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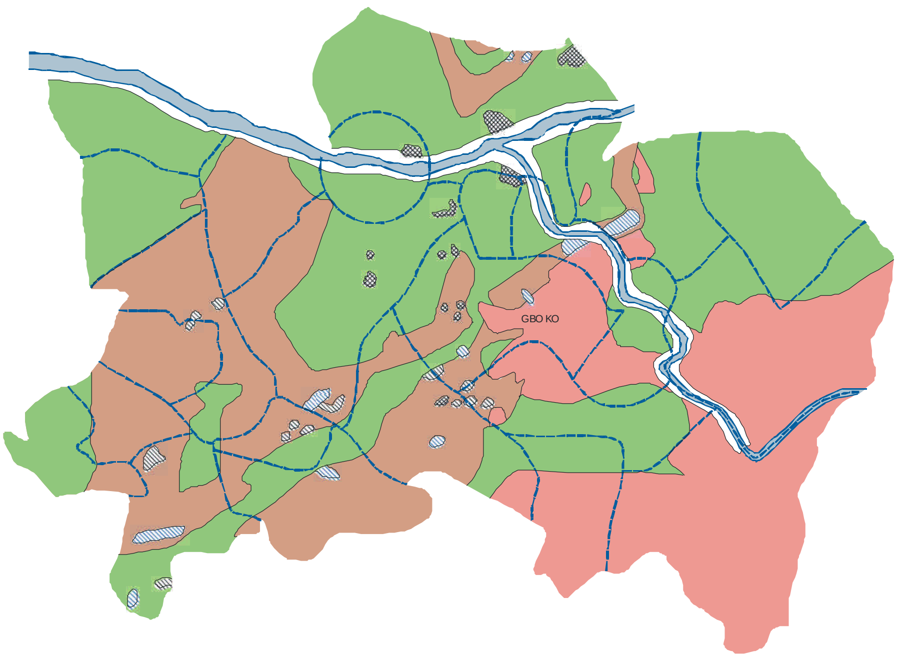
Report on visit to a WaterAid project, Nigeria, to carry out workshops and assess geology of Benue State

Groundwater Systems and Water Quality

Internal Report IR/01/18



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/01/18

Report on visit to a WaterAid project, Nigeria, to carry out workshops and assess geology of Benue State

Alan MacDonald

Front cover

Sketch map of the geology of Benue State.

Bibliographical reference

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Foreword

This report gives information from a 2-week visit to Benue State, Nigeria, by Alan MacDonald from 6-21 January 2001. It is a product of a DFID funded water supply and sanitation project in Benue State, Nigeria (CNTR 960023A). The British Geological Survey has been working there since 1996, helping the local government and WaterAid develop water sources in an area of highly complex geology and limited groundwater resources. Much of the findings of the BGS groundwater investigations are given in two previous reports, WC/99/32 and WC/00/07.

Acknowledgements

Several individuals helped organise and run the workshop in Oju and Obi. In particular I would like to thank the following:

Mr K Goyol (WaterAid)

Ms M Miller (WaterAid)

The Geological Survey of Nigeria freely offered information and maps concerning the geology of Benue State. I would like to thank Mr S Udeje and Mr E Ode from the Makurdi Office for their useful comments and discussions.

Contents

FIGURES

TABLES

Abbreviations and Acronyms

BERWASSA Benue Rural Water Supply and Sanitation Agency

BGS British Geological Survey

DFID Department for International Development

LGA Local Government Area

WASU Water and Sanitation Unit

Summary

This short report summarises activities and conclusions from a visit to Nigeria by Alan MacDonald (6-21 January 2001), other relevant information is attached. The terms of reference for the visit were:

- to train WaterAid/WASU/BERWASSA staff to find dolerite intrusions in Obi and Oju;
- to train staff in the use and interpretation of resistivity equipment in Oju and Obi;
- carry out a desk study of the geological conditions of 7 LGAs in Benue State.

To meet these terms of reference a seven-day workshop was undertaken in Oju/Obi comprising mainly fieldwork. Three days were spent in Makurdi consulting geological information available at the Geological Survey of Nigeria.
A summary of the main activities and recommendations from the visit are given below.

1. Boreholes drilled into dolerite intrusions offer the cheapest and most sustainable water supply for much of Obi. Therefore considerable time (1-2 days per community) should be given to try to locate dolerite in communities in Obi. The best method for finding it is to use EM34 and magnetics together and then validate using EM34 with 40-m coil separations. WaterAid and WASU are competent to carry out these activities.

2. All workshop participants could competently use the magnetic and EM34 equipment. Most could interpret the data to identify areas with dolerite. However, for this year, it is advisable for the WaterAid Engineer to validate interpretations of any surveys.

3. Resistivity is not a particularly useful technique in Oju and Obi. Similar information is given by using EM34 at 20-m spacings and then repeating with 40-m coil separation. All participants recognised the pros and cons of using resistivity and as a group we decided that we do not need to continue using it in Oju and Obi. Most participants can now roughly interpret resistivity data.

4. The geological conditions of the 7 LGAs vary greatly. The most difficult area for finding groundwater is probably Gwer West. The geological conditions of all seven LGAs are summarised in Table 3.

5. The records from the 2000 drilling programme highlighted several important issues.

- The boreholes were drilled and tested during the rainy season when yields are artificially high.
- They were only grouted to a depth of one metre, therefore leaving the laterite unsealed.
- The depth ranged from 22-51m (average 32.4 m) – well short of the minimum depth of 40 m suggested by BGS.
- The bailer tests were not carried out properly (and the raw data not given) therefore it is impossible to assess the yields of the boreholes.

6. Several other issues arose during the visit, such as the future use of the drilling rig; the distribution of reports (both within the project and to other stakeholders). These are discussed later in the report.

1 Introduction

This short report summarises the activities and conclusions from a short visit to the WaterAid/DFID water and sanitation project in Benue State, Nigeria. Mr Alan MacDonald visited the project from 6-21 January 2001. The terms of reference for the visit were:

- to train WaterAid/WASU/BERWASSA staff to find dolerite intrusions in Obi and Oju;
- to train staff in the use and interpretation of resistivity equipment in Oju and Obi;
- carry out a desk study of the geological conditions of 7 LGAs in Benue State.

To meet these terms of reference a seven-day workshop was undertaken in Oju/Obi comprising mainly fieldwork. Three days were spent in Makurdi consulting geological information available at the Geological Survey of Nigeria.
Other relevant material, such as handouts from the workshop, is attached.

2 Practical workshop for finding groundwater in Obi

Both BERWASSA and WASU have had problems locating water supplies in Obi. The geology is mainly Awgu Shale – a soft, sticky mudstone with little usable water within it. The best possibility for a cheap sustainable water supply is to drill boreholes into dolerite intrusions which occur sporadically throughout the area (Davies and MacDonald 1999). These hard igneous rocks are generally fractured and contain groundwater. However, particular geophysical methods are required to locate the dolerite.

The workshop in Oju and Obi was designed to help WASU, WaterAid and BERWASSA staff to learn how to successfully use geophysical equipment to locate dolerite in the Awgu Shale. The workshop was designed to be as participatory and practical as possible.

2.1 PROGRAMME AND PARTICIPANTS

The workshop programme allowed as much hands on experience with equipment and interpretations as possible. The general pattern was fieldwork at villages selected by WASU in the morning, with interpretation and group discussions in the afternoon. Each participant had the opportunity to use the equipment every day. All the handouts from the workshop are given in Appendix A.

9 Jan — Introductionary session, expectations of the workshop, needs, revision quiz etc…
Lesson and revision on magnetic fields by comparing the earth to a bar-magnet.
Setting up and caring for EM34 and magnetic survey equipment.
Survey near Edumoga, focussing on setting up and taking readings with the EM34 and magnetic equipment.

10 Jan — Magnetic and EM34 survey at Okpodum Ogore.
Plotting the data on graphs.
Interpretation of EM34 and magnetic data. Some dolerite was found.

11 Jan — Magnetic and EM34 survey at Ohuiye. Carrying out geological triangulation.
Plotting and interpreting the data. Dolerite was found.

12 Jan — Magnetic and EM34 survey at Ukpute Itogo (chairman’s village). Carrying out geological triangulation.
Plotting and interpreting the data. Dolerite was found within the village.

13 Jan — Group discussions about the implications of permeable laterite on borehole/well completion, borehole testing, latrine design and location.
Group interpretation of geophysical surveys in the different geological units of Oju and Obi.

15 Jan — Carrying out resistivity surveys (using the Offset Wenner array) and EM34 surveys (with 40 m coil separation) at Okpodum Ogore.
Group discussions on the pros and cons of using resistivity.
Qualitative interpretation of resistivity surveys.

16 Jan — Carrying out resistivity surveys (using the Schlumberger array) and EM34 surveys (with 40 m coil separation) at Ito Barracks.
Qualitative interpretation of resistivity and EM34 surveys.
Closing discussion and presentation of certificates.

The workshop was attended by technical staff from BERWASSA, WaterAid, Oju and Obi WASUs and the State Ministry of Water resources and the Environment. Unfortunately Mr J Daagu from BERWASSA could not attend because of duties in Makurdi. Table 1 lists the workshop participants.

Table 1 Workshop participants.

Name	**Position and Organisation**
Kitka Goyol	Engineer, WaterAid
Godwin Odike	Technician, Oju WASU
Godwin Ode	Student, Oju WASU
Dan Aje	Coordinator, Obi WASU
Innocent Okpasi	Technician, Obi WASU
Emmanuel Ongaji	Geologist, BERWASSA
Nathan Ichor	As. Director, Min of Water Resources and Environment

2.2 LOCATING DOLERITE IN OBI

Used together, the EM34 and magnetometer equipment can detect the presence of dolerite. If they are only used individually, however, there are too many uncertainties to confidently locate dolerite. Therefore, both sets of equipment should be used and, to avoid complications, the surveys carried out at the same time with the magnetometer trailing the EM34 by about 30 m.

Dolerite is generally indicated by variations in the magnetic field of greater than 10 nT over a few tens of metres, and usually a correspondingly low electrical conductivity measured with the EM34 compared with the surrounding shale. To further confirm the presence of dolerite at depth, an

EM34 survey with 40-m coil separation can be undertaken. This should also indicate low conductivity (less than 30-40 mmhos/m). More information on interpreting geophysics is given in the BGS final report (Davies and MacDonald 1999) and some of the individual data reports (e.g. WC/99/3R, WC/99/4R and WC/98/66R).
By the end of the workshop, all participants could successful carry out surveys, keep a proper notebook and plot the data on graphs. Most participants were confident at interpreting the graphs and locating points to drill.

2.3 RESISTIVITY

Resistivity surveys are not particularly useful in Oju and Obi. Similar information is given by carrying out an EM34 survey with 20-m coil separation and repeating with 40-m coil separation (the larger coil separation looks deeper into the ground – about 0.7 x the coil separation for vertical coils). Table 2 summarises the pros and cons of resistivity discussed during the workshop.

Table 2 Pros and cons of using resistivity.

Resistivity good points	Resistivity bad points
It can identify layers of different resistivity (in other words changes with depth).	Very susceptible to bad electrode connections.
	Difficult to interpret
It can penetrate deep into the ground.	Laborious and slow.
It is not affected by tin roofs etc.	It only takes a reading at one point

By the end of the workshop participants decided that the resistivity survey was too prone to difficulties in the Oju/Obi area – mainly due to poor contacts between the electrodes and the ground. They decided that resistivity surveys should not be routinely carried out, but that EM34 with 40-m cables could adequately substitute.
However, since BERWASSA have carried out many resistivity surveys, and because it can be useful in other areas, we spent some time discussing qualitative interpretation of the data. More information is given in the workshop handouts in Appendix 1.

2.4 RECOMMENDATIONS

Groundwater within dolerite remains the most reliable and cheapest water supply option for much of Obi and parts of Oju. Therefore considerable time (1-2 days) should be spent in each community trying to locate dolerite.
EM34 surveys and magnetic surveys should be carried out at the same time. The presence of dolerite can be further inferred by carrying out an EM34 survey with 40-m coil separation over areas of interest.
The WaterAid Engineer should help WASU and BERWASSA members interpret the surveys for this drilling year.
Resistivity surveys do not need to be undertaken in Oju and Obi. If information is required on the electrical conductivity at depth, the EM34 with 40-m coils will suffice.
Boreholes drilled into the dolerite should be carefully logged to help build information on the availability of groundwater in the dolerite throughout Obi and Oju.

3 Geology and hydrogeology of Benue State

WaterAid and DFID are considering extending the water project to include other Local Government Areas (LGAs) in Benue. Because of the complex geology of the area and the poor potential for groundwater, an investigation of the geology and groundwater potential will be required before any drilling or well construction begins. This may involve carrying out geophysical surveys, trial drilling and groundwater sampling, in a scaled down version of the investigations in Oju and Obi. To give a rough indication of the problems that might be encountered in the different LGAs, a desk survey of the geology of Benue State was carried out using existing maps and knowledge. A simple hydrogeological interpretation was given of the geology, using experience from Oju and Obi and BGS work elsewhere.

3.1 DATA SOURCES

There is little reliable geological information available for Benue State. What information exists is available from various sources: the Geological Survey of Nigeria (at Makurdi, Enugu and Kaduna), the University of Nigeria, Nsukka, and some international literature (see Davies and MacDonald 1997). There are only two published geology maps, and much of the geological information for the state is in hand coloured field maps kept by the geological survey. The Makurdi office does not have a complete set of these maps, but the Kaduna office should have.

Some of the data sources contradict each other. There was not enough time to resolve these difference during this visit, but this must be done before starting work in new LGAs. Another dated source of information is found in a report by Tahal Consultants (Nigeria Ltd) in 1982.

3.2 SUMMARY OF GEOLOGY FOR 7 LGAS

A rough sketch of the geology of Benue State is shown in Figure 1 (a slightly larger map is given in Appendix 2). The Geology of Benue State is complex. Much of the state is underlain by mudstone and sandstones which vary in character across the state. In some places the sandstone can be soft and porous, and contain much groundwater. In places it is hard and fine grained and contains little groundwater. Mudstone is generally poor for groundwater, particularly in the northwest where it is soft and sticky. Where weathered, the basement areas can contain water.

Seven local government areas were considered: Ador, Outkpo. Gwer West, Gboko, Logo, Ukum and Vandekia. Table 3 gives a rough indication of the geology, hydrogeology and groundwater potential for each LGA. An indication of the uncertainties and unknowns for each LGA is also given.

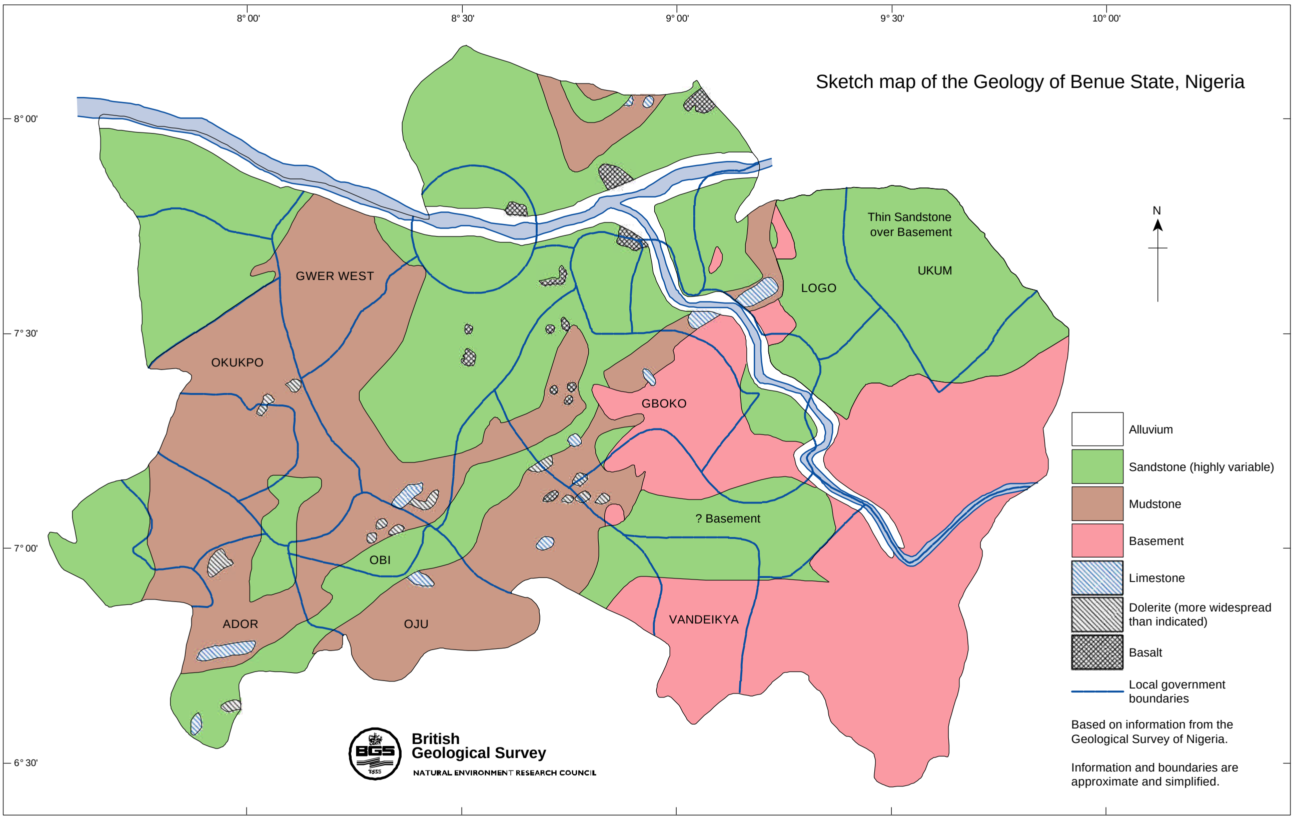

Figure 1 Sketch map of the geology of Benue State.

Table 3 The geological and hydrogeological conditions of various LGAs in Benue State.

LGA	Geological Information	Geology	Hydrogeology	Geophysics	Unknowns	Overall Potential*
Ador	Benue 1:500K Nigeria 1:2M	Shale (60%) Awgu and Upper Eze-Aku – soft and sticky Sandstone (35%) Hard fine grained Makurdi sandstone; coarse grained Otobi sand-stone to the north. Probably many intrusions, and limestone.	The Makurdi sandstone may be very hard and low yielding. The Otobi Sandstone to the north may be coarser and higher yielding but little information exists. Shales may be generally soft, sticky and low yielding. However the dolerite intrusions (and limestones) may significantly enhance the yield. Saline water is known to occur in this area.	Probably magnetics and EM34 to locate dolerite intrusions and sandstones. If sandstones are very hard, then aerial photographs (or maybe satellite interpreta-tion) may be needed to find fractures.	The Makurdi sandstone may change to be very hard and low yielding. The extent of the Saline wa-ter. How extensive the dolerite is. The nature and extent of the Otobi Sandstone in the North.	Moderate-Low
Otukpo	Benue 1:500k Nigeria 1:2M Aeromagnetic map 1:100k Field sheet 1:100k	Shale (80%) Awgu and Nkporo – soft and sticky. Sandstone (20%) – mainly Otobi – could be coarse grained. Also sandstone in northwest Some dolerite intrusions throughout LGA, also some limestone.	The shale is likely to be very low yielding except where intrusions have baked the shale. Intrusions exist but are not wide-spread. The groundwater potential of the Otobi sand-stone, and also sandstones to the north west is unknown, but should be better than the shales.	Probably magnetics and EM34 to locate dolerite intrusions and sandstones.	How extensive the dolerite is. The nature and extent of the sandstones. The nature and extent of any limestones.	Low-Moderate
Gwer West	Benue 1:500k Nigeria 1:2M Field sheet 1:100k	Shale (90%) Awgu and Nkporo – soft and sticky. Makurdi sandstone (5%) to the northeast. Some alluvium (5%) towards the River Benue	The shale is likely to be very low yielding. There is little indication of dolerite in the area, although aeromagnetic maps have not been studied. Makurdi sandstone may be higher yielding. Alluvium by the river should contain signifi-cant groundwater.	Probably magnetics and EM34 to locate any dolerite intrusions and sandstones.	If there is any dolerite in the area. The presence of any small sandstones or limestones within the shale. Nature of the small amount of Makurdi Sandstone.	Low
Gboko	Benue 1:500k Nigeria 1:2M Field sheet 1:100k	Shale (32%) Eze-Aku – many intrusions throughout so pos-sibly hard and fractured. Sandstone (32%) Makurdi sandstone, possibly baked and hardened by intrusions Basement (32%). Mainly granites, probably weathered.	Shales may be high yielding where baked and fractured. The sandstone may have been adversely affected by the many intrusions, lowering the porosity and permeability. Best target would probably be large fracture zones The granite basement where highly weath-ered should have good potential for ground-water.	EM34 to differentiate sand-stones and shales and to find fracture zones. Magnetics to fine intrusions in shales and sandstones. EM34 and possible resistiv-ity to find deep weathering in the basement.	How the many intrusions have altered the sandstone and shale. The extent of weathering in the basement. The nature of the Makurdi Sandstone in the area.	Moderate-High

LGA	Geological Information	Geology	Hydrogeology	Geophysics	Unknowns	Overall Potential*
Logo	Benue 1:500k Nigeria 1:2M Field sheet 1:100k	Uncertain – the three sources disagree. Some thin sand-stone (or weathered material) may mantle the basement. Distinguishing the sandstone and basement appears diffi-cult for the geologists. basement (30%?) Sandstone (20%?) can be quite coarse Shale (50%?) Eze-Aku – contains clay and siltstone	Where the sandstone and basement are highly weathered then groundwater potential is high and hand dug wells may be used. The shale may be soft and sticky and low yielding. There is no information regarding intrusions in the area. There is some lime-stone mapped, particularly in the south – this may have a greater potential for groundwa-ter.	EM34 to distinguish shale from sandstone and granite. EM34 also to identify thick-ness of weathering in the sandstone and granite (pos-sibly resistivity as well). If more detailed investiga-tions find any intrusions are found in the shale, then magnetic profiling may be needed.	The boundaries of the differ-ent geological units. The interaction of the sand-stone and granite, and where they are more deeply weath-ered. The nature of the shale and extent and nature of lime-stone within the shale. The existence of any dolerite. The relation between weath-ering and groundwater po-tential.	Moderate
Ukum	Benue 1:500k Nigeria 1:2M	Very little information. Possibly coarse sandstone (or weathered material, over-lying basement rocks.	Local knowledge suggests that the sand-stone (or weathered material) is coarse and highly weathered; therefore having good groundwater potential. There will be varia-tions in the thickness of the weathering. Hand dug wells could located where it is thickest.	EM34 and possibly resistiv-ity to find the thickness of weathering.	The interaction of the sand-stone and granite, and where they are more deeply weath-ered. The relation between weath-ering and groundwater po-tential.	Moderate-High

*For comparison: Oju would be moderate-high
Obi would be low-moderate

3.3 RECOMMENDATIONS

The geological information and knowledge available for much of Benue State is insufficient to produce groundwater development maps similar to those for Oju and Obi. More detailed studies in the two local government areas chosen for further work are required, before maps and techniques can be developed for use by BERWASSA, Local Government staff and WaterAid.

Some geological information and field maps do exist at the Geological Survey of Nigeria, however, which could be combined to produce a more detailed and accurate map of the geology of Benue State. This would be an important resource for BERWASSA, WaterAid, the Geological Survey of Nigeria and DFID.

Specific recommendations:

1. Once the two LGAs have been chosen, geological field maps (scale 1:100 000); aeromagnetic maps (scale 1:100 000), topographic maps (1:50 000 and 1:100 000) and aerial photographs should be located for the area.
2. Interpretation of satellite images for the areas, and the data above can be combined to produce more detailed geological basemaps.
3. Some limited and targeted test drilling can be carried out to assess the groundwater potential of the rock units present in the LGAs and to adapt the techniques used in Oju and Obi to these new areas.
4. BERWASSA and the local government can be trained in the effective use of these techniques to best find and develop groundwater in the areas.
5. The hand drawn geological field maps for Benue State stored in the geological Survey offices in Makurdi, Enugu and Kaduna could be digitised, simplified and printed as one map for Benue State, at relatively low cost. This would enable this useful and important information to be used by all stakeholders, not just the Geological Survey.

4 Miscellaneous

Once in Nigeria, I was asked to comment on several issues not originally in the terms of reference. These are discussed in this section.

4.1 BERWASSA DRILLING IN 2000

Twenty-eight boreholes were drilled by BERWASSA in Oju during 2000 at the request of WASU. The records of these activities highlighted several concerns about these activities.

The boreholes were all drilled and tested during the rainy season. Because of the high permeability of the shallow laterite layer in Oju, yields of wells and boreholes are often artificially high in the rainy season. Therefore testing in the rainy season does not give an accurate picture of the sustainability of the sources all year round.

The boreholes were only grouted to a depth of one metre. This is not sufficient to stop boreholes becoming contaminated. The shallow laterite layer can persist to about 3 m depth. Since it is highly permeable, and latrines are constructed into the laterite, contamination can move rapidly sideways and into boreholes. Therefore, all boreholes should be grouted to below the laterite layer (about 3-4 m).

The depth of the boreholes ranged from 22-51m (average depth of 32.4 m). The recommendations given by BGS were for boreholes to be a minimum of 40 m. This allows several fracture zones to be penetrated, and thereby increasing the sustainability of the source.

The pumping tests were not undertaken properly, and no raw data was given in the reports. Therefore it is impossible to assess whether the yield of each borehole is sufficient for a handpump. I think I uncovered the main error in interpretation, and a brief reanalysis indicates that most boreholes are probably ok. A new form for the bailer test is attached in Appendix 3 to help stop these errors happening again.

Recommendations for this year's drilling contract:

- boreholes to be tested in the dry season;
- all boreholes to be drilled to a minimum of 40 m;
- all boreholes to be grouted to 4 m;
- bailer tests to be undertaken in all boreholes – if the there is any doubt about the result of the test, a short constant rate test should be carried out.

4.2 THE DRILLING RIG

The project drilling rig was designed as an exploration rig, and is not as powerful or robust as those used by BERWASSA. During his last visit to the project, Peter Ball assessed the condition of the rig and made a detailed list of problems and spares required. Before the rig is used again in earnest, Peter Ball's recommendations should be implimented in full, to allow the continued and safe running of the rig.

If the drilling rig is to be leased to a third party, the liabilities must be clearly stated, and the rig in such a condition that no party is taking on undue risk.

An experienced driller must be used. Sunday from Jos, was trained by Peter Ball in the use of the rig, both for production boreholes and exploration boreholes. If another party is chosen to operate the rig, suitable training by someone like Peter Ball should be arranged.

It would be prudent to keep the rig in a condition, where exploration drilling can still be undertaken for any new difficult areas that WaterAid or DFID decide to work in.

It is interesting to note that currently BERWASSA are offering to drill at a fraction of cost (£1000 per borehole compared to true cost of £6000). Therefore the market for a private drilling contractor may be limited.

4.3 DISSEMINATION OF REPORTS

There still appear to be stakeholders who have not received copies of BGS reports. There was some confusion last year during the change of WaterAid country representative. The main report (WC/99/32) contains much of the information about groundwater occurrence in Oju and Obi and should be widely disseminated. In particular, Oju and Obi WASU, and BERWASSA should have received several copies. A copy of the report was given to Nathan Ichor (Ministry of Water Resources) and two copies to the Geological Survey in Makurdi. A further 20 copies will be sent to Makurdi for dissemination. The following should be sent copies:

- Dr Uma, Dept of Geological Science, University of Nigeria, Nsukka
- Prof Okogbe, Dept of Geological Science, University of Nigeria, Nsukka
- Chief Librarian, Geological Survey of Nigeria, Kaduna

In addition, the WASU have a copy of the relevant data reports for their LGA. Two more sets of data reports will be sent out, to be given to BERWASSA and one to the Geological Survey at Makurdi.

The short report (WC/00/07) gives a summary of the BGS findings and also discusses the rationale for the investigations and how they linked with the rest of the project. This forms a useful summary of the BGS work and can be widely disseminated.

4.4 VOLUME OF A HEMISPHERICAL TANK

WaterAid have constructed hemispherical rainwater tanks and would like to know the volume of water they contain. When the tank is full this is trivial, but becomes more complicated as the water-level falls. However, a suitable formula can be obtained using simple calculus.

Volume of a hemisphere with radius, R:

$$\tfrac{2}{3}\pi R^3$$

If the water level falls by *dh* then the volume of water left is given by:

$$\tfrac{2}{3}\pi R^3 \quad - \quad \pi r^2 \, dh$$

where *r* is the horizontal distance from the centre to the side of the tank. Integrating over the depth of the tank and substituting for r by Pythagorus theorem gives:

$$\tfrac{2}{3}\pi R^3 \quad - \quad \pi (R^2 - h^2)\, dh$$

Integrating gives the volume of water in the tank if the water level falls by h:

$$\boxed{V = \pi R^2 (\tfrac{2}{3}R - h) \quad + \quad \frac{\pi}{3} h^3}$$

References

The references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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Appendix 1   Handouts from the workshop

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Magnetic profiling with the GSM-19

General

The GSM-19 is a portable magnetometer. It measures changes in the Earth's magnetic field to a high degree of accuracy. It is the best method for identifying magnetic rocks such as dolerite. However the magnetometer needs to be treated gently and readings taken carefully. Interpretation of the results can also be difficult. This sheet gives a few points on how best to use and care for the instrument.

Setting up the instrument

IMPORTANT

If the GSM-19 is not being used for a few days always 'shelf' by going to the info menu (letter **C**) then pressing 'sh' (numbers **8** and **4** at the same time) and then **OF**.

It should also be recharged (along with the spare battery) every month.

1. Do not wear significant metal. Make sure you have no keys or knives in your pockets and are not wearing a belt or watch. Write down readings with a pencil if possible or a pen with little metal (like a biro).
2. Screw the staff and sensor together. Strap on the console and attach the sensor cable. Move away at least 40 m from any metal objects (such as landrovers or metal roofs).
3. Switch on the magnetometer by pressing 'power' (letter **B**). To survey press **A**. At the next screen press **A** again. Most of the other options in the GSM-19 are about storing readings and downloading them to a computer and therefore can be ignored.

You are now ready to take a reading. (To switch off the GSM-19 press **O** and **F** at the same time).

Taking a reading

Hold the staff vertically at arms length. Rotate the sensor so that it is pointing north/south. Press any button on the console apart from **A** or **1**. After a few seconds the reading will appear (see Figure 1). The first number is the strength of the field, given in nanoTesla (nT). The second number is the change in magnetic field from the previous reading. Always take 3 readings at a site. They should not vary by more than 0.5 nT (check this by using the second number). If they do, it may be that the sensor is not pointing north/south, that metal is very close or, more rarely, that the atmospheric magnetic field is varying (see section on **Noise**). The third number is a measure of the strength of the signal and should always read 99. If it is less then it means the sensor is not pointing north/south. In a notebook, write down the station number, distance, reading, and a comment (such as anthill left etc). See section on **Keeping a notebook**).

33,067.32 nT   **0.12nT**   **99**

A= menu, 1 = multirecord
000223230 readings left

Figure 1 The display of the magnetometer.

Move 10 metres to the next station and repeat the process. If the reading is more than about 10 nT different from the previous station decrease the station frequency to 5 m. (Only do this if your are confident about the distances and can avoid getting in a muddle). Always record the time you take for any stops you make (see section on **Noise**).

Keeping a notebook

At the start of each survey write the name of the community, the survey a number, date, time and the GPS. Also give a description of the start of the survey so you (or somebody else) can easily find it again and record the bearing of the survey. Also record the name of those carrying out the survey. If you are following an EM34 survey, then write down the number of the EM34 survey.

Divide your notebook into 4 columns: station (S); distance (D); reading (R) and comments (C). The comments column should contain sufficient information that you can easily locate any anomaly onto the ground. The presence of any metal should be carefully recorded. A metal roof 50 m away can still affect the readings.

Noise

Large variations in magnetic field are given by metal objects such as zinc roofs, bicycles, cars and metal basins. Stop taking readings if a bicycle, vehicle or basin passes you. Record any objects that can't be moved, such as metal roofs within villages. These will distort the readings, even if 40 m away. Therefore magnetics is always best carried out in conjunction with another technique, such as EM34. The EM34 is much less sensitive to metal than magnetics.

Everyday, the earth's magnetic field varies due to the sun. In Nigeria, the field gradually increases by about 100 nT by midday and then starts to decrease. This gradual change generally does not affect the ability to spot largevariations due to magnetic rocks. However, very occasionally a magnetic storm happens (although there is no visible sign in the weather). This is easily identified. If the magnetometer readings change significantly at the same location, with no sign of any cause, then it is likely to be a magnetic storm. The only thing to do is to go home stop surveys for a couple of days.

Interpretation

The data should be plotted on graph paper. Choose appropriate scales, possibly one division to 5 nT. Don't worry about accommodating large anomalies due to metal – you are looking for small anomalies 5 – 30 nT that might be due to dolerite. Your main task is to distinguish anomalies due to metal from those that are due to dolerite. Therefore mark on the graph any place that there was metal. Using EM34 in conjunction with magnetics is good for extrapolating results from non-noisy places into villages where there is metal. Often low conductivity is associated with dolerite. Report WC/99/32 gives more information on interpretation in Obi. Other signs of dolerite are: hard black rock, sands for making pots, or thick black soils.

Some theory

Magnetic methods in geophysical exploration involve measuring the intensity of the earth's magnetic field. Variations in the magnetic field are complex and often highly localised, due to differences in the magnetic properties of rocks near to the surface. This makes the technique useful and sensitive to identifying certain types of rocks, but can also make the data quite difficult to analyse.

The earth's main magnetic field originates from electrical currents in the liquid outer core. This magnetic field can be approximated by a dipole (bar magnet) located at the earth's centre and inclined at 11° to the spin axis. At Oju, the dip of the magnetic field is approximately -10° and the total field intensity about 35 000 nT.

Magnetic materials can cause localised anomalies in the earth's magnetic field. There are many different forms of magnetisation but generally the most significant for geophysical surveys are ferrimagnetic and ferromagnetic. Ferromagnetic materials are strongly magnetic. Although they do not occur naturally, such materials are in common usage (e.g. steel in bridges, vehicles etc.) and can give large anomalies on surveys. Some rock minerals are also magnetic (known as ferrimagnetic), e.g. magnetite, maghaemite and pyrrhotite. When these are contained in rocks in sufficient quantities, they can cause measurable anomalies in the earth's magnetic field.

How strong a magnetic anomaly will be produced from a substance is determined by the magnetic susceptibility of that material. Susceptibility is determined solely by the amount of ferrimagnetic minerals present in the rock. There is a wide variation, sometimes of several orders of magnitude, even for the same type of rock. In general sedimentary rocks have the lowest magnetic susceptibility; and basic igneous rocks the highest. Therefore, magnetic surveys are well suited for locating the dolerite intrusions within clays and shales, as is the case in Oju and Obi.

Extra tips for carrying out a magnetic survey

1. The earth's magnetic field varies naturally by about 100 nT per day. This usually causes a slow rise in the morning and a fall in the afternoon. If a survey is stopped for a few minutes, the readings will appear to jump. Therefore always marke in your notebook when you take a break.
2. If readings vary by more than 5 nT within 10 metres, then this is due to magnetic material - either dolerite or a metal roof etc. Therefore carefully look around to rule out any metal at the surface, before concluding that it is dolerite.
3. Always carry out a magnetic survey in conjunction with an EM34 survey, since EM34 surveys are not affected to the same extent by metal roofs. Often dolerite is marked by a reduced electrical conductivity as well as magnetic anomalies. Carrying out the surveys at the same time makes it easier to the tie the two together. (Keep the magnetometer about 30-40 m behind the EM34 to avoid the instruments affecting each other).
4. In the Awgu Shales, a resistivity survey can also help to confirm the existence of dolerite (see the BGS final report WC/99/32 for details). EM34 with 40 m coil separation can also help (see Itogo data report).
5. Very occasionally, the earth's magnetic field varies very rapidly causing unpredictable readings. This is called a magnetic storm. They are easily detectable. Just keep the magnetometer in one place (make sure the sensor is north-south), Take several readings in succession - you will find large variations which will swamp the signal for dolerite. If you confirm it is a magnetic storm, go home.

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Magnetic data form

Village name:

Village ID:

GPS start:

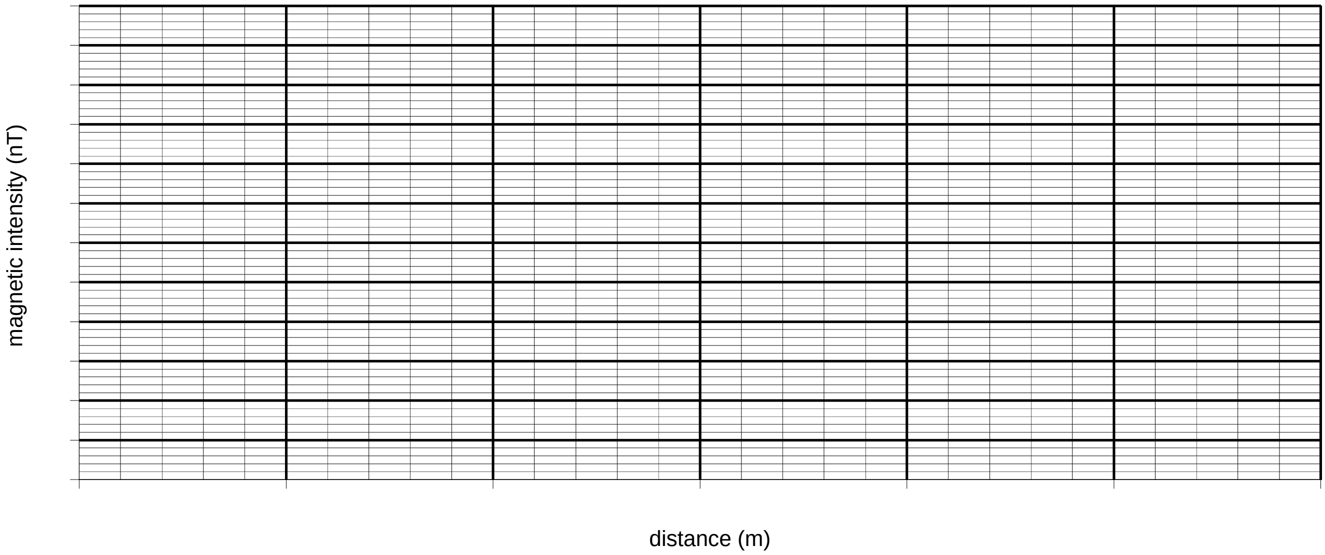
Date:

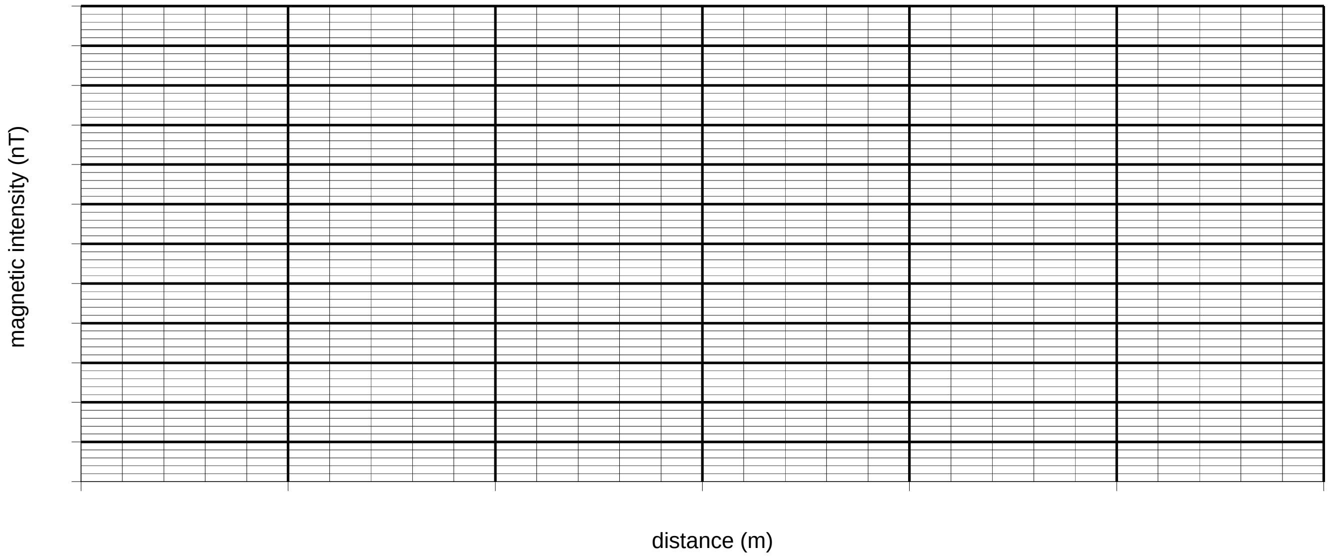
Suveys:

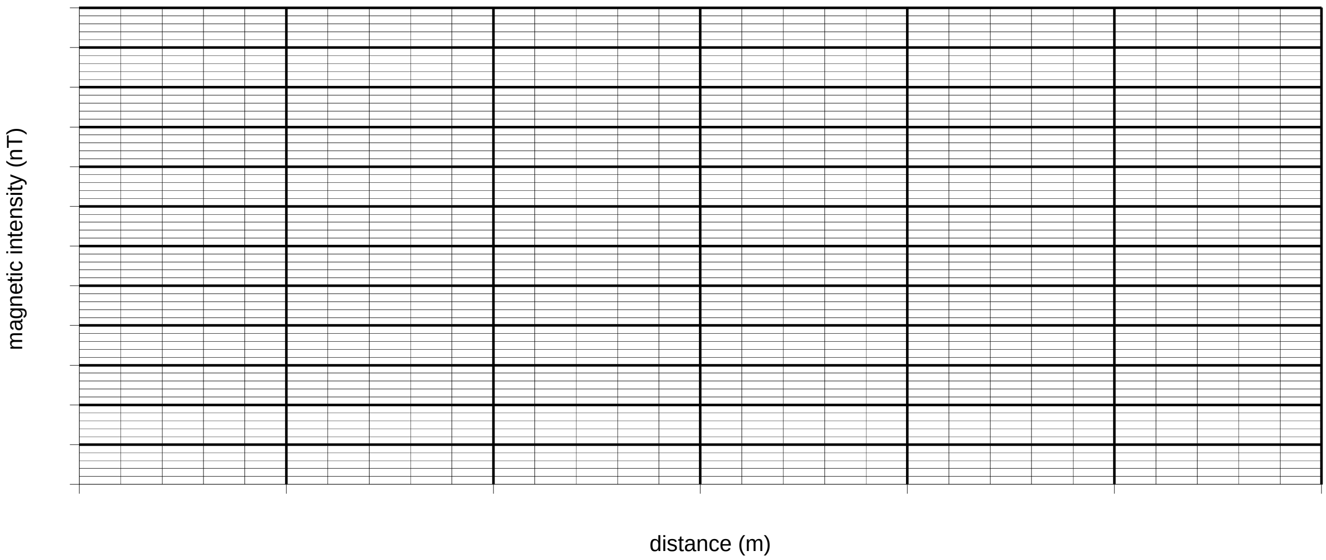
name of operator:

station	distance	reading	comments

station	distance	reading	comments


magnetic intensity (nT)
distance (m)


magnetic intensity (nT)
distance (m)


magnetic intensity (nT)
distance (m)

Measuring electrical conductivity using the EM34

General

The EM34 estimates the electrical conductivity of the ground. It is a simple method which allows rapid surveying to be done. It measures the same physical property as resistivity. Although the method is straightforward, there are a number of important factors that must be taken into consideration when using it. These are discussed here.

Setting up

1. Choose the appropriate cable for the separation you want to use. For a general survey, 20 m separation is best. A coil separation of 40 m is useful for looking deeper into the ground for dolerite or sandstone at depth. Connect up the coils and transmitter and receiver consoles as described in the manual.
2. Carry out the daily checks – check that both the transmitter and receiver batteries are ok. The receiver batteries should read more than 4.5 volts in the battery + and – position. The nulling of the instrument should also be checked (see overleaf).
3. Every few weeks carry out the full set of checks detailed overleaf.

The operation of the instrument

On both the receiver and transmitter, the separation should be set to the appropriate distance (20 m etc). Start with the sensitivity switch at 100 mmhos/m. If the readings become less than 10 then change to the 10 setting. If they become more than 100 then change to the 1000 setting. A meter on the receiver consul shows the error in the intercoil spacing; the receiver coil can then be moved until the error is negligible (and the needle is in the middle). The terrain conductivity can then be read directly from the receiver consul in mmhos/m.

The coils can be orientated either vertically or horizontally. Different orientation changes the direction of the inducing field and what the instrument is sensitive to. **For vertical coils the reading gives a good estimate of the electrical conductivity** (in mmhos/m). The maximum contribution is from the ground surface, and the response reduces with depth; the average depth of penetration is about 0.5 - 0.7 x the coil spacing. Horizontal coils do not give a good estimate of electrical conductivity beyond about 30 mmhos/m. In fact the highest reading the horizontal coils can give is 65 mmhos/m! However, w**hen the instrument is used with horizontal coils it is sensitive to vertical conductors**, such as dolerite dykes or vertical fractures - often good targets for groundwater. When passing over a vertical anomaly a *negative* response is given. Sometimes this can actually give readings of less than zero, which at first can be rather confusing!

When the coils are horizontal, the readings are very sensitive to misalignment of the coils. With vertical coils the instrument is not sensitive to misalignment of the coils, but is rather more sensitive differences in intercoil spacings.

Tips for undertaking EM34 survey

1. Make sure that the orange stickers are pointing in the same direction.
2. Make comments in the notebook, so that you can easily relate the survey to the ground. Use the SDVHC system (station, distance, vertical coil, horizontal coil, comments). Always be certain that the distance and comments marked in the notebook are from the receiver. It is usually easier if the receiver is always trailing.

IMPORTANT

Never turn the receiver and transmitter on when they are near each other – this will damage the electronics.

Never try to recharge normal batteries.

3. Metal objects close by, such as cars and zinc roofs will give slightly anomalous readings when the coils are horizontal (but is not as sensitive as the magnetics).
4. If the coils are not exactly horizontal, they will give erroneous readings. If you can't get the coils horizontal, then mark this in your notebook and treat the data with caution.
5. When trying to find dolerite or Agbani Sandstone, repeat surveys with 40 m coil spacing.
6. Interpreting the data depends very much on the geological conditions. Use the information in the BGS final report WC/99/32 and accompanying data reports to help interpret the data.

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EM34-3 & EM34-3XL OPERATING INSTRUCTIONS
(For Model with Digital Readout)

The following is the set-up and operating procedure for the EM34-3 Terrain Conductivity Meter.

1. INITIAL SET-UP

At the beginning of the survey select an area free of "cultural interference" and man-made conductors such as buried pipes, buildings, power lines, steel reinforced concrete, etc.

1.1 Having determined the coil separation to be used for the survey, lay the instrument out on the ground accordingly. Connect the reference cable (10, 20 or 40 meters) - one end to the 8-pin connector on the transmitter (Tx) coil and the other end to the **"REFERENCE"** connector on the receiver console. See attached sketch (page 17) for proper use of thimbles and snaps on the cable.

1.2 Connect the transmitter console to the transmitter coil using the appropriate short cable.

1.3 Put the **"LEVEL"** switch on the transmitter console to the **"NORMAL"** position. (See Section 6).

1.4 Set the receiver and transmitter coils to the selected coil separation with red circles on the coils both facing in the same direction.

1.5 Set transmitter **"SEPARATION"** switch to selected value <u>and turn on transmitter</u> (**"POWER/ON"** switch to **"ON"** position).

1.6 Check to see that Battery Monitor Meter indicator is in the black area of the scale. If not, batteries are low or are not making proper contact to the battery clips. During the transmitter battery check transmitter coil has to be far from metal objects including concrete floor.

1.7 Check condition of receiver digital meter battery by rotating receiver **"SEPARATION"** switch to **"BATT-"** position with **"POWER/ON"** switch in **"POWER"** (off) position. If the separation meter indicator is below the minimum battery level line, see section 5.2

1.8 Set receiver **"SEPARATION"** switch to selected value.

2. ELECTRONIC NULLING

To remove any offsets in the output (DC) circuitry.

2.1 Leave equipment set up and transmitter on as in Section 1.

2.2 Prior to turning receiver on, insure that **"SEPARATION"** meter reads zero. If it does not, adjust mechanical meter zero control located on the meter.

2.3 Turn on receiver (**"POWER/ON"** switch to **"ON"** position).

2.4 With receiver coil disconnected depress **"NULL"** push button switch. Both meter readings should go to zero.

2.5 If either meter is not at zero reading, release the lock on the appropriate **"NULL"** control potentiometer, by turning the lock nut on the **"NULL"** control anti-clockwise for one turn. Keeping the **"NULL"** switch depressed adjust the **"NULL"** control to zero the meter.

2.6 Lock the **"NULL"** control.

2.7 Connect the receiver coil to the receiver console **"COIL"** connector via the appropriate short cable.

3. RECEIVER COMPENSATION AND GAIN CHECK

3.1 Maintaining the receiver and transmitter coils in the same plane adjust the coil separation to obtain zero reading (centre of green area) on the **"SEPARATION"** meter. (Insure that red circles on coils face in the same direction). The coil separation should now be at the selected value.

3.2 With the **"SENSITIVITY RANGE"** switch set to the 1000 mS/m position move the receiver coil toward the transmitter until the **"SEPARATION"** meter deflects to full scale mark.

3.3 Measure the distance that the receiver coil has moved. This distance should be 24.2% of intercoil spacing.

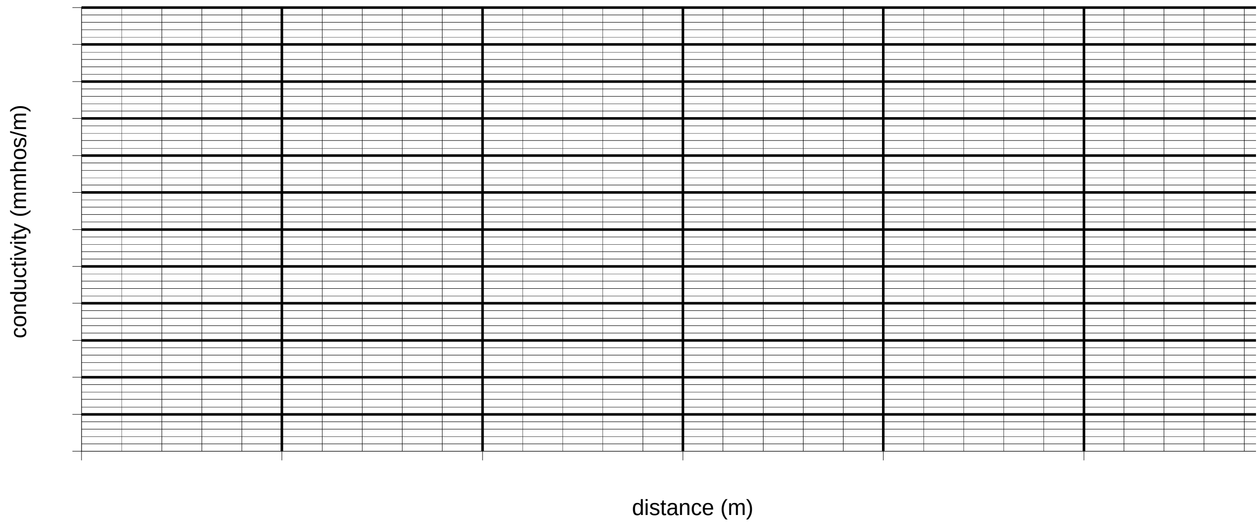
EM34 data form

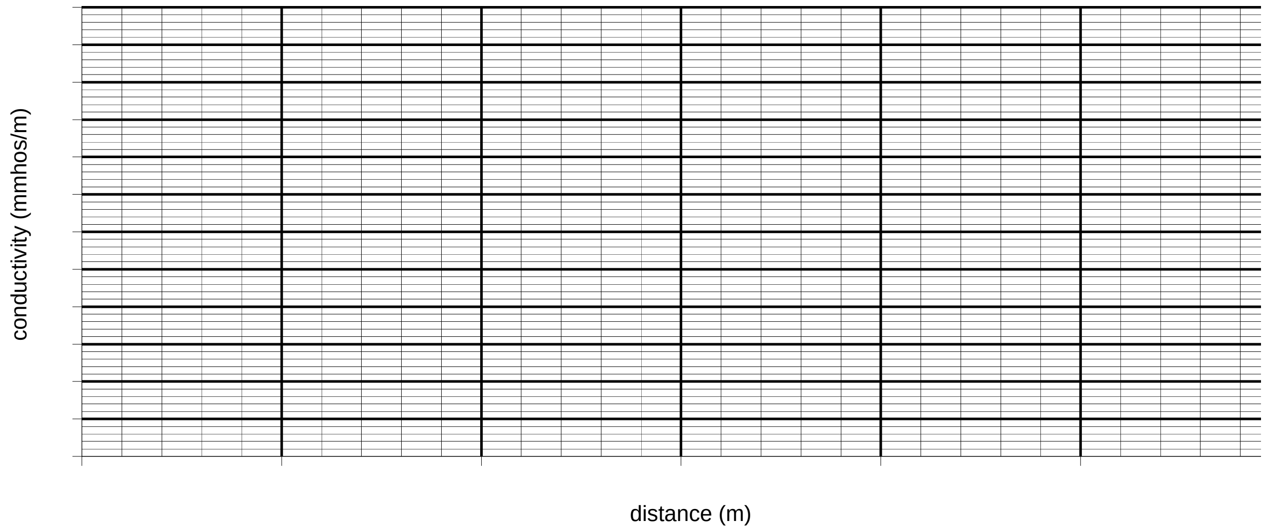
Village name: **Village ID:**

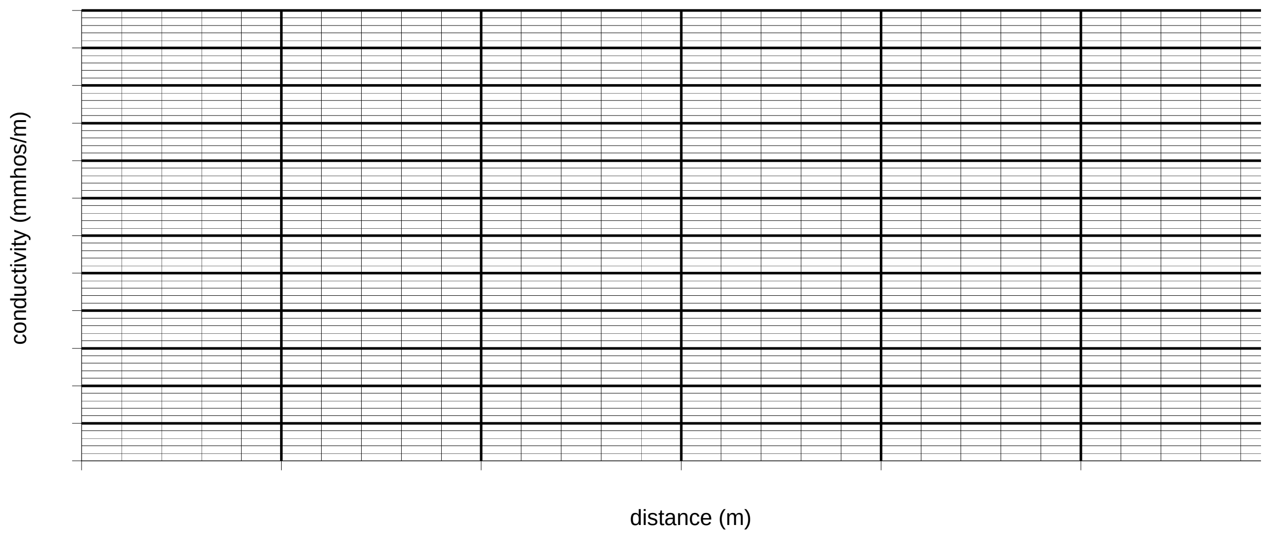
GPS start: **Date:**

Suveys: **position reciever: front / back**

station	distance receiver	distance midpoint	vertical coil	horizontal coil	comments


conductivity (mmhos/m)
distance (m)


conductivity (mmhos/m)
distance (m)


conductivity (mmhos/m)
distance (m)

Resistivity Data

General

Resistivity is a useful technique for looking at the variation of resistivity with depth. It has been widely applied in Africa, particularly in basement areas. There are two main survey techniques: the Schlumberger and Wenner arrays. A modification of the Wenner, called the Offset Wenner, is particularly useful. However, **in Oju and Obi, the resistivity survey is not as useful as an EM34 survey.** Resurveying with EM34 at 40 m spacings gives nearly as much information as a simple resistivity survey and is much easier to carry out. The purpose of this sheet is not to describe in detail how to carry out resistivity surveys, but to help interpret them if someone else has done them.

Theory

Ground resistivity is measured by passing an electrical current through the ground and measuring the potential difference between two points. Ohms law is then used to calculate the resistance. The resistance is then multiplied by a geometric factor (normally called a **K** factor) to calculate resistivity.

To carry out a depth sounding (VES), electrodes are expanded about a single point. When the electrode spacing is far apart, the electric currents pass deeper into the ground and are therefore measuring the resistance deeper into the ground. A depth sounding tells you information only about one point (the midpoint of the survey). The technique assumes that there are no large lateral variations in the rock type.

Good points and bad points

Resistivity good points	Resistivity bad points
It can identify layers of different resistivity (in other words changes with depth). It can penetrate deep into the ground. It is not affected by tin roofs etc.	Very susceptible to bad electrode connections. Difficult to interpret Laborious and slow. It only takes a reading at one point

Some tips for carrying out a survey

1. Choose an area for the inner electrodes that looks fairly homogeneous.

2. Always make sure the battery is fully charged and carry a spare.

3. Make sure the electrodes are hammered well into the ground and water them. At large electrode spacings a salt solution can be used.

4. For small electrode spacings a small current should be used (< 5 mA). Check that the resistivity is roughly the same at several current settings. If the current is too low, readings will vary.

5. At larger electrode spacings, higher currents are required since they have farther to travel.

6. Plotting the data as you go along allows you to see if any readings are anomalous. A resistivity curve should always look quite smooth.

Interpreting the data

Resistivity data is interpreted by plotting the apparent resistivity against electrode spacing on a log-log scale. This should produce a smooth curve. For a Schlumberger array, the curve will be in several segments. These can be combined into one smooth curve, by using the crossover points. Starting with the right-hand segment, move it down to match the cross over points of the segment to the left. Repeat the process (always moving the right-hand segment to meet the left-hand one) until you have one smooth curve (‘Field Geophysics’ page 89).

IMPORTANT

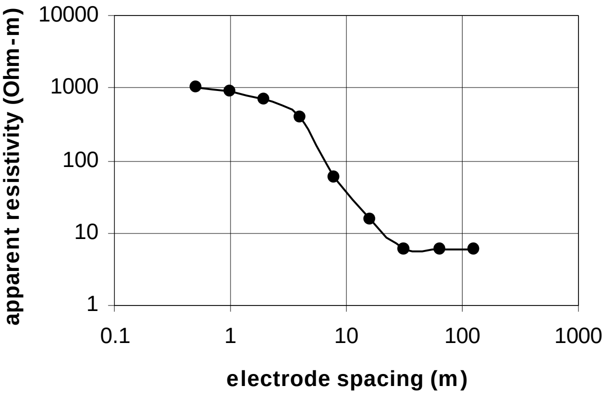
Resistivity is the inverse of conductivity. Resistivity in Ohm-m is related to conductivity (in mmhos/m) by the formulas:

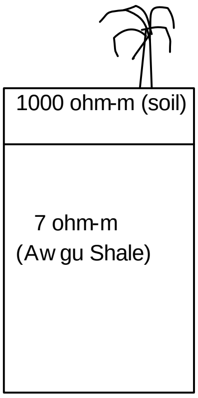
Resistivity = 1000 / (conductivity)

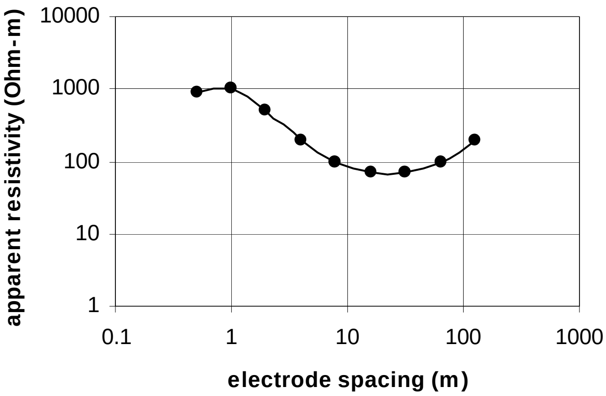
Conductivity = 1000 / (resistivity)

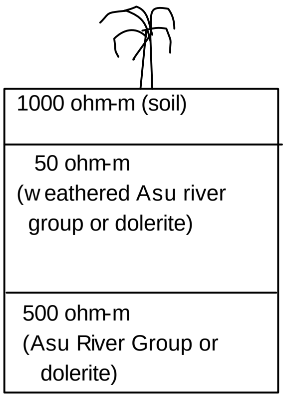
Readings at large electrode spacings refer to the resistivity at depth. Refer to the BGS final report and the individual data reports for the interpretation of resistivity curves for Oju and Obi. Resistivity curves produced from Schlumberger and Offset Wenner arrays at the same site will be roughly similar.

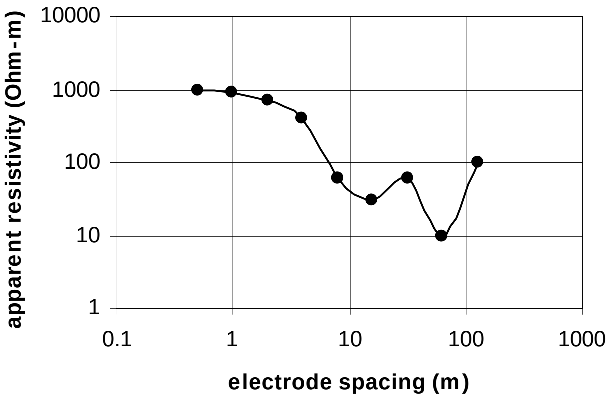
Some resistivity curves with example interpretations.











Curve is not smooth. Data beyond 10 m electrode spacing are subject to large errors probably because of bad electrode contact. Do not attempt to analyse. Repeat with EM34 with 40-m coil separations.

For these examples, EM34 with 40-m coil spacings would have given the same information. For example Awgu shale at depth will show high conductivity with 40-m separations (e.g 100 mmhos/m). Dolerite at depth will give low conductivity with 40-m coil separations (e.g. 30 mmhos/m). See BGS final report and data reports for Ugbodum and Itogo for further examples.

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Offset Wenner

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Village Name:

Survey Number……………

GPS:

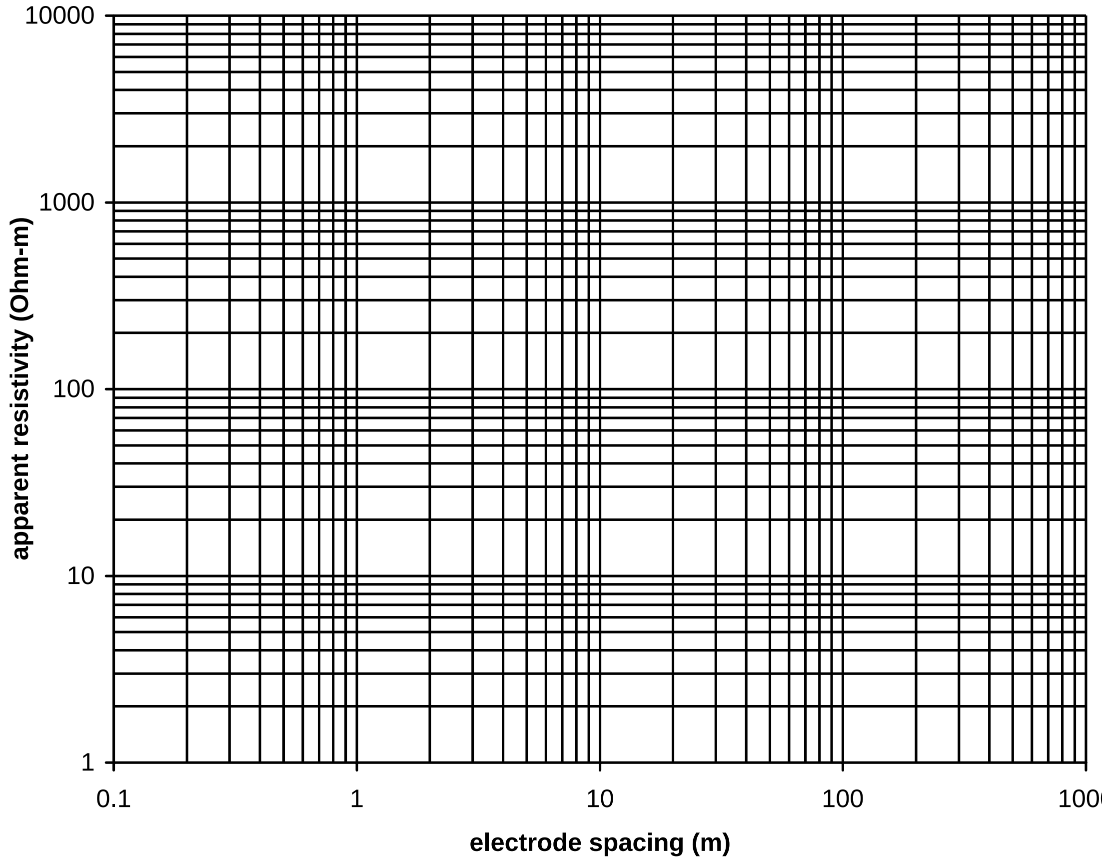
Date:

Location:

Name of surveyers:

electrode spacing (m)	terrameter measurements (Ohms) A	B	C	D1	D2	resistance (D1+D2)/2	K	apparent resistivity
0.5							3.14	
1							6.28	
2							12.56	
4							25.12	
8							50.24	
16							100.48	
32							200.96	
64							401.92	
128							803.84	

To check electrodes and cables OK then A = B + C (within 5%)



Schlumberger

Village Name:

GPS:

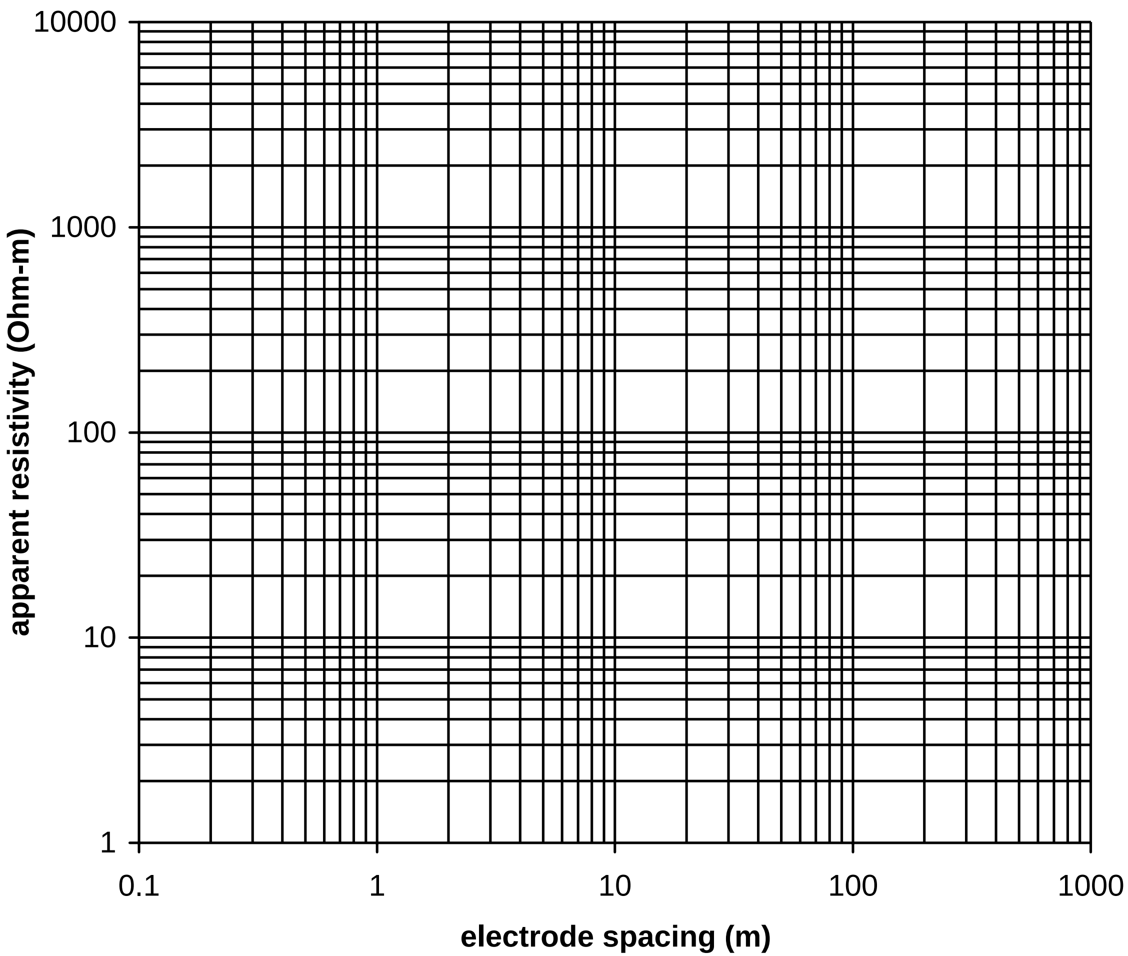
Location:

Survey Number……………

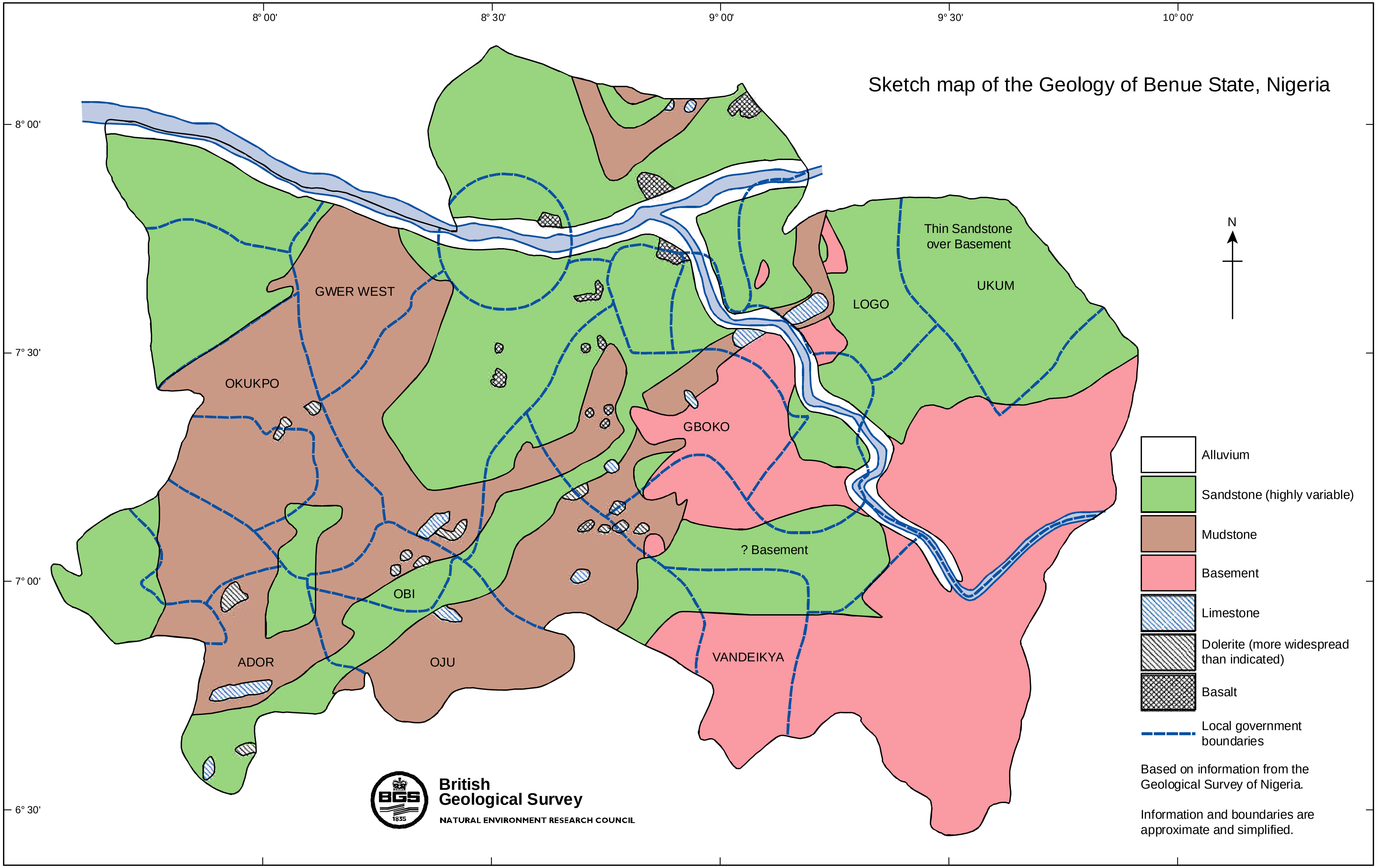
Date:

Name of surveyers:

Outer electrode half spacing (m)	Inner electrode half spacing (m)	resistance Ohms	K*	apparent resistivity
1	0.2		7.54	
1.5	0.2		17.3	
2	0.2		31	
3	0.2		70	
5	0.2		196	
7	0.2		384	
10	0.2		784	
7	1.5		49	
10	1.5		102	
15	1.5		233	
20	1.5		416	
30	1.5		940	
20	5		118	
30	5		275	
50	5		777	
70	5		1530	
100	5		3130	
70	10		754	
100	10		1554	
150	10		3520	
200	10		6260	



Appendix 2 Geological map of Benue State


Sketch map of the Geology of Benue State, Nigeria
8° 00'
8° 30'
9° 00'
9° 30'
10° 00'
8° 00'
7° 30'
7° 00'
6° 30'
N
Thin Sandstone over Basement
UKUM
LOGO
GWER WEST
OKUKPO
GBOKO
? Basement
OBI
ADOR
OJU
VANDEIKYA
Alluvium
Sandstone (highly variable)
Mudstone
Basement
Limestone
Dolerite (more widespread than indicated)
Basalt
Local government boundaries
Based on information from the Geological Survey of Nigeria.
Information and boundaries are approximate and simplified.
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Appendix 3 Bailer test form

10 minute bailer test datasheet

Note: **always measure all waterlevels (including rest-water-level) from the same point**

Community:

Borehole Number:

Screen diameter:

GPS:

Drilled diameter:

rest water level:

Gravel Pack Yes / No

Number of bails:

time (mins):
(should be about 10 minutes)

time since pumping stopped	water-level	time since pumping stopped	water-level	time since pumping stopped	water-level	time since pumping stopped	water-level

Interpreting the 10 minute bailer test

To interpret the bailer test, follow the steps below

Pumping rate in m^3/d = $\frac{\text{volume of bailer (in } m^3\text{) x number of bails}}{\text{time of pumping in days}}$ [ ]

Maximum drawdown

A = the earliest reading of water level after pumping stops [ ]

B = the rest water level [ ]

Maximum drawdown = A - B [ ]

Time for 50% recovery (t_{50})

divide the maximum drawdown by 2 [ ]

add the rest water level [ ]

t_{50} is the time at which the water level recovers to the level above [ ]
(from data overleaf)

Time for 75% recovery (t_{75})

divide the maximum drawdown by 4 [ ]

add the rest water level [ ]

t_{75} is the time at which the water level recovers to the level above [ ]
(from data overleaf)

Estimate the effective diameter of the borehole.
If it is open hole then this will be the drilled diameter.

If the borehole is screened and gravel packed then the effective diameter will be somewhere between the screen diameter and the drilled diameter. (Generally closer to the screen diameter). [ ]

Find the pumping rate and the diameter of the borehole in the table below.

The maximum drawdown, t_{50} and t_{75} for the test must all be **less** than that shown in the table.
If they are all much greater, then the borehole will have problems sustaining a handpump
If they are all much less than the table, then the borehole will sustain a handpump
If some are greater, and some are less then a proper pumping test must be carried out.

		10 m^3/d	15 m^3/d	20 m^3/d	25m^3/d	30 m^3/d
4 inch	Max drawdown	3.5	5.3	7.1	8.8	10.6
	t50 (mins)	6	6	6	6	6
	t75 (mins)	14	14	14	14	14
5 inch	Max drawdown	2.9	4.3	5.7	7.1	8.5
	t50 (mins)	9	9	9	9	9
	t75 (mins)	21	21	21	21	21
6 inch	Max drawdown	2.3	3.4	4.6	5.7	6.9
	t50 (mins)	12	12	12	12	12
	t75 (mins)	28	28	28	28	28
8 inch	Max drawdown	1.5	2.3	3.1	3.8	4.6
	t50 (mins)	19	19	19	19	19
	t75 (mins)	46	46	46	46	46