Seismic Refraction Survey of the Area Northeast of Minna, Nigeria

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Abstract

Seismic refraction survey was carried out in the area northeast of Minna to ascertain the suitability of the area as a residential area. The survey was carried out along 6 profiles equally spaced out at interval 100 m with each profile consisting of 16 sub profiles of 60 m. A total area of 1 kilometer by 500 m was gridded and surveyed. High velocity values were obtained in some part of the area, most especially, in the northeastern and southwestern portions of the area. Careful interpretation of the seismic data obtained shows two-layer geologic section within the survey area. The first layer velocity varies between 909.1 m/s and 1538 m/s with an average value of 1340 m/s The second layer velocity, otherwise known as the refractor layer velocity, ranges between 2160 m/s and 8364 m/s, with an average velocity of 5240 m/s. The velocity range for the layer indicates that the topsoil is mainly composed of clay, sand and alluvium whilst the bedrock is mainly composed of rocks of the basement complex. Thus, the study reveals that the sites most suitable for the construction of high-rise buildings are found around the northeastern and southwestern portions of he area where high refractor velocities are obtained.

Introduction

The survey area is the portion of land, which comprises Maryam Babangida Girls' Science College, Basso Secondary School, Tudun Fulani Primary School and the old abandoned site for Basso market. This piece of land extends westwards to hit the western by-pass, which joins the Minna-Zungeru express road at Tudun Fulani. The area is one 1000 m by 500 m and the entire area is reserved for residential purpose, hence, the principal focus of this survey is predicated on finding out the suitability of the place as a residential area. The survey area is a basement complex with superficial deposits being mainly granitic and lateritic rocks, coupled with the usual soil cover. Right in the area runs a stream in the north-south direction. The immediate vicinity of the stream is made up of fadama alluvial soil materials. Basically the lateritic rocks are very coarse textured and loose in nature and they are mostly dark-brown to reddish in colour A large portion of the area lies in the valley, and in the raining season the area is highly subjected to erosion and deposition of soil materials. The area is located between latitudes 9°38' and 9°4' north of the equator and longitudes 6°30' and 6°3' east of the Greenwich meridian in the lowland of the River Niger and River Benue, Fig 1. About half of the land is already covered with buildings, which are mostly the state government's secondary school buildings. Only residential buildings of the Tudun Fulani community occupy a small portion of land specifically the portion along the Minna-Zungeru express. The Inurat Plastic Factory is located at the extreme northeast corner of the land. The residents of Tudun Fulani and the staff members of Maryam Babangida Girls Science College use the remaining portion of the land intensively for farming activities.

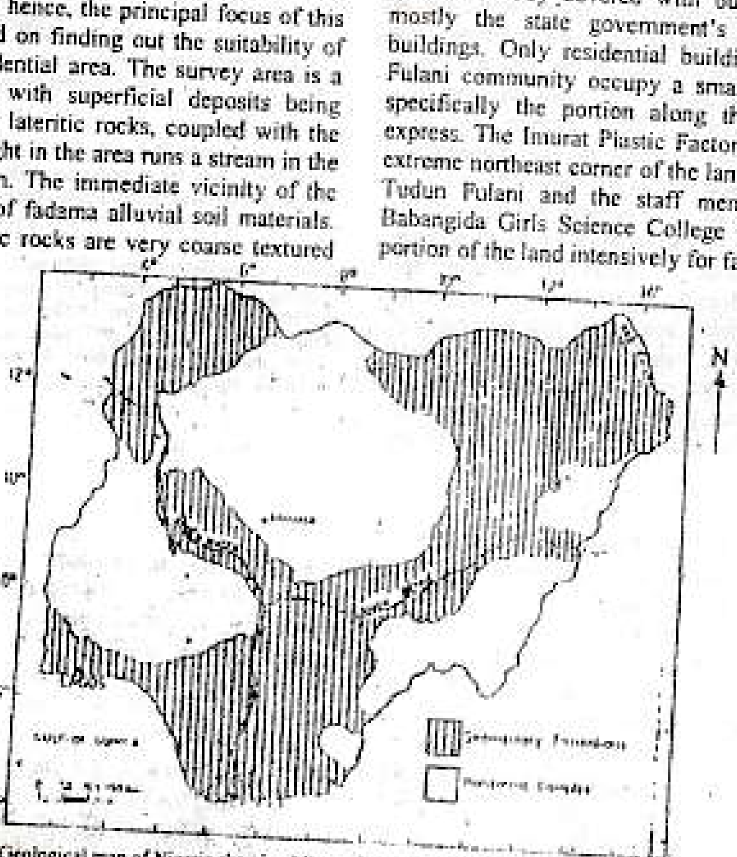

Fig. 1: Geological map of Nigeria showing Minna, the project location (After Udensi *et al.* 1986)

Geological Background

Minna and its environs fall within sheet 164 and are wholly covered by rocks of the basement complex. The basement complex consists of a floor of crystalline rocks of (1) migmatite-gneiss complex, (2) two low-grade schist belts and (3) an older granite suites '. The geology was described by Truswell and Cope (1963), Ajibade (1971, 1980), Grant, (1978) and Udensi *et al* (1986). The migmatite-gneiss complex is considered to be the oldest unit in the Nigerian basement complex based on age determination which show that it had gone through four major cycles of deformation, metamorphism and remobilization, in the Liberian (2700 Ma); the Eburnean (2000 Ma); the Kibaran (1100 Ma). and the Pan African cycles (600 Ma) (Grant *et al*, 1919; McCurry 1970; Gandu *et al*, 1986).

The schist belt consisting of gneiss and migmatite are of the upper proterozoic age which is comparable to the green stone belt of the Archean gneissic and granitic terrain. The schist belt extend into the area as two distinct elongated bodies each with a strike length of more than 30 kilometres and the belt are found around the Kusheriki and Kushaka areas. The Birnin-Gwari fomation lies to the west of the older granite suite, while the Kushaka schist formation lies to' the west. Grant (1978) described the structural dissimilarities between the two formations and concluded from geochronological measurements that the Birin Gwari and the Kushaka schist formation are different in age. However, this assertion has been disputed by Ajibade (1980) and Udensi *et al* (1986) through field evidence, that the two formations have been through the same number of age and style of deformation.

The term older granite was introduced to distinguish the Pan-African granites in Niger State from the Mesozoic tin-bearing volcanic granite ring complexes of the Jos plateau and environs, commonly referred to as the younger granites. The older granities are emplaced into the migmatites-gneiss complex in the schist belt. The older granite is a coarse to very coarse prophyritic granodiorite with large white or pink megacrysts of potash feldspars up to 4 cm long. Around Minna and environs, the older granities are found emplaced in the metamorphic rocks within the entire basement complex The largest granitic bodies occur in the southern part of the town. The Minna batholith as desc ibed by Ajibade (1980) cuts across the Birin-Gwari formation and the Zungeru mylonites. It is composed mainly of coarse-grained homogenous granodiorite. Other rocks include tonalite and granite, all are of granitic origin and conform with the general structure of grantitic rocks.

The Seismic Survey

The total area surveyed, about 1000 m 500 m, was gridded into portions of 60 m by 100 m, Fig 3. The method employed in the survey is the inline refraction profiles. It involves shooting an unreversed refraction profile along a line. The profiles were shot in segments of 60 m each for convenience purpose The basic techniques of refraction seismic exploration comprise of generating seismic waves in this case by striking a sledgehammer on a steel plate to generate compressional seismic waves. The time required for the waves to travel from the source to geophones dispersed along a straight line was measured from a 3- channel seismograph. A delay time of 150 ms was subtracted from the arrival time of the waves.

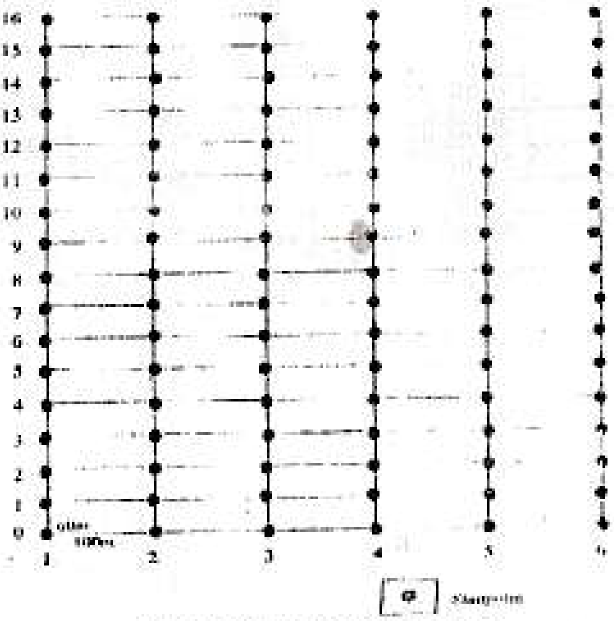

Fig. 3: Profile layout of the survey area

Data Analysis and Interpretation

The method used to analyze the data is that Wyrobek (Telford *et al*, 1976). This method uses graphic aid to compute the average velocities of v1 and v2 that is, first layer velocity and second layer velocity respectively. From the slope of the t - d (time-distance) graph, 't', in seconds measures the arrival times of the wave plotted against 'd' in metres, the geophone spacing. The intercept time t' and the crossover distance Xc are also determined from the graph. All these parameters are determined for all the profiles and shown in Tables 1 to 6. Depth to refraction, z, at each shot point is obtained by dividing intercept time by two to get half intercept time often called the "delay time: D". Values of the delay time at each shot point along the profile are multiplied by a factor F for conversion to depth. For homogeneous overburden as assumed for this survey:

$$\text{Slope} = \frac{\text{change in time}}{\text{change in distance}} \qquad 1$$

$$\text{Velocity} = \frac{1}{\text{slope}} \qquad 2$$

$$Z = t_0 F \qquad 3$$

Where F is given as

$$F = \frac{v_1 v_2}{\left[v_2^2 - v_1^2\right]^{\frac{1}{2}}} \qquad 4$$

This procedure was carried out for all the shot points to obtain V1 and v2, i.e velocity of the first layer and velocity of the second layer (refractor velocity). The two velocities along with intercept time yield z (depth to refraction). The depths to refractor for all shot points are also shown in Tables 1 to 6.

Table 1: velocity of overburden, refractor and critical distance for profile 1

Profile	Depth to refractor, z (m)	Velocity of overburden v_1 (m/s)	Velocity of refractor, v_2(m/s)	Critical distance X_c(m)
1.1	7.3	1538	4878	28.0
1.2	7.1	1666	3636	30.0
1.3	5.5	1333	2486	24.0
1.4	4.5	2000	4292	14.0
1.5	3.1	1250	3497	12.0
1.6	7.3	1333	6250	20.5
1.7	5.1	1176	4630	16.0
1.8	4.5	1600	3226	28.0
1.9	5.7	1420	8264	21.0
1.10	2.4	1333	3003	18.5
1.11	2.3	1666	4000	15.5
1.12	3.1	1429	4000	12.5
1.13	6.8	1538	4878	19.5
1.14	1.7	2000	8133	24.0
1.15	11.0	1000	8264	19.0
1.16	3.6	1176	3663	12.5
[illegible]	5.1	1466	4486	21.0

Table 2: Velocity of overburden, refractor and critical distance for profile 2

Profile	Depth to refractor	Velocity of overburden, V_1(m/s)	Velocity of refractor V_2(m/s)	Critical distance, X_c (m)
2.1	4.0	1176	4405	11.5
2.2	3.5	1176	3571	13.5
2.3	3.5	1538	4000	15.5
2.4	7.5	1666	5000	22.0
2.5	2.7	2222	3559	19.5
2.6	4.0	1538	3623	18.5
2.7	5.6	1666	4132	22.0
2.8	8.3	1818	5263	31.0
2.9	5.6	1429	5000	35.0
2.10	4.4	1538	4000	19.0
2.11	5.4	1538	4566	22.0
2.12	7.3	1432	5495	38.0
2.13	7.2	1333	4132	31.0
2.14	6.7	1176	4132	24.5
2.15	4.6	1250	4566	20.0
2.16	4.3	1111	4166	16.0
Average	5.2	1475	4353	21.7

Table 3: Velocity of overburden, refractor and critical distance for profile 3

Profile	Depth to refractor, z (m)	Velocity of overburden V_1(m/s)	Velocity of refractor V_2(m/s)	Critical distance X_c (m)
3.1	4.2	1143	4255	17.0
3.2	2.5	1143	3003	17.5
3.3	3.6	1250	3333	16.5
3.4	3.0	1081	4000	15.5
3.5	4.6	1538	4132	18.0
3.6	3.4	1250	3623	21.0
3.7	4.0	1053	3623	14.5
3.8	7.6	1429	4808	19.0
3.9	3.8	1212	3676	22.0
3.10	3.4	1538	4202	12.0
3.11	5.2	1818	3759	13.0
3.12	6.5	1481	4291	28.5
3.13	2.9	1053	3390	17.5
3.14	3.0	1053	3610	30.0
3.15	6.1	952.4	7407	16.5
3.16	5.0	1176	3891	11.5
Average	4.3	1242	4095	16.8

Table 4: Velocity of overburden, refractor and critical distance for profile 4

Profile	Depth to refractor, z (m)	Velocity of overburden v_1(m/s)	Velocity of refractor v_2(m/s)	Critical distance X_c (m)
4.1	3.7	1333	3472	20.0
4.2	4.4	1176	3861	15.0
4.3	5.6	1176	6024	18.0
4.4	1.9	1053	2907	17.0
4.5	2.8	1000	3125	11.0
4.6	1.9	1250	1740	13.0
4.7	5.6	1190	5814	17.5
4.8	2.0	1290	2817	15.0
4.9	2.1	1429	6003	18.0
4.10	2.3	1538	3534	21.0
4.11	4.6	1428	44132	13.0
4.12	3.4	1053	4000	18.5
4.13	4.9	1429	4166	15.0
4.14	4.2	1666	3333	18.0
4.15	3.4	1176	4000	12.5
4.16	3.5	1111	3774	18.0
Average	3.5	1264	3794	14.4

Table 5: Velocity of overburden, refractor and critical distance for profile 5

Profile	Depth to refi6.4actor	Velocity of overburden v_1(m/s)	Velocity of refractor v_2(m/s)	Critical distance X_c (m)
5.1	3.5	1053	3676	15.0
5.2	2.8	925.4	3759	18.0
5.3	6.4	1111	5682	18.0
5.4	6.4	1000	6024	24.0
5.5	4.8	1211	3663	15.0
5.6	5.8	1111	4608	20.5
5.7	7.5	1111	8000	19.5
5.8	7.6	1020	7519	16.5
5.9	8.7	909.1	3623	16.5
5.10	4.3	1052	4505	20.0
5.11	2.0	1111	5000	28.0
5.12	1.5	1538	3759	18.0
5.13	4.0	1176	3891	20.5
5.14	6.8	1143	6024	19.5
5.15	4.1	909.1	6024	21.0
5.16	4.9	1250	6024	20.0
Average	5.1	1104	5111	16.3

Table 6: Velocity of overburden, refractor and critical distance for profile 6

Profile	Depth to refractor, z(m)	Velocity of overburden, v_1(m/s)	Velocity of refractor v_2(m/s)	Critical distance X_c (m)
6.1	6.4	1111	6024	12.5
6.2	5.3	1000	5000	17.5
6.3	2.8	1000	6160	15.5
6.4	7.5	1333	7752	20.0
6.5	7.1	1111	6666	20.5
6.6	6.5	1176	5525	20.0
6.7	7.6	1111	7042	10.5
6.8	2.5	909.1	2777	15.0
6.9	6.1	909.1	6666	21.0
6.10	7.1	1176	6024	28.0
6.11	7.3	1333	6666	18.0
6.12	3.8	1429	3759	18.5
6.13	6.1	1111	6666	22.0
6.14	7.1	1212	6250	21.5
6.15	6.3	1250	5263	15.0
6.16	4.0	1111	3802	15.5
Average	5.9	1143	5503	18.0

Velocity is the most important parameter used in the interpretation of this work. This is the velocity of compressional seismic energy (wave) propagating through the various units of the sub-surface. Since different rock types have their characteristic velocities, it implies that obtained velocities can be used to predict or identify the sub-surface rocks and their associated materials or minerals. Based on the field data obtained the first layer velocity vi, the second layer velocity "12 and the depth to refractor for various profiles are calculated and shown in Tables 1 to 6.

Table 1 shows that the range of velocity of the first layer is between 1333 m/s and 2000 m/s, and the range for the second layer is between 3003 m/s and 8264 m/s with the average for both layers at 1555m/s and 4880 m/s respectively. The depth to refractor varies from 1.7 m to 11.0 m with an average depth of 5.3 m. Table 2 has the range for the first layer velocity to be from 1111 m/s to 2222 m/s whilst the second layers velocity ranges from 3571m/s to 5000 m/s. Both has average velocity of 1568 m/s and 4628 m/s respectively. The depth to refractor varies from 2.7 to 8.3 m with an average depth of 5.6.

Table 3 first layer velocity ranges from 952.4 m/s to 1818 m/s. second layer velocity range from 3003 m/s to 7407 m/s. with average velocities of 1338 m/s and 4324 m/s respectively. The depth to refractor varies from 2.5 m to 7.6 m, with an average depth of 4.6 m

Table 4 shows that first layer velocity range from 1000 m/s to 1666 m/s and second layer velocity range from 3003 m/s to 6024 m/s. with average of 1347 m/s and 4031 m/s respectively for both layers. The depth to refractor ranges between 1.9 m and 5.6 m with an average depth of 3.7 meters.

Table 5 shows that first layer velocity range from 909.1 m/s to 3623 m/s and second layer velocity varies from 3623 m/s to 8000 m/s. Both have average velocities of 1173 m/s and 5431 m/s respectively. The depth to refractor ranges between 2.8 m and 8.7 m with an average of 5.8. Finally in Table 6, first layer velocity range from 9091 m/s to 1333 m/s with an average velocity of 1214 m/s. Second layer velocity range from 2160 m/s to 7752 m/s with an average of 5550 m/s. The depth to refractor ranges from 2.5 m to 7.5 m an average depth of 6.2 m.

From the analysis, the average velocity is 1366 m/s and that for second layer velocity is 4807 m/s. The depth to refractor has average value of 5.2 m all for the total areas surveyed. The average range of velocity is as following, first layer velocity 1214 m/s to 1568 m/s, second layer velocity 4031 m/s to 5550 m/s. It is evident from the analysis that the first layer velocity value correlates with the nature (type) of topsoil characteristic of the survey area, which is alluvium and clay. The second layer velocity indicates basement complex rocks The shot points distance, cumulatively arranged and used as longitudinal parameters against the profiles spacing (latitudinal parameter) and using the appropriate computer software program the contour maps for v1, v2 and z are produced. Figs 4 to 6. The contour map for the first layer reveals some closures and close contour line spacing in the northwestern and southeastern ends of the survey area, with the closures trending from the northwest to southeast across the middle portion of the area. These are areas where high velocity for v1 is obtained. Compact fine granites characterized these areas. Low velocity v1 is obtained in the extreme west of the area where the depth to bedrock is high and loose coarse granite rocks are found mostly. Areas marked X on the contour map are probable sites for sinking boreholes. Very low velocity value for v1 and the highest depth to bedrock of about 9m are recorded in these areas.

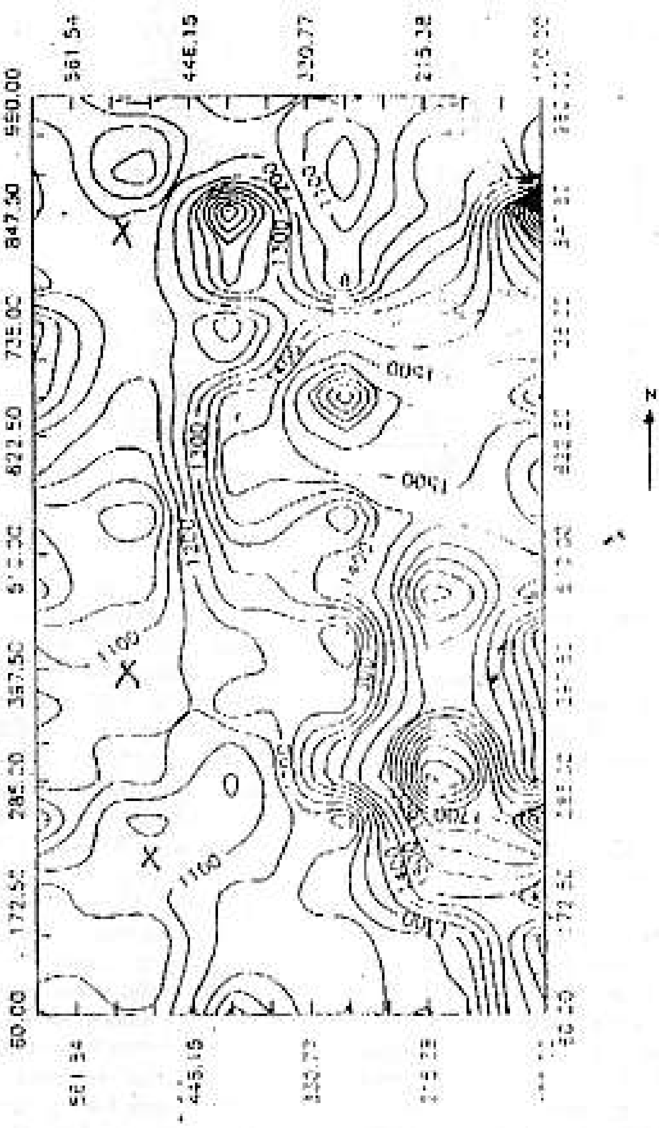

Fig. 4 Contour map v_1 showing some closures

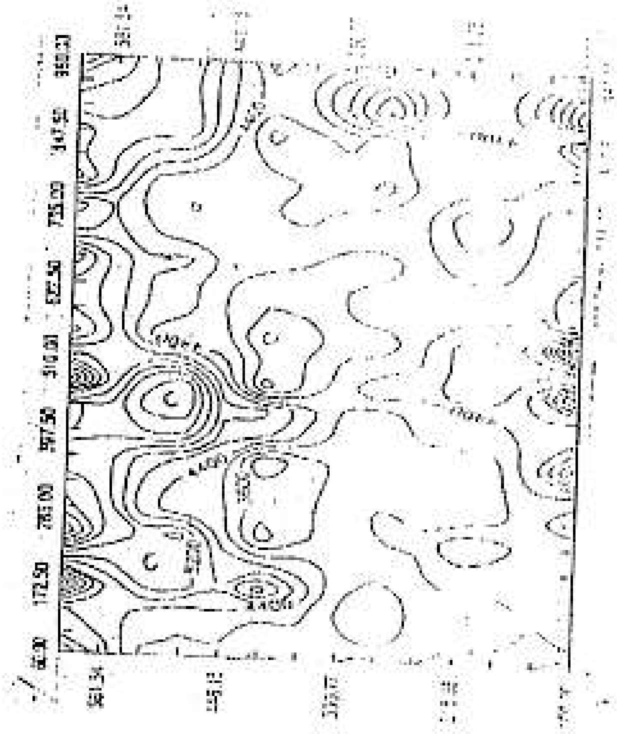

Fig. 9: Contour map v2 showing some closures

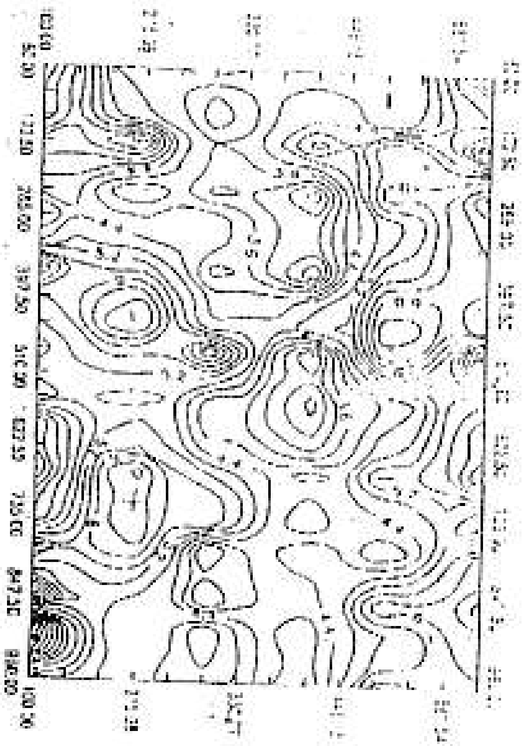

Fig. 4: Contour map of t showing some closures

The contour map of V2 shows high velocity in the southwestern and the northwestern corner of the survey areas some closures marked C can be seen in those areas. On average high velocity, over 4000 m/s is recorded all over the survey areas except in the central portion where the bulk of the stream is found

High velocity areas are likely to be suitable for erecting high rise buildings and access roads at much lower cost, because of the compact nature of the soil stratum and the nearness of bedrock to top soil. An average depth to bedrock of 4.0m is recorded in these areas.

Conclusion

The occurrence of different rocks types in the survey area is the cause of the difference in the overburden velocities (v1 and wide range of values obtained for the refractor velocities (v2). Areas where the basement rocks intrude into the top layer may provide solid foundations for high-rise buildings, and where troughs are observed are likely areas for sinking boreholes.

Recommendation

Unreversed seismic refraction shooting method has been used for exploration in this work. Reverse seismic refraction shooting method may also be used as a secondary seismic refraction method to confirm the finding of this work, most especially the presence of dipping refractors. Some other geophysical methods like magnetic or resistivity may also be employed to further verify the conclusion of this work.

References

Ajibade, A. C., 1971: The Geology of the Country around Zungeru North-West Niger State of Nigeria. Unpublished M.Sc Thesis, University of Ibadan, Nigeria, pp 20 – 55

Ajibade, A. C., 1980. Geotectonic Evolution of the Zungeru Region. Unpublished Ph.D Thesis. University College of Wales, England.

Gandu, A. H., Ojo, SB. and Ajakaiye D. E. 1996. A Gravity Study of the

Precambrian Rocks in the Mahamfashi Area of Kaduna State, Nigeria:

Tectonophysics., 126 Elsevier Science Publishers. Amsterdam. pp 181 – 194.

Grant, M. K., Ree O. C., Burke, R. C. 1969: The Geological sequence and Geochenology of Old Basement Rocks from Ibadan, Nigeria: Ann Fac. Sci. Univ. Clermont No 41, Geol. Mineral 19:84.

Grant, N. K., 1978: Structural Distinction Between a Metasedimentary Cover and Underlying Basement in the 600m.y. Old Pan-African Domain of Northwest Nigeria, WestAfrica. Am. Geol. Soc. Bull. 89.pp.50 – 58.

McCurry, P. 1970: The Geology of Degree Sheet 21(Zaria). M.Sc Thesis. Ahmadu Bello University of Zaria: 1 39pp.

Truswell, J. F., and Cope, R. N. 1963. The Geology of Parts of Niger and Zaria Provinces Northern Nigeria.

Udensi, E. E., Ojo S. B. and Ajakaiye, D. E., A 1986. Three Dimensional Interpretation of the Bouguer Anomalies over the Minna Batholith in Central Nigeria.