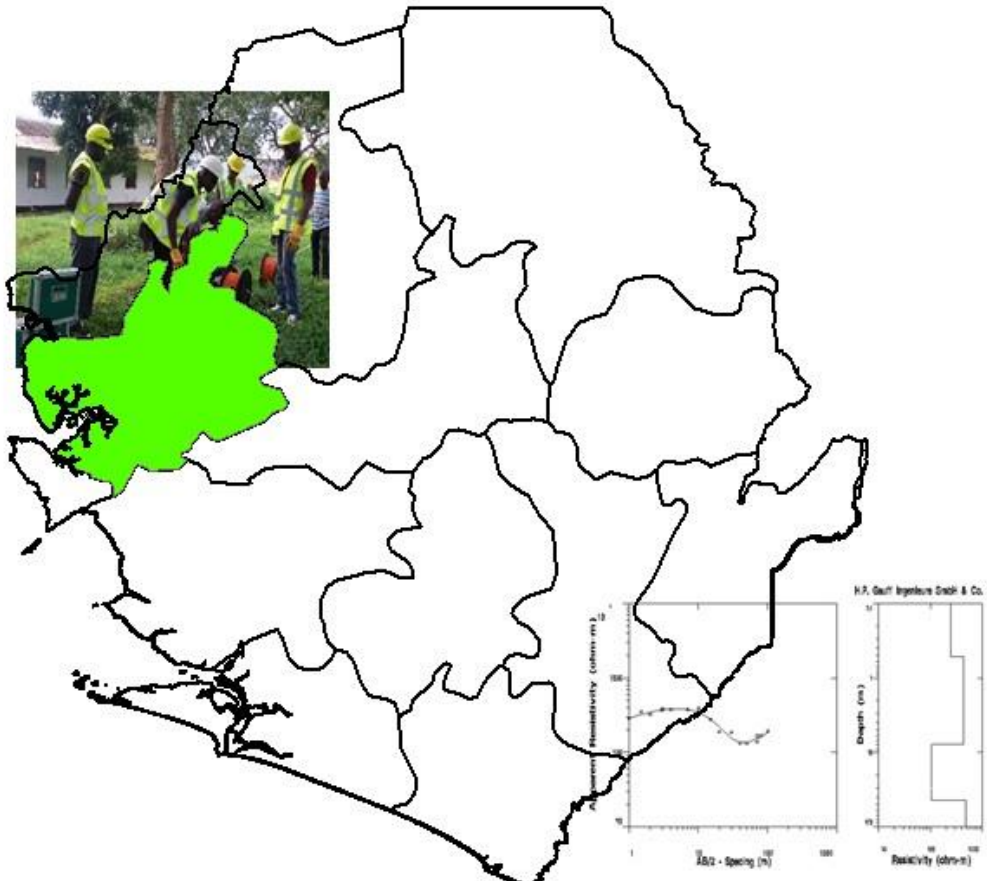
GOAL SIERRA LEONE

BOREHOLE GEOPHYSICAL SITING AT AT SELECTED DISTRICTS IN SIERRA LEONE –PORT LOKO DISTRICT



SITING REPORT

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SUMMARY

Resistivity profiles and Resistivity soundings were performed at Kaganthama, Mahera and Barbara CHCs in Port Loko District form the 17th of October 2015 to the 20th of October 2015 with the objective of recommending suitable drilling sites for the CHCs. The profiles were done at three different depth of investigations i.e. 15m, 25m and 40m, while the soundings were performed at maximum depth of investigation of approximately 100m.

Two drilling points are recommended for each CHC i.e. the priority drilling site and a backup site. Table 9 lists the drilling sites, provides the detailed rationale for the selection of the sites and the proposed drilling depths.

At Kagbanthama the ground geophysical survey was done along profile line (PL001P1) of 140m length as there was no other available space to extend it or locate another second profile. Three VES soundings were performed from which two drilling sites were recommended at 0756014E; 0991296N and 0755988E; 0991281N.

At Mahera no profiling was done as there was no survey space available, hence investigations were conducted through three VES which were conducted at spots available. Drilling is recommended at points 0698199E, 0951501N and 0698199E, 0951501N

At Barbara ground geophysical survey done along one profile line (PL003P1) which was 60m long, as there was no other available space to extend it or locate another second profile. The profile was surveyed with resistivity investigating at two different depths of investigations of 25m and 40m. Three soundings were done on the site, two of these on the profile line and one on outside the profile line. Drilling at Barbara is recommended at points 0705477E, 0976500N and 0705472E, 0976516N.

1 INTRODUCTION

Universal GeoScience Solutions in Joint Venture with Dynamic Integrated Geo-Hydro Environmental Services have been commissioned by GOAL SIERRA LEONE to train and supervise Department of Water Resources (DWR) personnel to carry out groundwater borehole siting for the implementation of Water, Sanitation and Hygiene activities in District Hospitals and Community Health Centers (CHC, s) in specific districts of Sierra Leone. GOAL has contracted the Department of Water Resources to undertake the siting of the boreholes on selected Hospitals and Community Health Centres under GOAL's remit, (3 in Port Loko District; 2 in Western District; 3 in Bo District; 2 in Kenema District and 2 in Western District).

This report discusses the geophysical surveys which were undertaken in Port Loko District (Barbara CHC, Kagbathanthama CHC and Mahera CHC) and recommends sites for drilling of planned 1 borehole for each of these CHC. The main objective of this project is to identify and develop additional groundwater abstraction points with sufficient volumes of potable water and within acceptable distance to the CHC to supplement the existing water sources and to meet the projected water demand.

Kagbathanthama CHC is at present supplied by one hand pump well which is located within the health center. This is located behind the main building and only 20m away from a pit latrine. There is another abandoned well about 90m away from the CHC boundary to the east and also about 30m from another pit latrine. In consequence, we expect both wells to be polluted with nitrates, which exhibit very high levels in excess of the WHO recommendations.

Mahera CHC is currently being supplied water from a borehole which is about 30m across the road passing on from of the Health Centre. No other information was obtained about this borehole during the time of writing this report. The available space for siting this CHC is about 15m by 5m hence there is virtually no space for doing any profiling. Spot soundings were done on the available place to check any suitable place for drilling a borehole for water supply.

The health facility at Barbara currently does not have an existing water facility. A hand dug was done to the Northern side of the facility for the community, however this well was abandoned after hard rock was encountered during construction before striking water. There are a number of septic tanks at the facility, which were considered in selecting drilling sites.

In view of the current supply situation and in particular that concerning water quality, it became necessary to identify additional water sources around the CHCs but unfortunately there isn't enough space available area to implement adequate geophysical borehole siting studies.

2 BACKGROUND

Considering the unavailability of information regarding results of drilled and hand dug wells in the vicinity of this community, the expected success rate for drilling boreholes with sufficient quantities of water require more geophysical techniques so as to map a number of different aquifer systems which includes weathered basement; fractured basement rocks and faulting zones. Considering the past experiences of the consultant, minimum requirements to facilitate improved groundwater borehole yields will aim at junctions of faults; thick weathered basement which is fractured underneath the weathered zone. Consequently the consultant recommended the use of profiling techniques using Magnetic Method and/or Horizontal Loop Electromagnetic Survey (HLEM) on every line to be surveyed with Resistivity profiling technique to aid better location of best points to be further investigated with VES technique (GOAL Final Geophysical Siting Report, November 2015). However the contractor is not in a position to source the equipment for Magnetic or HLEM surveys.

3 LOCATION

The three targets for Water, Sanitation and Hygiene activities in District Hospitals and Community Health Centers (CHCs) comprised of Barbara CHC, Kagbathanthama CHC and Mahera CHC in Port Loko district which is in the Northern Province of Sierra Leone. Kagbathanthama CHC is located on the north of Port Loko town, whilst Barbara CHC is to the north-west of Port Loko town and Mahera CHC to the east of the same town as shown in Figure 1. Port Loko is the most populous District in the North and the fourth most populous District in Sierra Leone. As of 2010, the District had a population of 500,992. Its capital is the town of Port Loko and its largest city is Lunsar. The other major towns in the district include Masiaka, Rokupr, Pepel, Lungi and Gbinti. The district of Port Loko borders the Western District to the west, Kambia District to the north, Bombali District to the east and Tonkolili District to the south. The district occupies a total area of 5,719 km^2 and comprises of ten chiefdoms.

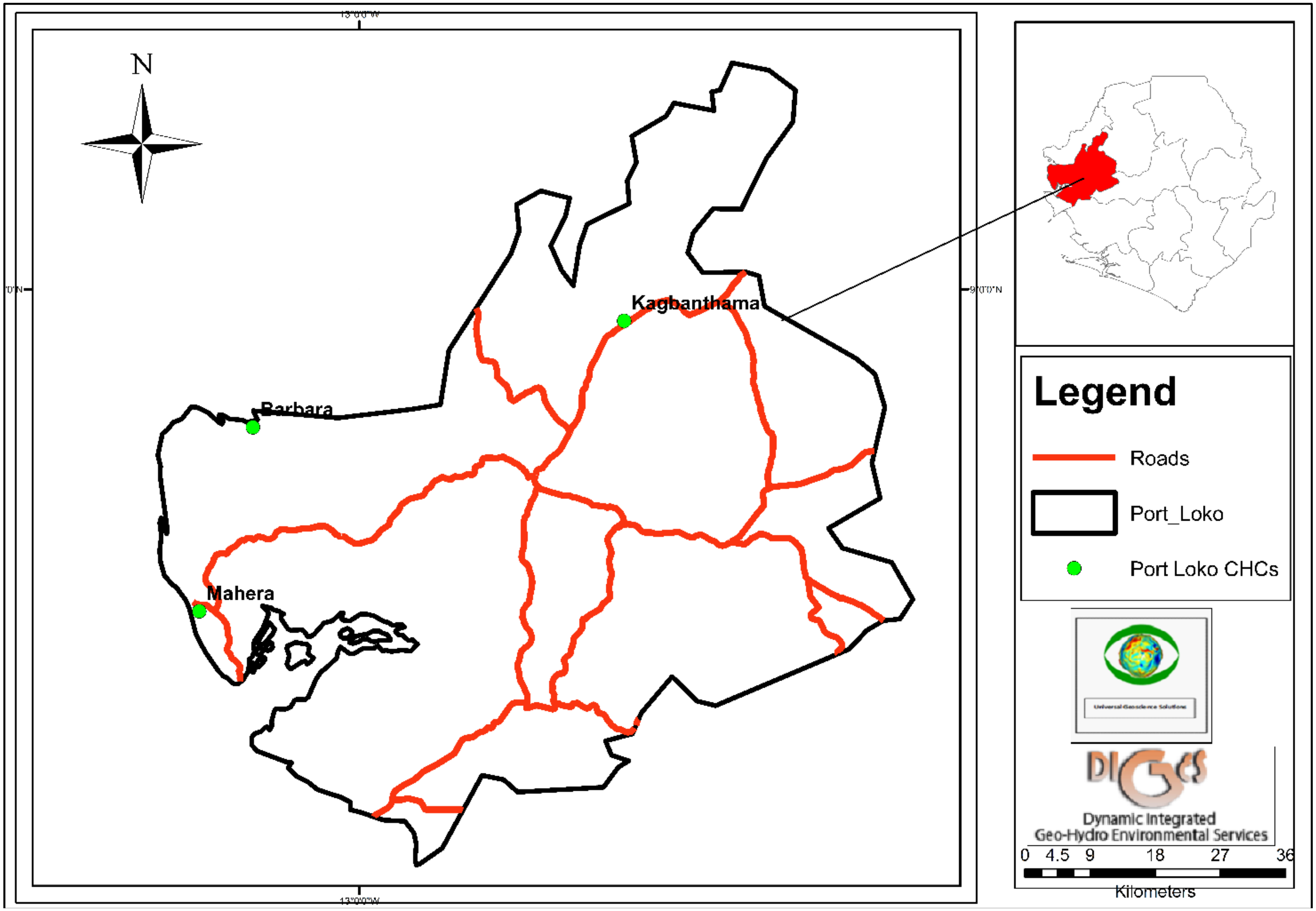

Figure 1: Location of the Target Community Health Centres in Port Loko District.

4 REGIONAL SETTING

4.1 Geology

The district is overlain by several geological units from the western part of the district to the eastern part of the district. Geologic contacts in the area strike in a NW-SE direction. To the west of the district in the area around Barbara and Mahera the surface geology comprises of the Bullom Group which is composed of alluvium, beach sand, clay and lignite is mainly found on the western part and also on the end of the eastern part of the district.

Rocks of the Bullom Group are in contact with the rocks of the Kasila Group. Kasila Group rocks comprise of quartzo feldspathic gneisses, and olivine bearing meta-gabroo. Inferred lineaments in this area are are striking in a general NW-SE direction. To the east of the Kasila group sediments are rocks of the Liberian Granite, these rocks have mapped and inferred structures striking in a NW-SE direction showing some signs of isoclinal folding and intensive shearing, the area around Kagbanthama comprises of these rocks.

The area around Lunsar comprises of the Marampa Group (Rokotolon and Matoto formation) which consists of metasediments, hematite, quartzite and specularite schist, banded ironstone massive and banded meta-andesite, ultrabasic lava and pillow lava. Variegated shale, laminated siltstone, orthoquartzite, arkose, grey mudstone and shale, siltstone, laminated silty shale, andesitic lava, purple and grey shale with interbedded quartzwacke bands, grey shale interbedded with quartzite, arkose and conglomerate are also part of the complex geology within the district.

Further west of the district are rocks of the Rokel river group, the group comprises of lithologies which are typically, Poorly sorted conglomerates, originally interpreted as a marine trangressive deposit, have been shown to be tillites. Closely associated with the tillites are laminated siltstones and fine sandstones with isolated granitic lasts which have been interpreted as possibly lacustrine rhythmites containing ice-rafted dropstones. Interbedded with the rhythmites are lenticular graded feldspathic sandstones which are considered to be channel turbidites. Rokel River Group was folded and slightly metamorphosed by the Rokelide Event c. 500 Ma ago, the time of the Pan-African thermotectonic event. None of the target areas is found in an area whose surface geology is the Rokel group.

The targets area Mahera and Barbra CHC are found on the western of the district whilst Kagbanthama CHC is located on the north west of the district, Figure 2.

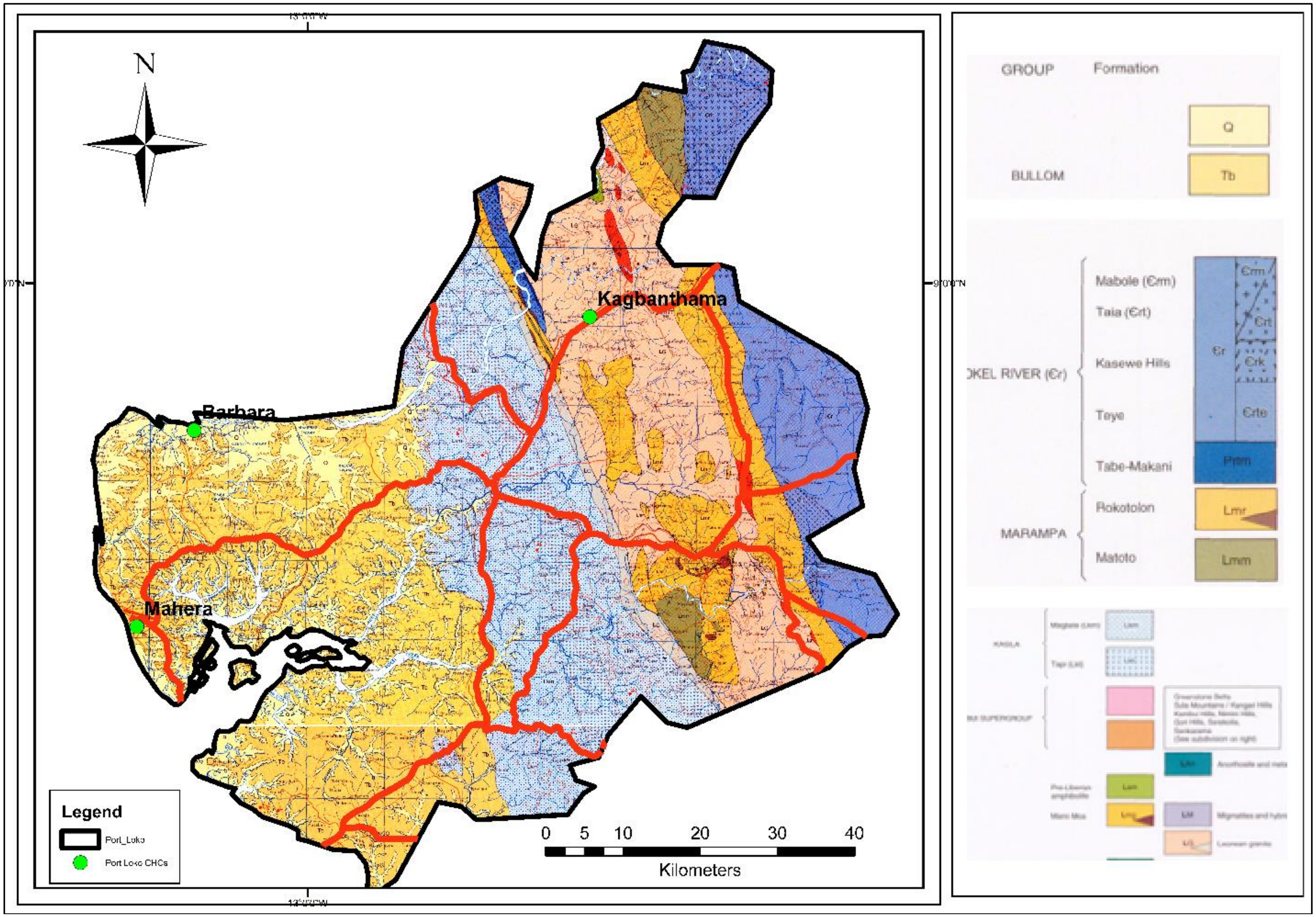

Figure 2 Geology map of Port Loko District with Community Health Centres in the district.

4.2 Hydrogeological Setting

The major hydrogeological targets are classified into two, being the basement aquifers and unconsolidated sandstone and gravels. Groundwater in this area generally occurs in the fractured rocks and frequently at the base of the top weathered rock or alluvium (overburden). However, some primary porosity may be expected in the north in the sandstone, although the groundwater potential of this area has not been explored and is largely unknown. Consequently, two different types of aquifer may be expected in the area. These are the Basement aquifer and sandstone and sand/gravel aquifer. Due to the varying nature of these two aquifers and their potentially different groundwater potential they will be discussed separately.

The Bullom Group is characterized by unconsolidated sedimentary rocks which can be described as poorly consolidated marine and estuarine sediments, sands, gravels and kaolinitic clays with some lignite. The Precambrian Basement Complex consisting of ancient crystalline granitic gneiss with supracrustal volcanic and sedimentary belts is described as having metasediments, volcanic basement granites, gneisses and migmatites and amphibolites. The aquifers expected in this area are characterized by fractured contacts at the base of the relatively thick weathered zones, fractured contacts between gneiss and dolerite or amphibolites, fractured geological contacts and faults which are trending NW-SE. We also target thick weathered zones of the basement rock. These can be very important if they occur on fractured basins of the basement rock, (Goal Inception Report, October 2015)

4.2.1 Basement aquifers

This unit may be divided into weathered and fractured aquifers. The weathered Basement aquifer often has high transmissivity and storage values to provide some yield, but such aquifers are severely affected by recharge and size of the catchment area. The higher yielding aquifers are found in areas where the contact zone between the weathered overburden and fresh rock is deeply fractured, but it is very sensitive to the amount of the recharge received. The highest yielding Basement aquifers are found in the fractured bedrock, which possesses high transmissivity and at locations where deeply weathered overburden provides some storage. Such fractured aquifers are often recharged through a system of interconnected fractures and fissures. Therefore, when siting high yielding boreholes, it is important to consider the distance to the prospective direct recharge area (current drainage system). Typical aquifers found in the Basement areas are:

- fractured contacts at the base of the relatively thick weathered zones,
- fractured contacts between gneiss and dolerite or amphibolites,
- fractured geological contacts and faults which are trending NW-SE in the project area.
- thick weathered zones of the basement rock. These can be very important if they occur on fractured basins of the basement rock, (Goal, Inception Report, and October 2015).

All the above targets can be readily mapped by means of geophysical techniques such as the applied Horizontal-Loop frequency domain ElectroMagnetic (HLEM) commonly done with MaxMin instrument and EM34 system, Resistivity profiling, Vertical Electric Soundings (VES) and Magnetic profiling. The EM system maps the variation in the overburden thickness and any subvertical conductive fractures, faults or contacts. The magnetic technique allows mapping any intrusions of dolerites, faults or contacts between lithologies, if such possess varying magnetic susceptibilities (readiness to magnetise in the Earth's magnetic field). Resistivity profiling will map the areas with thick weathered zones, finally VES is a direct way to map the thickness and composition of the overburden and to assess the fracturing at its base. Such a comprehensive suite of geophysical techniques is likely to provide a highly effective siting strategy.

4.2.2 Sandstone/Gravels/sand aquifer

Due to the fact that sandstone, gravel and sand possesses some inter-granular space, which may be available to the groundwater (provides storage), this type of aquifer is regarded as having a high groundwater potential. Unlike the Basement aquifers which are localised and very sensitive to recharge, the sandstone aquifer due to its primary porosity (inter-granular space filled with groundwater) may withstand long periods of drought and lack of recharge. Consequently, the sandstone aquifer is regarded as a more reliable and longer-lasting source of groundwater as compared with any other aquifer.

The sandstone aquifer may be investigated by means of several geophysical techniques, amongst them the HLEM profiling and VES soundings, which provide the information on the lateral and vertical distribution of formation resistivities. These in turn are characteristic of the particular lithologies such as resistive sandstone and conductive mudstone. Although it is possible to identify sediments based on the above techniques it is not always possible to differentiate between its lithologies, especially if sandstone is friable and saturated as in such case its resistivity would be comparable with the resistivity of a dry mudstone and grit. It is therefore not possible to identify the aquifer based only on the geophysical data hence additional information would be required to ascertain that the aquifer is indeed present.

5 GEOPHYSICAL SURVEY

5.1 Exploration Strategy

As discussed previously that underlying thick weathered, thick sediments and fractured bedrocks form the main aquifer units in this district. Deep weathered and fractured zones in the bedrock underlying thick sedimentary beds were considered as the main target feature for groundwater development and thus for geophysical surveys. Such features allow tapping thicker aquifer zones and are generally associated with geological lineaments, faults and lithological contacts. In the Inception phase these features were interpreted from geology only as there was no other variety of data sets including airborne magnetic data, ortho-photographs and Landsat imagery was available (Goal, Inception Report, October 2015). Details of the profile lines are summarized in

5.2 Siting Criteria

In the inception report, the criterion for siting boreholes at the given Community Health Centres was highlighted. In order of priority these are:

1) The site should be chosen principally on hydrogeological and related geophysical grounds so that the greatest chance of obtaining an adequate yield was achieved.
2) The site should be free from potential pollution by latrines, waste and animals.
3) The site should be within 400m of the CHC and preferably very close to the Health Centre.
4) The site should be either free from risk of flooding or capable of being protected from flooding by suitably designed headworks (i.e. a raised concrete).
5) The site should be one which was not a risk from erosion due to usage by animals.

Clearly it is not always possible to achieve all these criteria at all sites since the overriding criterion that of finding water, is often in conflict with one or more of the others. In most cases however, it was possible to achieve a reasonable compromise.

5.3 Survey Techniques and Equipments

Resistivity plus magnetic profiling followed by VES of Schlumberger array were considered to be the minimum geophysical techniques for this type of survey in this district. Resistivity profiling followed by VES techniques were the only available methods to consider for delineation of weathered and fractured zones in the project area. Magnetic profiling is an effective technique in delineating dolerite intrusions, lithological contacts and faults, while HLEM profiling is effective in delineating vertical and sub-vertical fractures zones but these were not available as the contractor couldn't source the equipment. Integrated use of both profiling techniques is very effective in areas like this, where significant resistivity conductivity contrast is expected in the bedrock geology such as highly resistive granites and less resistive weathered granites and gneiss rocks. Following profiling, potential anomalies were identified for further assessment using VES. VES provides depth and thickness estimates of weathered and fractured zones based on the resistivity values. Weathered and fractured bedrocks are generally represented by low resistivity values compared with massive bedrocks.

Geophysical techniques applied include resistivity profiling at a station spacing of 10 m. Where the survey space permits, two resistivity profiles of minimum 100m in Schlumberger array configuration were carried out at three different levels of investigation being 15m; 25m and 40m. Vertical Electrical Soundings (VES) were carried out at low resistivity anomalies picked by the profiling method. This was surveyed to a stretch of AB/2 equal to 100 m. The geophysical survey techniques, instruments, survey parameters and total input for district are provided in Table 1 to table 3, for Kagbanthama, Mahera and Barbara respectively

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Table 1: Summary of Geophysical Survey, Kagbathanthama

Community Health Centre, CHC	Geophysical Method	Survey Parameters, Direction	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Kagbathanthama CHC	Resistivity Profiling	Station spacing = 10m AB/2 = 15; 25; 40m MN/2 = 1	Profile 1	0756023	0991349	0755926	0991243
			Profile 2				
			Profile 3				
	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	PL001S1	0755988	0991281		
			PL001S2	0756014	0991296		
			PL001S3	0756033	0991308		

Table 2: Summary of Geophysical Survey, Mahera CHC

Community Health Centre, CHC	Geophysical Method	Survey Parameters	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Mahera CHC	Resistivity Profiling	Station spacing = 10m AB/2 = 15; 25; 40m MN/2 = 1	Profile 1				
			Profile 2				
			Profile 3				
	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	PL002S1	0698199	0951501		
			PL002S2	0698207	0951503		
			PL002S3	0698217	0951516		
			PL002S4				

Table 3: Summary of Geophysical Survey at Barbara

Community Health Centre, CHC	Geophysical Method	Survey Parameters	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Barbra CHC	Resistivity Profiling	Station spacing = 10m AB/2 = 15; 25; 40m MN/2 = 1	Profile 1	0705483	0976513	0705423	0976537
	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	PL001S1	0705472	0976516		
			PL001S2	0705451	0976524		
			PL001S3	0705477	0976500		

6 SURVEY RESULTS AND DISCUSSION

The objectives of ground geophysical survey in this area were to delineate fractured/weathered zones associated with geological interpreted lineaments. These were interpreted as important structural features for groundwater development but unfortunately there was virtually no space to undertake profiling. The resistivity profiling data were plotted using Microsoft Excel and interpreted qualitatively to locate the best positions for carrying out depth investigations (VES). Vertical Electrical Soundings (VES) were carried out at low resistivity anomalies. The soundings were surveyed to a stretch of AB/2 equal to 100 m which gives a theoretical investigation depth of 100m.

The VES were processed and interpreted with the Interpex forward and inverse modeling software RESIXIP. Discussion of the survey results in each CHC area is as follows:

6.1 Kagbathanthama CHC – PL001

The ground geophysical survey was planned along one profile line (PL001P1) across the geological trends of these features amounting to a total of 140m, as there was no other available space to extend it or locate another second profile. The profile was surveyed with resistivity investigating at three different depth of investigations of 15m, 25m and 40m. The most important being the deep zones which were picked at 25m and 40m deep. The profile results are as plotted and presented in Appendix 1. Following the interpretation of profiling data, 3 VES were conducted over low resistivity points which were considered as best groundwater potential anomalies. VES data plots with geo-electric model are also presented in Appendix 1. The discussion of the survey results along the profile line in the area are presented in Table 4. VES results and the interpretations are presented in Table 5.

Table 4: **Summary Resistivity Profiling for line PL001P1-Kagbanthama**

Profile Line	Resistivity	Comment
PL001P1	Low resistivity contacts at stations 30m, 60m, 80m; 130m and 140m.	VES 1 at 130; VES 2 at 80m and VES 3 at 60m

Table 5: Summary of Vertical Electrical Soundings Kagbanthama

	Coordinates	Layer	Resistivity (Ohm-m)	Depth (m)	Comments
VES 1 – PL001S1	0755988 0991281	1	180	3	Backup Site - Priority site B
		2	340	22	
		3	9000		
VES 2 - PL001S1	0756014 0991296	1	390	2	Priority site A There is thick overburden with a thicker weathered zone .
		2	140	5	
		3	346	23	
		4	16252		
VES 3 - PL001S1	0756033 0991308	1	780	5	
		2	330	7	
		3	170	13	
		4	28000		

6.2 Mahera CHC -

There was no profiling done on this site as there was no survey space available, hence investigations were by means of three VES which were conducted at spots available. The area confirms thick overburdens of sediments. VES data plots with geo-electric model are presented in Appendix 2.

Table 6: Summary of Vertical Electrical Soundings Mahera

	Coordinates	**Layer**	**Resistivity (Ohm-m)**	**Depth (m)**	**Comments**
VES 1	0698199 0951501	1	320	29	Priority site A
		2	1120	51	
		3	25		
		4	160		
VES 2	0698207 0951503	1	400	7	Priority site B – Backup Site
		2	600	21	
		3	1200	42	
		4	20		
VES 3	0698217 0951516	1	320	3	
		2	120	6	
		3	560	13	
		4	160		

6.3 Barbara CHC – PL003

The ground geophysical survey was planned along one profile line (PL003P1) across the geological trends of these features amounting to a total of 60m, as there was no other available space to extend it or locate another second profile. The profile was surveyed with resistivity investigating at two different depths of investigations of 25m and 40m. The profile results are as plotted and presented in Appendix 3. Following the interpretation of profiling data, 3 VES were conducted over low resistivity points which were considered as best groundwater potential anomalies. VES data plots with geo-electric model are also presented in Appendix 3. The discussion of the survey results along the profile line in the area is are presented in

Table 7 while the VES results are presented in Table 8.

Table 7: **Summary Resistivity Profiling for line PL003P1 Barbara**

Profile Line	Resistivity	Comment
PL003P1	Low resistivity at stations 10m, 30m, and 60m.	VES 1 at 10; VES 2 at 30 and VES 3 was selected at one good space provided as a spot sounding not necessarily in the line

Table 8: **Summary of Vertical Electrical Soundings Barbara CHC**

	Coordinates	Layer	Resistivity (Ohm-m)	Depth (m)	Comments
VES 1	0705472 0976516	1	716	5	Priority site B – Backup Site
		2	1290	21	
		3	280	26	
		4	10		
VES 2	0705451 0976524	1	580	4	
		2	1700	18	
		3	280	23	
		4	10		
VES 3	0705477 0976500	1	230	1	Priority site A
		2	1245	22	
		3	270	1332	
		4	10		

7. RECOMMENDATIONS FOR DRILLING

7.1. Recommended Drilling Sites

A total of three drilling sites including three backup sites have been recommended for drilling. The list of sites with selection criteria and recommended drilling depths are provided in **Table 1.4**. The first site is recommended to be drilled in Barbra or Mahera. There is need to verify and evaluation of incoming drilling results from these sites in corroboration with the geophysical data. There is a chance that if drilling if done over 35m, salt water or brackish water might be struck. In these two areas we might rely on the shallow aquifers for freshwater but these results will only be determined from drilling as there is no information on boreholes in this area to understand the very conductive layer at depths over 30m in these VES data collected. Drilling in this area will be initiated after the assessment of the results from these two sites.

Table 9: List of Recommended Drilling Sites for Port Loko

Site	Site Reference	Coordinates	Site Selection Criteria	Recommended Maximum Drilling Depth (m)
PL001DS1 - Kagbathanthama CHC	VES 2 - PL001S2 Priority site A	0756014 0991296	- Possible Fault/ contact between weathered zone and basement rocks as interpreted from Resistivity Profiling; Thick weathered layer. - A low average resistivity (140 to 360 Ω-m) layer between 5m to 22 m on VES inversions.	70 m
PL001DS2 -	VES 1 – PL001S1 – Backup Drill Site	0755988 0991281	- Possible Fault/ contact between weathered zone and basement rocks. Thick weathered layer. A low average resistivity (350 Ω-m) layer between 3m to 22 m on VES inversions.	70 m
PL002DS1 – Mahera CHC	VES 1 - PL002S1 Priority site A	0698199 0951501	- A low resistivity values (320 Ω-m) layer between 0 and 29m underlain a very high resistive layer extending to a depth of 51m. This is underlain by a very conductive layer of resistivity 25 Ω-m which is also a potential aquifer at depth.	70m
PL002DS2 – Mahera CHC	VES 2 – PL002S2 Priority site B – Backup Site	0698207 0951503	- There is a thick overburden of 27m represented by low resistive (400 Ω-m - 600 Ω-m) layers.	70m

PL003DS1 – Barbra CHC	VES 3 – PL003S3 Priority site A	0705477 0976500	- There is a thick overburden of 22m weathered layer represented by low resistive (230 Ω-m) layers. This is underlain by a high resistive layer underlain by a low resistivity layer which is a potential aquifer at depth.	
PL003DS2 – Barbra CHC	VES 1	0705472 0976516	- There is a thick overburden of 22m weathered layer represented by low resistive (230 Ω-m) layers. This is underlain by a high resistive layer underlain by a low resistivity layer which is a potential aquifer at depth.	70m

7.1.1. Drilling

- It is proposed to use 40m as normal minimum drilling depth and 70 m as a normal maximum drilling depth which shall only be exceeded under typical circumstances and when drilling takes place in rock under the sediments found in Kissy and Port Loko targets. In the extreme situations, the drill depth may go to a maximum of 100m.
- It is proposed to use 15 m as the normal minimum depth to the top screen in order to avoid contamination of boreholes.
- It was observed during the hydrogeological reconnaissance survey that many boreholes in the area have failed due to siltation, which is the result of improper well design or construction. The well design and construction is of particular importance due to abundant fine grained material in the aquifer. It will thus be crucial that gravel pack of suitable grain size is placed against the screens and that correct gravel pack installation is done. It is there by recommended that Goal follow this up in order to achieve high quality borehole construction.
- It is recommended that a sump of minimum 6 m shall be installed below the screen for boreholes in unconsolidated formations. For boreholes in consolidated formations, the sump shall be of minimum 3 m
- Yield should be measured at least every six meters, and recorded after the first water strike, such information is critical in determining when to terminate the bore.
- It is highly recommended that drill chips are logged by a qualified geologist before installation of casing, and that such installation is supervised by a qualified hydrogeologist.

7.1.2. Borehole Development

- We recommend Air lifting and jetting methods using a single pipe system as the most effective borehole development method to be employed.

7.1.3. Test Pumping

- It is recommended that test pumping shall comprise of a 4 stage steps test of minimum 2 hours (120 minutes) each step with measurement of yield, drawdown and recovery.
- We also recommend a Constant Rate Test (CRT) for a minimum of 24 hours.
- The above is followed by a Recovery test, which will consists of measurement of residual drawdown after constant rate test until static water level is achieved.

7.1.4. Groundwater Sampling and Hydro-chemical Analysis

- We recommend that water samples for chemical analysis of major ions, selected metals and bacteriological contamination be taken at the end of borehole development and at the end of CRT.

- Field water quality parameters should be measured during drilling and test pumping. Typical water quality meters will measure TDS, EC, pH and Temperature. Measuring these field water quality parameters serves to provide an early indication of deteriorating water quality. This is important in cases where saline water intrusion might be expected.

7.1.5. Disinfection

- It is recommended that disinfection could be carried out immediately after pump installation, using chlorine granules. This would make disinfection of the pump parts unnecessary. The drilling contractor will accordingly be given a choice between disinfecting after test pumping, and disinfecting after pump installation.

7.1.6. Criteria for Successful Boreholes

- The criteria for declaring boreholes successful may have to be flexible considering borehole yield, water quality and distance of existing water source in the dry season. The Consultants will liaise with the Client in cases where such a flexible approach appears relevant. The consultant will immediately report cases where WHO water quality limits are exceeded so that a decision to stop superstructure construction or pump installation can be made if needed.

8. REFERENCES

The following reports provide more information on the geology and hydrogeology of Sierra Leone. Some, and others, can be accessed through the Africa Groundwater Literature Archive

Camus Y and Cukor D. 2012. NI 43-101 Technical Report on the Resource Update Nimini Gold Project, Kono Region, Sierra Leone. SGS Canada Inc., submitted to Polo Resources Ltd.

Flinch JF, Huedo JL, Verzi H, Gonzalez H, Gerster R, Mansaray AK, Painuly LP, Rodriguez-Blanco L, Herra A, Brisson I and Gerard J. 2009. The Sierra Leone-Liberia Emerging Deepwater Province. Adapted from oral presentation at AAPG Annual Convention, Denver, Colorado, June 7-10, 2009.

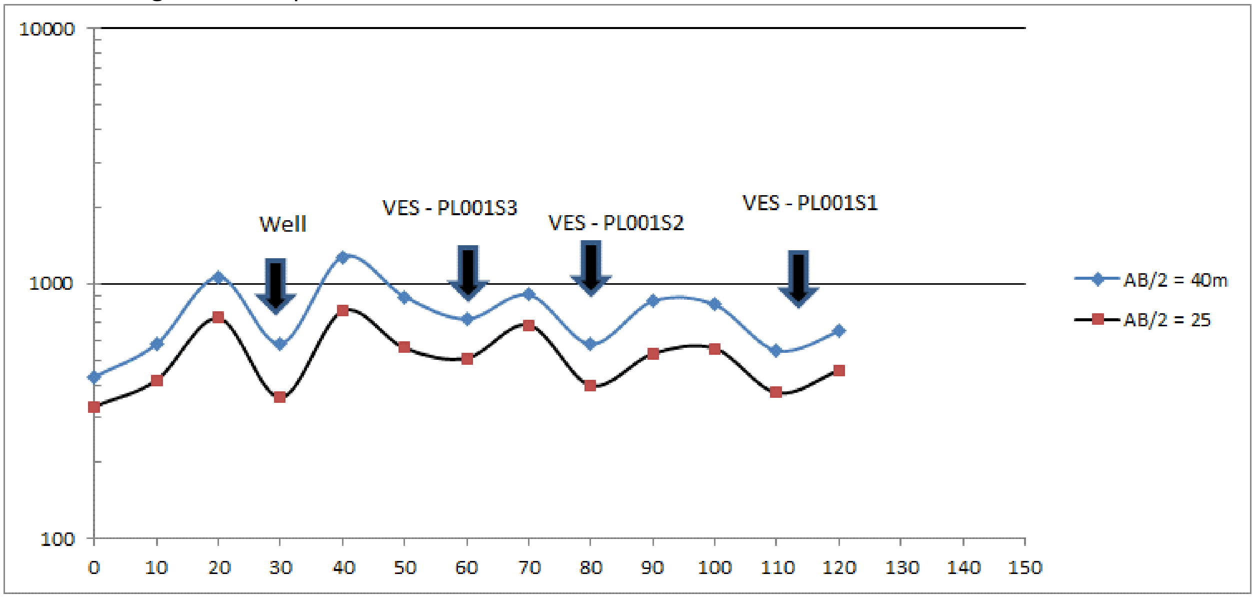
Lapworth DJ, Carter RC, Pedley, S and MacDonald AM. 2015. Threats to groundwater supplies from contamination in Sierra Leone, with special reference to Ebola care facilities. British Geological Survey Technical Report OR/15/009, Nottingham, UK, 87pp.

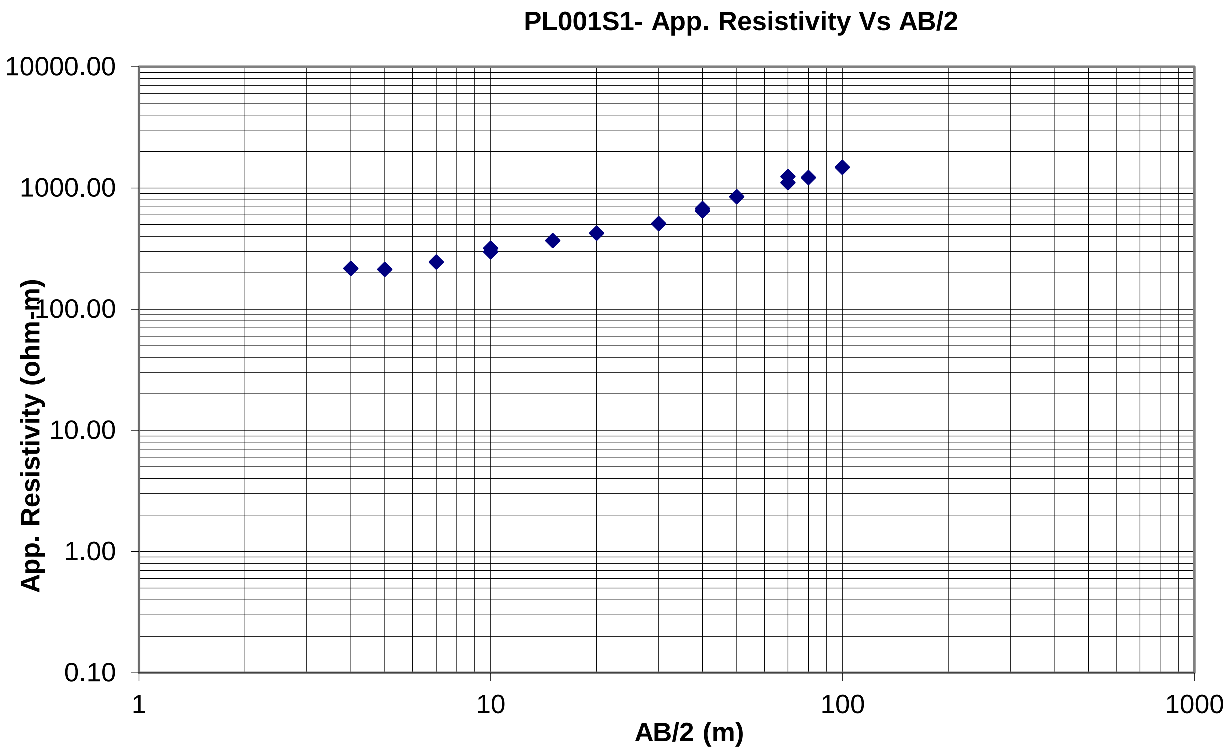
United Nations. 1988. Groundwater in North and West Africa: Sierra Leone. United Nations Department of Technical Cooperation for Development and Economic Commission for Africa. Department of Technical Cooperation for Development and Economic Commission for Africa, Natural Resources/Water Series No. 18.

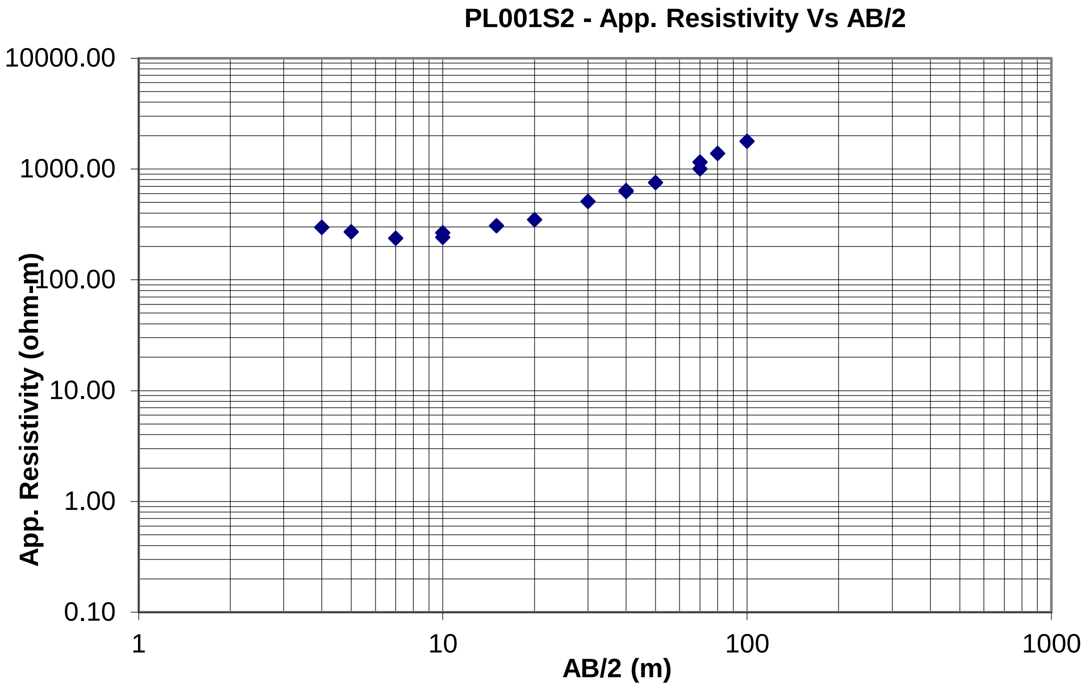
APPENDICES

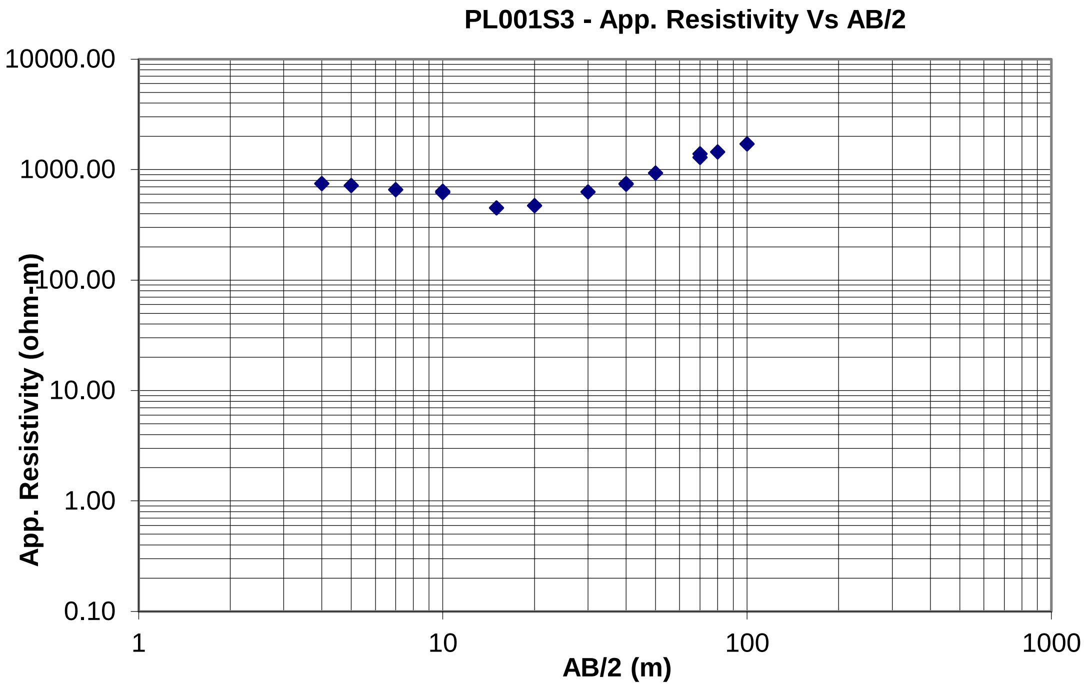
Appendix 1: KAGBANTHAMA GEOPHYSICAL RESULTS

PL001P1- Kagbanthama profile






PL001S2 - App. Resistivity Vs AB/2
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)


PL001S3 - App. Resistivity Vs AB/2
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
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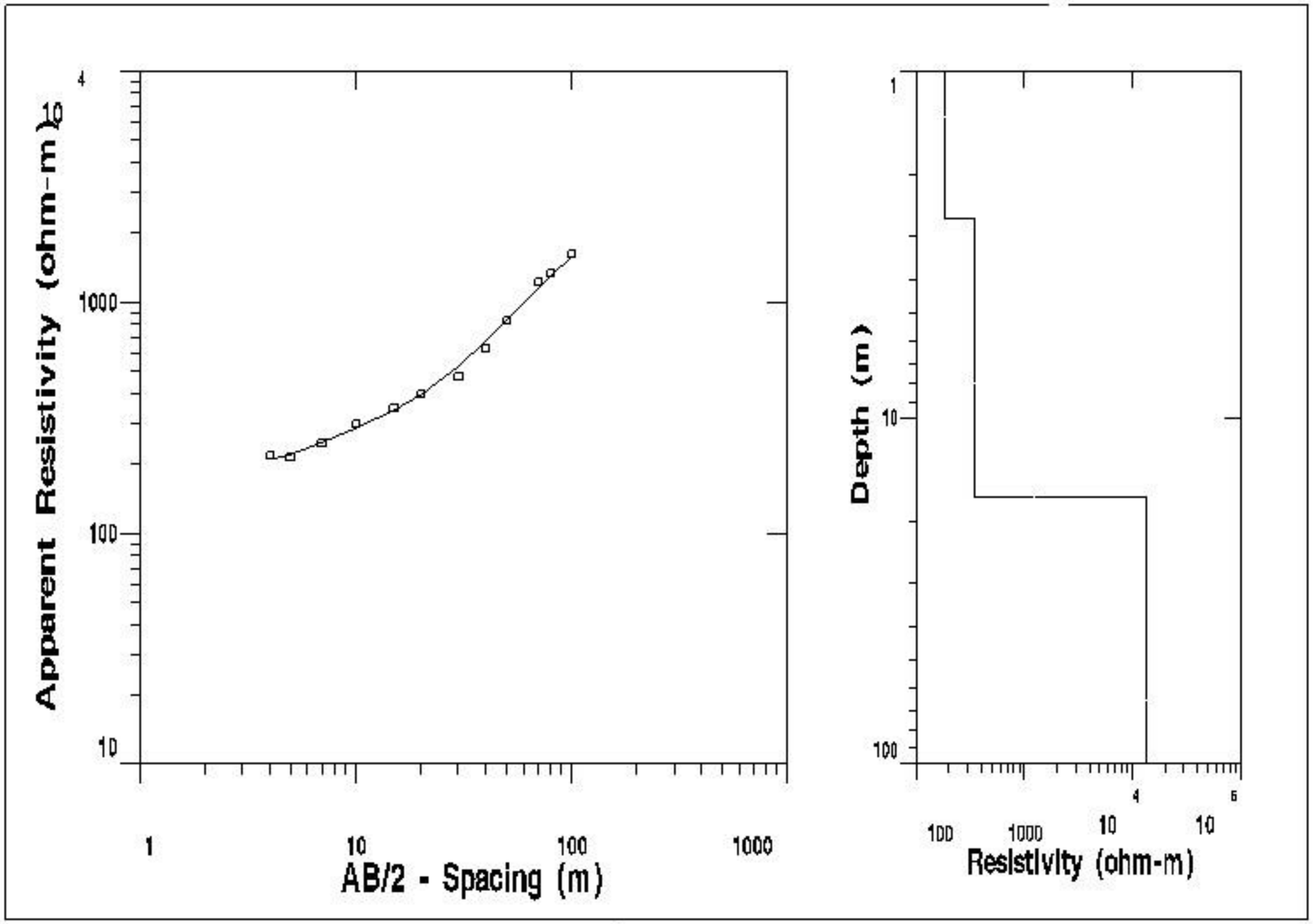
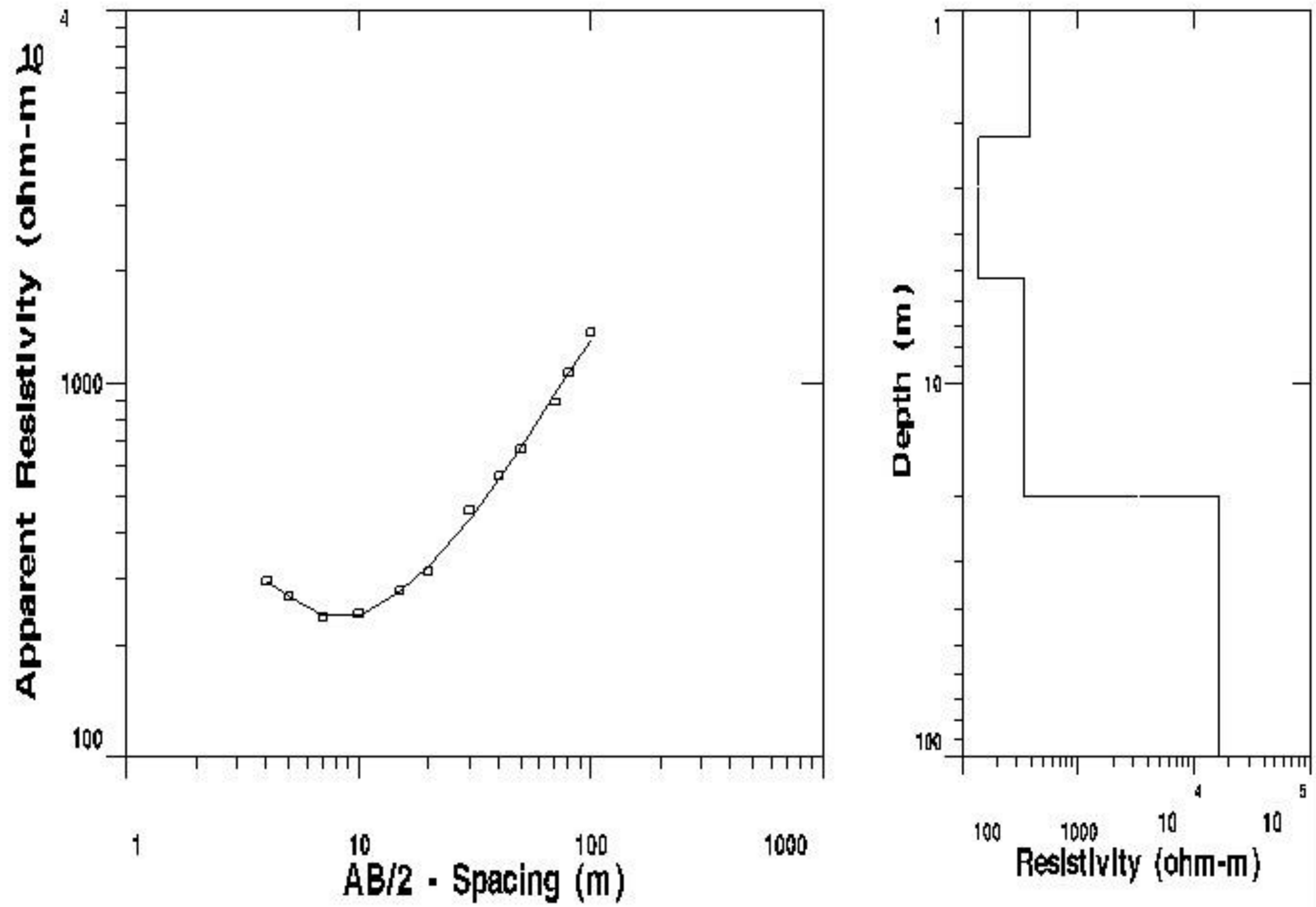
10
100
1000
AB/2 (m)



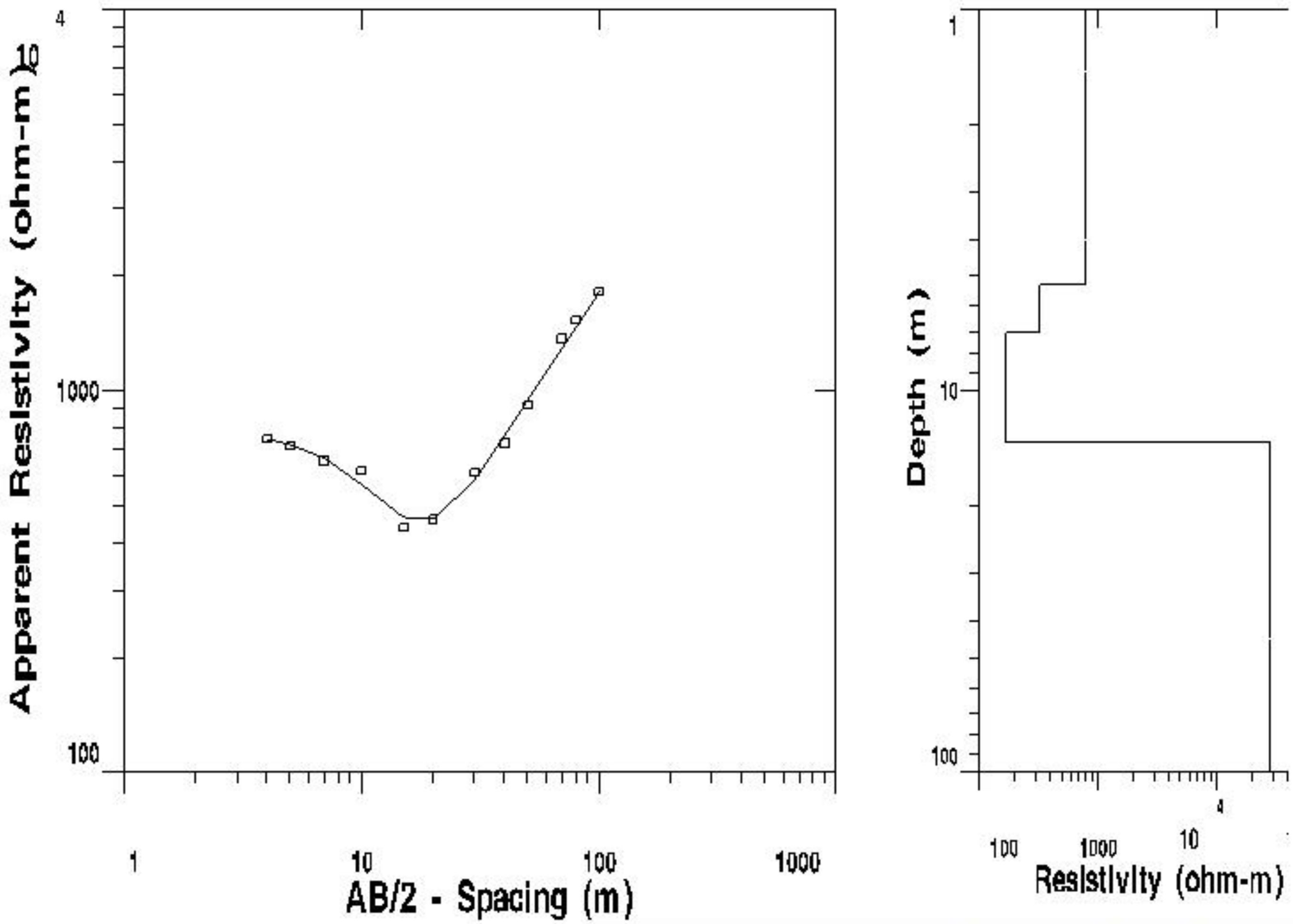
GOAL SIERRA LEONE

Kagbanthama CHC; PL001S1

Enkelbert Chinwada



GOAL SIERRA LEONE
Kagbanthama CHC; PL001S2
Enkelbert Chinwada

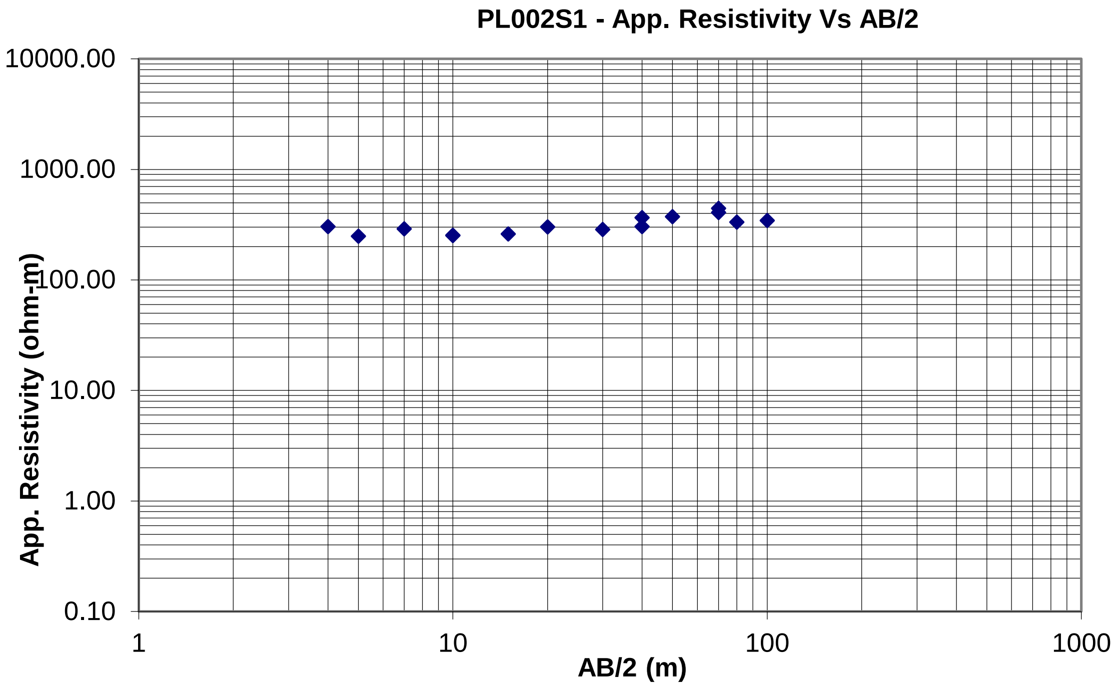


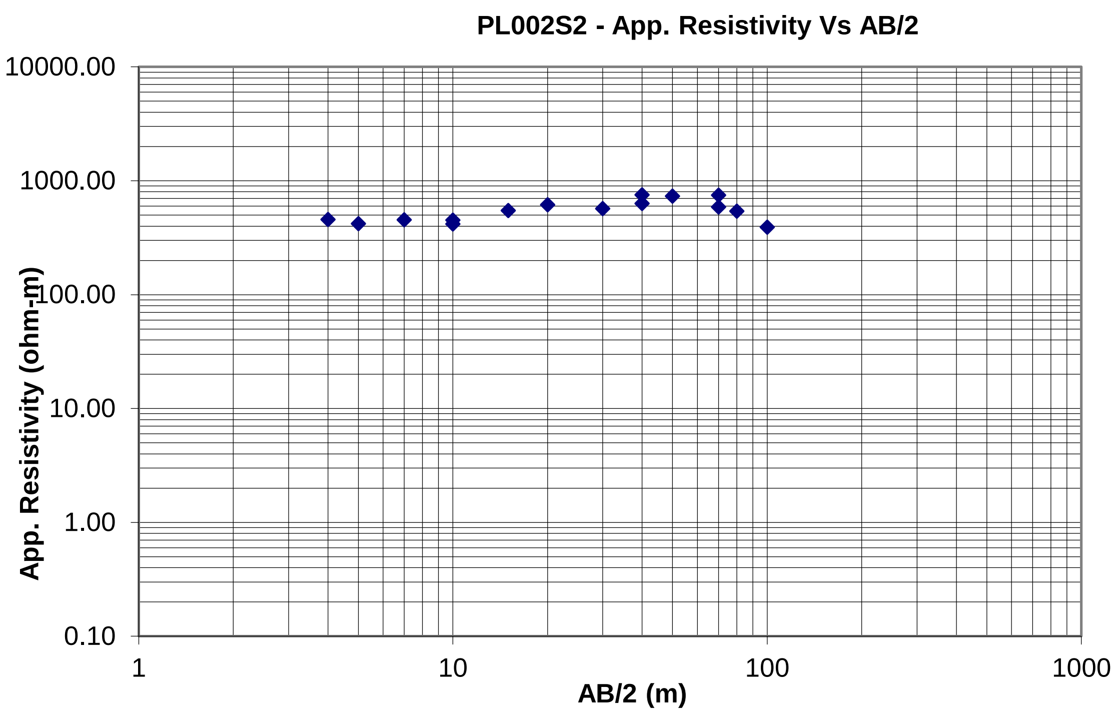
GOAL SIERRA LEONE

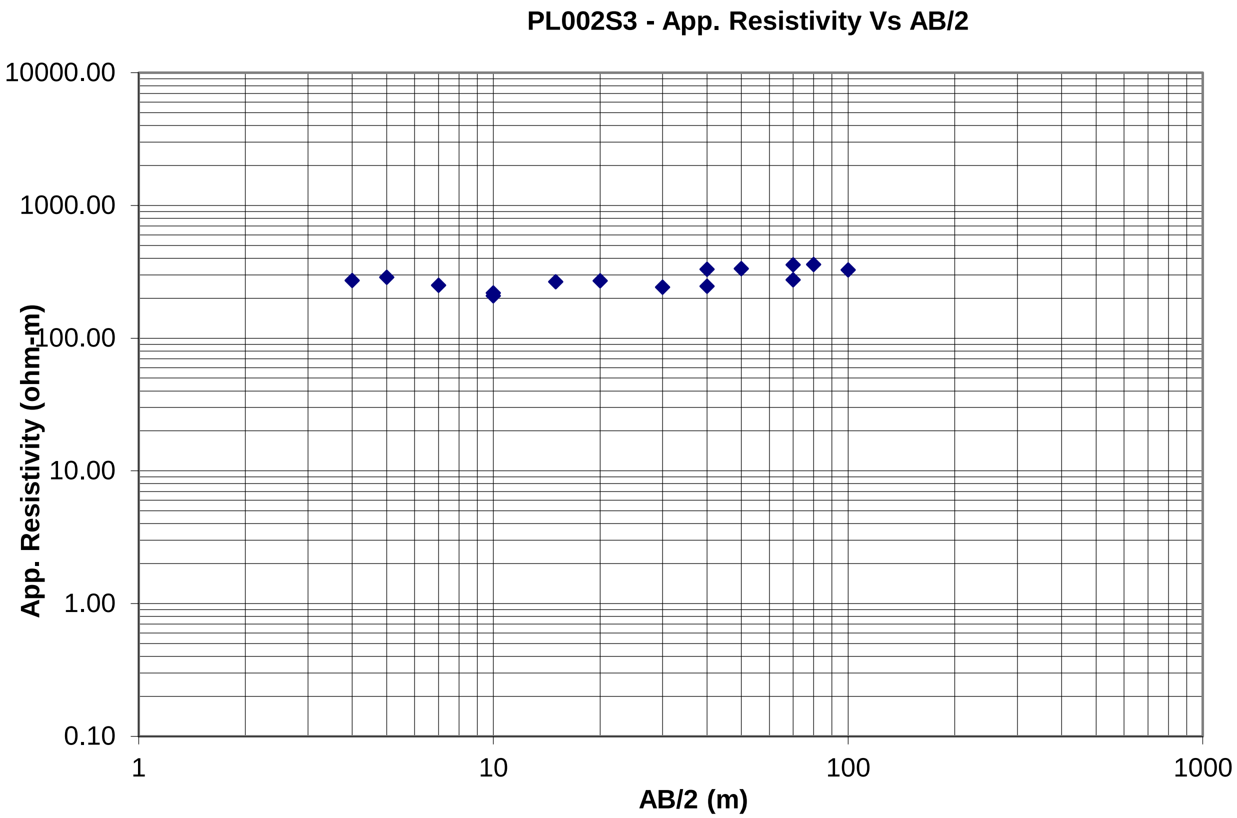
Kagbanthama CHC; PL001S3

Enkelbert Chinwada

Appendix 2: MAHERA GEOPHYSICAL RESULTS



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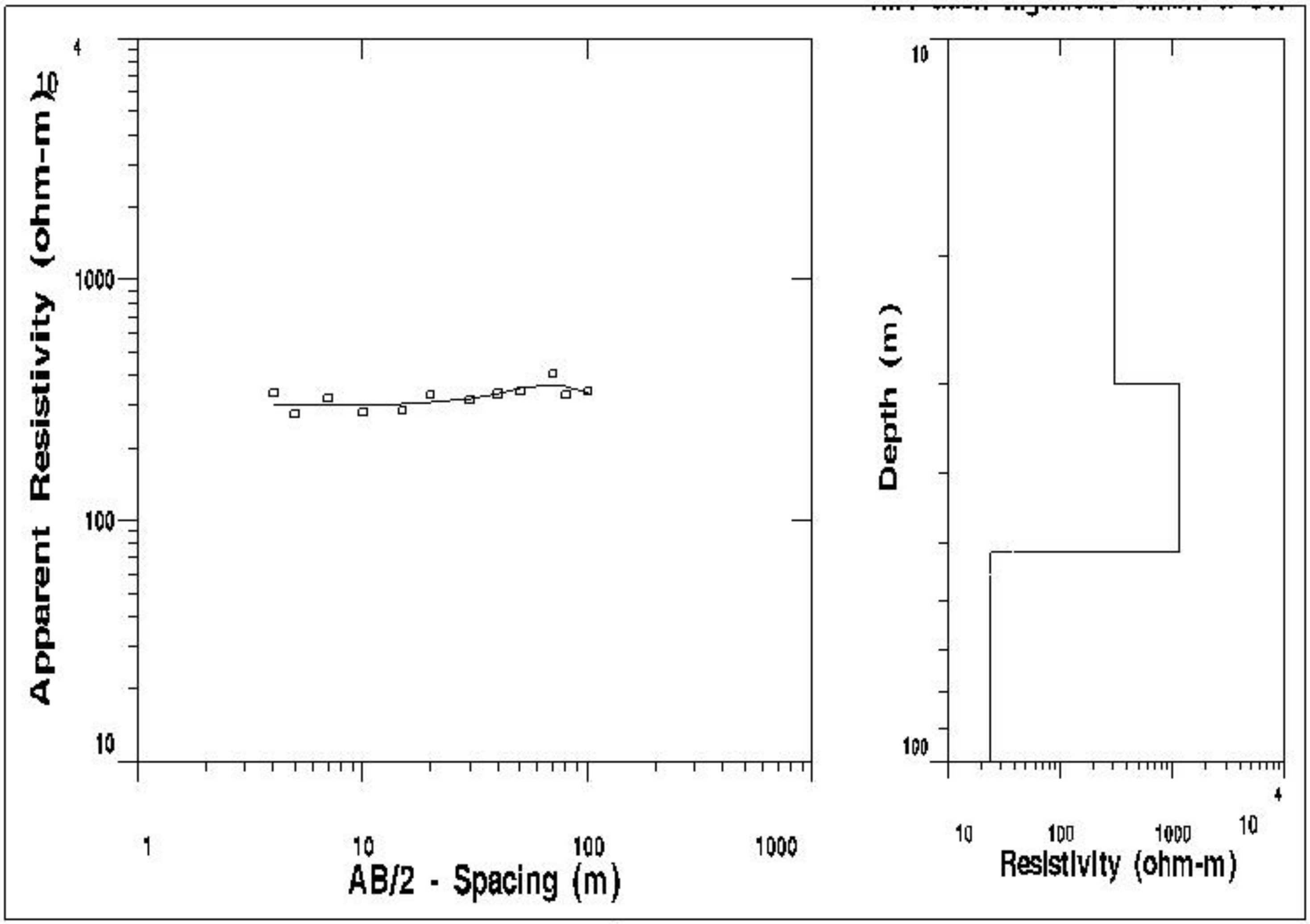
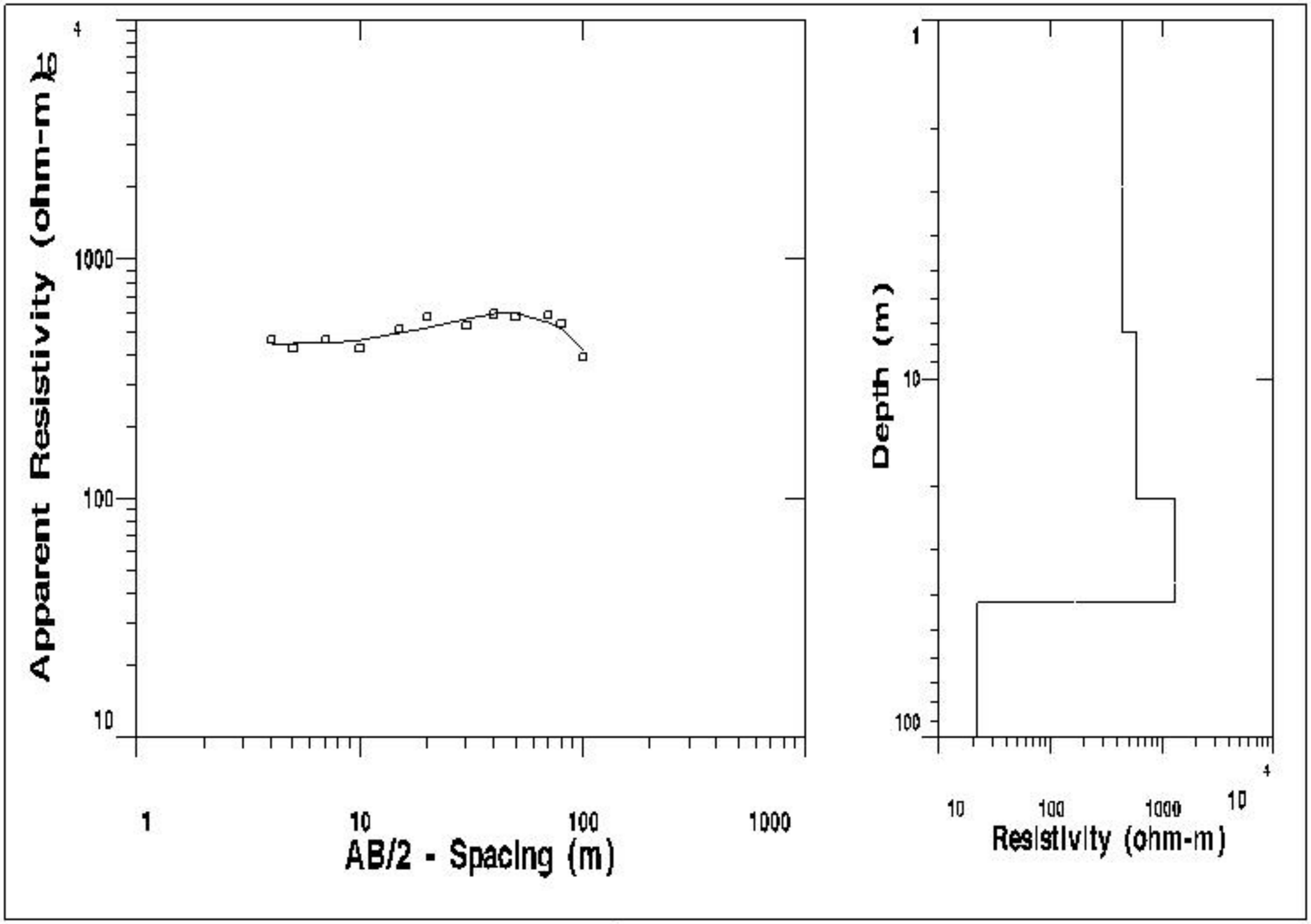
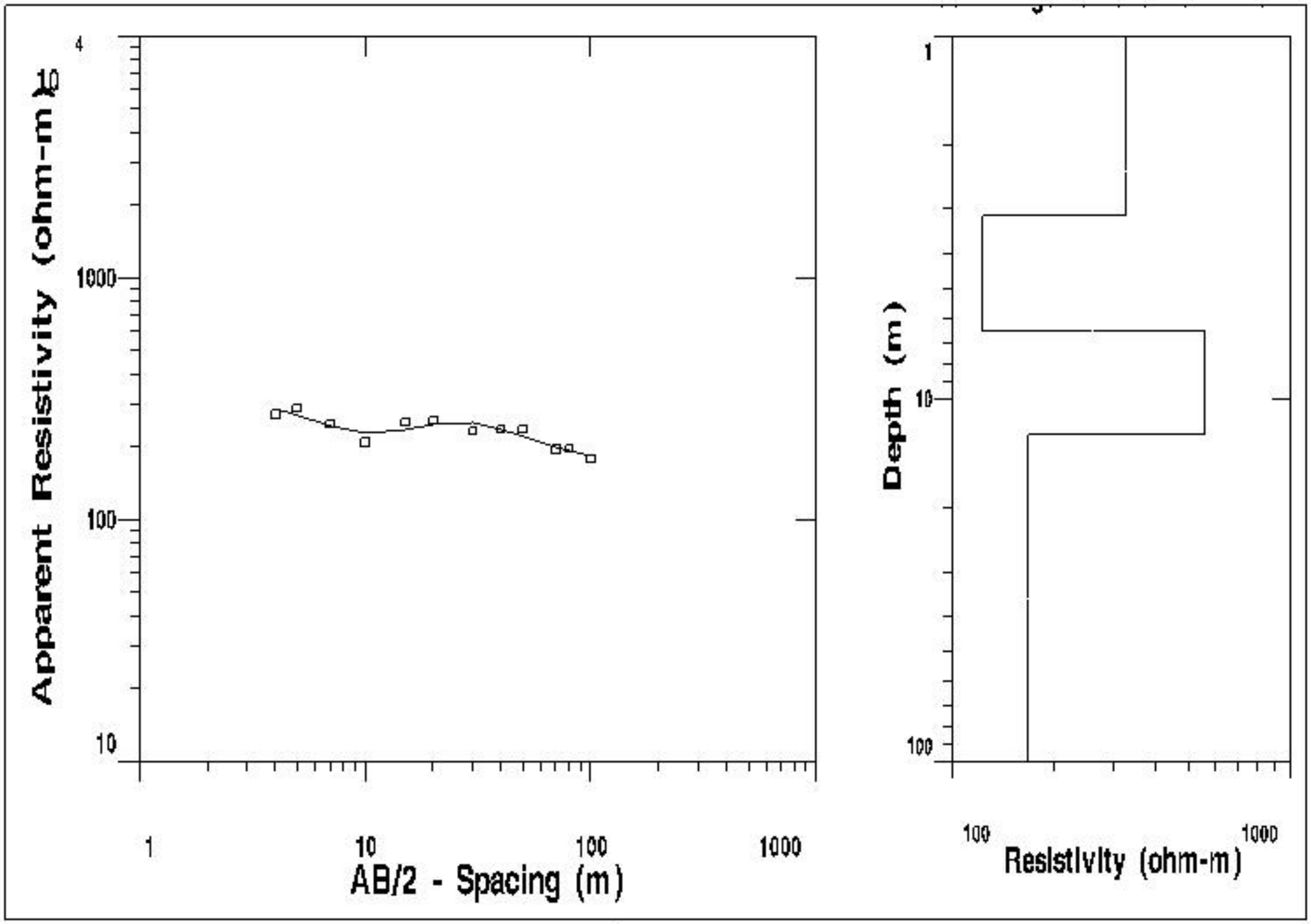
1000.00
100.00
10.00
1.00
0.10
App. Resistivity (ohm-m)
1
10
100
1000
AB/2 (m)



GOAL SIERRA LEONE
Mahera CHC; PL002S1
Enkelbert Chinwada



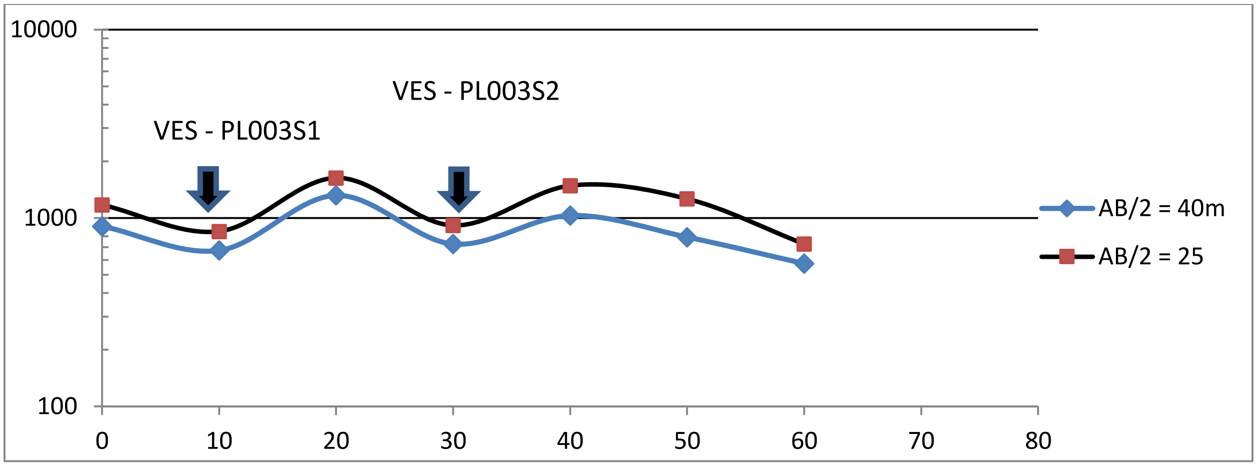
GOAL SIERRA LEONE
Mahera CHC; PL002S2
Enkelbert Chinwada

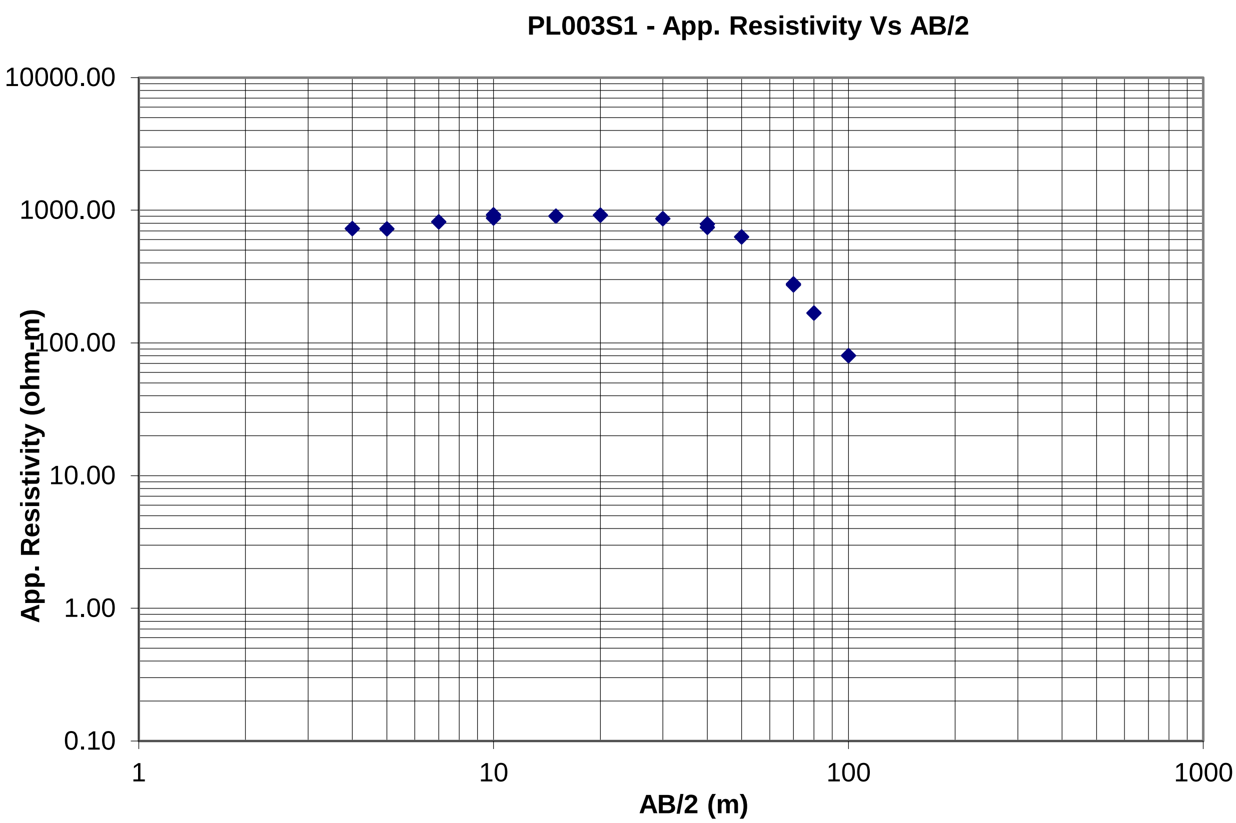


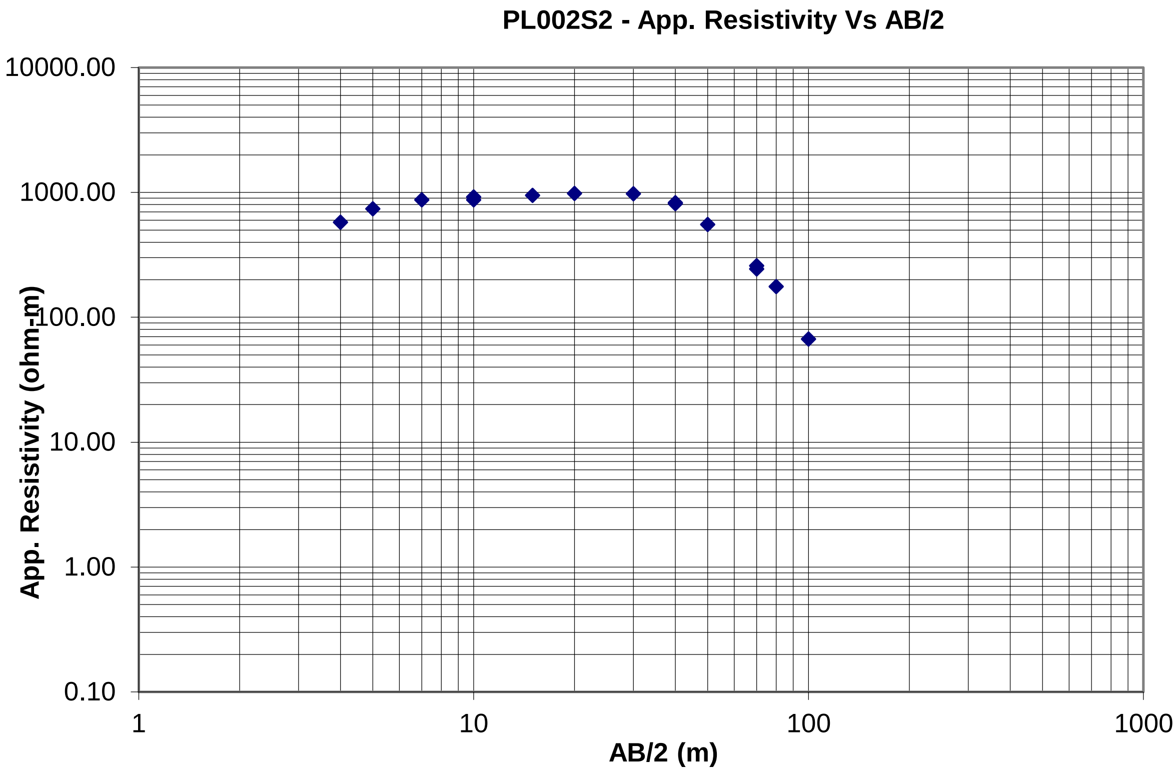
GOAL SIERRA LEONE
Mahera CHC; PL002S3
Enkelbert Chinwada

Appendix 3: BARBARA GEOPHYSICAL RESULTS

Pl003P1






PL002S2 - App. Resistivity Vs AB/2
App. Resistivity (ohm-m)
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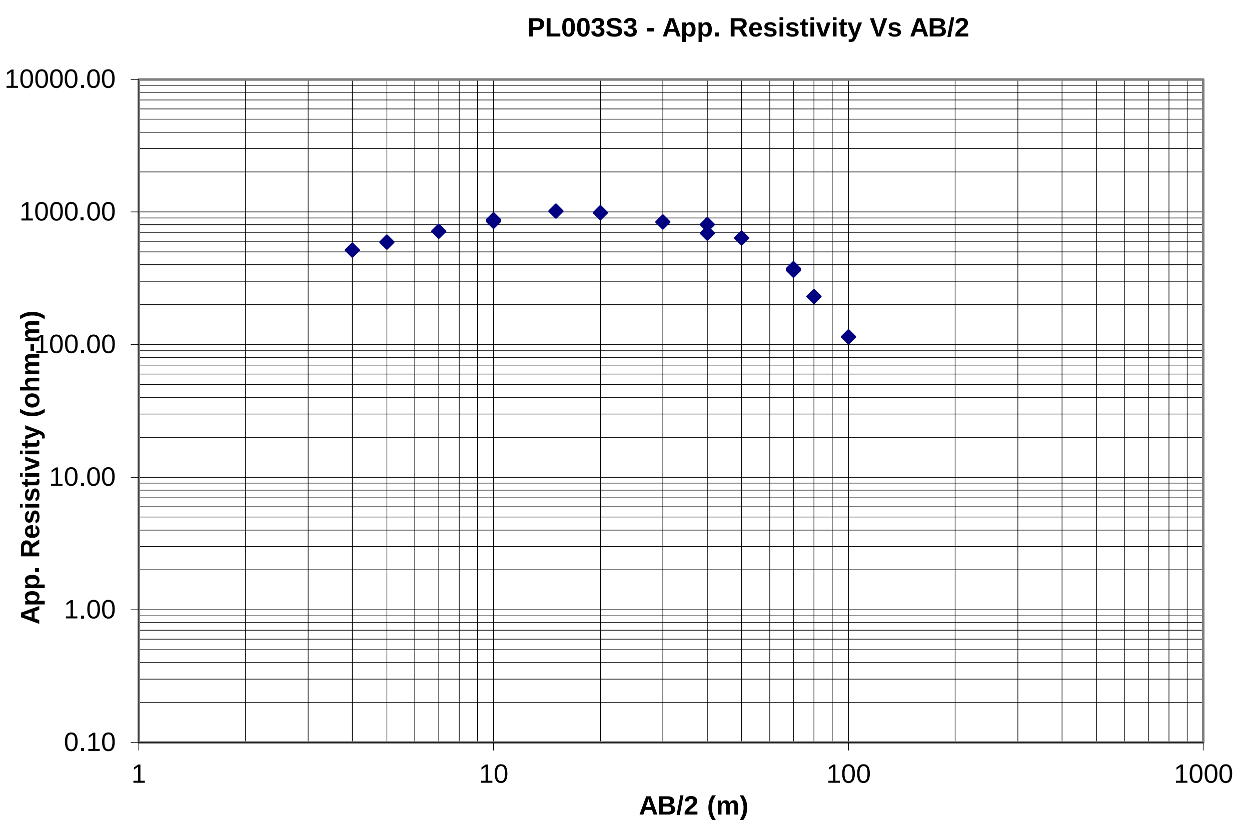
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)


PL003S3 - App. Resistivity Vs AB/2
App. Resistivity (ohm-m)
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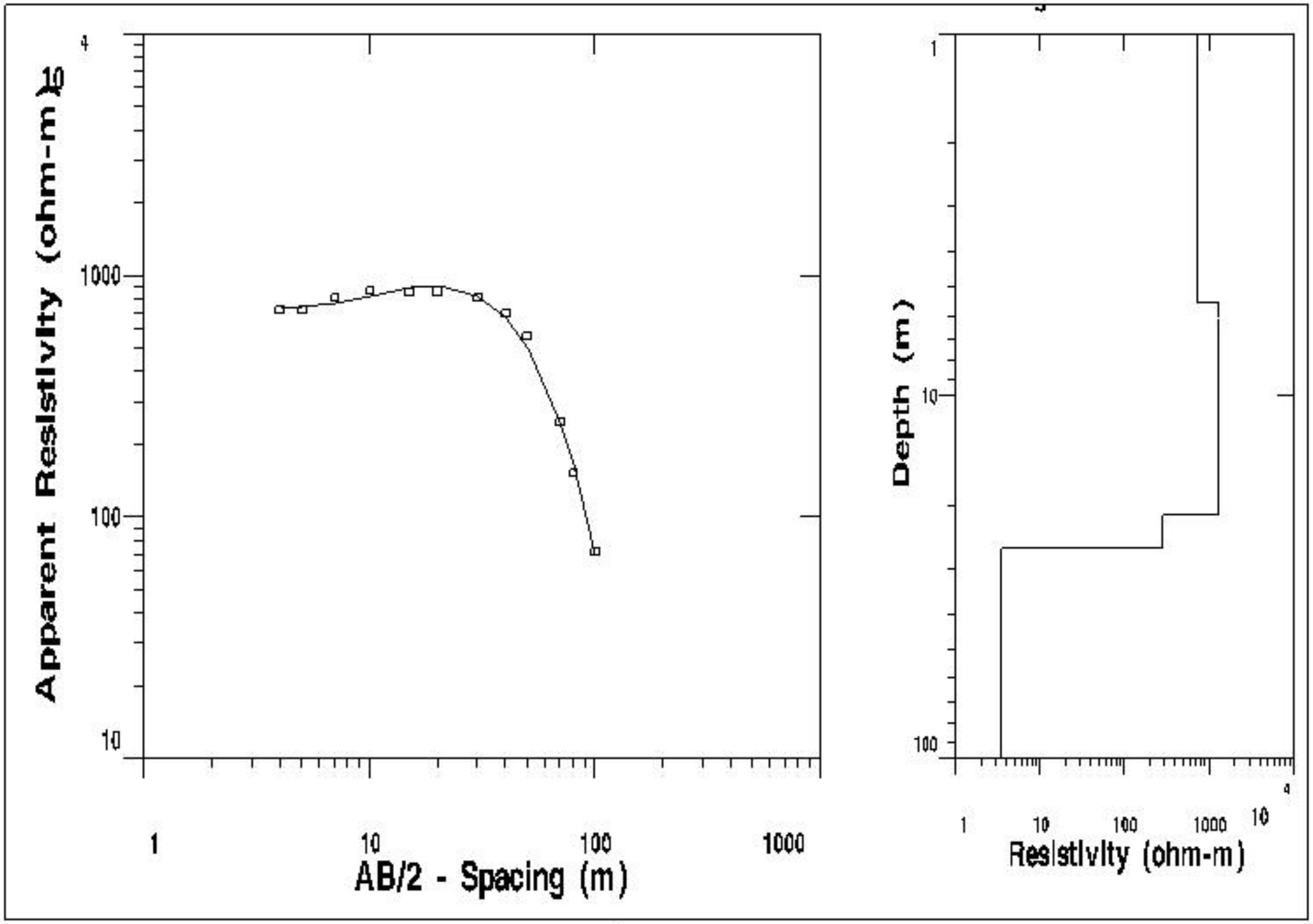
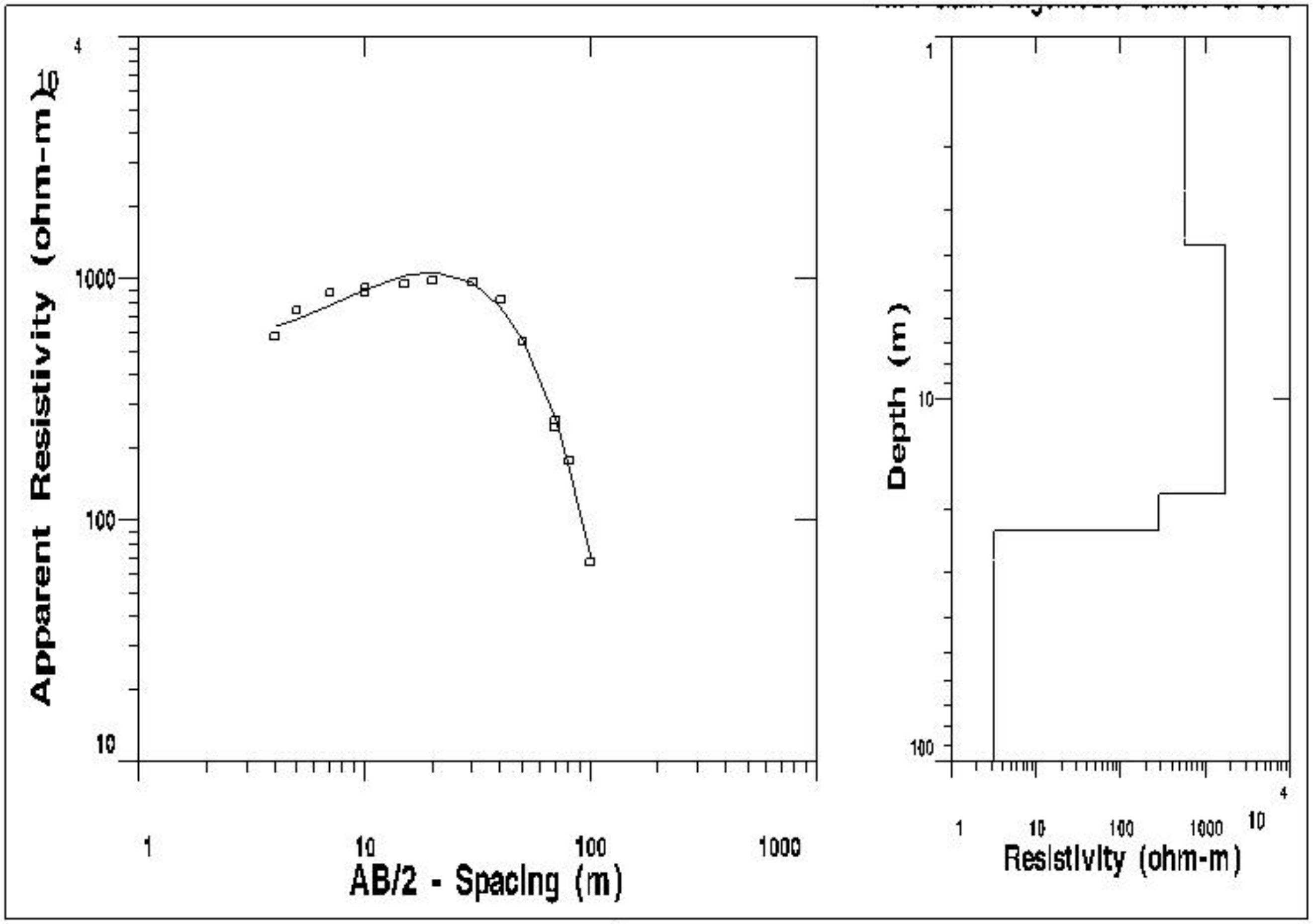
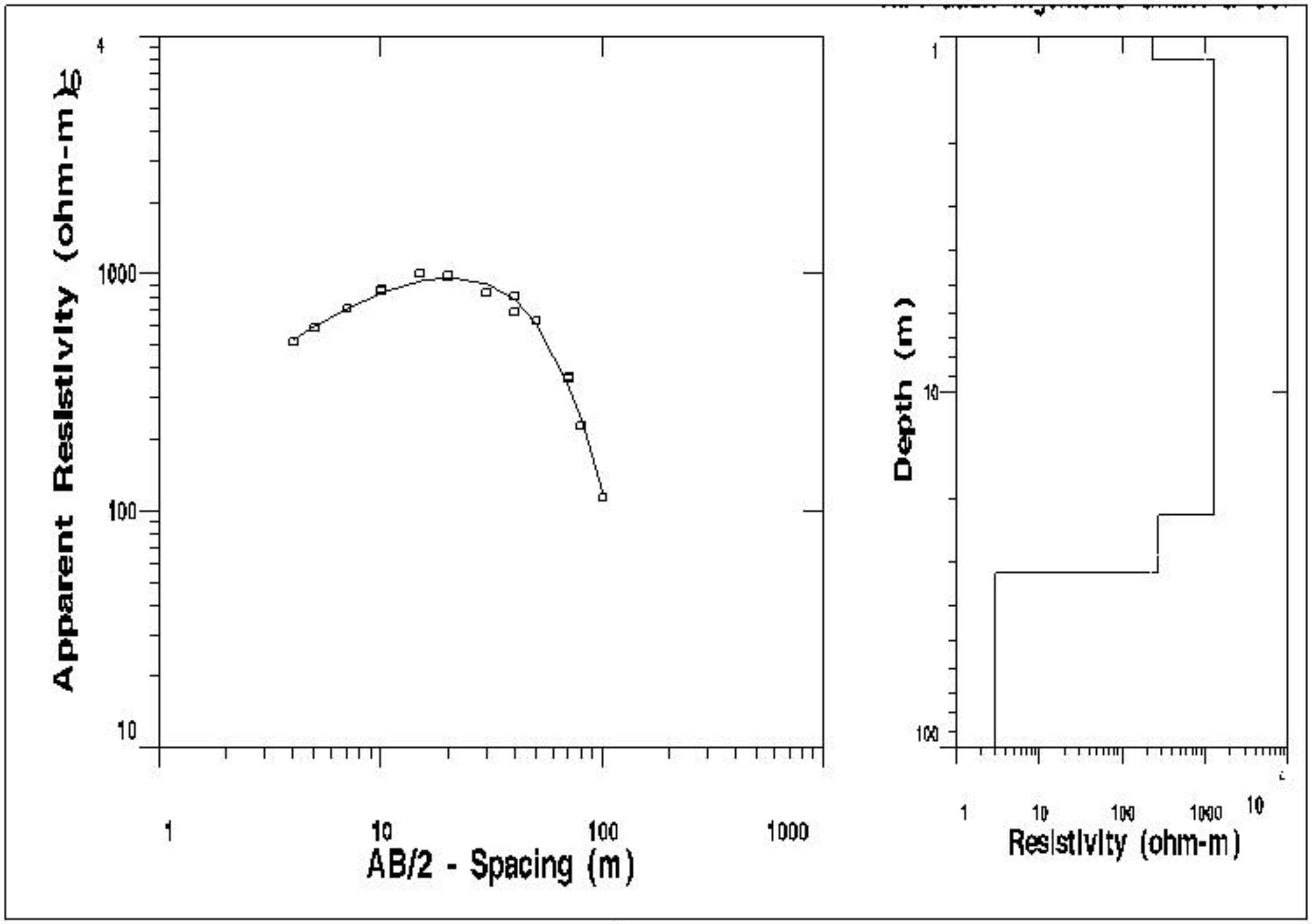
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)



GOAL SIERRA LEONE
Barbra CHC; PL003S1
Enkelbert Chinwada



GOAL SIERRA LEONE
Barbra CHC; PL003S2
Enkelbert Chinwada



GOAL SIERRA LEONE

Barbra CHC; PL003S3

Enkelbert Chinwada