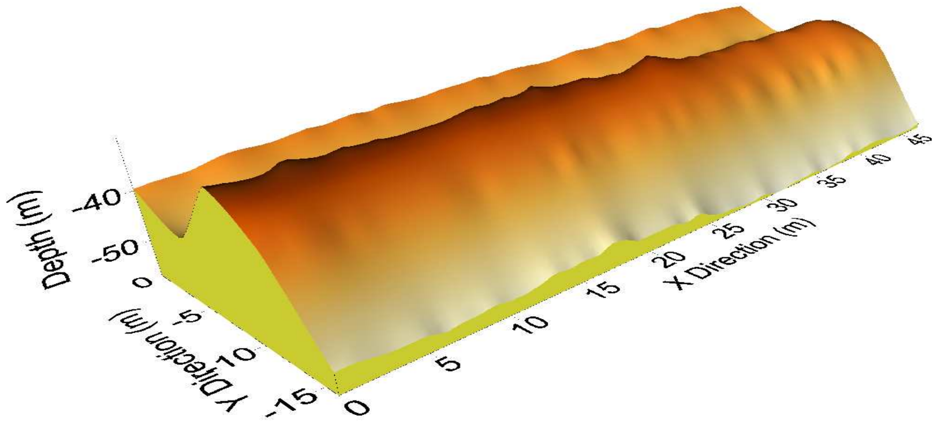

Figure 5: Generated 3D surface of the fresh basement

CONCLUSION

The tomography model was used to determine the velocities distribution within the subsurface. It was able to map out the depth and thickness of the various strata within the subsurface and delineate the position of the water table, but did not provide enough structural view of the subsurface, to be reliably used alone to determine the best aquifer point. However the 3D surfaces gave a better picture of the structural complexity of the subsurface, that aided the location of the best point of an aquifer making use of the earlier information provided by the tomography model. It can be concluded that a joint inversion of both method has aided in the location of the best point of aquifer, than a single method used alone.

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