JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 9 2001

INTERPRETATION OF GEOELECTRICAL DATA OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, YOLA, NIGERIA

A. Nur
G.I. Obiefuna
N.E. Bassey

Department of Geology, P.M.B.
Federal University of Technology
Yola, Nigeria

Fifty Schlumberger vertical electrical soundings (VES) carried out in the Federal University of Technology, Yola, Nigeria, have been interpreted. The data were first interpreted using conventional partial curve-matching techniques in order to obtain the initial model parameters. The model parameters obtained were used as an input into an optimizing computer program utilized for this study. Information from boreholes were incorporated to enhance and obtain realistic geologic models in the study area. The results obtained from the interpretation revealed three geoelectric layers. The depth to aquifer in the study area is 50 m. The transmissivity and hydraulic conductivity values compare well with the aquifer characteristics in the study area.

INTRODUCTION

The study area consists of several communities located within Girei and Jimeta local government areas of Adamawa State, including communities of the Federal University of Technology (FUTY), Gokra, Sangere, Adamu, and Bagalchi. It lies within the Yola arm of the Upper Benue Basin of northern Nigeria (Figure 1).Moderate to high productivity of some boreholes already drilled in the area supports the prolific nature of aquifers. However, the evolution of a proper water resources management program requires accurate data from a variety of sources, including hydrologic, geologic, and hydrogeologic surveys, as well as test drilling, pumping tests, and water analyses.

The evaluation of aquifer parameters such as hydraulic conductivity and transmissivity is normally conducted using data obtained from well pumping tests. However, many authors (Kelly, 1977;

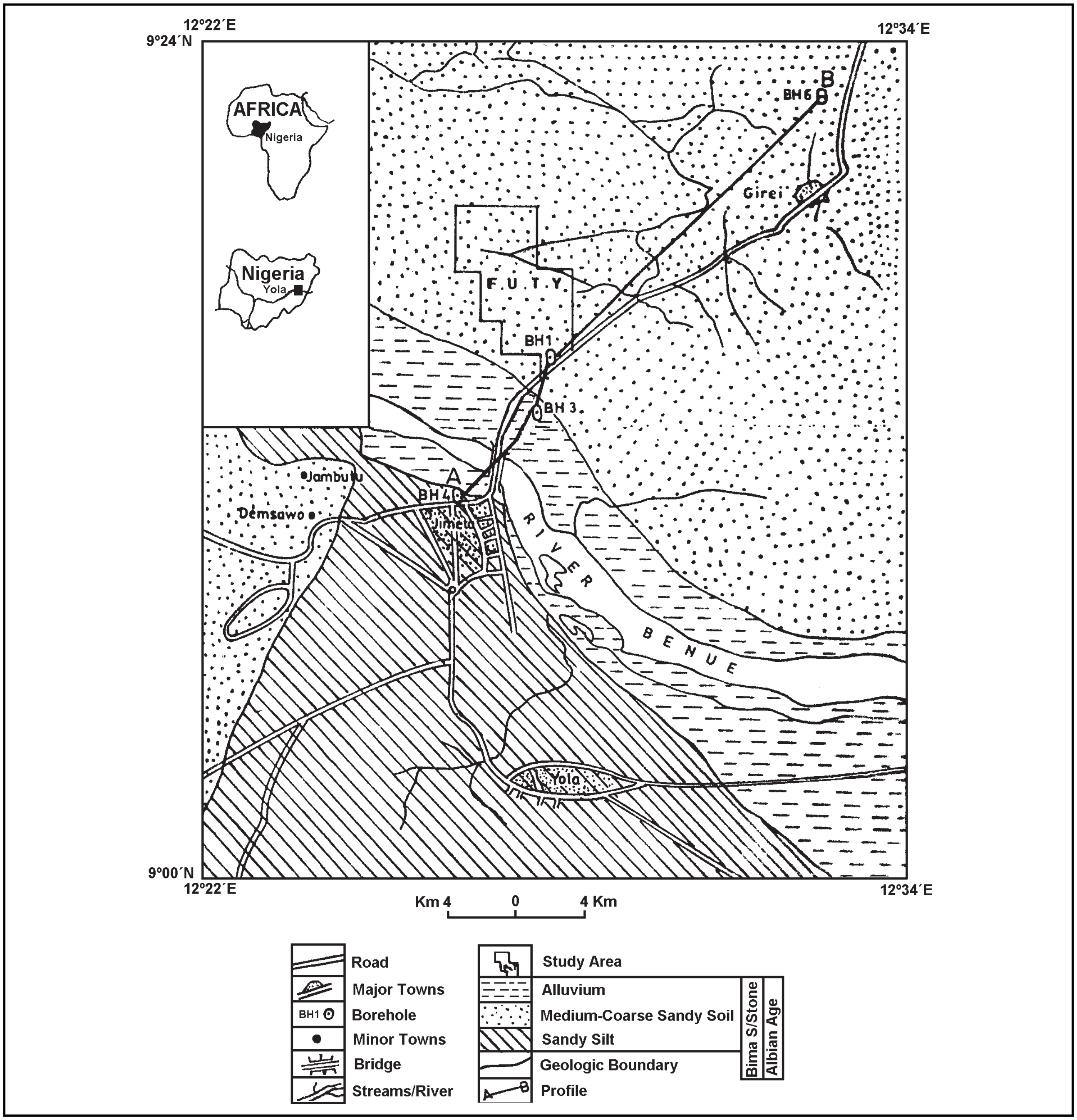

Figure 1. Geologic map of the study area and its surroundings. (Modified after Obiefuna et al. 1998)

Niwas and Singhal, 1981; Onuoha and Mbazi, 1988; Mbonu et al.,1991) have achieved remarkable results of detailed determination of aquifer characteristics through surface electrical sounding.

The main objectives of this study are to define the aquifer geometryof the Federal University of Technology Yola, and correlate some aquifer properties determined from pumping test analysis with those obtained from results of surface geoelectrical sounding. Also variations of some hydraulic and electrical properties of the aquifer across the study area will be presented.

PHYSIOGRAPHY, GEOLOGY AND HYDROGEOLOGY

The study area with its access roads and location of the sounding stations is shown in Figure 2. The area is easily accessed by motorable roads. Prominent landforms in the study area are the Bagale hills characterized by high relief, scarps and plains. The relief of the hills ranges between 550 m to 950 m above mean sea level. The western, northern and southern parts consist of plains and scarp slopes with scattered patches of Bima sandstone outcrops (Figure 1). Undulating ridges of the Bagale hills, with maximum elevations of about 950 m above the sea level, occur on the eastern edge of the study area. The southern part is drained by two small streams which rise from the Bagale hills and flow into the Benue river.

The observable landforms are a result of geological processes such as folding, faulting, jointing, unconformities and geomorphological processes such as weathering, erosion and deposition

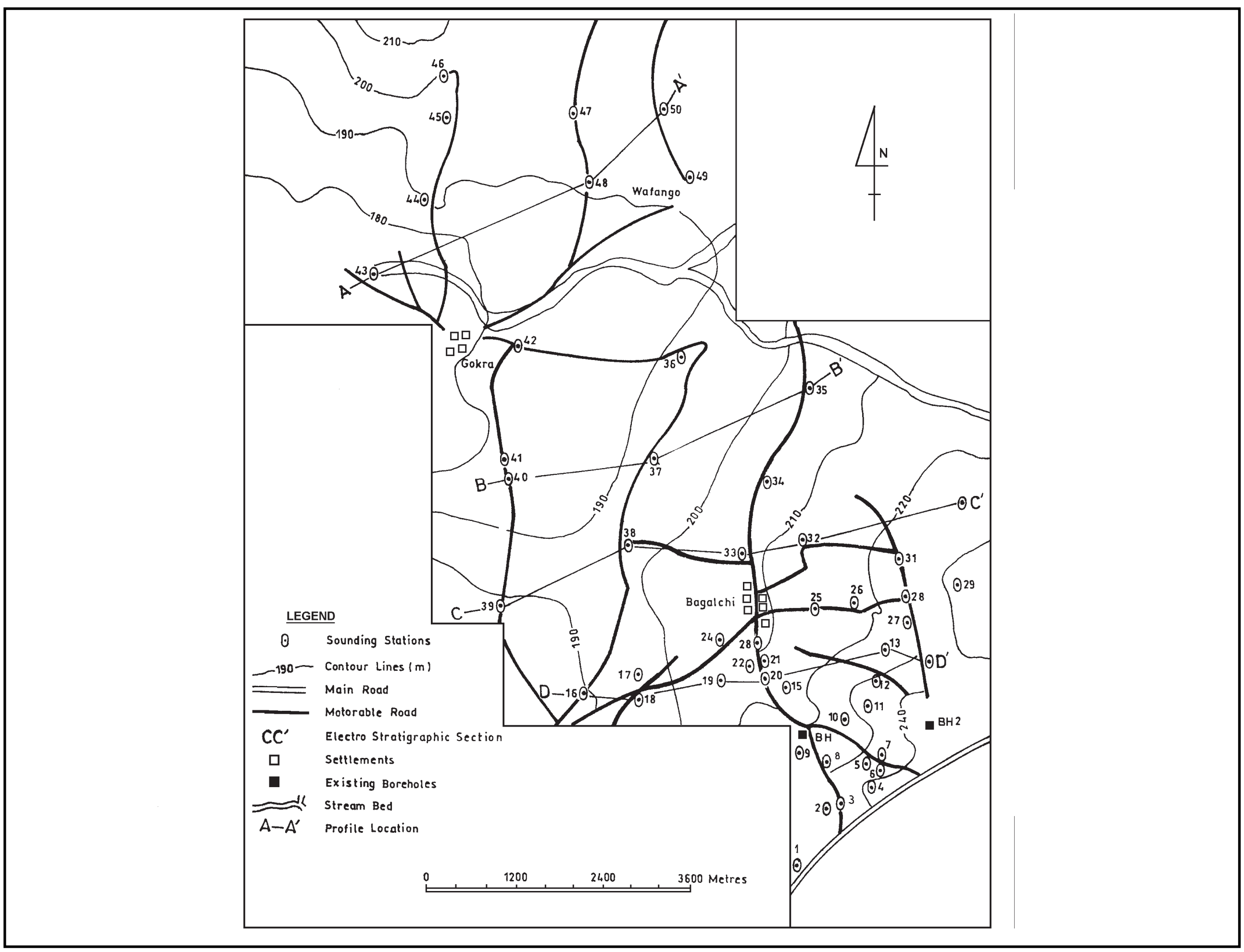

Figure 2. Map of the study area showing access roads and location of the 50 sounding stations (Modified after Alolis Geosciences - Nig. Ltd. 1986)

(Yakoshova, 1986). The study area is underlain by the Bima sandstone of Albian age, and it consists of moderately consolidated, fine to coarse grained sandstone with intercalations of whitish and red siltstones, mudstones and shales. The sandstones are generally poorly to moderately sorted, well cemented, competent and occasionally cross bedded. Both primary and secondary structures have been observed. The primary structures include cross stratifications, shrinkage cracks, flow marks, ripple marks and pebble accumulation, whereas the secondary structures include faults, folds, joints and fissures.

The Bima sandstone unconformably overlies the Basement rocks and consist of three beds, namely the Upper beds, Middle beds and the Lower beds (Falconer, 1911). The lower bed is invariably feldspathic but the higher bed, which accumulated as the basin subsided and at greater distance from the granitic basement, generally contains less feldspars. The relatively high permeability of the Bima sandstone, its fractured nature, the weathered topsoil of this formation as well as the intercalation of siltstones, mudstones and shales, provide the hydrologic conditions favoring aquifer formation in the area. Locally, a multi-aquifer system is formed by the localized shales and mudstones which separate the sandstone. The moderately high annual rainfall ensures adequate groundwater recharge.

DATA ACQUISITION AND INTERPRETATION

Fifty Vertical Electrical Soundings (VESs) were made in 1986 by Ililos Geo-sciences Nigeria, Ltd., in the study area (Figure 2). Modified Schlumberger electrode spreading was used with maximum separation AB/2 of 500 m. The apparent resistivity from the field plotted in a log-log graph paper shows that most of the sounding curves reflect the presence of three geoelectric layers. Most curve types found in the study area are of the K and H type, and some are combinations of QH or HK.

The initial interpretation of the VES data was accomplished using a conventional partial curve matching technique with a two layer master curve and auxiliary diagrams. Estimates of resistivity layers and thicknesses were obtained and used afterwards as starting models. The computer aided interpretation was based on optimization techniques. The Program (Resist.for) was obtained from the Rivers State University of Science and Technology, Port Harcourt. It is known that resistivity inversion is nonunique, therefore constraints were introduced in the analysis to obtain realistic and representative geologic models. Borehole information was incorporated and the layered earth models from the VES interpretation were kept as simple as possible by not allowing results with too many thin layers. The results obtained from the computer modeling for the fifty soundings are presented in Table 1, while Figure 3 shows examples of some vertical electrical soundings and their interpretation.

Model Parameters

Consider a unit square cross sectional area cut out of a group of n layers of infinite lateral extent. The total transverse unit resistance R is given by

$$R = \sum_{i=1}^{n} h_i \rho_i \qquad (1)$$

where h_i and ρ_i are the layer thickness and resistivity of the i^{th} layer in the section respectively. The total longitudinal conductance S is as follows:

$$S = \sum_{i=1}^{n} h_i / \rho_i \qquad (2)$$

The longitudinal layer S_i is can also be represented by:

$$S_i = \sigma_i h_i \tag{3}$$

where σ_i is the layer conductivity.

The transmissivity Tr_i is represented by : $Tr_i = k_i h_i$, where k_i is the hydraulic conductivity of the i^{th} thickness h_i. The transversal resistance (R) and the longitudinal conductance (S) are called Darzarrouk parameters, and have been shown as useful aids in the interpretation for groundwater surveys (Zohdy, 1989). More mathematical formulation used for this study could readily be found in Mbonu et al., 1991.

RESULTS

The isoresistivity map is a qualitative interpretation tool that shows variation in resistivity at a given electrode spacing chosen by the interpreter. According to Kunetz (1966), current penetration in an electrode spread ranges between 1/4 to 1/3 the current electrode separation. The isoresistivity map for AB/2 =100 in Figure 4, shows that four zones of greater than 100 ohm-m can be identified within

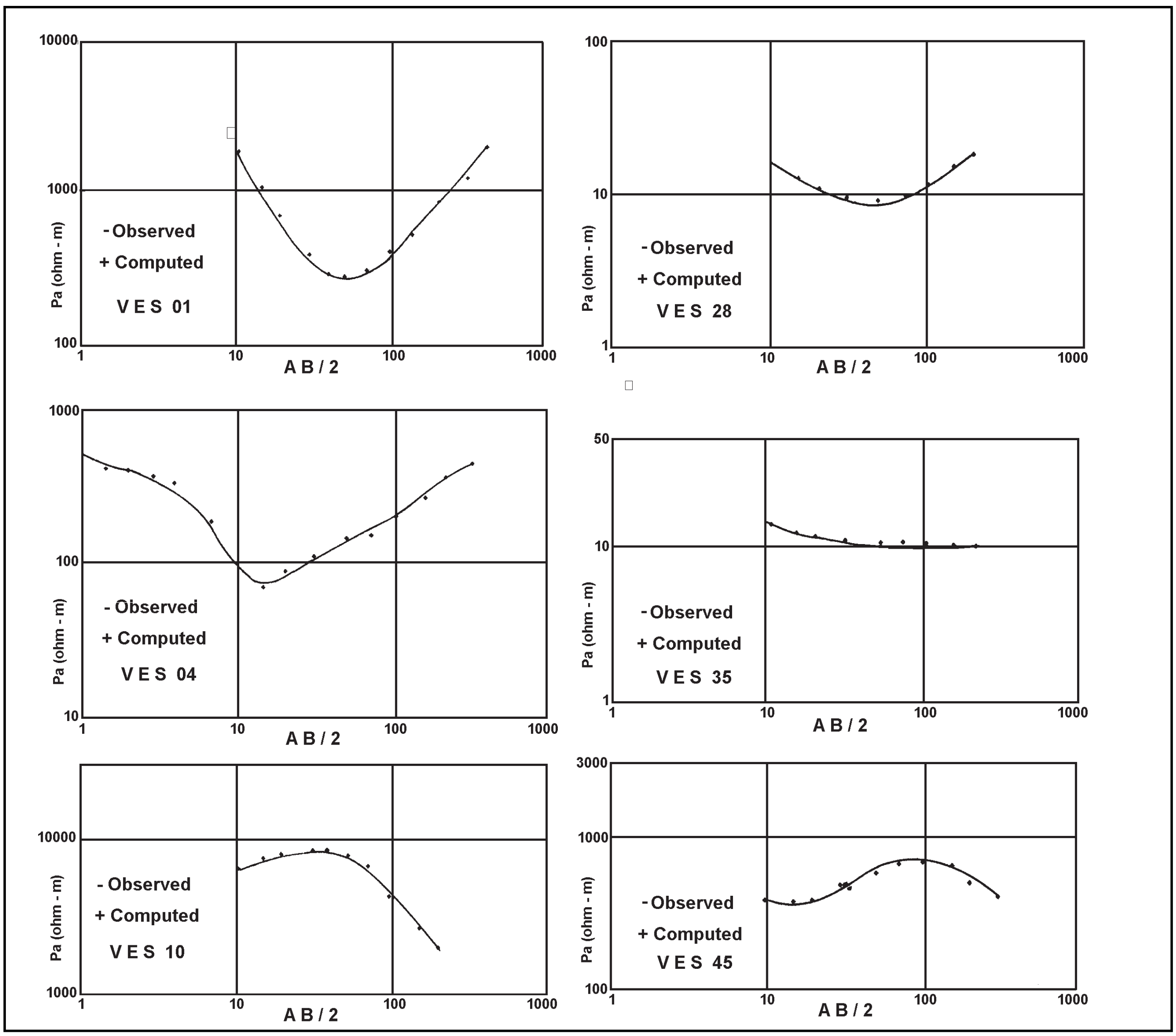

Figure 3. Examples of computer interpretation for VES 01, VES 04, VES 10, VES 28, VES 35, VES 45.

Table 1. Summary of Results from Computer Modelling for all the 50 Sounding Stations

VES Station	**Resistivity of Layers (ohm. m)**				**Thickness of Layers (m)**			**Conductance of Layers (Siemens)**			**Resistance of Layers (ohm)**			**Fitting Error for Stations**
No	**P1**	**P2**	**P3**	**P4**	**t1**	**t2**	**t3**	δ_1	δ_2	δ_3	**R1**	**R2**	**R3**	**%**
1	1997.103	230.086	8285.583	----	5.72	46.84	----	0.003	0.204	----	11426.930	10777.690	----	4.931
2	1457.832	71.596	1234.941	----	22.99	20.32	----	0.016	0.284	----	33521.730	1457.973	----	4.197
3	190.235	329.535	0316.035	----	44.93	0.46	----	0.236	0.001	----	8547.564	150.111	----	5.126
4	418.666	58.497	215.479	1538.956	3.73	17.81	154.39	0.009	0.305	0.717	1562.541	1041.957	33268.650	4.763
5	903.904	180.055	1499.141	----	0.29	32.98	----	0.000	0.183	----	260.819	5937.759	----	3.224
6	137.156	2285.466	829.901	----	3.79	33.00	----	0.028	0.014	----	520.027	75421.090	----	4.903
7	279.580	410.898	517.082	178.929	0.47	3.31	261.76	0.002	0.024	0.506	132.788	568.936	135348.900	6.753
8	15143.600	8843.945	3455.557	----	2.91	18.13	----	0.000	0.002	----	305724.100	160361.500	----	5.986
9	734.147	7963.681	1293.353	237.710	3.25	23.60	333.40	0.004	0.003	0.258	2387.227	187933.800	43123.300	5.019
10	5262.015	9776.175	1682.475	----	5.06	52.02	----	0.001	0.005	----	226631.570	508522.000	----	1.294
11	1480.473	1117.824	613.918	----	40.53	22.00	----	0.027	0.004	----	60000.430	1.117	----	3.186
12	21099.840	2853.317	1511.715	----	9.45	42.93	----	0.000	0.015	----	199303.400	122486.600	----	5.951
13	20.159	652.917	----	----	10.28	----	----	0.510	----	----	207.213	----	----	7.418
14	929.356	7991.980	1700.594	----	3.57	68.67	----	0.004	0.009	----	3318.826	548770.000	----	7.274
15	4961.125	3982.322	810.353	----	38.44	23.56	----	0.008	0.003	----	190690.500	3.982	----	4.221
16	16.589	88.852	36.739	----	9.65	447.43	----	0.582	5.036	----	160.160	39754.970	----	3.018
17	17.067	16.329	7425.149	----	19.89	85.09	----	1.163	1.837	----	339.263	3942.273	----	7.288
18	14.738	94.412	891.666	----	9.83	121.97	----	0.667	1.292	----	144.910	11515.820	----	3.684
19	19.768	50.042	418.647	----	8.84	49.19	----	0.447	0.983	----	174.744	2461.667	----	3.170
20	14.747	313.586	986.494	----	8.39	189.96	----	0.569	0.606	----	123.665	59567.860	----	2.907
21	52.313	13318.030	----	----	71.64	----	----	0.370	----	----	3747.906	----	----	6.330
22	20.061	114.445	898.618	----	8.47	57.33	----	0.422	0.501	----	169.828	6560.718	----	4.978
23	90.035	10.942	34.920	----	3.52	30.48	----	0.039	2.905	----	316.741	319.802	----	3.469
24	10.729	38425	1809551.000	----	13.18	139.37	----	1.228	3.627	----	141.377	5355.367	----	3.086
25	648.931	7.373	15.174	----	0.83	4.09	----	0.001	0.555	----	541.041	30.184	----	6.555
26	437.231	10.952	498.874	----	3.66	95.91	----	0.008	8.757	----	1601.888	1050.430	----	7.223
27	339.724	18.882	595.237	1319.919	5.45	55.91	64.93	0.016	2.961	0.109	1851.730	1055.716	38648.280	7.343
28	19.614	7.808	37.696	----	7.06	48.08	----	0.360	6.157	----	138.507	375.392	----	2.614
29	130.470	19.940	3000.464	----	6.67	104.53	----	0.051	5.224	----	870.744	2084.268	----	6.558
30	290.977	1204.338	310.022	----	1.98	44.25	----	0.007	0.037	----	575.694	53296.570	----	5.496
31	28.152	40.411	87.977	----	18.04	132.74	----	0.641	3.285	----	507.857	5363.953	----	1.326
32	15.759	36.407	49.240	----	13.14	186.35	----	0.834	5.119	----	207.029	6784.626	----	1.536
33	11.714	62.700	41.394	----	5.26	54.47	----	0.449	0.869	----	61.555	3415.485	----	2.018
34	24.725	15.296	49.570	----	5.89	169.87	----	0.238	11.105	----	145.677	2598.389	----	1.451
35	16.469	11.609	9.836	----	4.21	16.68	----	0.256	1.437	----	69.416	193.642	----	0.748
36	2834.747	1191.234	9719.074	----	6.28	196.74	----	0.002	0.165	----	17808.550	234361.300	----	3.577
37	478.417	1501.656	3344.868	----	4.20	29.24	----	0.009	0.019	----	2024.089	43905.110	----	2.417
38	14.908	66.005	0.001	----	9.02	212.99	----	0.605	3.227	----	134.522	14058.110	----	2.370
39	27.409	14.809	108.438	----	3.38	62.79	----	0.123	4.240	----	92.684	929.825	----	3.473
40	10478.930	200.819	511.658	----	0.38	5.60	----	0.000	0.028	----	3959.314	1124.677	----	6.063
41	499.724	84.099	18.679	----	12.51	71.68	----	0.025	0.852	----	6253.379	6026.378	----	2.393
42	667.059	1631.191	3436.853	----	3.69	57.17	----	0.006	0.035	----	2461.642	93256.070	----	1.878
43	25.066	66.046	0.490	----	9.47	514.99	----	0.378	7.797	----	237.478	34012.850	----	2.395
44	14.132	11.438	150.351	----	4.37	43.47	----	0.309	3.800	----	61.800	497.156	----	1.963
45	343.166	1539.687	302.358	----	18.95	30.01	----	0.055	0.019	----	6503.510	46200.280	----	7.738
46	665.256	519.557	240.103	----	10.56	78.05	----	0.016	0.150	----	7026.613	40550.520	----	5.211
47	30.847	88.842	25.085	----	5.08	141.58	----	0.165	1.594	----	156.792	12578.440	----	2.357
48	11.414	47.341	13.918	----	3.43	33.51	----	0.301	0.708	----	39.177	1586.565	----	4.818
49	6.903	26.282	150.705	----	3.21	104.80	----	0.465	3.987	----	22.144	2754.333	----	1.492
50	210.109	55.001	28.048	----	10.65	20.92	----	0.051	0.051	----	2237.675	1150.658	----	4.836

the study area on the basis of resistivity values. The first zone located northwest of Wafango (VES 45) the resistivity is up to 500 ohm-m. The second zone is located almost at the center of the study area. The highest resistivity values for this zone was found at VES 37, where the resistivity was 2000 ohm-m. The third zone is in the southeast of the study area. This area is characterized by high resistivity values of up to 6000 ohm-m. This is not surprising because in this zone the Bima sandstone is well compacted and outcrops on the surface. The Bima Sandstone is highly cemented and crystallized in some places and therefore presents hydrogeologic conditions similar to basement rocks.

The four zones are found eastwards with resistivity values between 100 to 500 ohm-m. The variation on the isoresistivity map in the study area could be attributed to the known variations in mineralogical composition and compactness of Bima Sandstone. Four electrostratigraphic sections were taken, and the locations of these four interpretative cross sections AA', BB' , CC', and DD' are shown in Figure 2. The results of the VES obtained from the computer modeling show different

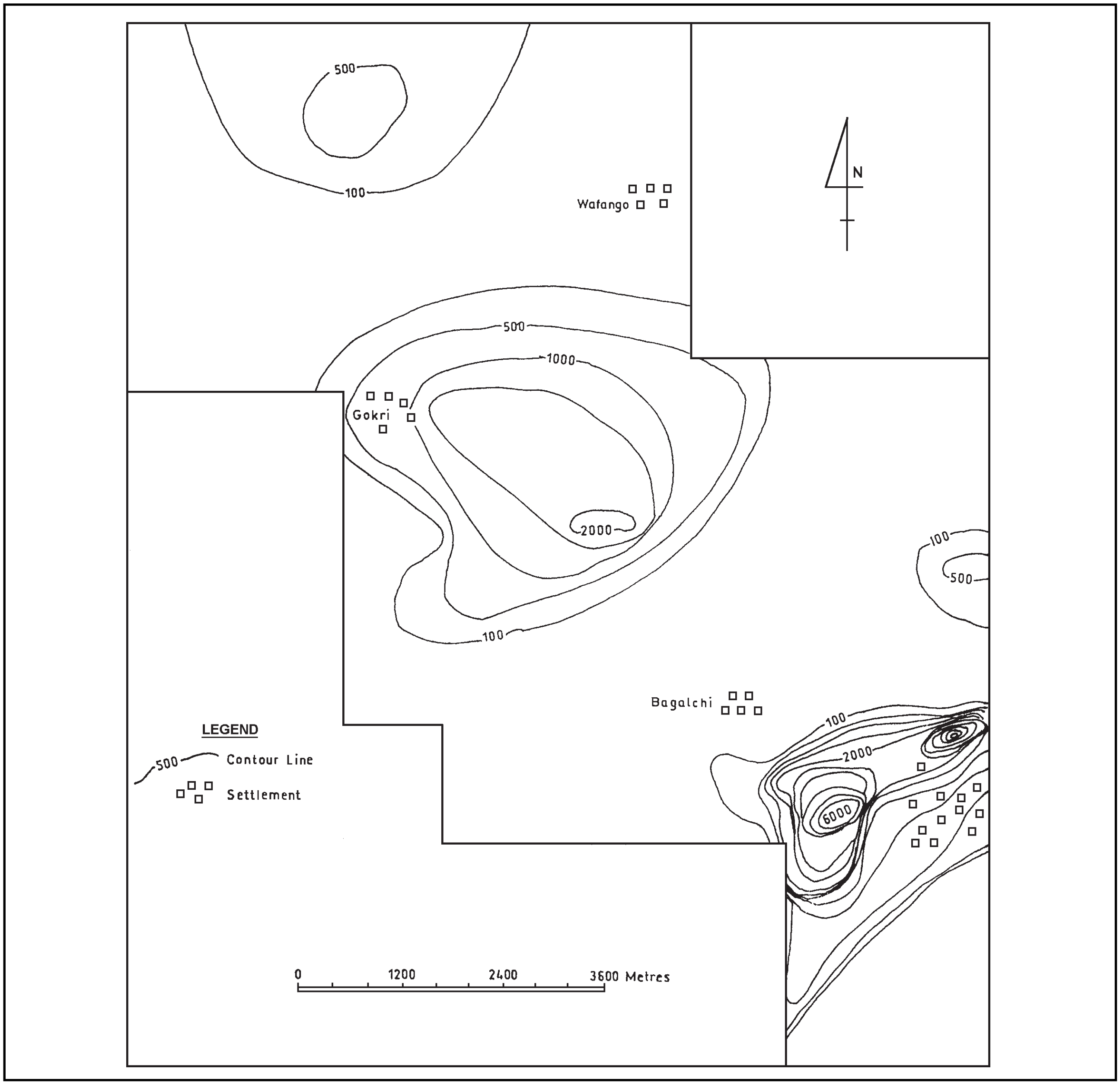

Figure 4. Isoresistivity map for AB/2 = 100 (Contour Interval = 100 ohm-m).

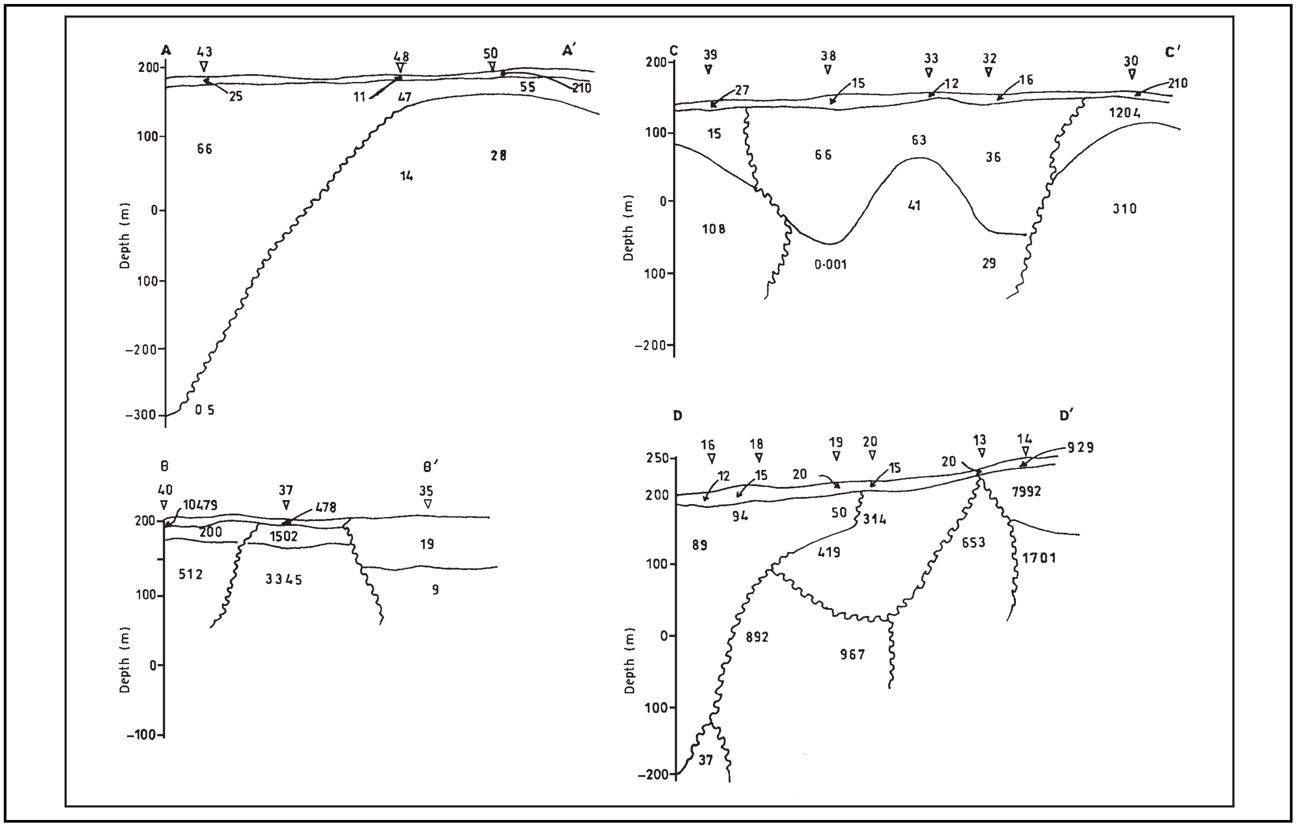

Figure 5. Electro-stratigrasphic section of AA’, BB’, CC’, and DD’; (ρa in ohm-m).

electrical characteristics and are presented in Figure 5. The results from the analysis compare fairly with the geological data and lithologic logs in the study area (Figure 6).

DISCUSSION AND CONCLUSIONS

The results of this study have led to the delineation of four zones that have resistivities of more than 100 ohm-m which indicates that the sand components increase until the formation becomes purely compacted sandstone. This sandstone is outcropping on the surface in the southeastern part of the study area, and four electrostratigraphic sections of nearly northeast directions were taken from Figure 2 as shown in Figure 5.

The interpretive cross-section AA’ shows three layers. The first layer has resistivity values ranging from 11 ohm-m to 25 ohm-m, except VES 50 which has a resistivity of 210 ohm-m. The thickness of the layer ranges between 3.4 m to 10 m. The second layer has resistivity values from 55 ohm-m to 66 ohm-m and a thickness between 20 m to over 400 m. The third layer, which is a conductive layer, has resistivity values between 0.5 ohm-m to 28 ohm-m.

The interpretive cross section BB’ also shows three layers, except VES 35 where there are two layers. The first layer has resistivity values ranging from 19 ohm-m to 10,479 ohm-m and thickness from 0.40 m to 4.20 m. The second layer has resistivity values ranging between 9 ohm-m to 1502 ohm-m with thickness ranging from 5.60 m to infinity. The third layer was only penetrated in VES 37 and 40, here the resistivity values recorded are 512 ohm-m and 3345 ohm-m respective1y. The cross-section CC’ shows three electrostratigraphic layers with the first layer having values ranging from 12 ohm-m to 210 ohm-m. In the second layer the resistivity values range between 15 ohm-m to 1204 ohm-m. The third layer has resistivity values ranging between 0.001 ohm-m and 310 ohm-m.

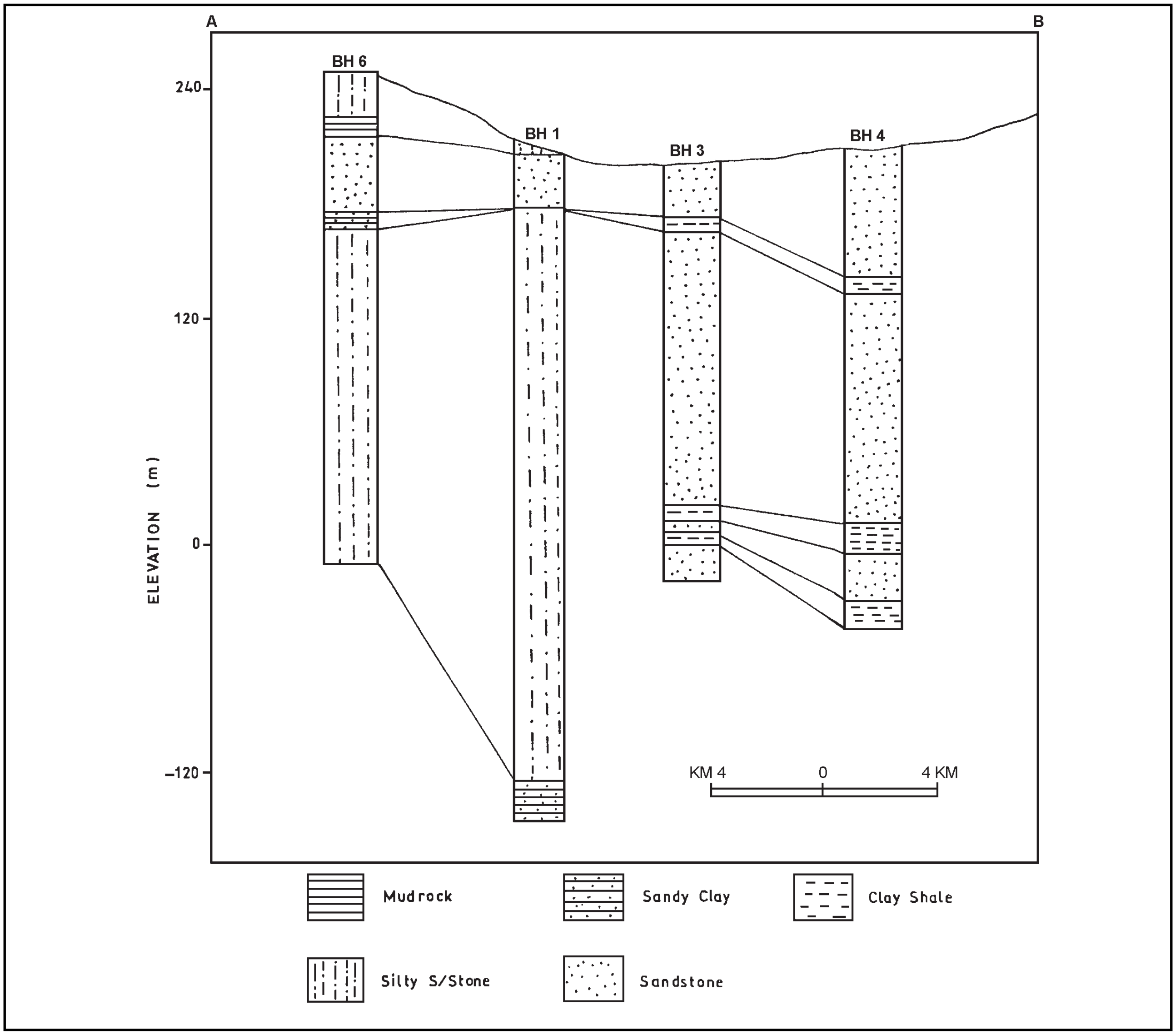

Figure 6. Lithologic Logs of some boreholes in and around the study area (Modified after Obiefuna et-al., 1998).

Cross section DD' also shows three electro-stratigraphic layers except VES 13 where two layers were obtained. The first layer has resistivity values ranging from 15 ohm-m to 929 ohm-m with thickness from 4 m to 10 m. The second layer has resistivity values from 50 ohm-m to 7,992 ohm-m and thickness ranging between 9 m and above. The third layer has resistivity values ranging from 37 ohm-m to 1701 ohm-m.

The four electro-stratigraphic sections presented in Figure 5 show high variations of resistivity values which are a result of lithologic variations within the Bima Sandstone. The Bima Sandstone is characterized by intercalations of clay, silty sandstone, mudstone and compacted sandstone. These lithological variations could occur both vertically and laterally. Thus the four electro-stratigraphic sections compare well with the geology of the area.

Transmissivity values of 491m^2/day and 210 m^2/day and hydraulic conductivity values of 189 m/day and 540 m/day were recorded for the Federal University of Technology Yola at borehole BH1 and the Girei borehole BH6 (Obiefuna et al.,1998). A transmissivity va1ue of 51.8 m^2/day and hydraulic conductivity value of 1.1 m/day were recorded for BH3 Jimeta south, which is outside of the study area. The results are consistent with the aquifer being consolidated, fine medium grained sandstone in the south of the study area and probably less consolidated and fractured in the north. The above relationship is expected because transmissivity is a function of aquifer thickness, and hydraulic conductivity is assumed constant.

The results obtained from the VES are comparable to the lithologic logs of boreholes in the study area shown in Figure 6. The water table in the study area was found to lie between 48 m around the Bagalchi area, while in VES 9 the depth was 51 m. The situation is different where clay and shale materials are the main lithology and the resistivity values are less than 100 ohm-m. In these areas the occurrence of shallow aquifers is unlikely. There is thus the possibility of having a confined aquifer in these areas.

ACKNOWLEDGMENTS

The authors are grateful to the Federal university of Technology Yola by providing raw resistivity data of the University land.

REFERENCES

Alolis Geo-sciences (Nig.)Ltd.; (1986). University of Maiduguri Yola Campus Geophysical and Hydrogeological Investigation. (Unpubl. report, Federal University of Technology, Yola, Nigeria).

Falconer, J.D.; (1911). The geology and geography of northern Nigeria. McMillan London 1-25.

Kelly E.W.; (1977). Geoelectriic sounding for estimating aquifer hydraulic conductivity: Groundwater, 15 420-424.

Kunetz, G.; (1966). Principles of direct current resistivity prospecting. Borntraeger.

Mbonu, P.D.C.; J.O. Ebeniiro, C.O.Ofoegbu, and A.S. Ekinee; (1991). Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia area of Nigeria. Geophyics. vol. 56 No.2. 284-291.

Niwas, S. and D.C. Singhal; (1981). Estimation of aquifer transmissivity from Dar Zarrouck parameters in porous media. J. Hydrology, vol. 50. 393-399

Obiefuna, G.I., A.S. Shuaibu, and S.A. Okirigwe; (1998). Physico-chemical properties of groundwater in Yola area and its influence on agricultural productivity. (submitted for publication to Water Resources, Journal of Nigerian Association of Hydrogeologists (NAH).

Obiefuna, G.I., A. Nur, N.E. Bassey and A.U. Baba; (1999). Geological and geotechnical assessment of selected gully sites, Yola area, northeast Nigeria. Journal of Environmental Hydrology, Paper 6, Vol.7, 1999.

Onuoha, K.M. and F.C.C. Mbazi; (1988). Aquifer transmissivity from electrical sounding data: The case of Ajali Sandstone aquifers southwest of Enugu, Nigeria. In Ofoegbu, C.O. (Ed.) Groundwater and Mineral resources of Nigeria. Vieweg-Verlag. 17-30.

Yakushova, A. F.; (1986). Geology with elements of geomorphology. Mir. Pub. Moscow 71-86.

Zohdy, A.A.R.; (1989). A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. Geophysics 54. 245-253.

ADDRESS FOR CORRESPONDENCE

A. Nur
Department of Geology
P.M.B.Federal University of Technology
Yola, Nigeria

Email: visascientist@skannet.com