GEOTECHNICAL AND HYDROGEOPHYSICAL INVESTIGATION OF SUBSURFACE SEDIMENT IN BAUCHI AND ENVIRONS, NE NIGERIA.

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ABSTRACT

The study area falls within latitudes 10º00ˈ and 10º30ˈ N and longitudes 9º30ˈ and 10º00ˈE. A total of thirteen soil samples from different locations were used for geotechnical analysis. The geotechnical result indicated mean plasticity index of 17.20%, mean optimum 9.30cm^3, moisture content of 7.67% at mean maximum dry density of 2.50g/cm^3. A mean cohesion values of 0.25cm^2/kg and a mean angle of internal friction value of 30.80º suggesting very erodible of the soil. Seven Schlumberger vertical electrical sounding (VES) and fifteen Seismic refraction profiles carried out around Bauchi and its environ have been interpreted. The resistivity data were first interpreted using conventional partial curve matching technique in order to obtain the initial model parameters. The model parameters obtained were used as input into an optimizing computer program. The results obtained from VES 6 and 7 display the presence of three-layer earth model. The first layer consist loose topsoil materials; the second is weathered and/or fractured basement, while third layer is the bedrock. However, VES 1-5 display four-layer earth model, whereby the thickness of the weathered and/or fractured basement is over 19m, except VES 2 where the thickness is 8.7m. The results obtained from the fifteen seismic refraction profiles indicate also a three-layer model. The first layer represents the topsoil with an average of 146 m/s and a mean thickness of 3.1 m. The second layer has an average velocity of 1809 m/s and a mean thickness of 13.6m. This represents the weathered/fractured basement. Third layer has a mean velocity of 4496 m/s, and represents fresh basement. The results from this study will serve as background information for groundwater prospecting and subsequent exploitation.

Keywords: Geology, Sediment, Resistivity, Seismic refraction, Groundwater, Bauchi.

INTRODUCTION

The study area falls within latitudes 10º00' and 10º30' N and longitudes 9º30' and 10º00'E. It is bounded to the south-east by Alkaleri to the west by Tafawa Balewa, to the north by Ganjuwa. It is easily accessible by the Bauchi – Jos link road, Bauchi – Kano link road and Bauchi – Maiduguri link road. The study area is located in high relief. As a result run-off is relatively high and infiltration rate is low. The groundwater storage which is already limited by geological factors is further reduced by adverse climatic conditions.

Crystalline rocks weather more easily and deeply under humid conditions. More water is available for storage under favourable rainy environments. Hence, in the Bauchi area underlain by crystalline formation, groundwater and surface water are scarce and problematic. Experience all over the World has shown that the rate of failure of boreholes is usually highest in the basement complex terrains. This is due mainly to an inadequate knowledge of shallow aquifers which results from in-situ weathering and/or denudation basement rocks. It is only around the late 1950's that geophysical techniques have been realized as a very reliable tool to solve this sort of exploration problem (Hazell et al., 1988). The hydrogeochemical investigation of the sub-surface water is very important in determine the chemical characteristics and content of heavy metals in the groundwater. Some geotechnical parameters were also measured with a view of providing lacking geotechnical information on the weathered basement rocks of the study area.

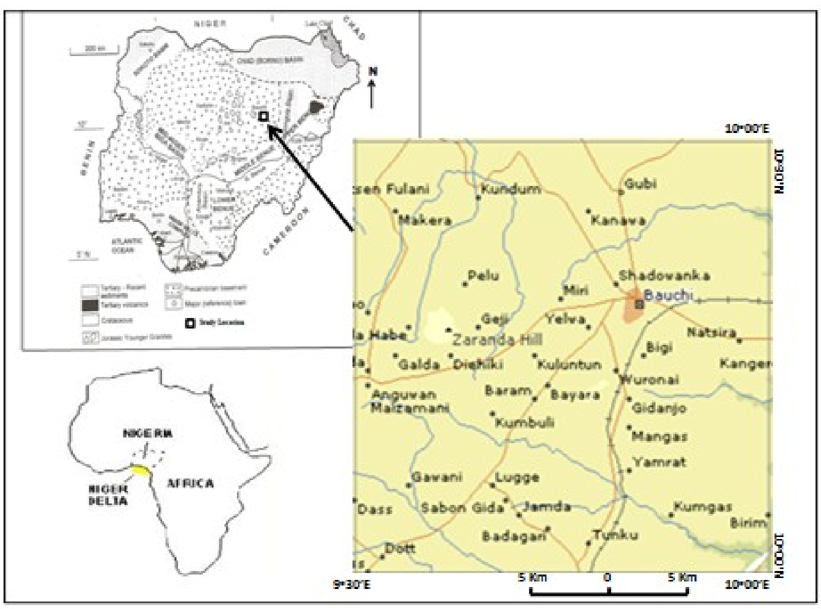

Fig. 1: Map showing location of the study area (In-set: Geological map of Nigeria and Africa).

Previous work in the area involving groundwater investigation dates back 1928 when the Geological Survey of Nigeria commenced the hydrogeological investigation in Nigeria. They undertook the actual exploitation of groundwater for rural communities by means of hand-dug and concrete-lined wells. Then in 1947 the exploitation aspect of the water supply work was handed over to the public works department but the responsibility for making systematic studies of the distribution of groundwater remained with the Geological Survey.

Carter et al. (1963), published maps and description of the geology of parts of Northeastern Nigeria which includes the Adamawa, Bauchi, and Borno province. This forms the basis for further groundwater studies around the area. Subsequently, Du Preeze and Barber (1965) and Kiser (1968) gave some details on the chemical quality of groundwater of the old Northern Nigeria which includes the study area.

Finally, Ali et al. (1993) carried out a geophysical study of the Basement structure of Barkumbo Valley of Bauchi area of Nigeria. The present study is an integrated study that will include the geotechnical investigation that will assist the government in finding solutions to the perennial water problems that is bedeviling the area.

GEOLOGY OF THE STUDY AREA

The study area is underlain by rocks of the Precambrian crystalline Basement Complex of Nigeria. The major lithologic units are: the Bauchite (Fayalite-quartz-monzonite); the biotite-hornblende-granite; the porphyroblastic biotite-granites, granulites and undifferentiated migmatites and gneisses (Fig. 2). In most part of the area, these rocks are covered by the unconsolidated weathered overburden materials consisting of laterites, clays, sands and gravels.

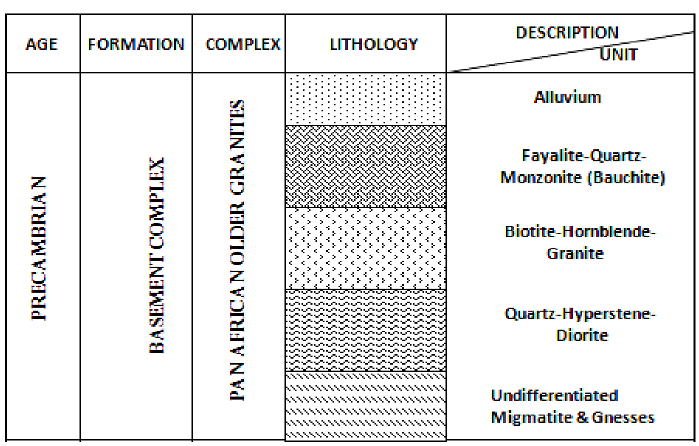

Fig. 2: Showing sediments formed from the weathered basement rocks in the study area.

The unconsolidated weathered overburden materials are of two types namely; the Alluvium and the Elluvium. However, outcrops of fayalite-quartz-monzonite (Bauchite) and biotete-hornblende-granite occur at two locations such as Idi and Lush hills.

Outcrops of these rocks show that they have been fractured due to tectonism. Thus fractures, fissures, joints and fracture-zones exist in places. The prominent fault zones trend towards the NE-SW and N-S zones as illustrated by Oyawoye (1970).

River Course Alluvium

The low-lying plains of the study area are essentially mantled by lateritic pebbly soils resulting from in-situ weathering of the crystalline rocks. Where exposed by erosion, the soil profile consists of a laterite topsoil underlain by a clay horizon which in turn is underlain by partially weathered parent rock materials. Talus and deposits of alluvial pebbles and sands are abundant. The talus is found on the alluvial deposits of river channels and the river banks.

The Hadejah valley around the northern part of the study area and it's tributaries have alluvial flood plains and the Gongola valley around the eastern part which also are underlain mainly by unconsolidated coarse to medium grained sandy materials, clays and silts. From the observation it was found that at higher altitudes these sediments are coarse grained and fine towards the low-lying plains.

Elluvium

The elluvium consists essentially of gravels and sands which are very good aquifers and have given very high yields to wells. The processes in the formation of deep weathering which led to the development of lateritic profiles as the overburden form the elluvium. The parent materials – migmatites, gneisses which are cut by pegmatite, aptite and quartz veins are weathered to varying degrees and depths. The depth of weathering varies from 34 to 129m. It was found that water bearing zones are mainly found in the fractures of the poorly decomposed rock; intergranular permeability in moderately decomposed coarse-grained igneous and metamorphic rocks and fractured pegmatites, aptite and quartz veins within highly and moderately decomposed gneisses and migmatites.

Fayalite – Quartz – Monzonites (Bauchite)

Fayalite – bearing quartz- monzonites have been described in Bauchi area (Oyawoye, 1970). It contains quartz (72%), K- feldspar (14-72%) and plagioclase (4-52%). This unit is characterized by almost equal amount of alkali feldspars and plagioclase. It has dominant accessory minerals such as biotite and hornblende. In others, augites are present and are normally accompanied by hyperstene and olivine. The K- feldspars in monzonite is usually orthoclase (rarely microdine). Quartz occurs in minor amounts. This unit is found around Guni, Wambai, Idi and Dumi hills in the central and northeastern area and some to the western portion (Fig. 1).

Biotite-Hornblende-Granite

In this rock unit the dominant minerals are biotite and hornblende. Other minerals found associated with them are muscovites, augites, sodium-rich amphiboles, pyroxenes and minor quartz or olivine. The biotite is often dark coloured and hornblende is green coloured. This can be found in Lush and Inkil hills. It covers parts of southeastern area and also outcrops at North and northwestern area of the map (Fig.1).

Quartz - Hyperstene – Diorite

This unit contains mostly of quartz in association with hyperstene and olivine. It has as sub-hedral granular texrure. It outcrops at the Northeastern extreme.

Undifferentiated Migmatite and Gneisses

These are mixed rocks of mainly two sources – the pre-existing host rock and a rather indefinite diffusion of other rock materials which are granitic in composition through the host rock. The host rock is usually the meta-sedimentary schists and the intruded materials include mostly granites, pegmatites and quartzite. They occur also mostly around the northwestern and southeastern portions and are less weathered than the schists.

MATERIALS AND METHODS

Geotechnical

The samples were collected from thirteen different pits (Dumi, Dunglusi, New G.R.A, Zaranda, Gwalameji, Durum, Inkil, Wunti, Yelwa, Guni, Dandango, Shadawanka and Nassarawa) at varying depths of 2-3 meters using hand augar.

Laboratory analysis were carried out on the disturbed soil samples collected from the field in other to determine the geotechnical index properties. These were done in the Engineering Laboratory of Setraco Nigeria limited Company. The analysis was carried out on the disturbed samples include; Liquid limit, plastic limit (Atterberg limit), Compaction test, Sieve analysis (Grading) and California bearing ratio.

According to Atterberg, 1911, a Swedish agricultural scientist who engaged in agriculture and ceramic proposed four states of soil consistency based on water content and stated that the liquid limit of a soil is the moisture content at which the soil passes from plastic state to liquid state as determined by the liquid limit test.

Particle size distribution refers to the percentage of the various grain sizes present in a rock as determined by sieving or sedimentation. It is one of the geotechnical index properties used to classify a soil based on size.

Soil engineers have established defined limit for the difference particle size found within a soil. The amount of particle size present is determined by mechanical analysis. Particles size distribution yield information on the size group of a sample's solid particles and relative proportion of the sizes, and this is a very important property which influences the engineering behavior of soil.

Geophysical Data

Seven Vertical Electrical Soundings (VES) and fifteen seismic refraction profiles were conducted in 1984 by Bauchi State Water Board in the study area (Fig. 1). Schlumberger array was used with maximum separation of AB/2 = 225m. The apparent resistivities obtained from the field were plotted on log-log graph paper. The curves types found in the study area are A, H, QH, HA, and HK. These types of curves are typical of basement complex area. The initial interpretation of the VES data was accompanied using conventional partial curve matching technique utilizing two-layer master curves and the corresponding auxiliary curves from which resistivities and thicknesses of the layers were obtained. The program (RESIST.FOR) was used for refining the partial curve matching interpretative results. The computer assisted interpretation was based on optimization technique. Details of the mathematical formulae used in the interpretation can be found in Mbonu et al. (1991) and Nur et al. (2001).

The results obtained from the computer modeling are presented in Table 3, while Figure 3 shows examples of the vertical electrical sounding (VES) curves and their interpretation models. Figure4 also indicates the typical geoelectrical section of the eastern part of the study area.

The seismic equipment used for the fifteen profiles consisted of a compact Nimbus ES – 1210F multi-channel seismograph. The equipment has filtering, staking, storage, display and recording options.

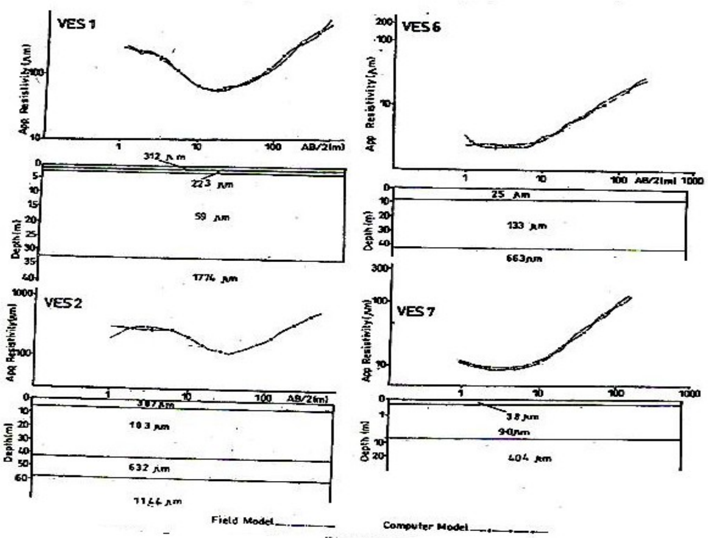

Fig. 3: Examples of computer interpretation in the study area.

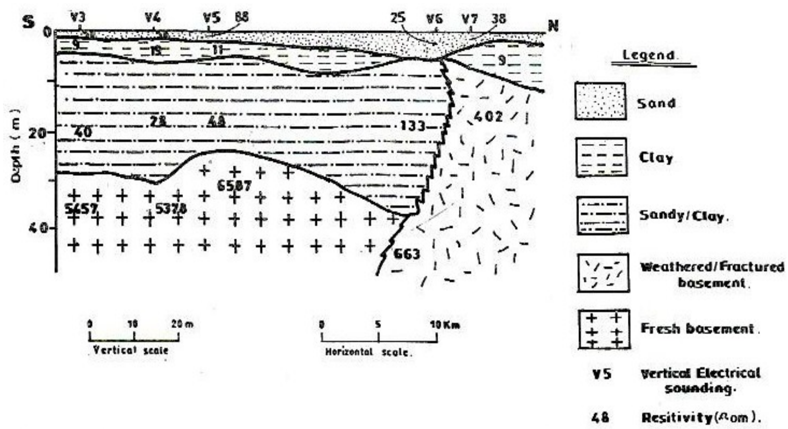

Fig. 4: Geo-electric section along a S-N profile in the eastern part of the study area.

The surface elevations at all the fifteen stations were obtained with the altimeter levelling method. Travel-time was plotted against source-receiver distance for both forward and reverse profiles. The compressional waves velocities of the various layers, depths to refractors and dips (where applicable) were obtained. The results are summarized in Table 4, while Figure 5 shows three seismic sections in the study area.

RESULTS AND DISCUSSIONS

Geotechnics

Incipient gullies were observed in different parts of Bauchi and its environs which is underlain by the Basement complex rocks. The menace of this badland devastation was found in Federal

Lowcost Housing Estate, Shadawanka, Zaranda and Tirumn. The Basement complex rocks of the area have undergone complete weathering or decomposition leading to about 4 to 7m thick unconsolidated weathered overburden- layer consisting of loose sands, gravels, silts and clays. The average depth of incision of these gullies observed is about 2.5 to 3m. It is the geotechnics of these areas that determine their susceptibility to gully erosion or their erodability.

Therefore, to determine the causes and to suggest solution to the problem, the geotechnical parameters or characteristics of the soils at thirteen locations using soil mechanic laboratory tests such as the liquid (LL) and plastic limits (PL), moisture content, specific gravity and shear strength tests were carried out (Table 1). While the result for the grain size analysis is in Table 2. The LL and PL were used to obtain the plasticity index (PI) which is a measure of the plasticity of the soil. The values obtained ranges from 6.5 to 28.5% with a mean value of about 17.2% which indicates slight to medium plasticity. Thus the soil samples are soft and could be crushed by fingers and hence erodible.

Table 1: Showing result of the Atterberg Limit.

Location	Sample N0.	Depth (m)	Atterberg Limit parameters (%) LL	PL	PI	MC (%)	Density (g/cm3)	Soil Description	Shear Strength θ	Cohesion
Dumi	AA1	5.00	32.60	23.40	9.20	8.10	2.40	Sandy-clay, coarse-medium	33.00	0.27
Dunglusi	AA2	7.00	41.50	24.00	17.50	13.60	2.60	Predominantly medium-coarse sand with some gravel	35.00	0.29
New G.R.A	AA3	4.00	40.60	17.70	22.90	10.00	2.40	Sandy gravel	33.50	0.25
Zaranda	AA4	0.02	28.60	*	28.60	5.80	2.40	Silty fine medium- coarse sand		
Gwalameji	AA5	0.02	24.10	17.60	6.50	5.70	2.60	Medium -coarse sand with some gravel		
Durum	AA6	0.05	34.30	16.30	18.00	6.10	2.50	Medium -coarse sand		
Inkil	AA7	0.03	28.30	*	28.30	5.90	2.50	Fine-medium coarse sand		
Wunti	AA8	0.05	33.80	17.70	16.10	10.50	2.50	Predominantly medium-coarse sand with some gravel		
Yelwa	AA9	0.02	23.40	*	23.40	6.20	2.50	Medium -coarse sand		
Guni	AA10	0.03	33.50	16.20	17.30	11.40	2.40	Sandy very silty clay	31.00	0.26
Dandango	AA11	0.02	26.00	16.50	9.50	3.80	2.50	Fine-coarse sand with some gravel		
Shadawanka	AA12	0.03	25.50	17.30	8.20	15.00	2.30	Sand Alluvium	25.00	0.22
Nassarawa	AA13	0.02	37.50	18.80	18.70	19.20	2.40	Sandy very silty clay	27.00	0.23
Total					224.20	121.30	32.00			
Average					17.20	9.30	2.50			

Table 2: Showing the grain size analysis result of soil samples in the study area.

Grain Size Distribution B.S. Standard (% passing)					4	14	36	52	100	200	
Location	**Sample NO.**	**Depth (m)**	**2.36 mm**	**2.00 mm**	**1.18 mm**	**600 µm**	**425 µm**	**300 µm**	**212 µm**	**150 µm**	**63 µm**
Dumi	AA1	5.00	79.00	72.90	50.80	24.60	15.10	9.10	5.50	2.80	0.30
Dunglusi	AA2	7.00	65.50	59.30	39.70	25.20	19.10	15.60	11.90	8.50	2.00
New G.R.A	AA3	4.00	78.50	68.20	42.10	22.80	15.80	11.40	7.70	5.00	1.00
Zaranda	AA4	0.02	77.20	71.30	54.20	29.90	14.40	2.10	0.60	0.20	0.03
Gwalameji	AA5	0.02	47.90	42.30	30.70	19.70	14.50	11.20	8.00	5.80	1.00
Durum	AA6	0.05	76.00	70.50	48.50	26.20	17.30	11.60	8.10	5.60	1.50
Inkil	AA7	0.03	57.70	52.90	42.30	27.50	19.20	13.80	8.10	4.10	1.50
Wunti	AA8	0.05	59.10	53.20	37.00	23.30	17.20	12.70	9.20	6.80	1.70
Yelwa	AA9	0.02	71.90	65.60	47.50	29.90	21.20	15.40	11.00	7.60	1.20
Guni	AA10	0.03	84.80	78.10	59.40	40.80	32.20	26.40	20.50	14.10	2.70
Dandango	AA11	0.02	64.90	60.20	47.50	32.00	22.50	17.40	12.20	8.30	2.10
Shadawanka	AA12	0.03	78.70	73.70	56.50	35.30	26.70	20.60	14.30	7.90	1.10
Nassarawa	AA13	0.02	86.00	80.20	61.20	40.10	30.30	23.70	17.10	11.70	1.40

The shear strength of the soil samples was also determined. Shear strength is the maximum internal resistance of the soil to movement of its particles by sliding or slipping. The forces that resist shear are the intergranular friction and the cohesion. The values of the cohesion obtained range from 0.22 to 0.29cm^2/kg which is relatively low. Also, the shear angle of the internal friction ranges from 25 to 35^{o}. The significance of the shear strength test is that the force due to run-off and the seepage flux are only resisted by the angle of internal friction since the value of cohesion is low.

The moisture content result ranges from 3.8 to 19.2% with an average of 9.3% which is low. This indicates that the amount of water content the soil can retain is small.

The specific gravity of soil samples was determined and it showed that the density in the medium to coarse samples is very high compare to fine particles. The density ranges from 2.3 to 2.6g/cm3 with an average of 2.5g/cm3. This is done to know the weight of soil samples and to determine the amount of water in which the soil particles can resist without loosen its shear strength and also its stability to loads and absorption of water.

The grain size result shows that texturally the soils are essentially gravels and sands and are greater than 50% on 200 percent passing (Table 2). The soil has indicated high percentage of gravels and sands which implies that the soil is very porous and very low interconnectivity among the particles and could absorb water easily via erodability of material.

Hydrogeophysical

The interpretation results of five VES (1-5) stations in the study area delineate a four-layer earth model, while VES 6 and 7 located near Gulawa delineate three-layer earth model. The first layer has thickness between 0.2 and 4.7 m and resistivity value of between 25 and 312 ohm-m. The second layer has thickness that ranges from 1.0 to 38.9 m and resistivity of between 5 and 222 ohm-m. The third layer has thickness of 8.7 to 34.5 m and resistivity of between 40 and 662 ohm-m. The fourth layer has resistivity values between 1144 and 6587 ohm-m.

Table 3: Summary of results from computer modeling for the seven (7) VES in the study area.

VES N0.	Thickness of Layers (m)			Resistivity of Layers (ohm-m)				Conductivity (Seimen)			Resistance (ohm-m)			Fitting
	H1	H2	H3	ρ1	ρ2	ρ3	ρ4	Σ1	σ2	σ3	R1	R2	R3	Error (%)
VES-1	0.50	1.20	34.50	312	222	60.00	1774	0.002	0.005	0.658	159	333	2094	4.90
VES-2	4.70	38.90	8.70	307	103	632	1144	0.016	0.373	0.013	1399	4053	5926	3.40
VES-3	1.30	1.00	25.90	50.00	5.00	40.00	5457	0.025	0.206	0.641	64	5.00	1047	7.80
VES-4	1.00	5.00	25.40	52.00	19.00	28.00	5378	0.020	0.259	0.411	54	97.00	715	6.60
VES-5	0.80	3.80	19.60	88.00	11.00	48.00	6587	0.009	0.333	0.411	68	43.00	939	6.30
VES-6	7.50	35.60	*	25.00	133	663	*	0.308	0.270	*	186	4670	*	6.80
VES-7	0.20	8.10	*	38.00	9.00	402	*	0.006	0.900	*	9	73.00	*	2.20
Average	2.30	13.40	22.80	125	72.00	265	4068	0.055	0.335	0.427	277	1325	2144	5.40

Geoelectrical section taken along South - North profile in the eastern part of the study area indicates that the depth to fresh basement is shallower beneath VES 3, 4 and 5. The Seismic Refraction profiles also indicate three-layer earth models; which basically correspond to the topsoil, the weathered/fractured basement and the fresh basement. Typical example of T-X graph is shown in Figure 5 while results of the fifteen seismic profiles (S1 to S15) are summarized in Table 4.

Seismic profiles S1 to S6 are located in the western part of the study area (Fig. 1). The velocities obtained are between 82 and 240 m/s with a thickness of 0.6 to 5 m for the first layer. The second layer has velocities between 1073 and 2723 m/s with thicknesses of between 6.0 to 24.0

m. The third layer has velocities between 2304 and 7400 m/s. The depth to fresh basement is shallower in the western part of the study area. Two seismic sections (Fig. 6a, b, c) were taken in the northeastern part of the study area. The depth to fresh basement is deep.

Table 4: Interpretation of the fifteen (15) Seismic stations in the study area.

S/N	Profiles	Depth (m)		Velocity (m/s)		
		h1	h2	v1	v2	v3
S1		5.00	15.00	82.00	1316.00	7400.00
S2		4.60	8.40	78.00	1322.00	5700.00
S3		4.00	24.00	76.00	2723.00	6400.00
S4		1.00	6.00	240.00	1190.00	2304.00
S5	A - B	0.80	8.00	231.00	1073.00	3258.00
S6		0.60	9.00	188.00	1630.00	4762.00
S7		2.40	16.00	277.00	520.00	6666.00
S8		2.00	6.00	300.00	570.00	1084.00
S9		0.20	3.60	264.00	477.00	869.00
S10		6.00	19.00	75.00	2372.00	3000.00
S11	C - D	3.60	18.00	72.00	2843.00	3778.00
S12		5.00	26.00	76.00	2773.00	5556.00
S13		4.00	12.00	75.00	3000.00	5455.00
S14	E - F	4.20	14.00	78.00	2549.00	6667.00
S15		3.80	19.00	82.00	2775.00	4546.00
Mean		3.10	13.60	146.20	1808.90	4496.40

The velocities obtained range between 72 and 300 m/s with a thickness of 0.2 and 5m for the first layer. The second layer has velocities that are between 447 and 3000 m/s with thicknesses of 3.6 to 26 m.

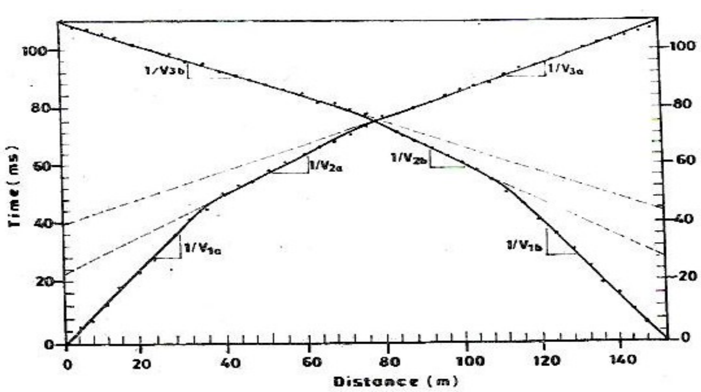

Fig. 5: Example Time – Distance (T – X) graph of the study area (Shot points S13).

The third layer has velocities between 869 and 6667 m/s. The above results compare fairly well with those observed by Ali et al. (1993).

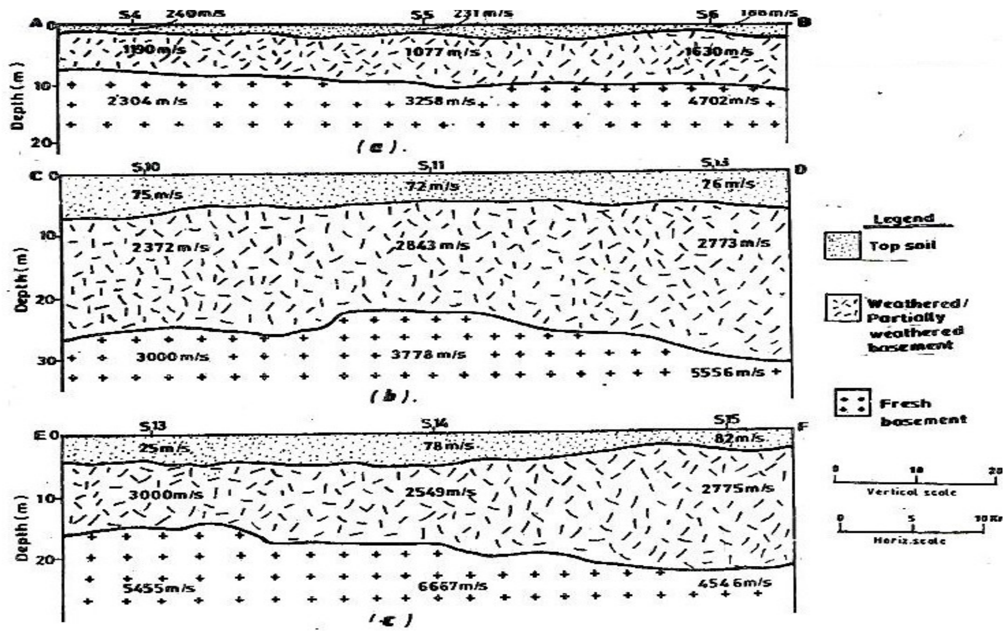

Fig. 6: Examples of seismic sections in the study area and their interpretation.

CONCLUSION

Seven Schlumberger VES and fifteen seismic refraction profiles were conducted in Bauchi and environs. 29% of the VES showed three-layer earth model. Fifteen Seismic Refraction profiles also conducted indicate three-layer earth model. The geotechnical study indicates that the soil sample have plasticity index ranging from 6.5 – 28.8% with an average value of 17.20% which indicates slight to medium plasticity. Thus the soil samples are soft and could easily be crushed by fingers and hence erodible. Thus the soil has little or no cohesion. Shear strength test was conducted and cohesion values range from 0.22 – 0.29cm^2/kg which is low. Also shear angle of the internal friction ranges from 25-35^o. The values indicate that the soil is erodible and will generally provide good quality aquifer system for groundwater prospectivity and exploitation.

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