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Determination of the Aquifer System of the Northern Sector of Bida Basin, Nigeria Using Electrical Resistivity Method

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Abstract

The northern sector of the Bida Basin extends from Gulu in the south to Kontagora in the north, where it contacts the crystalline rock of the Basement Complex system. It lies between latitudes 5°80' and 10°50' N and longitudes 4°50' and 7°00' E. The Basin consists of Maastrichtian sedimentary deposits comprising of the Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone Formations, with a total sedimentary pile of between 3500 to 4500 m. The aquifer is composed mainly of coarse to medium grained sandstone. Geoelectric survey was conducted using the Schlumberger configuration to a total AB/2 separation of 300 m. 140 Vertical Electrical Sounding (VES) points were established along nine profiles spread across the Basin. The resulting curves were interpreted both qualitatively and quantitatively using visual inspection of the field curve, curve fitting using standard master and subsidiary curves as well as by computer iteration (Interpex IX1D). The results indicate that the dominant curve types are the AA, QQH and KQ. Four groups of curve types were obtained in the Basin, Group 1 (H, K), Group 2 (A, AA, KHK), Group 3 (HK, HKQ, KHKQ, KHKHK, QQH) and Group 4 (QHK, KQQ, KQ, QHK, Q). Based on these four groups the Basin was divided into a northern, central and southern sectors as well as geological contact areas. Geoelectric sections, developed from geoelectric logs show that three types of aquifers exist at various depths; a perched aquifer with a depth of between 5 to 20 m, a semi confined / confined aquifer at between 30 to 60m and an unconfined aquifer with undetermined thickness. The topsoil has a resistivity range of 50-500 Ohm-meters, ferruginised sandstone, 800-2000 Ohm-meters, sandy clay, 150-500 Ohm-meters, sandstone 300-1500 Ohm-meters and clay/shale, 10 to 100 Ohm-meters. The aquifer is represented by the sandstone.

Keywords: Bida Basin, resistivity, aquifer, curve type

1. Introduction

The Mid-Niger Basin otherwise known as the Bida Basin or the Nupe Basin is a NW-SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south. It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments (Adeleye, 1974). The basin is a gently downwarped trough whose genesis may be closely connected with the Santonian orogenic movements of southeastern Nigeria and the Benue valley, nearby. The basin is a NW-SE trending embayment, perpendicular to the main axis of the Benue Trough and the Niger Delta Basin (Figure 1). It is frequently regarded as the northwestern extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in Late Cretaceous times (Obaje, 2009). Interpretations of Landsat images, borehole logs, as well as geophysical data across the entire Bida Basin suggest that the basin is bounded by a system of linear faults trending NW-SE (Kogbe et al., 1983). Gravity studies also confirm central positive anomalies flanked by negative anomalies as shown for the adjacent Benue Trough and typical of rift structures (Ojo, 1984; Ojo & Ajakaiye, 1989). The area of study is the northern sector of the Basin which extends from Gulu area in the south to Kontagora/Auna in the north (both in Niger state) where it contacts the crystalline rocks of the Basement Complex system. It lies between latitude 8°50' N and 10°50' N and longitude 4°50' E and 7°00' E covering an area of about 300 km^2 north of River Niger.

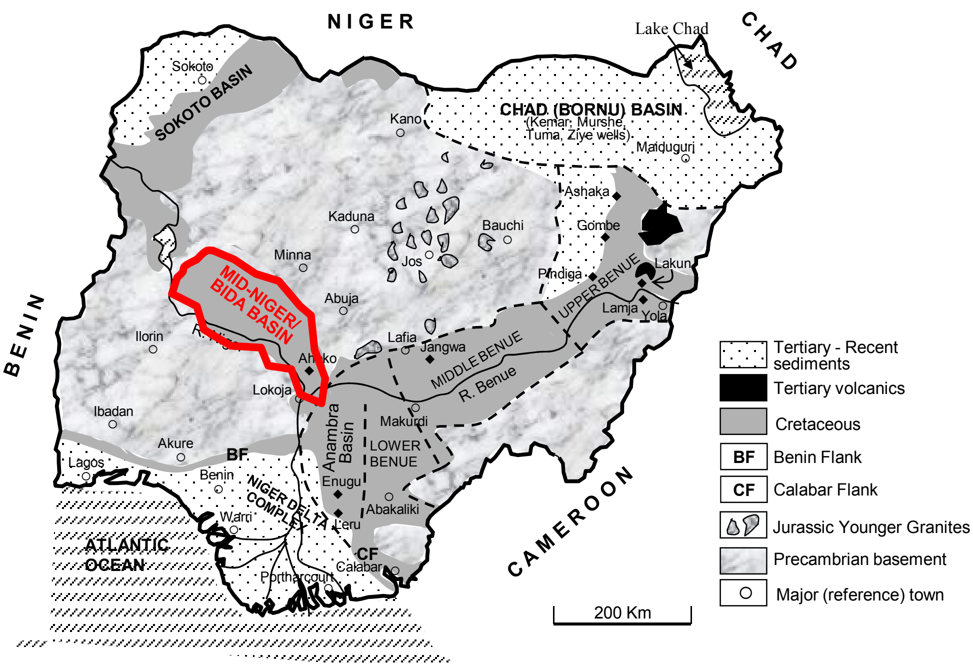

Figure 1. Sketch geological map of Nigeria showing the location of the Bida Basin (modified after Obaje, 2009)

2. Geology

The thickness of the sedimentary pile has been variously put at, 1.0 km (Whiteman, 1982) using aeromagnetic observations; 3.5 km (Ojo & Ajakaiye 1976) using gravity measurements, Adeniyi (1985, 1986) also suggested 3.5 km using gravity measurements, while Udensi (2005) suggested an average thickness of 3.39 km using statistical spectral analysis of the residual total magnetic field, though two of the areas studied showed a thickness in excess of 4.50 km. The oldest rocks exposed in the Bida basin are Maastrichtian in age but sedimentation may have started earlier. The rocks outcropping have been variously called the Nupe series, Nupe-sandstone series (Falconer, 1911; Geological survey of Nigeria, 1956). Jacques (1945) divided the Bida Basin sandstone into Nupe sandstone and the Nupe Basal conglomerate. The Geological survey of Nigeria (1956) assigned a Senonian age to the rocks. The Basin is poor in fossils and the age of the formation has been determined mainly by photogeological correlation with the post-Santonian sequence of the Anambra Basin (Dessauvagie, 1972). The stratigraphy and sedimentation of the Bida Basin have been studied in detail by Adeleye (1972) and Adeleye and Dessauvagie (1972).

Table 1. Stratigraphic section of the Bida Basin (Adeleye, 1972)

Age	Southern Basin	Northern Basin		
Post Cretaceous	Laterite, alluvium	Laterite, alluvium		
Upper Cretaceous	Agbaja Formation	NUPE GROUP	Batati ironstone Formation	Edozhigi member Kutigi member
	Patti Formation		Enagi siltstone Formation	
			Sakpe ironstone	Wuya member Baro member
	Lokoja Formation		Bida Sandstone Formation	Jima member Doko member
Pre Cambrian	Basement complex			

3. Methodology

Geophysical survey was conducted in the area using the Electrical Resistivity method. The subsurface data of interest in this study using surface geophysical surveys include the determination of the following;

i. Detection of the position, extent and volume of potential aquifers,

ii. Estimation of the thickness of the various geological units,

iii. Determining discontinuity in extent of the aquifers,

iv. Detection of aquitards and connections between different aquifers,

v. Establishing lateral and vertical variations in lithology with distance and depth,

vi. Determining resistivity range for the materials that make up the Basin.

These parameters were determined using the Electrical Resistivity method of survey, electrode configurations deployed for the study were the Schlumberger and modified Schlumberger arrays.

Over 300 Vertical Electrical Soundings (VES) were conducted across the Basin out of which 140 were done along nine profile lines covering the Basin (Figure 2), an attempt was made for the profiles to cover the entire study area, with between seven to twelve soundings along each profile. The equipment used for the study was the Geotron Resistivity meter model G41. Survey points were established using a Garmin Global Positioning System (GPS) Etrex Legend. Results of the geophysical surveys are shown in Table 2 and the curves are shown in Figure 4a and 5a.

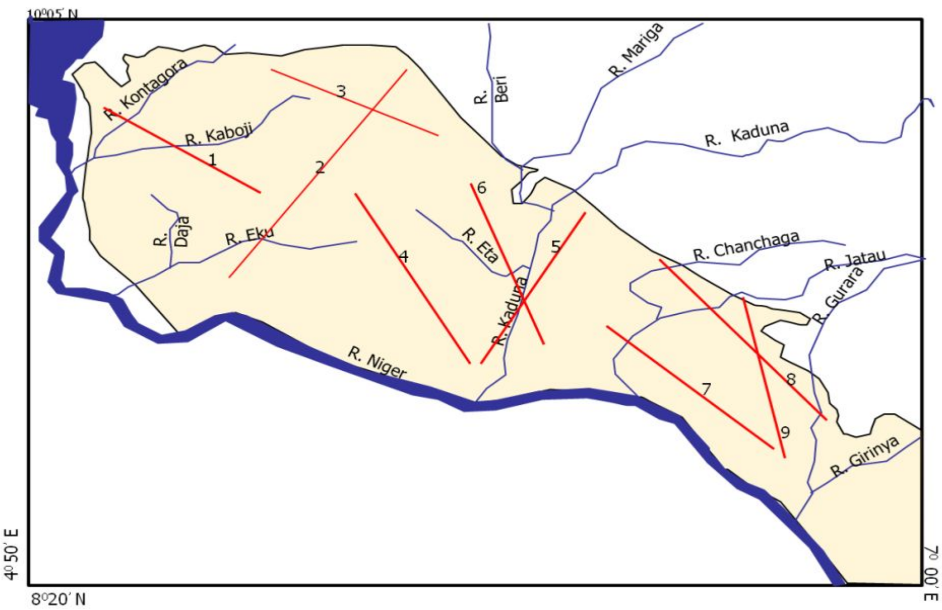

Figure 2. Profiles along which geophysical investigations were carried out

4. Results and Interpretation

4.1 Results

The Vertical Electrical Sounding (VES) curves were interpreted both qualitatively and quantitatively. The qualitative interpretation involved curve inspection, while the quantitative interpretation involved partial/complete curve matching with standard master and subsidiary curves, and also by field curve layering. The quantitative interpretation results were refined by computer iteration technique using the computer program Interpex IX1D.

The resulting geoelectric logs were correlated to establish the geoelectric sections which were used to characterize the aquifer types in the area. The lithologic logs obtained from boreholes in the area were correlated with the VES interpretations results, Figure 3. The correlation in depth between the VES results and lithological logs is, in most cases, better than 80 percent.

The interpreted curves were joined to bring out the geoelectric logs, geoelectrical sections were then drawn from the logs. The aquifer geometry in the area was determined using this method. Characteristic resistivity values were also determined for the various geological materials that make up the Basin. Figure4 shows a typical interpretation of the VES curve in a part of the Basin using the Interpex IX1D.

Table 2. Results of geoelectric surveys in the Bida Basin

No	AB/2	MN/2	K	RESISTIVITY (Ohm-meter)									
				Muye	Kpada	Pati Ndaloke	Lokogoma	Tungan Kawo	Manigi	Bida	Makera	Salka	Matane
				8.25N6.72E	8.63N 6.67E	9.15N 6.26E	9.34N 6.03E	10.49N 5.08E	9.75N5.51E	9.07N5.99E	9.68N5.40E	10.18N 4.58E	10.01N 5.38E
1	1	0.5	2.36	137	1011	258	107	128	321	1450	83	90	349
2	2	0.5	11.8	238	966	324	135	140	469	1359	121	51	283
3	3	0.5	27.5	263	1040	114	378	127	516	1124	151	42	283
4	5	0.5	77.8	257	1600	83	107	100	609	1053	227	40	330
5	6	0.5	112	210	1694	76	105	152	1378	967	260	43	327
6	6	1	55	220	1462	67	118	137	378	1133	241	38	319
7	8	1	99	161	1305	66	136	148	480	1012	274	47	287
8	10	1	156	120	1097	64	147	150	708	1069	308	59	273
9	10	2.5	58.9	121	1187	66	132	81	741	1273	262	65	281
10	15	2.5	137	54	800	54	177	177	860	1134	362	93	277
11	20	2.5	247	25	485	46	219	147	1008	810	481	110	292
12	30	2.5	562	19	415	35	245	113	1382	928	627	101	348
13	40	2.5	1001	17	459	29	239	100	1577	869	685	96	363
14	40	7.5	323	18	564	37	206	97	888	807	676	98	325
15	50	7.5	512	14	694	32	108	83	963	788	748	93	338
16	60	7.5	742	13	776	28	141	75	994	518	818	82	393
17	70	7.5	1014	12	847	26	118	67	1149	445	820	70	473
18	80	7.5	1329	13	903	21	98	60	1147	392	851	75	529
19	80	15	647	30	1067	24	102	66	1124	411	904	82	445
20	90	15	825	13	1096	18	78	48	1098	350	918	89	580
21	100	15	1024	13	1256	14	69	46	1001	322	948	86	566
22	110	15	1244	18	1508	18	64	44	946	308	1002	94	490
23	120	15	1488	29	1921	22	62	42	883	292	1040	102	452
24	130	15	1746	41	2124	30	66	38	767	286	1079	114	466
25	130	30	1234	43	2167	51	68	40	669	297	1182	121	551
26	140	30	2384	67	2218	77	72	36	520	277	1191	126	601
27	150	30	2748	88	2230	91	29	33	499	281	1221	148	742

No	AB/2	MN/2	K	RESISTIVITY (Ohm-meter)									
				FGGC Bida	Wuya Kede	Katcha	Salka	Gurai Kawo	Daja-Najata	Bwaje	Mokwa	Kutigi	Lapai
				9.07N 6.01E	9.09N 6.02E	8.76N6.31E	10.18N 4.58E	10.14N 4.54E	9.58N4.75E	8.42N6.73E	9.19N 5.09E	9.18N5.59E	8.25N 6.72E
1	1	0.5	2.36	1041	146	122	294	82	382	857	1051	298	137
2	2	0.5	11.8	356	138	103	281	97	328	1203	608	399	238
3	3	0.5	27.5	353	114	82	285	103	337	1300	522	450	263
4	5	0.5	77.8	362	82	48	1047	212	343	1727	538	574	257
5	6	0.5	112	367	69	34	1215	119	339	1873	381	601	210
6	6	1	55	313	67	35	470	114	298	1690	334	564	220
7	8	1	99	261	59	27	932	111	294	1905	266	573	161
8	10	1	156	239	55	23	1884	114	280	2145	225	596	120
9	10	2.5	58.9	243	60	24	69	126	273	2353	274	597	121
10	15	2.5	137	237	56	18	92	130	233	2029	314	560	54
11	20	2.5	247	233	50	16	177	151	235	3417	454	520	25
12	30	2.5	562	200	46	15	1046	201	280	1224	379	558	19
13	40	2.5	1001	153	53	15	1152	261	285	795	993	855	17
14	40	7.5	323	125	78	20	407	252	269	2242	1202	798	18
15	50	7.5	512	113	56	17	555	316	267	560	1054	812	14
16	60	7.5	742	108	58	15	493	353	260	350	1517	791	13
17	70	7.5	1014	102	60	14	415	404	268	218	1478	695	12
18	80	7.5	1329	85	62	15	382	462	275	130	1822	577	13
19	80	15	647	87	64	16	336	504	285	254	1411	747	16
20	90	15	825	59	73	17	297	553	302	63	1332	726	13
21	100	15	1024	61	79	20	236	586	361	45	1290	776	13
22	110	15	1244	58	81	28	198	600	386	42	1306	820	13
23	120	15	1488	54	72	33	164	634	390	51	1372	887	16
24	130	15	1746	53	63	36	133	677	398	62	1383	937	22
25	130	30	1234	50	60	42	137	691	401	78	1387	961	28
26	140	30	2384	47	61	49	145	708	420	91	1148	994	37
27	150	30	2748	48	58	57	157	717	443	102	1150	1102	46

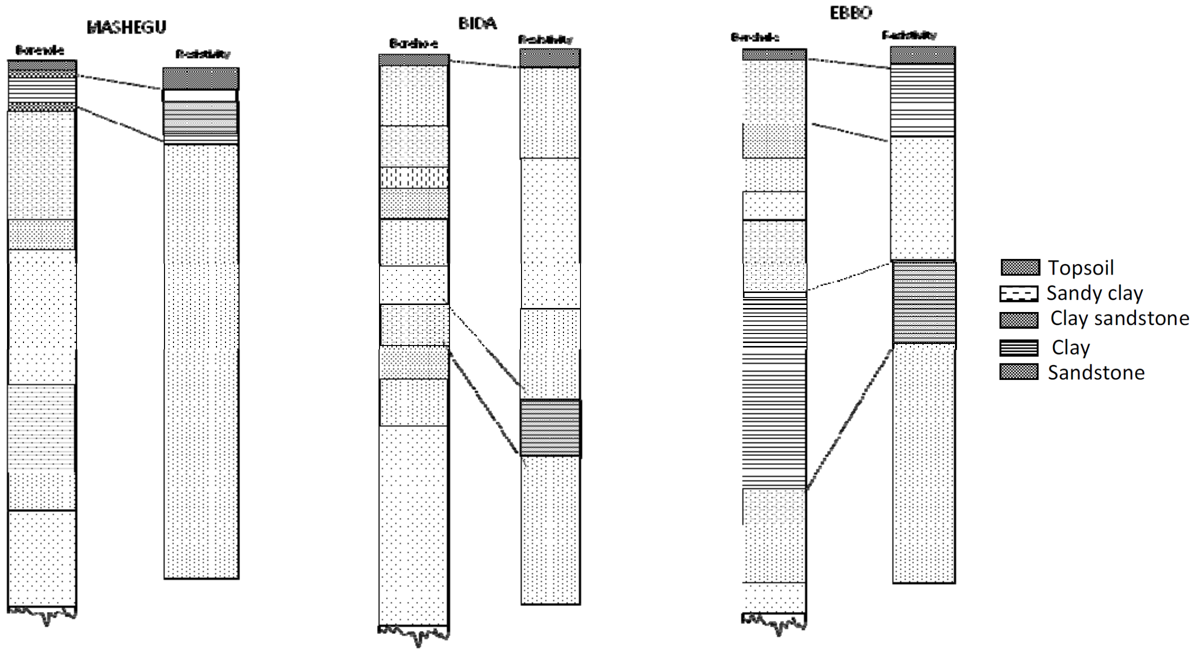

Figure 3. Correlation of VES data with borehole lithological logs

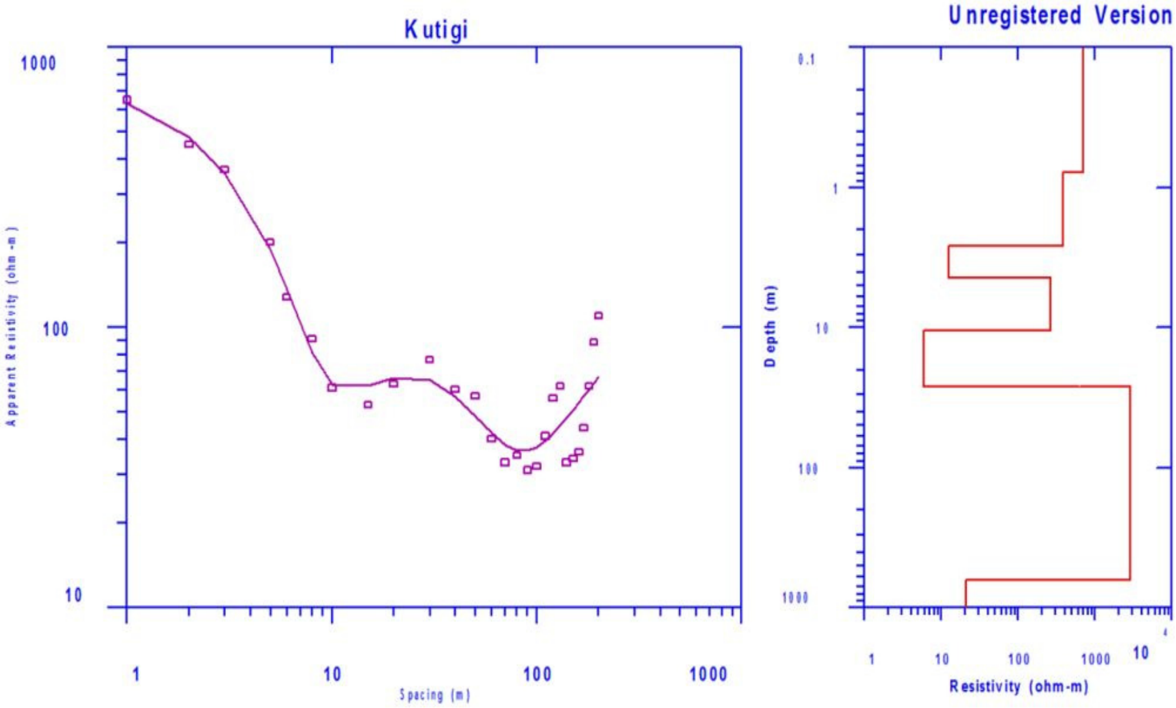

Figure 4. Interpreted VES curve for Kutigi in the Bida Basin

4.2 Interpretation

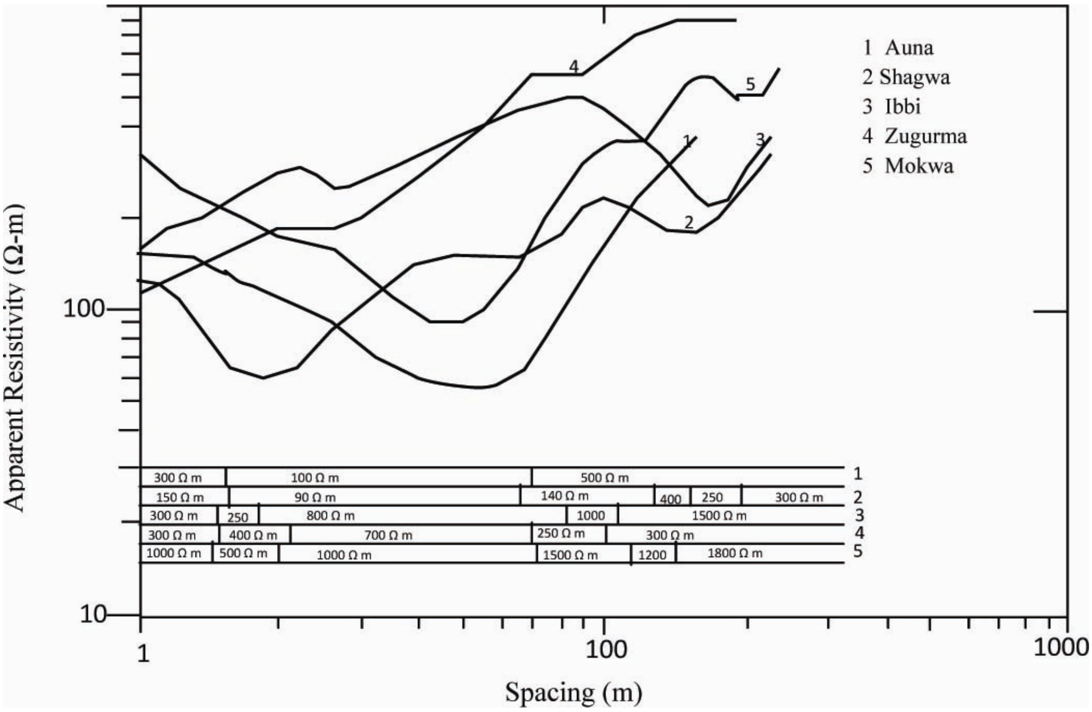

Figure 5a. Typical resistivity type curve and interpretation for profile 1 (NW-SE)

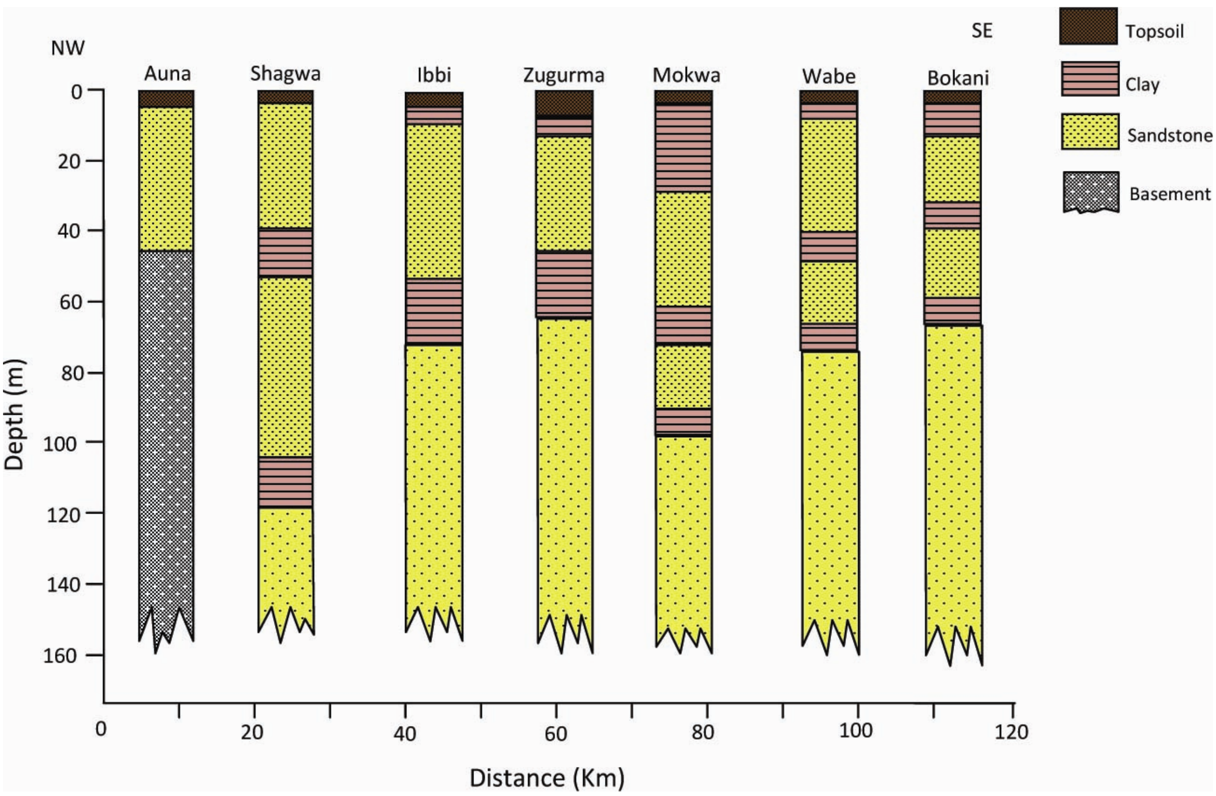

Figure 5b. Geoelectric logs of profile 1 (Auna to Bokani) in the NW-SE direction

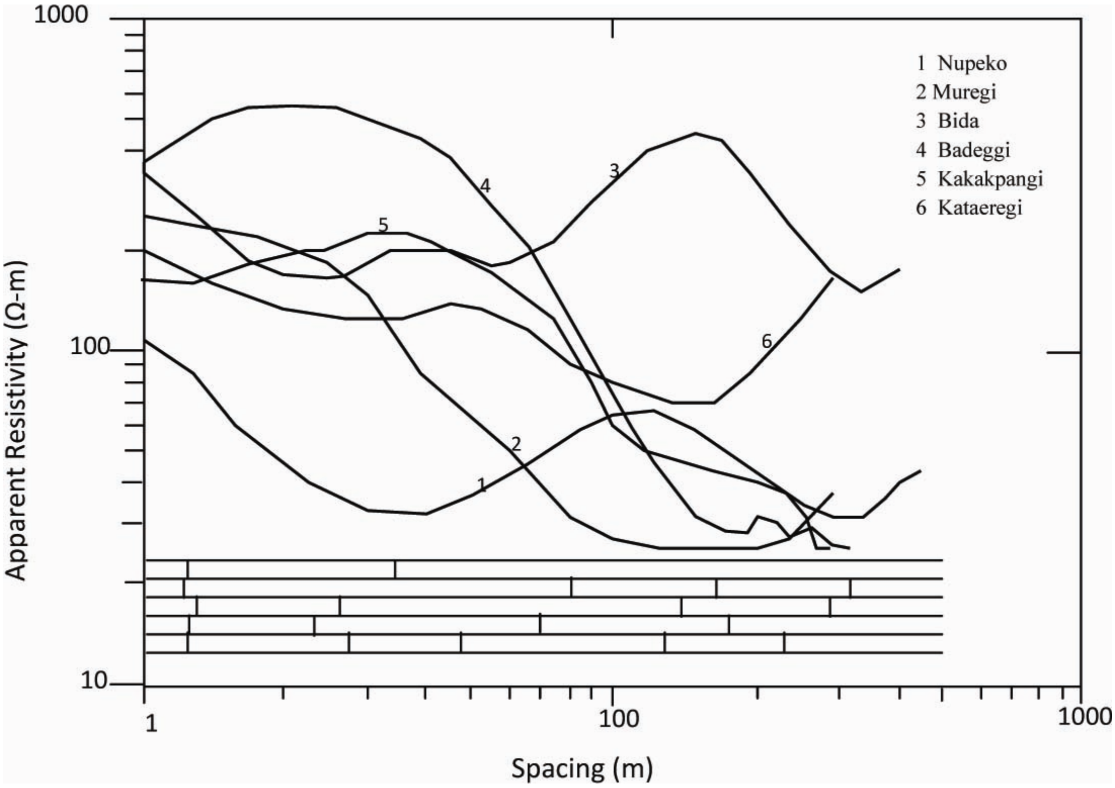

Figure 6a. Typical resistivity curves for profile 5 (Nupeko to Kataeregi) in the NE-SW direction

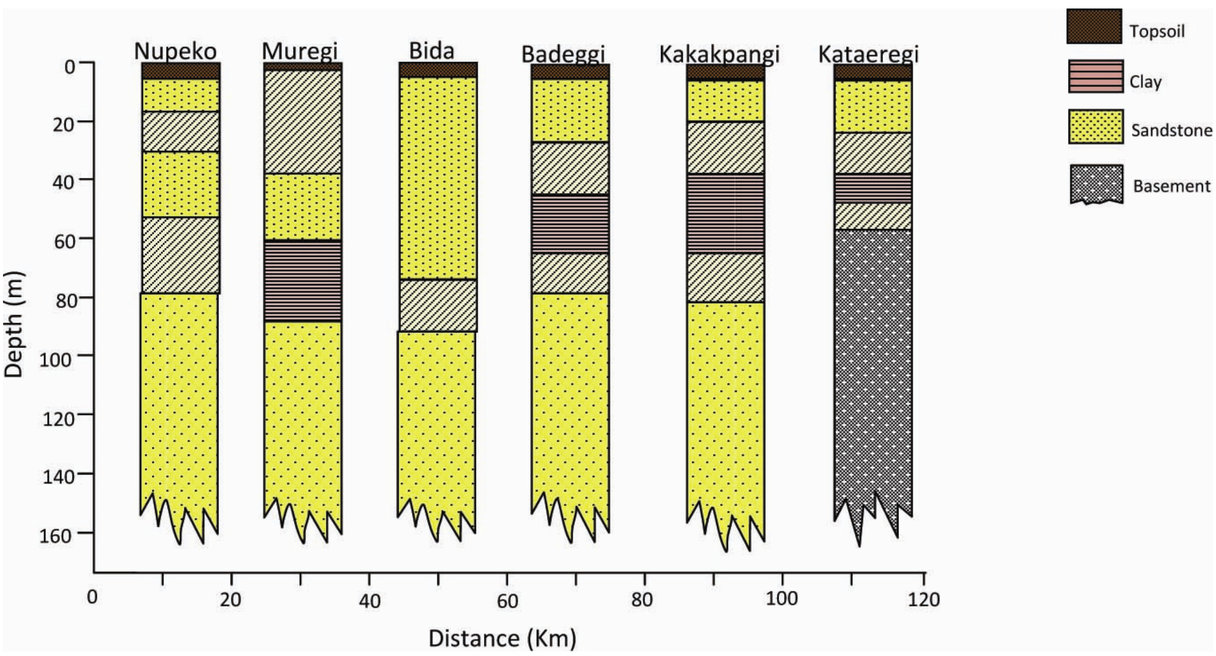

Figure 6b. Geoelectric logs for profile 5 (Nupeko to Kataeregi) in the NW-SE direction

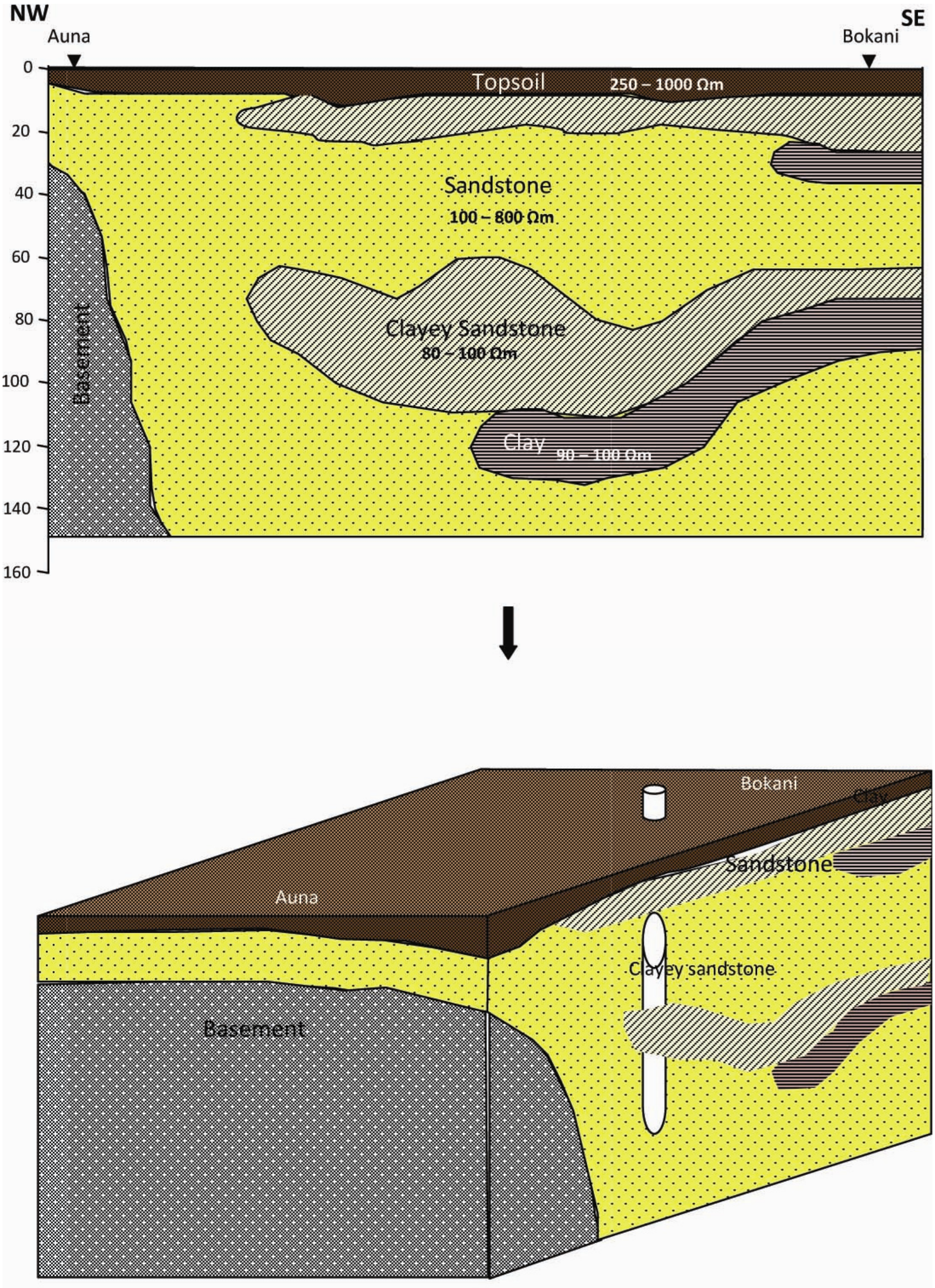

Figure 7. Geoelectric section for section 1 (Auna to Bokani)

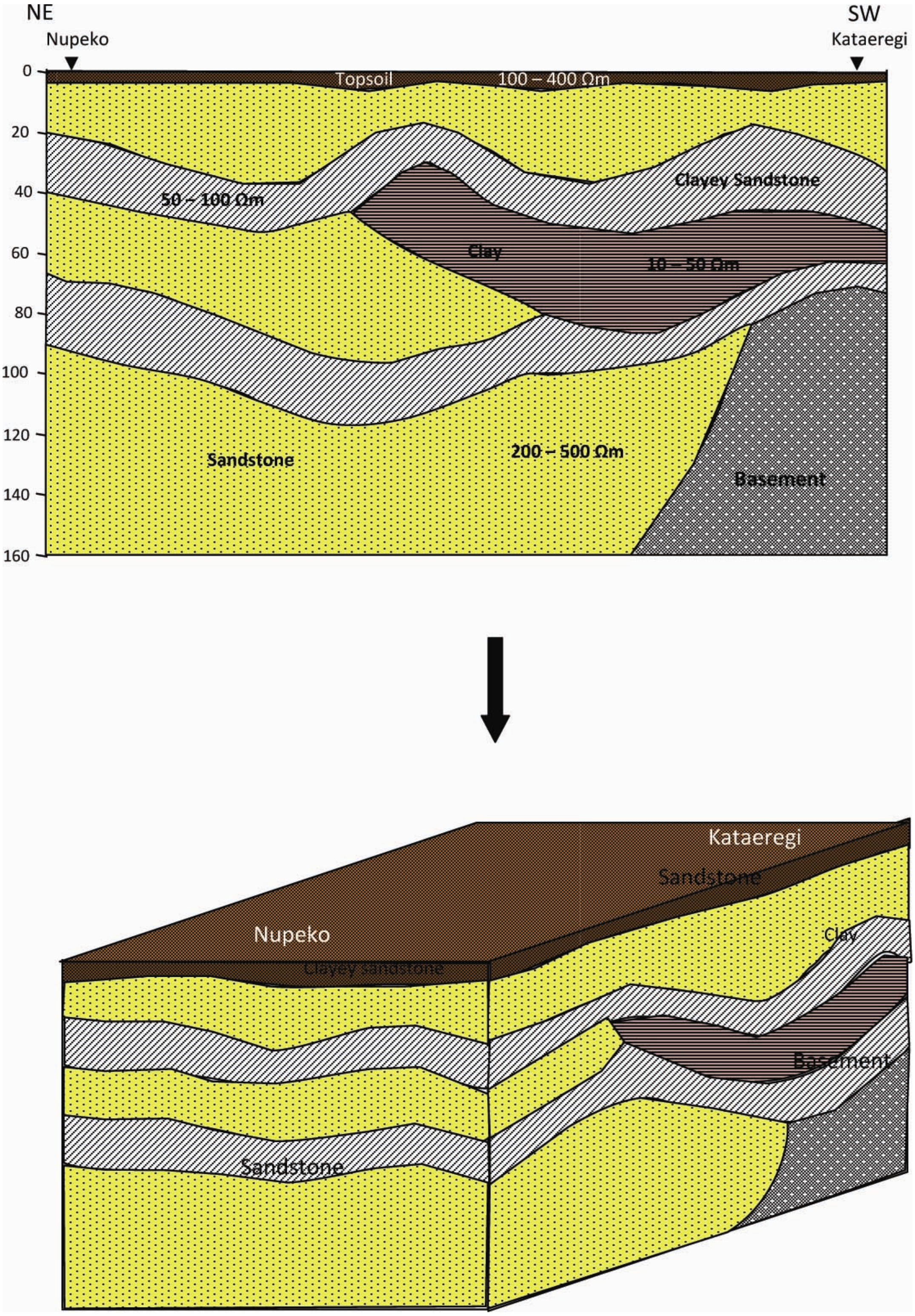

Figure 8. Geoelectric section for section 5 (Nupeko to Kataeregi)

5. Discussion of Results

The different type curves observed in the area and the various sectors they represent are shown in Table 3, based on distinctive geoelectrical characteristics the type curves have been classified into four groups, with each group representing a different geologic environment. Table 4 shows the frequency of resistivity type curves and the associated geology, while Figure 9 is the percentage frequency curve for the various curve types in the Basin.

Table 3. Representative curve types for the various sectors in the Basin

GROUP	CURVE TYPES	GEOLOGIC SECTOR
1	H, HK	Geologic contact areas / fringes of the Basin
2	A, AA, KHK	Northern Sector
3	HK, HKQ, KHKQ, KHKHK, QQH	Central Sector
4	QHK, KQQ, KQ, QHK, and Q	Southern Sector

Table 4. Frequency of resistivity type curves and their geologic environment

Curve Type	Frequency	Percentage Occurrence	Geologic Environment
H	10	7	Fringes of the Basin (contact areas with the Basement Complex)
K	2	1.5	Southern Sector, mostly Clay /Shale
Q	4	2.8	Southern / Central sector, alternation of sandstone and clay
A	6	4.3	Northern sector, mostly sandstone with some clay
AA	34	24	Northern sector, mostly sandstone with little or no clay
HK	6	4.3	Central / Southern sector, clayey surface, alternation of sandstone and clay at depth.
HKQ	10	7	Central sector, clayey up to 30 / 50m then sandstone at depth.
KHK	2	1.4	Central to southern sector, alternation of sandstone and clay.
QQH	26	18	Southern to Central sector, mostly clay / shale and sandstone.
QHK	4	2.8	Southern sector, mostly sandstone and shale.
KQ	18	13	Southern / Northern sector, lateritic/ironstone top, alternation of sandstone and clay at depth.
KQQ	4	2.8	Northern / Central sector, alternation of sandstone and clay.
KHKQ	8	6	Central to Southern sector, alternation of sandstone and clay/clay.
KHKHK	6	4.3	Central sector, ferruginised sandstone and sandstone.
TOTAL	140	100	

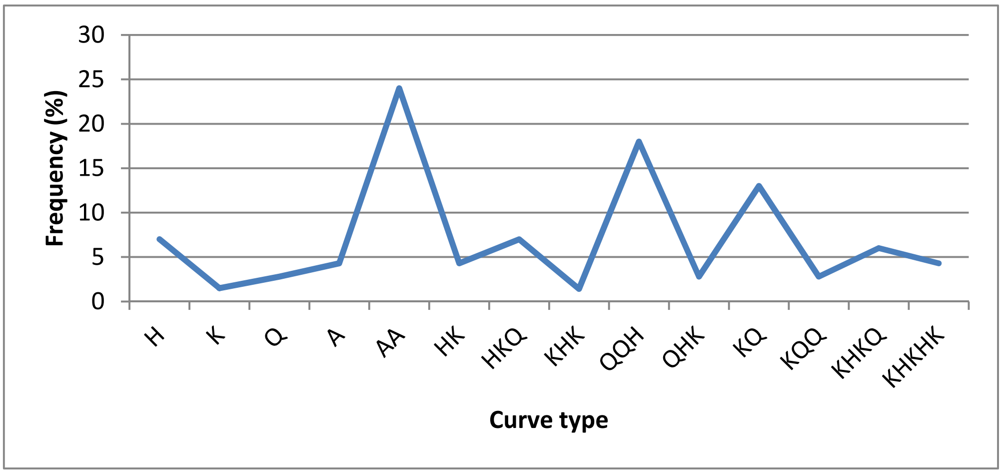

Figure 9. Percentage frequency curve for the various curve types in the Basin

5.1 Group 1 (H, HK)

These are typical curve types obtainable from the basement complex and geological contact areas. H curves are obtained where the basement is considerably shallow, typically less than 12 m. It consists of the topsoil, weathered basement and the underlying bedrock. HK curve types are obtained where the basement is considerably deeper, mostly greater than 30 m. The geology is represented by distinguishable beds of sandstone / clay, weathered basement (fairly to deeply weathered) and the underlying bedrock. Geophysical surveys have enabled a determination of the basement structures in the fringes of the basin. Significant differences occur over short distances in the basin ranging from 12 m to over 60 m depth to basement within a span of just 1km. This is the least of the four groups.

5.2 Group 2 (A, AA, KHK)

These are mostly obtained in the Northern sector of the basin. The A type typifies a geological sequence of mainly ferruginised sandstone at a shallow depth, clayey sandstone and sandstone that is fairly loose to compact. Type AA shows a rapidly alternating sequence of thick layers of loose sandstone and slightly clayey sandstone. This sequence is seen to continue until it changes into the KHK type which shows a highly compact and ferruginised sandstone at a shallow depth of less than 20 m, then clayey sandstone with a low resistivity loose to fairly compact sandstone at depth. These curve types characterize a very large area, extending from the Northern part of Kutigi to Mokwa, Makera, Mashegu Kaboji and Kontagora. It indicates a clearly distinct geology from the other parts of the Basin. Greatest percentage of curves falls within this group.

5.3 Group 3 (HK, HKQ, KHKQ, KHKHK, QQH)

These curve types mostly occur in the Central sector of the Basin. The HK, KHK and KHKHK types are obtainable from around the contact areas as well as the areas where the sector grades into the Northern sector. The geology is mainly an alternating sequence of sandstone, clayey sandstone and clay. The sandstone is ferruginised in some places and is also fairly compact. The HKQ, KHKQ and QQH represent areas with thick layers of clay overlying the mostly compact sandstone. They are found mostly in the middle to southern part of the central sector where it grades into the southern sector. It extends from the southern part of Kutigi through Bida, Agaie, Lapai, Duma to Badeggi, Gbako, Lemu, down to Wushishi where it contacts the Basement Complex rocks. The sector shares the characteristics of both the Northern and Southern sectors. This is the second largest percentage among the four groups.

5.4 Group 4 (QHK, KQQ, KQ, QHK, Q)

These typically occur in the Southern sector of the basin. The geology is mainly compact sandstone, clay/shale and ferruginised sandstone. Where ferruginised sandstone / laterite occur at shallow depth, the QHK curve is obtained, indicating a sequence of clay, laterite, sandstone and clay/shale. KQQ also indicates laterite at shallow depths underlying which is the clay/shale with a marked absence of sandstone. The alternation of sandstone and clay that was noticed in the Northern and Central sectors is missing in this sector, instead thick layers of clay/shale predominates. This is the third in percentages among the four groups.

The Northern sector has a characteristic A type curve, while the Southern sector has the Q type. The central sector occupies an intermediate position between the two and the geological contact areas have the H type as the characteristic curve type.

The interpreted VES data have been used to draw the geo-electrical sections along the nine profiles. These are shown in Figures 7 and 8. The thicknesses and the resistivities of the various geo-electric layers have been indicated. These are considered essential in characterization of the various aquifers in the area. The characteristics of the various geo-electric layers are shown in Table 5. Six geo-electric layer types have been recognized;

Table 5. Summary of Layer resistivity

1	Topsoil characterised by resistivity of 50 to 500 Ohms-meter
2	Laterite/ Ferruginised Sandstone characterised by resistivity of 800 to 2000 Ohm-meters
3	Sandy Clay characterised by resistivity of 80 to 200 Ohm-meters
4	Clayey Sandstone characterised by resistivity of 150 to 500 Ohm-meters
5	Sandstone characterised by resistivity of 300 to 1500 Ohm-meters
6	Clay / Shale characterised by resistivity of 10 to 100 Ohm-meters

6. Conclusion

Geo-electrical properties of the basin indicate that three major curve types predominate; these are the AA, QQH and KQ types. These curve types are diagnostic of the three sectors the basin was divided into in this study, the Northern sector has type AA, the central sector has QQH while the southern sector is characterized by the KQ type. The H - type indicate mostly contact areas with a shallow pile of sedimentary deposits. These are found mostly along the fringes of the Basin.

The Geoelectric section for profile 1 show a sedimentary pile of 2 to 30 m at the fringe of the basin and a steep drop of the basement structure to over 140 m over a short distant (< 1 km). It can be deduced from this that the basin may have resulted from faulting that led to a down thrust of the middle portion, which eventually became infilled with sediments. The aquifer is mostly in the unconfined state. Profile 4 extends from Nupeko, which occurs at the extreme southern end of the study area where River Kaduna joins River Niger, to Kudu shows an aquifer that is mostly in a semi-confined state with perched aquifer conditions around Nupeko, Kusoko and Kutigi, ferrugious laterite/ironstone which forms the cap of the Basin occurs mostly around Kudu. It can be deduced from this that the environment of deposition of the sediments from profiles 1 to 4 is a high energy environment, judging from the relative absence of fines (clay and silts) with the sands predominating. Profile 5, which extends from Nupeko to Kataeregi shows an aquifer that is also mostly in an unconfined to semi-confined condition, it is also perched around Kataeregi area. Ketaeregi represents the Eastern contact of the Basin with the Basement complex rocks, the town is about 45 km from Minna, the capital of Niger State. The sedimentary pile ranges from a thickness of 20 m to over 100 m within a span of 1km. The environment of deposition is mostly low to high energy.

Profile 6 extends from Bida to Akerre and shows an aquifer that is mostly in the semi-confined to confined state with the confining layer being mostly clay the upper confining layer occurs at a depth of about 40-60 m with a thickness of about 20-30 m, while the lower confining unit occurs at a depth of about 90-120 m with a thickness of about 10-20 m. In between the two units is the first confined aquifer with a thickness of about 10m occurring at a depth of 70-100 m. The lower aquifer contacts the basement in the SE and occurs at a depth of between 100-120 m.

Profile 7 extends from Badeggi to Ebbo and occurs from the central to southern parts of the Basin in the NE-SW direction. The geology consists mostly of perched and confined aquifers. The confining unit is mostly clays and shale. The clayey sandstone are aquitards that transmits water to wells placed in them in small quantities to be almost negligible, deep hand dug wells in the area tap their water from this unit. The aquifer, which is basically sandstone, occurs at below 100 m with an undetermined thickness. The sandstone has a low resistivity of between 100 to 250 Ωm, while the clay/shale has a resistivity of between 10-50 Ωm.

Profile 8 extends from Lapai to Ebbo and shows a transition from the central to the Southern sector of the basement. The Basement structure in Lapai occurs at between 4m to over 100 m within a span of 1km (Local Government Secretariat and Emirs palace respectively). The aquifer is in the semi-confined to confined state. The area is charaterised by a layer of ferruginised sandstone with a high resistivity of >1000 Ωm and thickness of between 5 to 10m. Two units of aquifers occur in the area at 90m and 140 m. The two are separated by a clay/shale unit with a thickness of between 10-20 m. The clayey sandstone is also an aquitard that yields very low quantity of water to wells placed in them.

Profile 9 extends from Ndaloke to Muye, this profile is also typical of the southern sector where clays/shale predominates over the sandstone. The aquifer in this area is also perched to confined, the gravelly sandstone occurs as a perched aquifer resting on the clayey sandstone, it has thickness of about 10-20 m and occurs at between 3-6 m depth. The shale/clay unit occurs at between 30-60 m at Ndaloke and generally at below 100 m.

It becomes quite evident that three major sectors occur in the basin, the Northern sector with mostly unconfined aquifers, the extensive central sector with semi-confined to confined aquifers and the southern sector with perched to semi-confined and confined aquifers.

The environment of deposition indicates a high energy environment in the northern sector with a marked reduction in deposition energy towards the southern sector of the basin in the NW-SE direction.

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