APPLICATION OF SEISMIC REFRACTION TOMOGRAPHY FOR SUBSURFACE IMAGING IN CENTRAL NORTHERN NIGERIA

C.C. Chiemeke and I.B. Osazuwa
Department of Physics, Ahmadu Bello University, Zaria, Nigeria

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Abstract

Seismic refraction tomography involves the measurement of the travel times of seismic refracted raypaths in order to define an image of seismic velocity in the intervening ground. This technique was used to estimate the depth to the fresh basement, estimate thickness of the weathered basement and to determine the subsurface lithology within the Basawa area of Zaria, which lies within the basement complex of northern Nigeria. Results of this study show that the thickness of the overburden within the survey area is about 10.05m which is also the depth to the weathered basement. The thickness of the weathered basement is about 7.04m. That is, the depth to the fresh basement is about 17.09m. The lithology analysis revealed that the top soil is made up of laterite and silty clay. The main aquifer is made up of weathered basement, pebbles and gravels, while the fresh basement is composed of granite, and quarzites occurring with gneisses.

***Keywords**: Seismic refraction, tomography and Central Northern Nigeria.*

Introduction

Before the seismic refraction was introduced as a tool for oil exploration, its principles had been applied for some time by earthquake seismologist, to plot the distribution of seismic-wave velocities as a function of depth and thus obtain clues to the earth internal constitution (Dobrin, 1976).

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. Seismic energy is provided by a source ('shot') located on the surface or in a shot hole. For shallow applications this normally comprises a hammer and plate, weight drop or small explosive charge (blank shotgun cartridge). Energy radiates out from the shot point, either traveling directly through the upper layer (direct arrivals), or traveling down to and then laterally along higher velocity layers (refracted arrivals) before returning to the surface. In practice, the refracting interface is often not horizontal. The assumption of flat layers then leads to error in the velocity and depth estimates. 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 (Lowrie, 1997).

According to Osemeikhian *et al* (1994) the refraction method is mainly used for mapping of the weathered layer, for determining depth to water table and for engineering purposes, also for applying correction to reflection data.

Tomography is define as an imaging techniques which uses array of detectors to collect information from a beam of rays that has passed through an object, which is used by a computer to reconstruct the internal structure to produce an image (Tien-When *et al.*, 2002). The technique was introduced by a man called J.N. Honsfield in 1972 by first applying it in the area of medicine. He used it to view the internal structure of the body by making use of the rate of attenuation of x-ray. He and his men where able to view the internal structure of the body without initial operation carried out by doctors. Honsfield made use of rate of attenuation of x-ray but today it has been employed into the area of seismic by taking advantage of the difference in seismic velocities in different rock type.

Seismic refraction tomography is an imaging technique, which involve the measurement of travel time of the seismic wave, to determine the distribution of velocities within the subsurface. The shots and receivers are arranged in a straight line, to give a two dimensional image of the subsurface. Shots are taken before the first receiver, at each receiver point and beyond the last receiver position. The initial model is divided into grid of mesh cells, an initial velocity is assigned to each of the cells, which a process of forward modeling method. Synthetic travel time is calculated for each of the raypath that crosses each of the cells. The observe travel time with the calculated or synthetic travel time is now compared, if the observe travel time is not equal to the calculated travel time, the velocity in each cells is iteratively adjusted to update the models until the observe travel time becomes equal to the calculated. The resulting velocity model is what we referred to as a tomogram, which leads to accurate estimate of velocity within the subsurface.

The aim and objectives of the present work include estimating the thickness of the overburden, to define the basement topography, to identify different rocks unit within the subsurface and to determine the depth to the water table and aquifer.

The major instrument employed for this work include the Terraloc mark6 digital seismograph that has 24 channels, with very high dynamic range that is suitable for both reflection and refraction work. It has facilities for Infield velocity measurement. Another set of instrument is the vertical Geophone with frequency range of 4 to 100Hz, to pick both refracted and reflected seismic wave. Other instruments include reels of cable that has takeouts for the connection of geophones and a sledge hammer as the energy source.

Geology of the Study Area

Zaria area forms part of the northern Nigeria basement complex and apart from an extensive superficial cover, the rocks in this area can be divided into:

(i) a crystalline complex of migmatite and gneisses probably of Dahomeyan age, including relicts of an ancient Birrimian metasedimentry sequence,

(ii) a younger metasedimentry series of Katangan age occupying north-south trending synclinal belts in the crystalline complex, and

(iii) A suite of intrusive syntectonic to late tectonic granites and granodiorites of the late Precambrian to low Paleozoic age associated with extensive aplite and pegmatite development.

These rocks have been variably metamorphosed and granitized through at least two tectono-metamorphic cycles and folded during the Pan African orogeny resulting in tight isoclinal folding about an East-West and North-South axes and the alternating and deformation of rocks from low grade phyllites to high grade gneisses (McCurry, 1970).

Methodology

The layout geometry involves putting the receivers and shots in a straight line. The receivers were place at an interval of 5m, which resulted in a spread length of 120m. The shots were deployed at an interval of 5m before the first geophone at each geophone point and beyond the last geophone. The geophone at the shot position was offseted each time a shot is to be taken which would have been completely removed if an explosive was used instead of a sledge hammer as the energy source to avoid damage to the geophones. The traces were recorded at a sampling interval of 0.25 ms with 4096 number of sample which gives a record length of 1 second.

Processing

The raw data (Figure 1a) was subjected to spectrum to determine the dominate frequency of the seismic signal. Bandpass filter of 4 to 100Hz to get rid of any undesired unset. The gain filter was applied to enhance the weak seismic amplitude of the far traces. The first arrivals times (figure 1b) were then picked for each recorded and stored, which was used for inversion employing the method of wavefrontinversion to generate a model (Sandmeier, 2003).

The series expansion method which include curved ray paths was used in the model computation. Thus for a given source receiver pair the line integral of the model function M(r) over the raypath is

$$p^{obs} = \int_{ray} M^{true}(r)dr \quad (1)$$

where the observed projection given by the data function pobs represents the measured line integral (observed tomography data) and Mtrue (r) is the true model function which remains to be determined. The last equation is used to formulate the forward modeling by setting

$$p = \int_{ray} M(r)dr \quad (2)$$

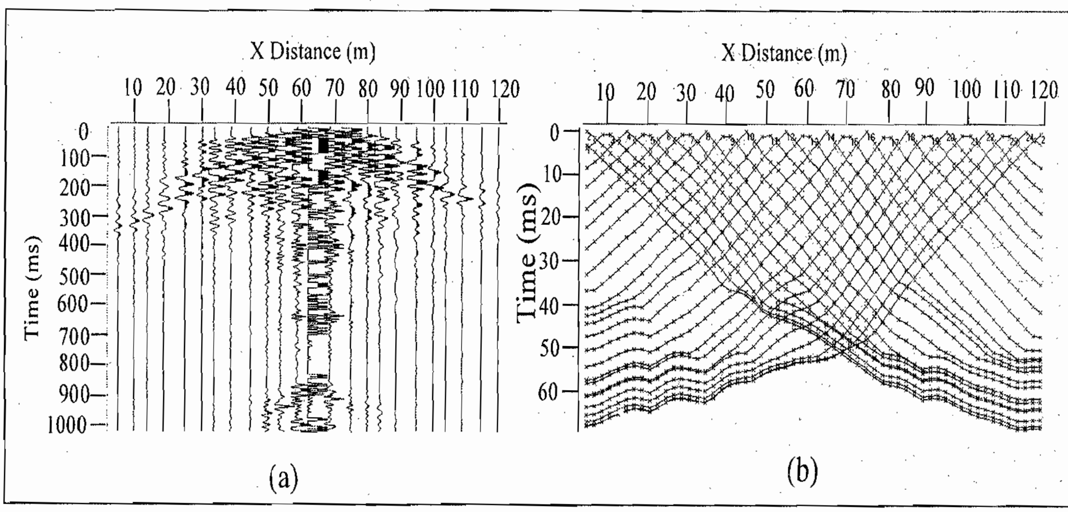

Fig. 1: (a) Raw data, (b) picked arrival times

where p is now the predicted function and M(r) is the estimated model function. Thus forward modeling is defined as determining the predicted data function from the line integral along the raypath through known, but estimated, model function

For a discretized model function function equation 2 is rewritten in discrete form, to describe ray through the discrete model function as .

$$p = \sum_{j=1}^{J} M_j S_j \quad (3)$$

where Mj is the estimated model function for the jth cell, Sj is the raypath length of the ray within the jth cell, and J is the total number of cells in the gridded target.

The addition of extra rays will make all the cells to be interrogated by this network of rays. Therefore we modify the index of equation (2) to include a projection value for every ray. If pi represent the projection, or line integral predicted for the ith ray, then equation (2) is rewritten as

$$p_i = \sum_{j=1}^{J} M_j S_{ij} \quad {for\ i=1,......I} \quad (4)$$

Where I is the total number of rays, Sij is the path length of the ith ray through the jth cell.

Result and Discussion

Figure 1 is a tomography model showing the distribution of velocities within the subsurface. It represent a cross sectional map of the seismic velocity distribution within the subsurface. 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 (Kearey el al 1984).

The pole like structure at the center of the spread represents a borehole sank at the

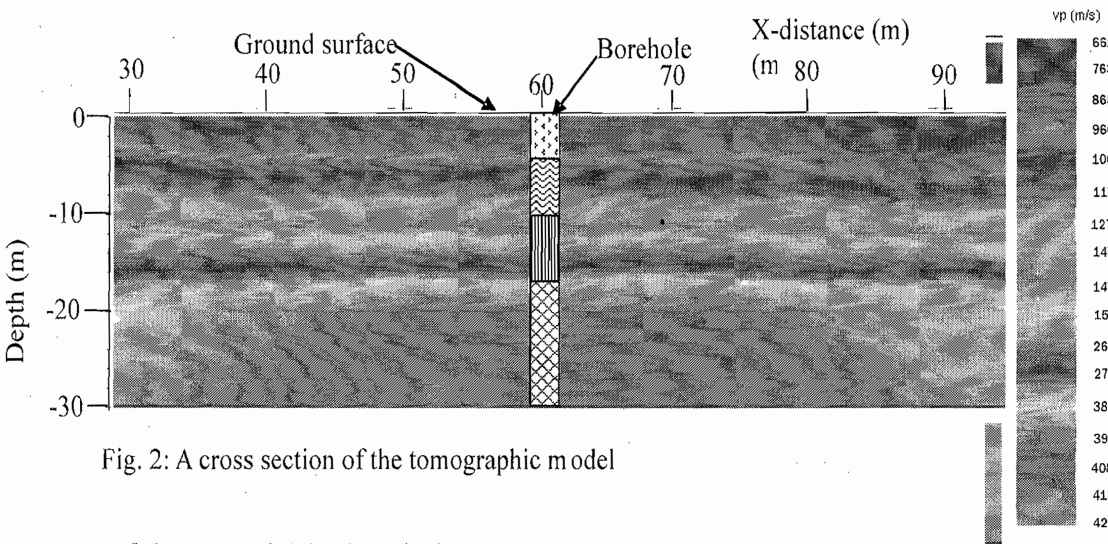

Fig. 2: A cross section of the tomographic model

centre of the spread. The borehole data are shown in Table 1. The borehole log was correlated with tomography section, and it was discovered to be in one to one correspondence in terms of depth and lithology when the tomography section was related to standard velocities table.

The result obtained from the tomographic models indicates that the top soil (Figure 3) which is highly weathered extended to a depth of 4m below the surface. The overburden thickness which comprises the top soil and the weathered layer is about 11.05m, which also stands as the depth to weathered basement. The depth to the fresh basement is about 17.09m, thereby giving the thickness of the weathered basement as 6.04m. The

Table 1: Lithology and aquifers borehole log

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

Note :
* Limit of refraction tomographic investigation
** Limit of geological borehole log
† The calibration is not to scale, it is only representative

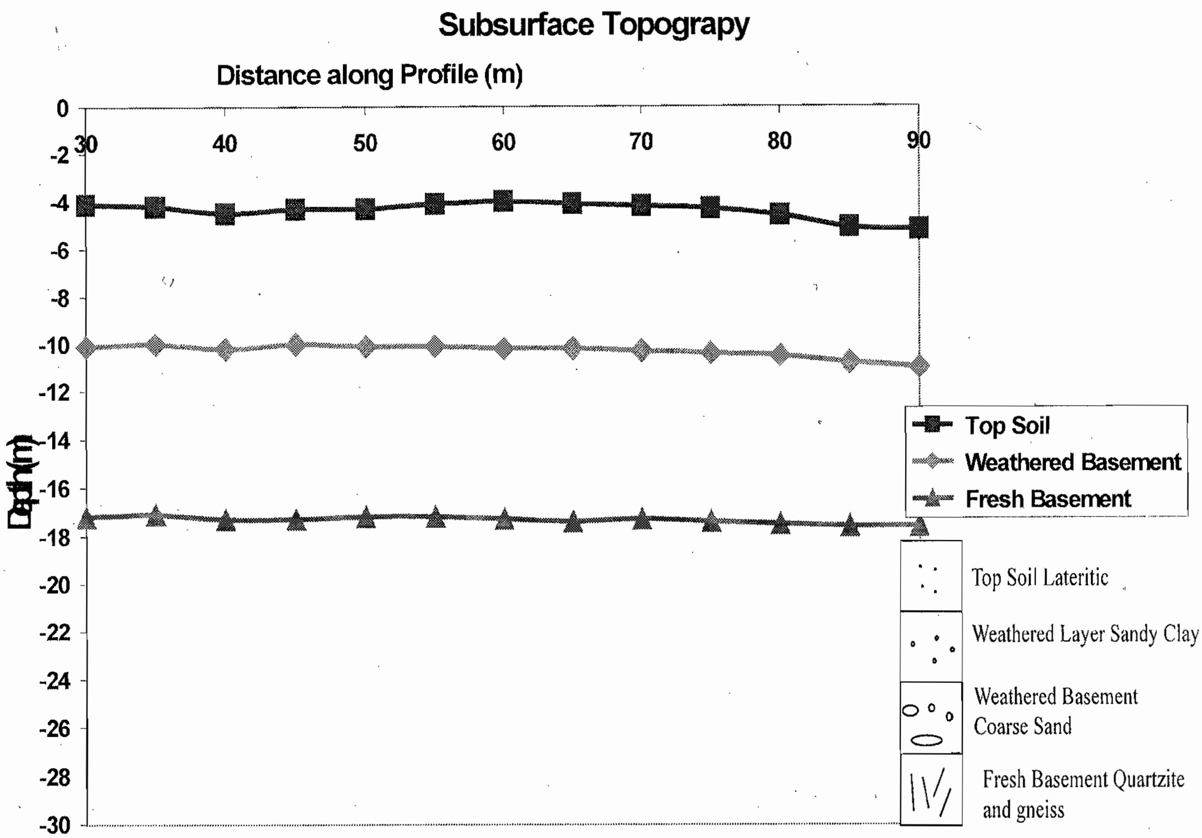

Fig. 3: Equivalent geologic section derived from the tomographic model

lithology analysis revealed that the top soil and the weathered layer is made up of laterite and silty clay, the weathered basement which is the aquifers, is made up of pebbles and gravels, while the fresh basement is composed of granite, quartzite occurring with gneisses.

Conclusion and Recommendations

The result has shown that seismic refraction tomography can be used to image the subsurface to delineate the various strata within the subsurface. The thickness of the overburden and the weathered basement couple with the depth to fresh basement was accurately determined. The distribution of velocity within the tomographic section indicates that it can be used to characterize the lithology of a formation in the availability of a borehole data and standard velocity table. Another advantage of the tomography section is that it can tell us to what extent a particular structure identified by borehole log extends along the profile. It is recommended seismic tomography which gives a more detailed and accurate result should be used to image the subsurface instead of the conventional forward and reverse seismic refraction method which gives information at only the shot point. In the case of geotechnical survey, seismic tomography should be used being more cost effective in the determination of elastic parameter than drilling.

References

Dobrin, M. B. (1976): Introduction to Geophysical Prospecting (3rd Edition), Mcgraw-Hill, New York. 630pp.

Kearey, P. and Brooks, M. (1984): An Introduction to Geophysical Exploration. Adlard and Sons Limited, The Garden City Press, Letchworth, Herts. 296pp

Lowrie, W. (1997): Fundamental of Geophysics Cambridge University Press 354 pp.

McCurry, P. (1970): The Geology of The Zaria Sheet 102 S.W. And It's Region. In: Mortimore, M.J. (Ed.). Department of Geography, Occasional Paper, No.4. Ahmadu Bello University, Zaria.

Osemeikhian, J. E. A and Asokhia, M. B. (1994): Applied Geophysics, Stamatas Services Ltd.

Sandmeier, K. J. (2003): User's Guide, Manual on Reflex Software, K.J. Sandmeier Zipser Strabe 1 D-76227 Karisruhe Germany .

Telford, W. M., Geldart, L. P., Sherriff, R. E. and Keys, D.A. (1976): Applied Geophysics, Cambridge University Press.

Tien-When, L. and Philips, L. (2002): Fundamentals of Seismic Tomography. Society of Exploration Geophysicists.