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HYDRO-GEOPHYSICAL INVESTIGATION OF BAUCHI AND ENVIRONS NE OF NIGERIA.

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ABSTRACT

Seven Schlumberger vertical electrical soundings (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 displays the presence of three-layer earth model. The first layer consists of loose topsoil materials, the second is weathered and/or fractured basement, while third layer is the bedrock. However VES1-5 display four-layer earth model, whereby the thickness of the weathered and/or fractured basement is over 19 m, except VES2 where the thickness is 8.7 m. The results obtained from the fifteen seismic refraction profiles indicate also a three-layer model. The first layer represents the topsoil with an average velocity 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 13.6 m. This represents the weathered/fractured basement. The third layer has a mean velocity of 4496 m/s, and represents fresh basement. From the Hydrogeological studies of borehole data, a mean depth to water table of 4.12 m, a mean hydraulic conductivity of 0.91 m/day and an average transmissivity of 19.88 m^2/day, were recorded. Finally the geochemical analysis for hand-dug wells indicates a mean value of Chlorite and hardness of 186 and 381 mg/l respectively. The results from this study will no doubt serve as background information for groundwater prospecting and subsequent exploitation.

KEYWORDS: Geology, Hydrogeology, Resistivity and Seismic Refraction data interpretation of Bauchi and environs.

INTRODUCTION

The Bauchi area falls between latitudes 10° 00' and 10° 30' N and longitudes 9° 30' and 10° 00' E (Fig 1). It is easily accessible via Bauchi-Jos, Bauchi-Kano and Bauchi-Maiduguri Roads. Other access routes are Bauchi-Tafawa Balewa and Bauchi-Gombe Roads. It is located in the high relief of Bauchi and the run off is relatively high, while the infiltration rate is low. The geological features, in addition to the adverse climatic condition of the area, control the groundwater storage. The surface waters in the study area are seasonal. There is the need therefore to exploit the groundwater resources. The area is underlain by crystalline basement complex, where the occurrence of groundwater is due largely to the development of secondary porosity and permeability by weathering and /or fracturing of the parent rocks (Acworth, 1987; Olorunfemi and Fasuyi, 1993 and Edet and Okereke, 1997).

Experience all over the world has shown that the rate of failure of boreholes is usually highest in the basement complex terrain. This is mainly due to an inadequate knowledge of the basement aquifers, which results from in-situ weathering and/or denudation of basement rocks.

Geophysical survey of the sub-surface for aquifers is very important in basement complex where groundwater occurrence is erratic. Investigations involving detailed geophysical work for groundwater particularly in the area covered by this study are few. Ali et al. 1993 conducted, similar work (The basement structure in Barkumo Valley, Bauchi) located at the eastern part outside of the present research area. The primary objective of this study is to determine the hydrogeological and geophysical characteristics of the study area.

GEOLOGY OF THE AREA

Rocks of the crystalline basement rocks of Nigeria underlie the study area. These include Fayalite-quartz-monzonite (Bauchite), biotite-hornblende granite, porphyroblastic, biotite-granites, granulite and undifferentiated migmatites and gneisses (Fig.2). The weathered overburden materials consisting of laterite, clays, sands and gravels cover most parts of the study area. However, Outcrops of the Fayalite-quartz-monzonite and biotite-hornblende granites are found at Idi and Lushi hills around the southwest whereas those of the undifferentiated migmatites and gneisses are found in the northwestern portion of the study area. Numerous fissures, joints and fractures traverse these rocks with prominent fault zones trending NE-SW and N-S directions Oyawoye (1970).

DATA COLLECTION AND INTERPRETATION

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 = 225 meters. The apparent resistivities obtained from the field were plotted on log-log graph paper. The curve 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 accomplished 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 readily be found in Mbonu et al., (1991) and Nur et al., (2001).

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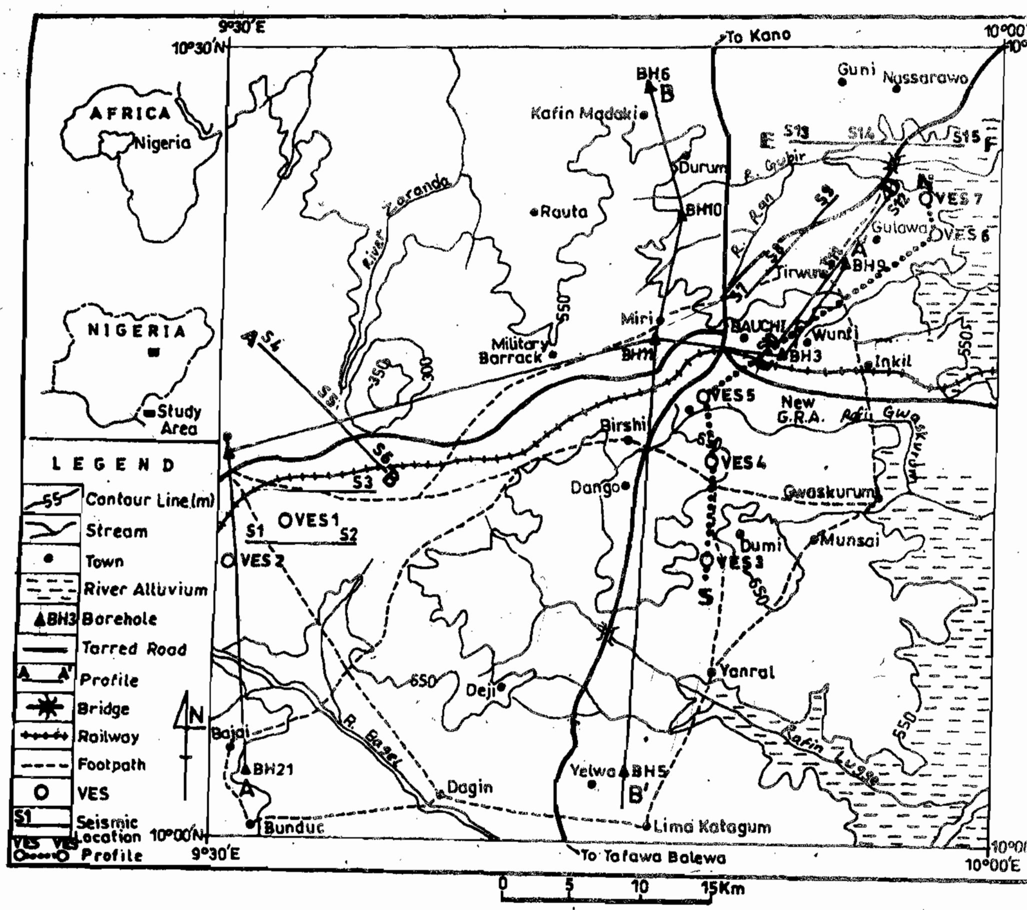

Fig. 1: Map of the Study Area Showing Topogrphic Features, Drainages, Access Road, Boreholes VES and Seismic Refraction Locations.
(Modified after Bauchi State Agric. Dev. Board (B.S.A.D.B.) 1984)

The results obtained from the computer modeling are presented in Table 1, while Figure 3 shows examples of the vertical electrical sounding (VES) curves and their interpretation models. Figure 4 also indicates the typical geo-electrical 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. 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 wave velocities of the various layers, depths to refractors and dips (where applicable) were obtained. The results are summarized in Table 2, while Figure 5 shows three seismic sections in the study area.

Hydrogeology

The hydrogeological studies were carried out in three stages. The first stage involved literature review and reconnaissance field trips during which topographic maps were used in the identification of the rock types and their structures. Borehole records and pumping test results were collected from the Federal Ministry of Aviation and the Upper Benue River Basin Development Authority Yola. The second stage involved detailed surface and sub-surface hydrogeologic studies during which depths to static water levels in wells were measured and water samples collected. Physico-chemical analysis of the samples was done in the Laboratory employing Atomic Absorption spectrophotometer for cations and conventional titration for anions. Ions were converted to milli-equivalent per liter and anions balanced against cations as control check on the reliability of the analysis. The last stage was interpretation of geophysical and hydrogeological results in the study area.

DISCUSSION

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 values 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 between1144 and 6587 ohm-m. 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 2.

TABLE 1. SUMMARY OF RESULTS FROM COMPUTER MODELING FOR THE SEVEN (7) VES IN THE STUDY AREA.

VES No.	Thickn. of Layers (m)			Resistivity of Layers (ohm-m)				Conduct. (Siemen)			Resistance (ohm.m)			Fitt. Error %
	H1	H2	H3	ρ1	ρ2	ρ3	ρ4	Σ1	σ2	σ3	R1	R2	R3	
1	0.5	1.2	34.5	312	222	60	1774	0.002	0.005	0.658	159	333	2094	4.9
2	4.7	38.9	8.7	307	103	632	1144	0.016	0.373	0.013	1399	4053	5926	3.4
3	1.3	1.0	25.9	50	5	40	5457	0.025	0.206	0.641	64	5	1047	7.8
4	1.0	5.0	25.4	52	19	28	5378	0.020	0.259	0.411	54	97	715	6.6
5	0.8	3.8	19.6	88	11	48	6587	0.009	0.333	0.411	68	43	939	6.3
6	.7.5	35.6	--	25	133	663	--	0.308	0.270	--	186	4670	--	6.8
7	0.2	8.1	--	38	9	402	--	0.006	0.900	--	9	73	--	2.2
Av.	2.3	13.4	22.8	125	72	265	4068	0.055	0.335	0.427	277	1325	2144	5.4

Table 2. 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		5.0	15.0	82.0	1316.0	7400.0
S2		4.6	8.4	78.0	1322.0	5700.0
S3		4.0	24.0	76.0	2723.0	6400.0
S4		1.0	6.0	240.0	1190.0	2304.0
S5	A – B	0.8	8.0	231.0	1073.0	3258.0
S6		0.6	9.0	188.0	1630.0	4762.0
S7		2.4	16.0	277.0	520.0	6666.0
S8		2.0	6.0	300.0	570.0	1084.0
S9		0.2	3.6	264.0	477.0	869.0
S10		6.0	19.0	75.0	2372.0	3000.0
S11	C – D	3.6	18.0	72.0	2843.0	3778.0
S12		5.0	26.0	76.0	2773.0	5556.0
S13		4.0	12.0	75.0	3000.0	5455.0
S14	E – F	4.2	14.0	78.0	2549.0	6667.0
S15		3.8	19.0	82.0	2775.0	4546.0
Mean		3.1	13.6	146.2	1808.9	4496.4

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 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 (Figure 6a,b,c) were taken in the northeastern part of the study area. The depth to fresh basement is deep. 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 477 and

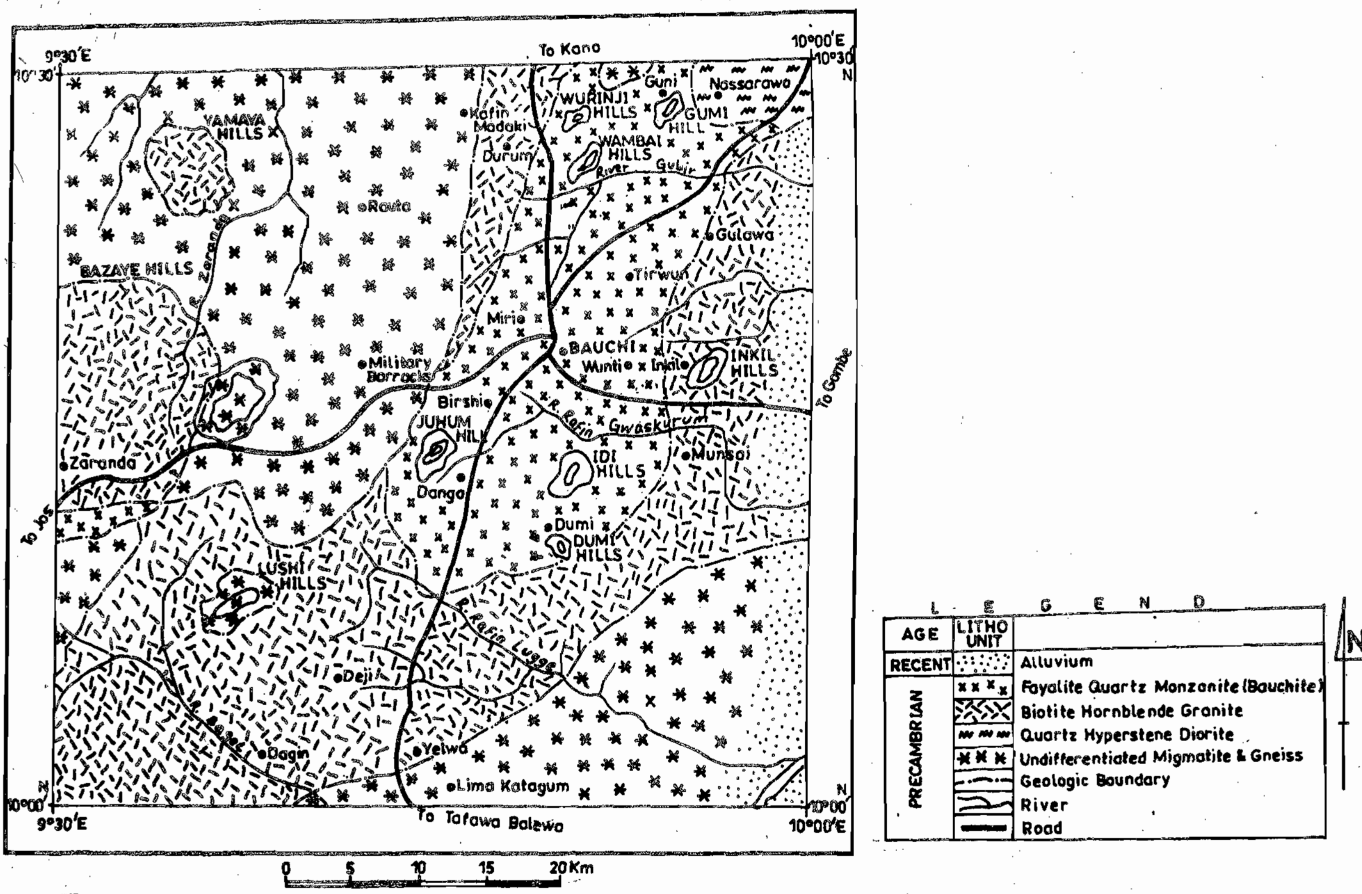

FIG. 2: GEOLOGIC MAP OF THE STUDY AREA (AFTER B.S.A.D.B. 1984)

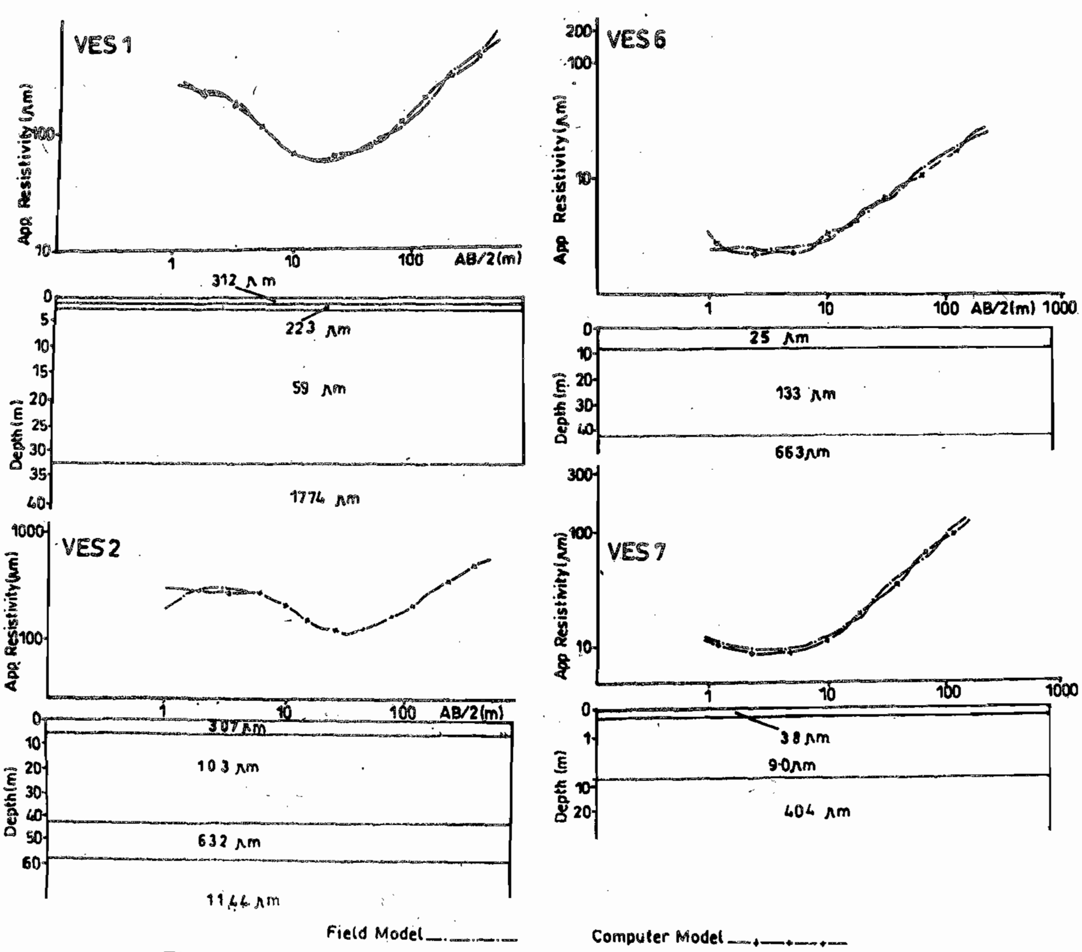

FIG. 3: EXAMPLES OF COMPUTER INTERPRETION IN THE STUDY AREA

TABLE 3: COMPUTED HYDRAULIC CONDUCTIVITY (K) AND TRANSMISSIVITY FROM BOREHOLE DATA

BORE-HOLE No.	DEPTH TO WATER(M)	TOTAL DEPTH(M)	AQUIFER THICKNESS(M)	HYDRAULIC CONDUCTIVITY (M/DAY)	TRANSMISSIVITY (M^2/DAY)
BA1	6.42	129.00	36.00	0.12	4.32
BA2	2.52	149.00	20.00	0.27	5.40
BA3	6.20	96.00	32.00	0.38	12.16
BA4	4.35	96.00	52.00	0.28	14.56
BA5	2.33	65.00	14.00	1.75	24.50
BA6	2.95	54.00	20.00	2.31	46.20
BA7	4.09	56.00	26.00	1.27	33.02
AVERAGE	4.12	92.14	28.57	0.91	19.88

Table 4. Hydraulic properties of some samples of the unconsolidated weathered overburden aquifer of the study area (Obiefuna and Nur 2003)

S/No	Hydraulic Conductivity (m/s) x 10^{-3}					Transmissivity (m^2/s) x 10^{-3}			
	Location sample No.	1	2	3	4	5	1	2	3	4
1	Dumi AA1	10.57	6.78	0.40	5.91	5.00	52.85	33.90	2.00	29.55
2	Tiruwn AA2	3.44	2.21	0.13	1.93	7.00	24.08	15.47	0.91	13.51
3	New GRA AA3	8.66	5.54	0.33	4.85	4.00	34.64	22.16	1.32	19.4
4	Zaranda AA4	14.71	9.43	0.56	8.23	10.00	147.10	94.30	5.60	82.30
5	Dajin AA5	8.34	5.35	0.32	4.67	26.00	216.84	139.10	8.32	121.42
6	Durum AA6	7.11	4.56	0.27	3.98	8.00	56.88	36.48	2.16	31.84
7	Inkil AA7	7.11	4.56	0.27	3.98	24.0	170.64	109.44	6.48	95.52
8	Wunti AA8	5.97	3.83	0.23	3.34	19.60	117.01	75.07	4.51	65.46
9	Yelwa AA9	3.85	2.47	0.15	2.15	15.00	57.75	37.05	2.25	32.25
10	Guni AA10	1.66	1.06	0.06	0.93	6.00	9.96	6.36	0.36	5.58
11	Dango AA11	3.31	2.12	0.13	1.85	9.50	31.45	20.14	1.24	17.58
12	Miri AA12	3.71	2.38	0.14	2.08	11.20	41.55	26.66	1.57	23.30
13	Nasarawa AA13	2.16	1.38	0.08	1.21	12.50	27.00	17.25	1.00	15.13
	Mean	6.22	3.97	0.24	3.47	12.14	982.00	626.95	37.14	547.44

1. Hazen method (1893) 2. Harleman et al method (1963) 3. Uma et al method (1989)
4. Average values 5. Aquifer thickness (in meters)

3000 m/s with thicknesses of 3.6 to 26 m. 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).

From the analyses of borehole logs, the fractured basement aquifer thickness varies between 14 meters at Liman Katagum to 52 meters at Bauchi with an average thickness of about 26.6 meters. It directly underlies the weathered aquifer unit. All boreholes tap their water from this aquifer. The hydraulic properties of the seven boreholes penetrating the fractured aquifer as determined from pumping test method indicate a mean hydraulic Conductivity (K) value between of 0.12 and 2.31 m/day and a mean transmissivity (T) value ranging between 4.32 and 46.29 m^2 /day (Table3). Obiefuna and Nur

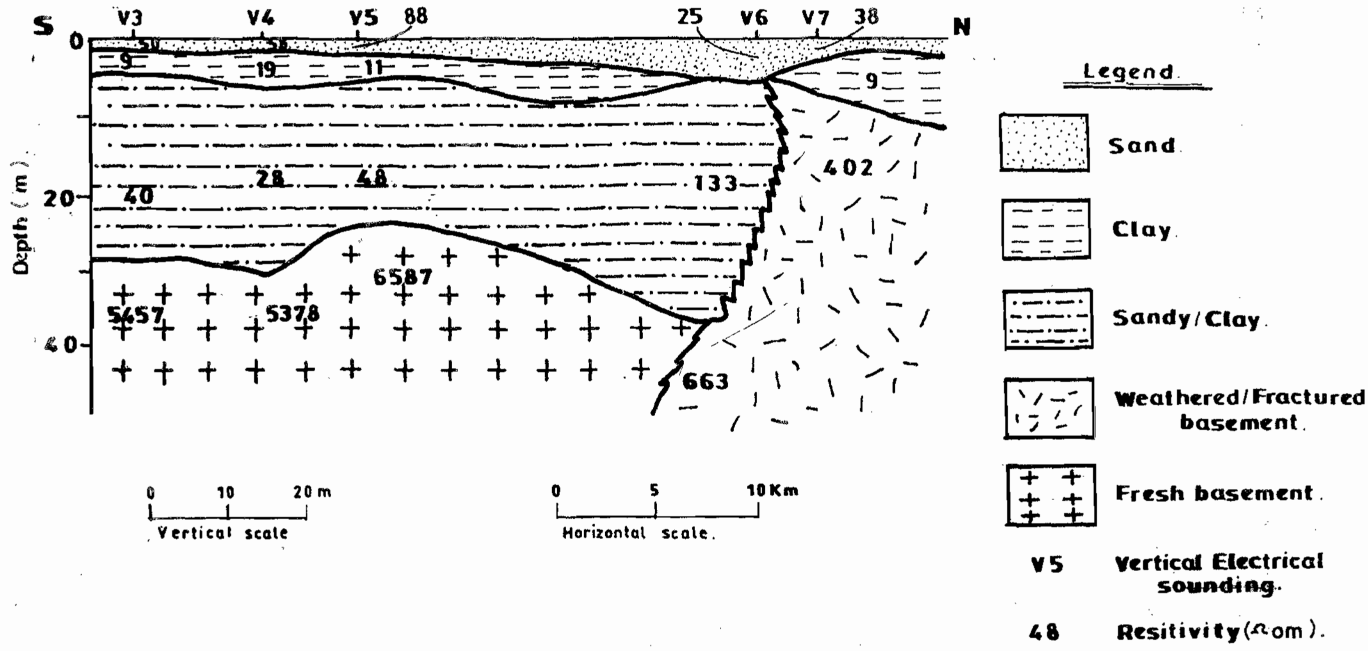

Fig. 4: Geo-electric section along a S-N profile in the eastern part of the study area.

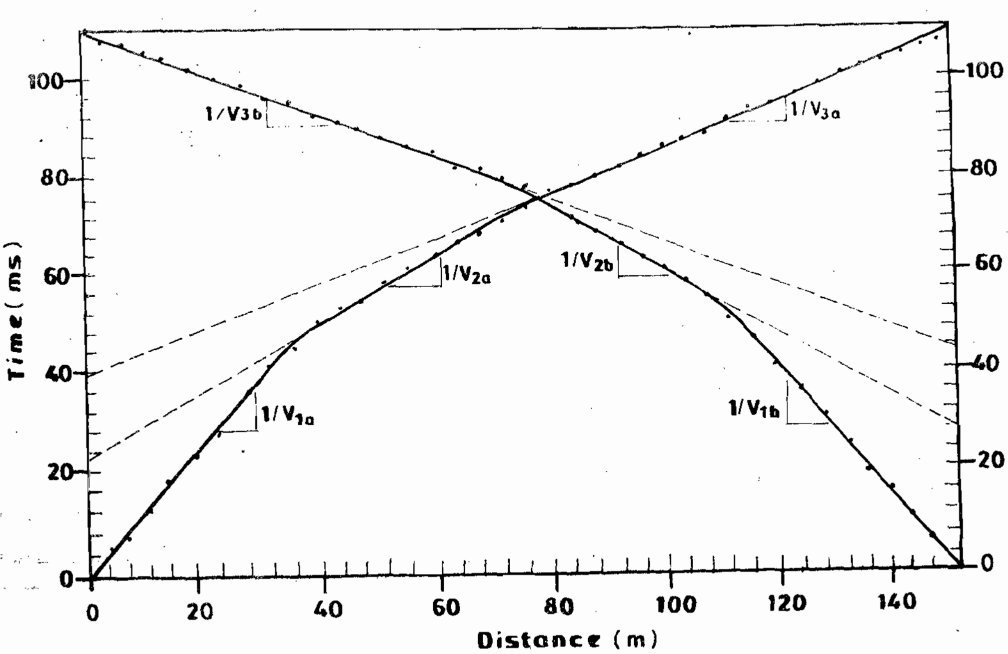

Fig. 5: Example Time - Distance (T - X) graph of the study area (shot points S13).

Table. 5 Summary of the Geo-chemical properties for the Nine Hand-dug wells (mg/l)

Location	pH	Sodium	Magnesium	Carbonate $HCO_3 8CO_3$ Alkamity	Sulphate	Calcium	Chloride	Iron	Zinc	Hardness
Yelwa (HW1	7.0	55	85	15.0	95	26	150	7.3	0.10	414.95
New GRA (HW2)	7.1	50	80	15.0	90	30	145	8.5	0.10	404.35
Gov.House (HW3)	6.7	40	85	9.0	98	40	165	9.6	0.08	449.91
Nassarawa (HW4)	7.4	60	60	16.0	94	45	175	10.0	0.12	359.45
Wunti (HW5)	7.1	35	55	13.0	100	60	170	9.8	0.10	376.31
Railway Qauters (HW6)	7.1	50	45	13.0	105	65	155	8.7	0.10	347.62
Gombe Road (opp. FGGC) (HW8)	6.9	45	60	9.64	110	55	140	9.0	0.10	384.42
Barrack (HW8)	7.0	55	60	10.0	85	50	185	7.5	0.10	371.93
Tiruwn (HW9)	7.2	60	45	14.0	85	55	180	7.9	0.10	322.65
Mean	7.1	50	64	10.9	95.8	47.3	185.9	8.7	0.10	381.29
Standard Deviation	0.20	8.66	15.77	2.69	8.51	13.3	14.95	0.96	0.10	37.99

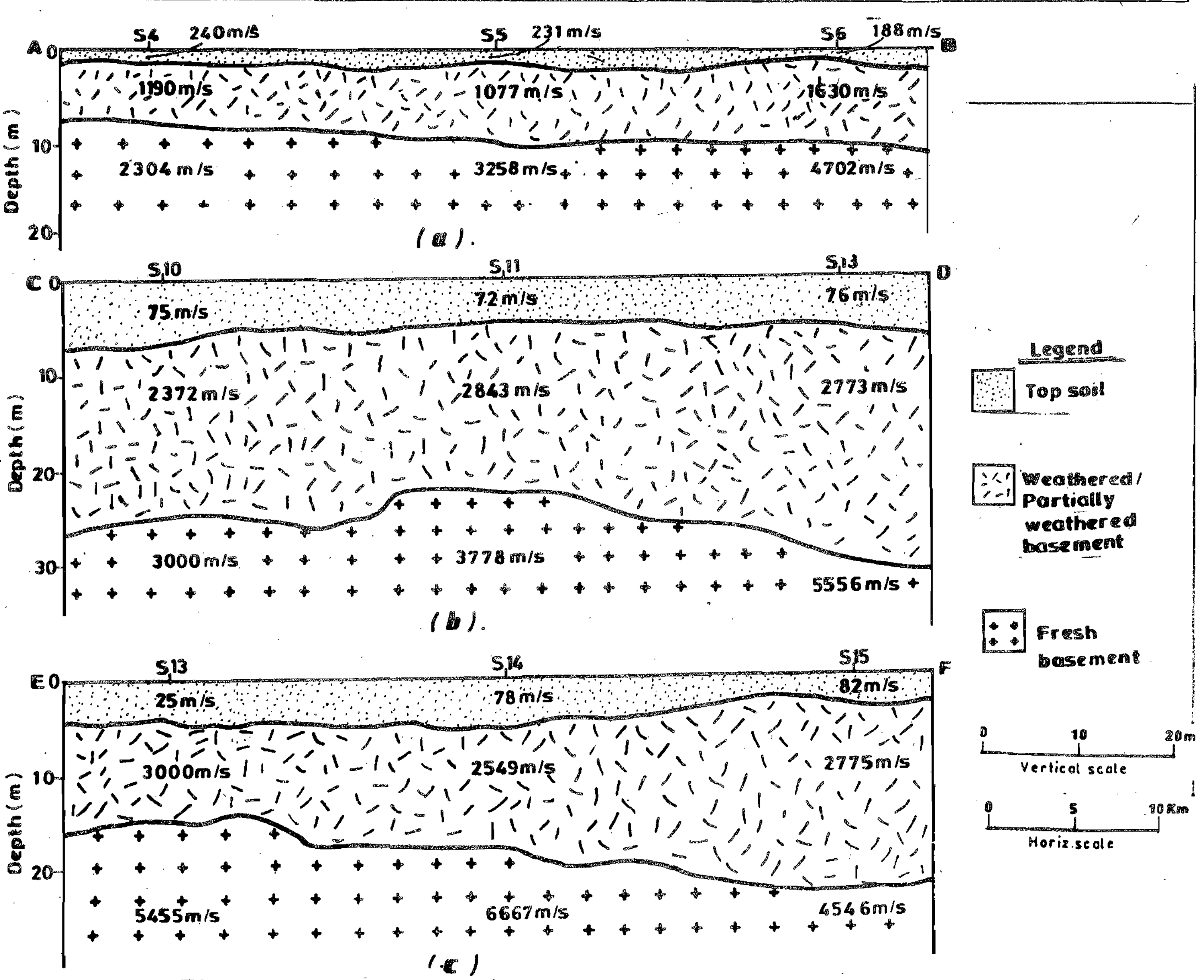

Fig. 6a, b, c,: Examples of Seismic sections in the study area and their interpretation.

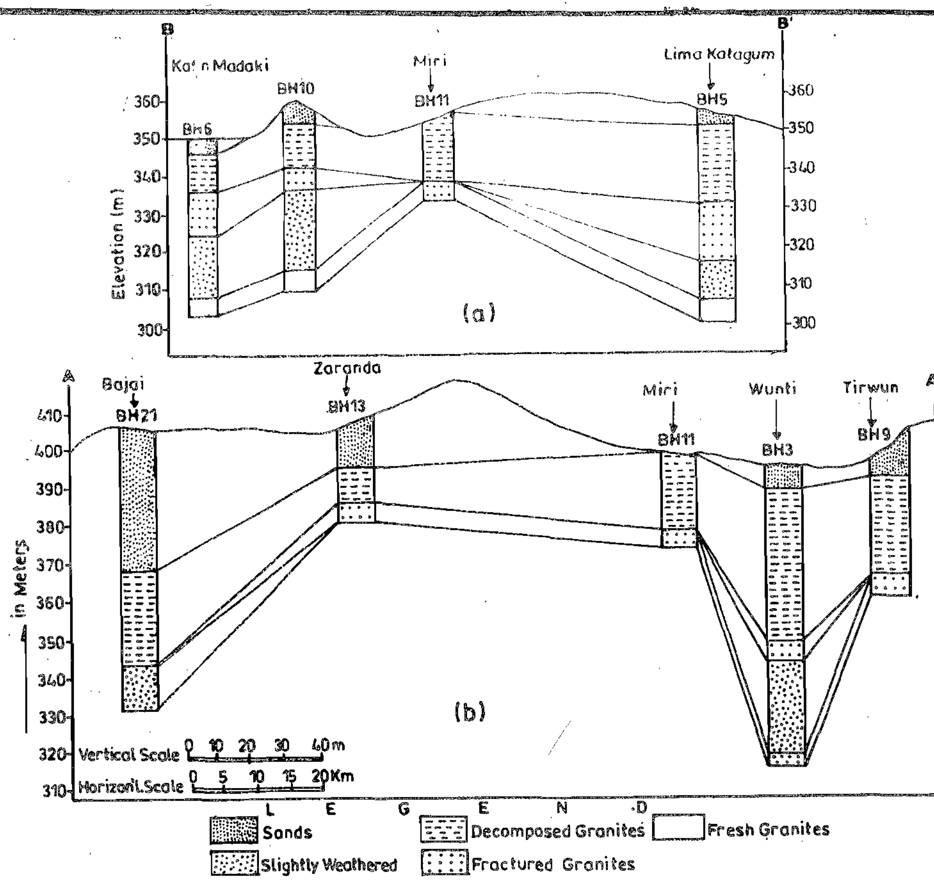

FIG. 7 : CORRELATION OF BOREHOLE LITHOLOGIC LOGS IN THE STUDY AREA

2003 carried out hydrogeological and geotechnical study of the present area of study, and determined the hydraulic properties of thirteen hand-dug wells using the statistical grain-size methods of Hazen 1983, Harleman et 1963 and Uma et al 1989, which indicate a mean hydraulic conductivity (k) value of 3.47×10^{-3} m/s and a mean transmissivity (T) value of 5.47×10^{-1} m/s (Table.4). Geochemical analyses of water samples collected from nine hand-dug wells are summarized in Table 5. The Sodium and Magnesium contents varied between 35-60 mg/l, and 45-85 mg/l respectively. The contents of Sulphate range between 85 and 110 mg/l, while the Calcium and Chlorite contents range between 26 and 65, and between 140 and 185 mg/l respectively, The Iron, Zinc and Hardness contents of the rock samples analyzed show 7.3 and 10 mg/l for Iron, 0.08 and 0.12 mg/l for Zinc, and between 322.6 and 449.9 mg/l for the hardness (Table.5).

From the results of this study, there are two main aquifer units, which were identified, based on analysis of borehole logs, geophysical investigations and geologic reconnaissance. These are weathered and the fractured basement aquifer units. The weathered aquifer unit is derived from the partial and/or complete weathering of the granitic rocks. The weathered material consists mainly of gravels, sands, silts and clays. These residual soils extend from Toro to Bauchi and from Liman Katagum to Kafin Madaki. The thicknesses vary from 3 m at Liman Katagum to 33 m at Toro with an average thickness of about 10.4 m (Fig. 7a,b). The depth to static water level varies from 2.3 m to 6.4 meters with an average of about 4.1m.

CONCLUSION

Seven Schlumberger Vertical Electrical Sounding (VES) and fifteen seismic refraction profiles were conducted in Bauchi and environs, Bauchi State. 29% of the VES showed three-layer earth model. Fifteen Seismic Refraction profiles also conducted indicate three-layer earth model. Nine boreholes of depths that range between 54 and 149 m., and an average hydraulic conductivity of 0.91 m/day, and transmissivity value of 19.86 m^2/day. Geochemical analysis conducted showed a mean Sodium and Magnesium contents of 50 and 64 mg/l respectively. The average contents of Sulphate, Calcium and Chlorite are 95.8, 47.3 and 185.9 mg/l respectively, while the Iron, Zinc and Hardness indicate 8.7, 0.1 and 381.3 mg/l respectively. The values indicate that the water is of Chlorite type and is generally of good quality and also suitable for both agricultural and industrial proposes.

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