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The hydrogeology of the Oju/Obi area, eastern Nigeria: Ochingini area - data report

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The hydrogeology of the Oju/Obi area, Eastern Nigeria: Ochingini area data report

A M MacDonald and J Davies

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Water being collected during a pumping test on BGS12.

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PREFACE

Oju is a remote part of south-eastern Nigeria that suffers from severe water shortage during the annual dry season. From November to April, unprotected ponds, seepages and hollows are the primary source of domestic water. Unfortunately, these sources become less reliable towards the end of the dry season and many are contaminated. As a consequence, much of the population of Oju (300 000 approx.) is badly affected by a variety of water related illnesses, of which guinea worm and malaria are endemic; outbreaks of cholera, typhoid and dysentery are also common. In response, DFID have commissioned WaterAid to provide improved village level, year round water sources, primarily utilising the limited groundwater resources of the area.

Due to the complex hydrogeology, WaterAid have asked the British Geological Survey (BGS) to assist with the project. BGS are applying the results of TDR projects undertaken within other parts of the world to study these marginal groundwater resources.

The groundwater investigations by BGS started in September 1996. There are three main aims of the research: (1) to assess the potential of the Oju area for sustainable groundwater supplies; (2) to develop appropriate methods for siting wells or boreholes in the Oju environment; and (3) to recommend appropriate methods and designs for exploiting groundwater.

This report forms one of a series of data reports designed to complement the summary assessment of the hydrogeology of the Oju/Obi area and the Groundwater Development Map. The data presented were collected on five separate trips, August-September 1996, November-December 1996, February-March 1997, October-December 1997 and January-April 1998.

EXECUTIVE SUMMARY

The geological nature and groundwater development potential of the Upper Eze-Aku and Makurdi Sandstone Formations in eastern Obi were investigated along an east west traverse through Ochinginyi. The appropriateness of using EM34-3 surveys to locate and differentiate between sandstones and mudstones was assessed. Testing was carried out from December 1997 to March 1998. EM34-3 and magnetic profiles were carried out over an 8.2 km traverse. Nine boreholes were drilled to prove the bedrock and chip and core samples analysed and logged. Six boreholes (BGS4, BGS6, BGS7, BGS8, BGS10, BGS12) were completed with screen and casing. Test pumping and water quality analysis was carried out on these six boreholes. The following conclusions can be made from the test site.

- The Upper Eze-Aku comprises soft mudstones with several significant sandstone layers and thin limestones.
- The Makurdi sandstone comprises inter-bedded fine-medium grained sandstone and thin mudstones; the sandstones are commonly cross-bedded; load cast features are also present.
- The boundary between the Makurdi Sandstone and Eze-Aku is indistinct and is defined only by changing proportions of mudstone and sandstone.
- The rocks are highly weathered over the first 10-12 m. Weathering in the mudstone produces thick clay sequences, within the sandstone a thin clay layer is present and kaolinised and discoloured sandstone is present beneath the clay.
- EM34-3 could distinguish the sandstones from the mudstones-sandstones had conductivities of 10-20 mmhos/m, while mudstone was generally in excess of 30 mmhos/m.
- Sandstones generally contained sufficient groundwater for a hand dug well if dug to below 15 m.
- Mudstone, even where fractured (e.g. BGS5), contained no significant groundwater.
- Limestone layers were generally fractured and contained significant groundwater, however, they could not be located using any surface geophysics method.
- Resistivity soundings (VES) could be used to distinguish sandstone and mudstone by differences in the weathered zone however, this technique is best used to calibrate the EM34-3.
- Test pumping indicated boundary or de-watering affects in the sandstone boreholes – the long term sustainability of supplies from the sandstones or limestone has not been tested.

1. BACKGROUND INFORMATION

The geological nature and groundwater development potential of the Upper Eze-Aku and Makurdi Sandstone Formations in eastern Obi were investigated along an east-west traverse through Ochingini. The appropriateness of using EM34-3 surveys to locate and differentiate between sandstones and mudstones was assessed. A long, straight road passes through Ochingini which cuts across the outcrops of the Makurdi Sandstone and the Upper Eze-Aku Shale formations. The Ochingini village boundaries extend for several kilometres along this road, either side of the location of village centre as shown in Figure 1. The village centre is located on the main element of the Makurdi Sandstone; marked on the map as part of the Upper Eze-Aku Shale Formation. There are many shallow wells in the village, but most collapse due to a swelling clay layer. Figures 2 and 3 show the available map data for the area and also the location of the geophysics traverse line and the test boreholes. Table 1 shows the appropriate maps and aerial photographs for Ochingini.

The Upper Eze-Aku Formation is primarily composed of dark grey to black carbonaceous shaley mudstones with thin interbedded dark grey shelly limestones and thin fine to coarse grained sandstones. This formation overlies the Makurdi Sandstone which is composed of a sequence of fluviatile sandstone layers interbedded with shaley mudstones and thin shelly limestones. These sandstone layers thicken and coarsen upwards, forming a sandy fluviatile facies of deposition within the essentially pro-delta mudstone deposition facies of the Eze-Aku formation.

Along the traverse line there are marked topographic variations; villages or grass covered areas with well spaced trees are located upon several sandstone ridges, where as hollows occupied by dense vegetation or cultivated areas are underlain by shaley mudstones

Table 1. Available map information for the Ochingini traverse.

Data type	Source
Aerial Photographs	Sheet 270, run 13, 16-20
Topographic maps	Sheet 270, run 14, 186-190
Geology map	Sheet 289, run 1, 93-97
	1:50,000 Sheet 270SE Oturkpo SE
	Makurdi Area, Map No. 64, Scale 1:250,000

2. GEOPHYSICS

Various geophysics surveys were carried out at along the Ochingini traverse. The traverses were designed to cut across the Makurdi Sandstone and Upper Eze-Aku Formations (see Figure 2). Table 2 gives a summary of the various traverses and soundings. The data are presented in Appendix 1.

Large variations were observed in the EM34-3 data over the traverse (see Figure 4). Within Ochingini village and several of the higher ridges, conductivity values were low, indicating the presence of sandstone. At a few locations high values indicating the presence of mudstones were encountered, even though the soil was very sandy, suggesting that the sandy soil is not indicative of the underlying rock, but has been washed or blown there. To the south-east of the village, there are two noticeable highs of about 30-40 mmhos/m; these are located at about 900 m and

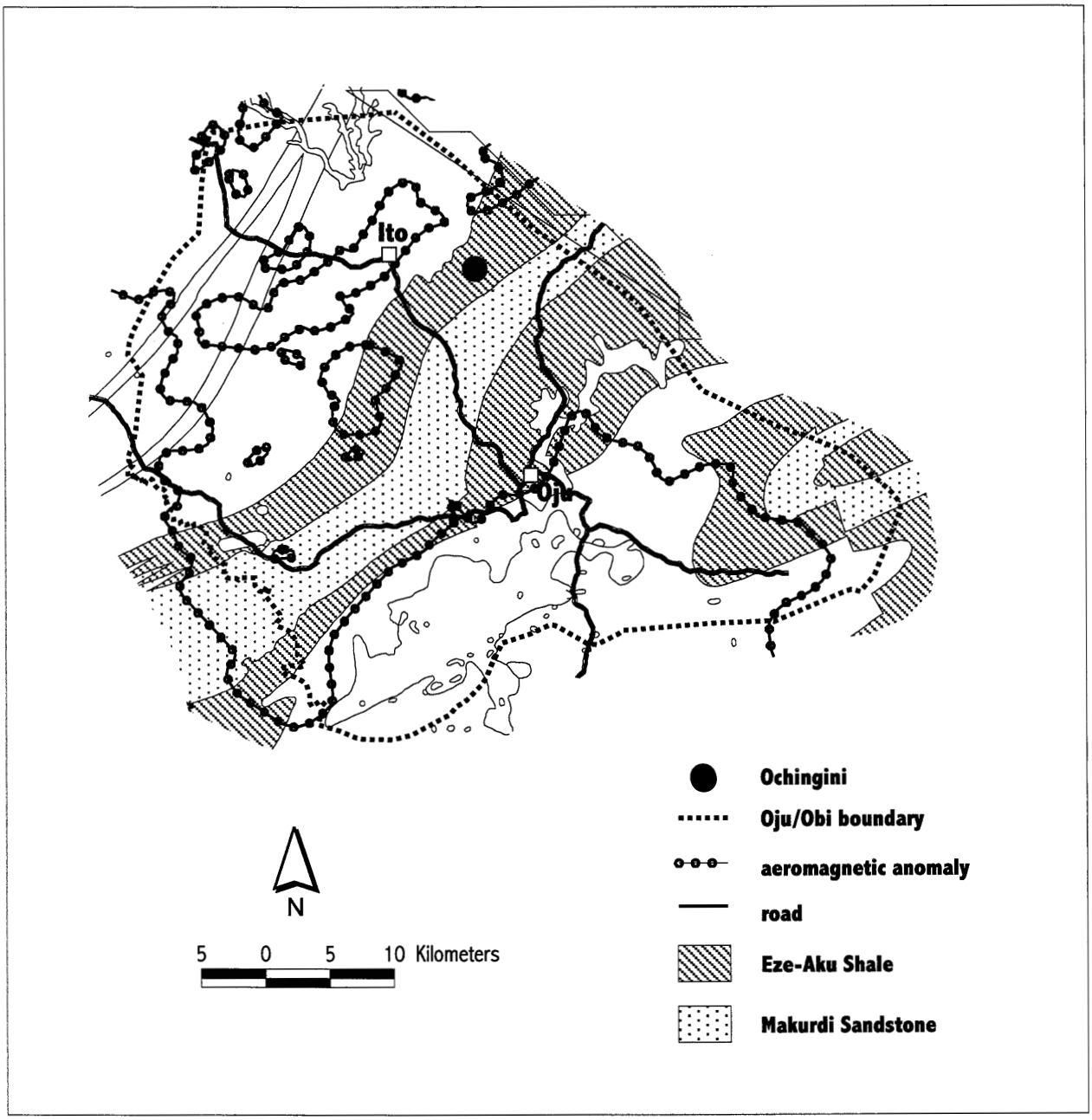


Figure 1. The location of Ochingini village and the outcrop of The Eze-Aku Shale and Makurdi Sandstone.

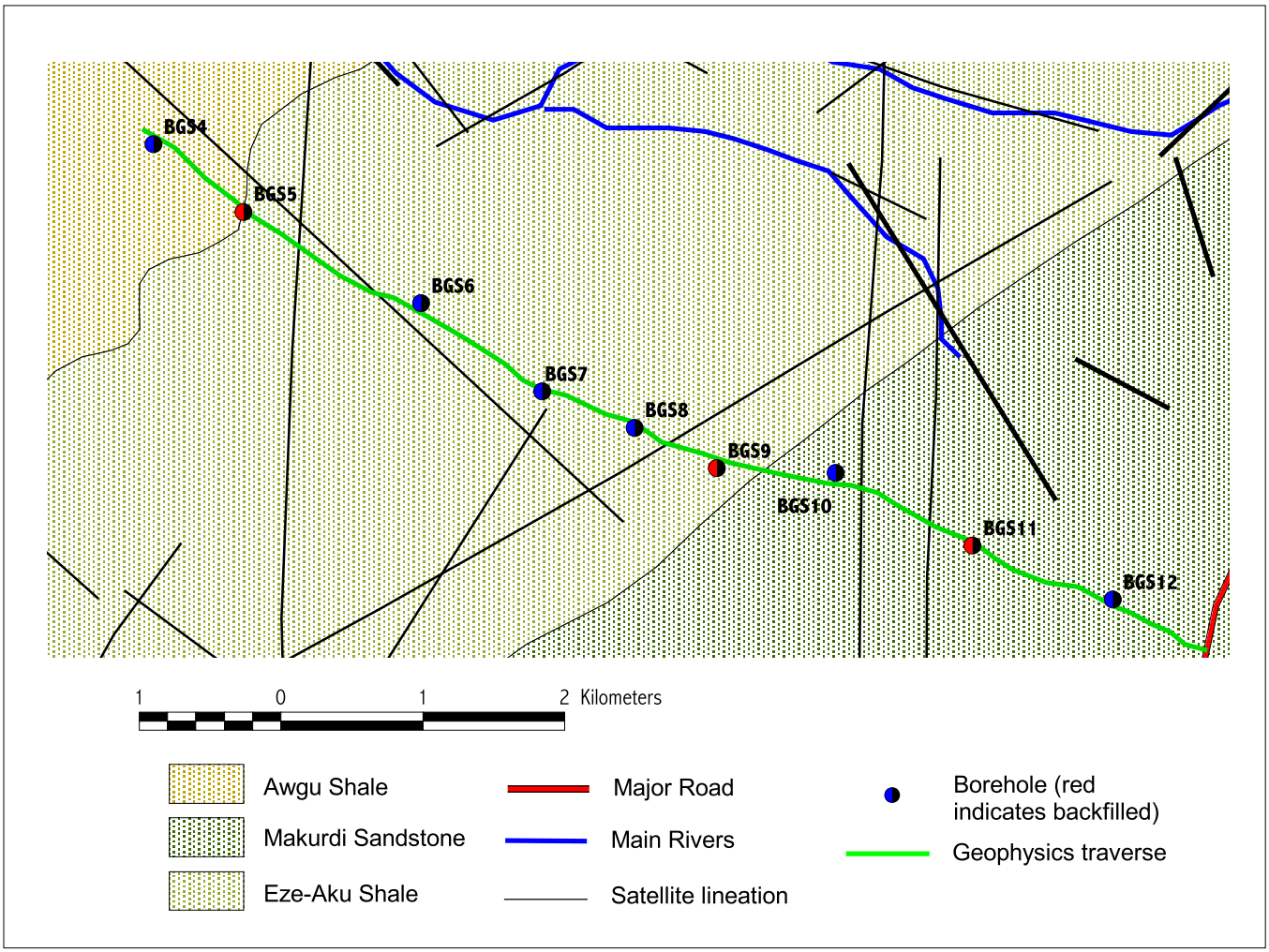


Figure 2. Available map information for Ochingini and location of boreholes and geophysical traverses.

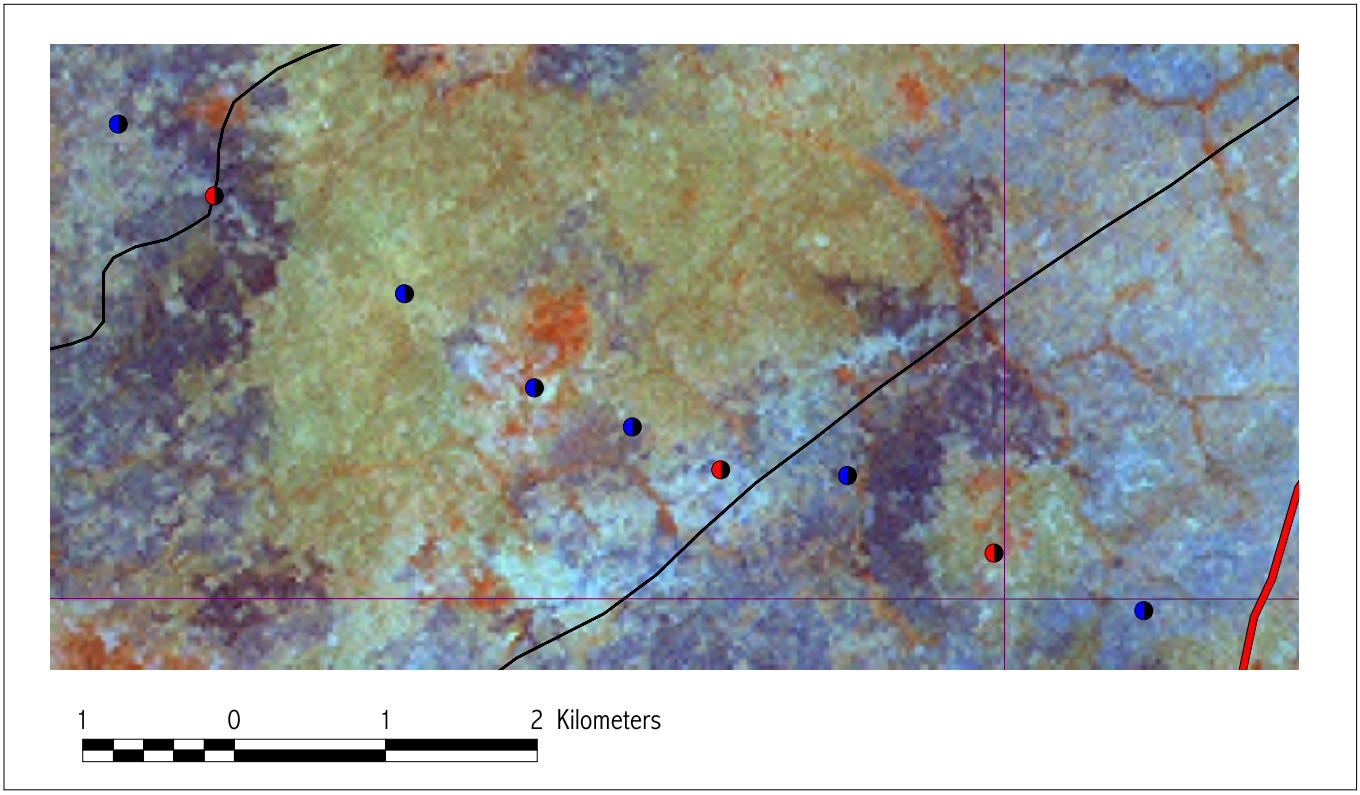


Figure 3. Satellite image for Ochingini.

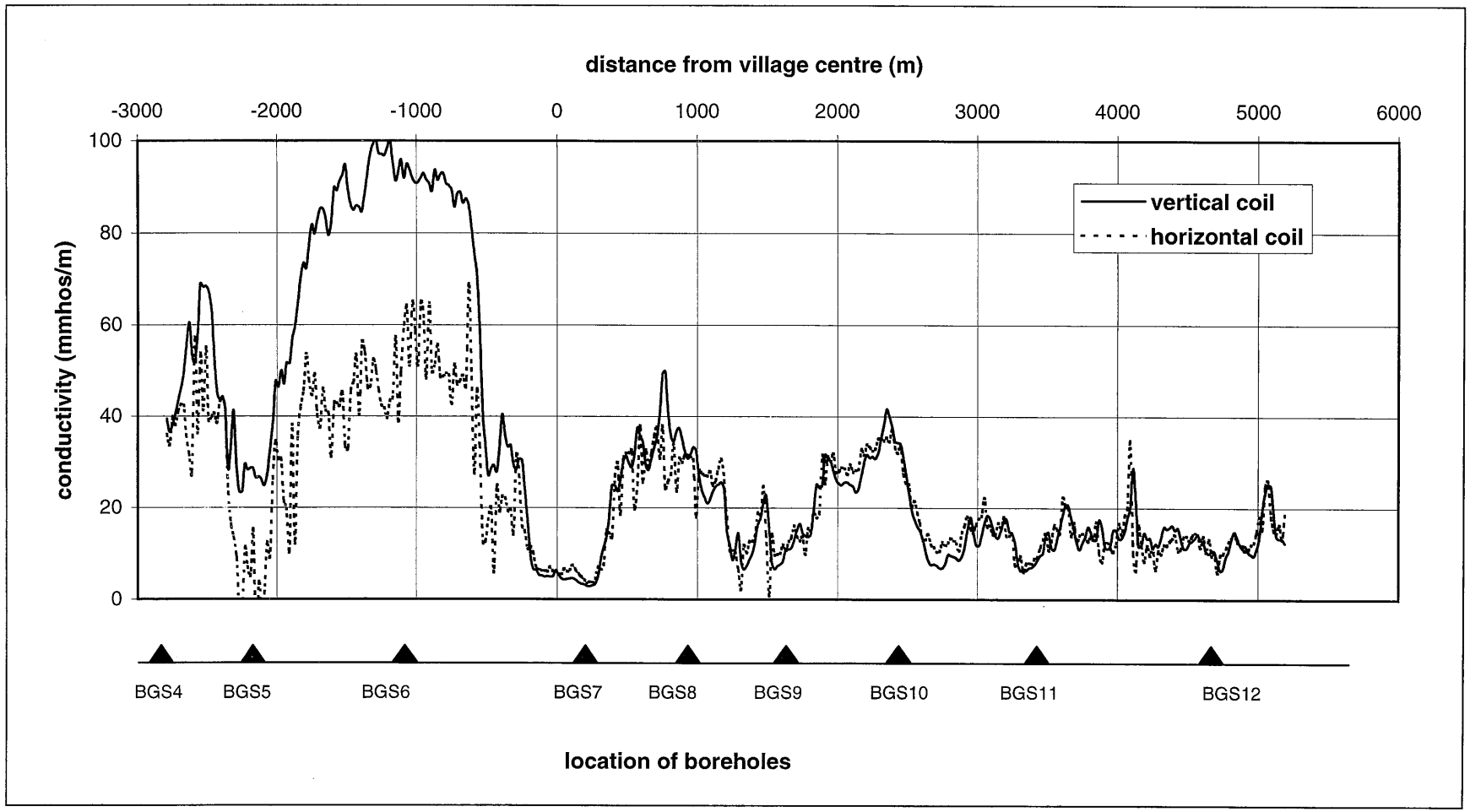


Figure 4. EM34-3 traverse across Ochingini. The village is located at 0 m. Locations of the test boreholes are shown.

2100 m and are marked by shallow depressions. Further to the south-east, beyond 2500 m, the conductivity values average about 15 mmhos/m indicating a change to a more sandy lithology. This corresponds approximately to the Makurdi Sandstone marked on the geology map. To the north-west of Ochingini village, very large conductivity values are observed from -500 m to -2000 m. A marked negative anomaly was noted at about -2100 m; this gave negative readings with the vertical dipole, which can be interpreted as a highly conductive vertical body, possibly a fracture zone or igneous intrusion.

The magnetic traverse was generally fairly quiet – apart from noise created by reinforced concrete constructed culverts and steel sheet roofs. However, there were a few short wave length anomalies that might have represented narrow dykes or could be due to noise. Three resistivity soundings were successfully carried out. Soundings OC5 and OC7, located at BGS7 and BGS12 respectively showed similar profiles – resistive soil, a 10 m thick low resistive layer (30 ohm-m) then a resistive bedrock (>100 ohm-m). Sounding OC6, located at BGS8, showed a similar profile, except that the middle layer had a considerably lower resistivity (10 ohm-m).

From the survey, nine sites were identified for test drilling:

- Borehole BGS4, 3000 m along OC2
- Borehole BGS5, 2170 m along OC2
- Borehole BGS6, 870 m along OC2
- Borehole BGS7, 130 m along OC1 - next to Catholic Church
- Borehole BGS8, 860 m along OC1
- Borehole BGS9, 1620 m along OC1
- Borehole BGS10, 2300 m along OC1
- Borehole BGS11, 3360 m along OC1 – in leprosy village
- Borehole BGS12, 4520 m, along OC1

Table 2. Main geophysical surveys carried out along the Ochinginyi traverse (data in Annex 1)

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
OC1	7° 00.873' 8° 23.284'	5.2 km	20 m	EM34 (20 m)	From small junction in village, past church 134° to leprosy village and beyond
OC2	7° 00.873' 8° 23.284'	5.2 km	10 m	Magnetic	As OC1 using Proton Precession Magnetometer
OC3	7° 00.873' 8° 23.284'	3 km	20 m	EM34 (20 m)	From small junction in village, (start OC1) at 309° past school along main road.
OC4	7° 00.873' 8° 23.284'	3 km	10 m	Magnetic	As OC3 using Proton Precession Magnetometer
OC5	7° 0.754' 8° 23.313'		0.5 – 64 m	Offset Wenner	Located at primary school (BGS7)
OC6	7° 0.615' 8° 23.666'		0.5 – 64 m	Offset Wenner	Located in depression (BGS8)
OC7	6° 59.958' 8° 25.499'		0.5 – 64 m	Offset Wenner	Located on BGS12

3. DRILLING

Nine boreholes were drilled at Ochingini. Rather than drilling full production boreholes, shallow boreholes were drilled to identify the nature of rocks within and just below the weathered zone. The primary purpose of the drilling exercise was to collect sufficient data for accurate interpretation of the geophysical data so that the geophysical survey methods used could be applied to the study of similar sedimentary rock formations with more confidence elsewhere. Summary information on the boreholes is given in Table 3. Details of borehole construction and penetration rate data are given in Annex 2.

The following sections give a brief summary of the lithological logs. Full details are given in Annex 3. Figure 5 shows a schematic of the borehole logs.

Summary lithological log: BGS4

0.0 - 2.6	Soil/ferricrete horizon
2.6 - 5.1	Clayey very weathered horizon
5.1 - 6.6	Weathered shales
6.6 - 8.1	Fairly weathered shales
8.1 - 9.3	Fine to medium grained sandstone - fairly weathered
9.3 - 10.8	Weathered sand mudstones
10.8 - 11.1	Hard medium grained sandstone - fairly weathered
11.10 - 11.75	Interbedded shaley mudstones and fine to medium grained sandstones
11.75 - 12.23	Faulted and very weathered shales
12.23 - 12.70	Medium to fine sandstones

Table 3. Summary details of drilling. Full details given in Annex 2

Borehole ID	Location	Date completed	Total depth	Drilled diameter	Section cored	Water strike	Casing above gl	comments
BGS4	7° 01.700' 8° 21.822'	1/12/97	12.7 m	216 mm	11 – 12.7 m	8.4 (flowing)	0 m	Screened and cased
BGS5	7° 1.441' 8° 22.166'	2/12/97	23.4 m	165 mm	20.6 – 23.4 m	dry	none	back-filled
BGS6	7° 1.091' 8° 22.847'	3/12/97	19 m	165 mm	16.7 – 19 m	8.1, 8.6, 9,7 (flowing)	0.25 m	Screened and cased
BGS7	7° 0.754' 8° 23.313'	4/12/97	16.5 m	165 mm	14.6 – 16.5 m	11.1 , 16.4 m	0.37 m	Collapsing. ingress of sand
BGS8	7° 0.615' 8° 23.666'	5/12/97	13.1 m	165 mm	11.15 – 13.1	10.6 m (flowing)	0.4 m	Screened and cased.
BGS9	7° 0.460' 8° 23.982'	6/12/97	5.8 m	165 mm	2.6 – 5.8 m	none	none	Back-filled – didn't reach water
BGS10	7° 0.441' 8° 24.437'	8/12/97	11.4 m	165 mm	8.7 – 11.4 m	1.0 (flowing), 2.0 m	0.1 m	Much collapse from top
BGS11	7° 0.163' 8° 24.962'	9/12/97	6.05 m	165 mm	3.1 – 6.05 m	none	none	Didn't reach water
BGS12	6° 59.957' 8° 25.499'	10/12/97	15.7 m	165 mm	11.9 – 15.7 m	10.1 (flowing) 11.6, 15 m	0.35 m	Cased and screened

Summary lithological log: BGS5

0.0 - 2.6	Soil/ferricrete horizon
2.6 - 7.6	Clayey very weathered horizon
7.6 - 12.1	Weathered mudstones
12.1 - 15.1	Fairly weathered shaley mudstones
15.1 - 18.1	non-weathered mudstones
18.1 - 20.6	Calcareous shaley mudstones
20.6 - 23.4	Dark grey soft carbonaceous shaley mudstones, no hard bands

Summary lithological log: BGS6

0.0 - 2.1	Soil/ferricrete horizon
2.1 - 3.1	Clayey very weathered horizon
3.1 - 7.6	Very weathered mudstones
7.6 - 9.6	Weathered shaley mudstones
9.6 - 10.1	Muddy limestone some weathering
10.1 - 10.6	Silty mudstones, some weathering
10.6 - 11.1	Thin muddy limestones and non-calcareous shaley mudstones, some weathering
11.1 - 13.6	Shaley mudstones
13.6 - 14.1	Muddy limestone
14.1 - 16.1	Shaley mudstones

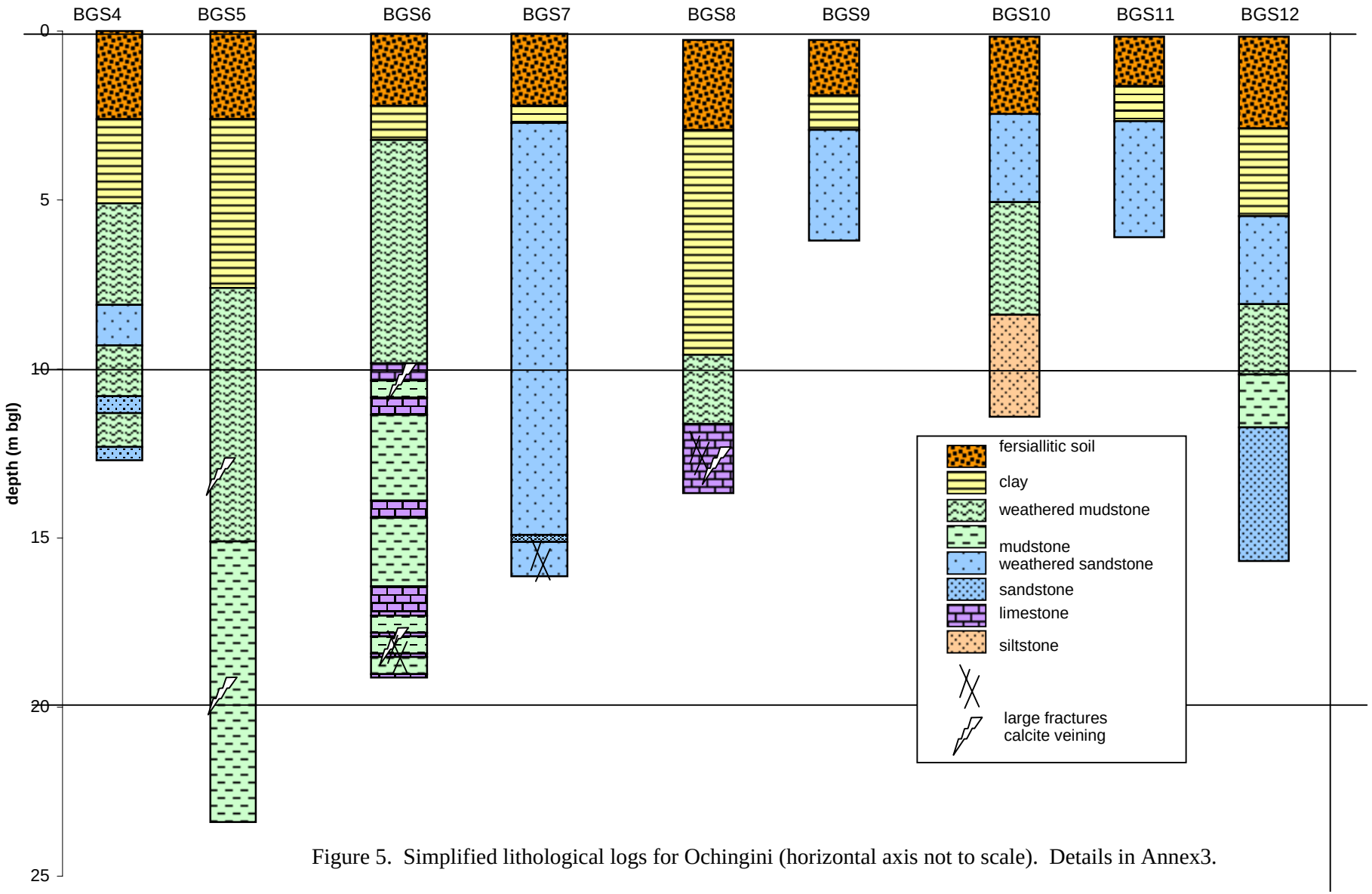


Figure 5. Simplified lithological logs for Ochingini (horizontal axis not to scale). Details in Annex3.

16.1 - 16.95	Hard shelly limestone
16.95 - 17.45	Shaley mudstones
17.45 - 17.50	Hard muddy limestone, some pyrite
17.5 - 18.28	Shaley to silty sometimes calcareous mudstone
18.28 - 18.3	Nodular fractured limestone
18.3 - 18.9	Silty mudstone
18.9 - 19.1	Muddy limestone

Summary lithological log: BGS7

0.0 - 2.1	Soil/ferricrete horizon
2.1 - 2.6	Clayey very weathered horizon
2.6 - 5.6	Very weathered fine to medium grained sandstone horizon
5.6 - 14.6	Weathered fine to medium sandstone horizon
14.60 - 15.34	Hard siliceous fine to medium grained sandstone
15.34 - 15.54	Fine to medium sandstone, fairly weathered
15.54 - 16.20	Fractured fine to medium sandstone with thin clay layers, fairly weathered

Summary lithological log: BGS8

0.0 - 2.6	Soil/ferricrete horizon
2.6 - 9.1	Clayey very weathered horizon
9.1 - 10.1	Weathered mudstones
10.1 - 11.1	Fairly weathered mudstones
11.1 - 13.1	Hard shelly massive to broken limestone, some weathering

Summary lithological log: BGS9

0.0 - 1.6	Soil/ferricrete horizon
1.6 - 2.6	Clayey very weathered sandstone horizon
2.6 - 5.8	Weathered fine to medium sandstone

Summary lithological log: BGS10

0.0 - 2.2	Soil/ferricrete horizon
2.2 - 4.7	Clayey very weathered fine to medium nodular sandstones
4.7 - 8.5	Weathered clayey shaley mudstones
8.5 - 8.6	Weathered siltstones to fine grained sandstones with clay
8.6 - 11.4	Weathered clayey silty mudstones

Summary lithological log: BGS11

0.0 - 1.4	Soil/ferricrete horizon
1.4 - 2.4	Clayey very weathered nodular sands
2.4 - 2.9	Weathered fine to medium grained sandstones, some clay
2.9 - 5.7	Fine to medium grained sandstone, fairly weathered

Summary lithological log: BGS12

0.0 - 2.6	Soil/ferricrete horizon
2.6 - 5.1	Clayey very weathered sandstones
5.1 - 7.6	Weathered sandstones
7.6 - 9.6	Fairly weathered shaley mudstones and fine grained sandstones
9.6 - 11.1	Shaley to silty mudstones
11.1 - 11.9	Interbedded fine to medium sandstones and silty mudstones
11.9 - 12.2	Fine to medium grained sandstone
12.2 - 15.2	Interbedded fine to medium grained sandstone and fissile to shaley mudstones
15.2 - 15.7	Fine to medium grained sandstone

4. TEST PUMPING

Various pumping tests were carried out on the boreholes drilled along the Ochingini traverse. The results of these tests should be treated with caution. The boreholes were not drilled and equipped for testing purposes, but only to prove the rock type at locations along the geophysics traverse. Therefore most of the boreholes are shallow (<15 m) and of these two boreholes (BGS9 and BGS11) were not drilled to the water-table. Although screen and casing were erected within the six boreholes, none of these were adequately cleaned nor developed after completion. However, since WaterAid's preferred water abstraction technology for Oju/Obi is the hand dug well, and these are generally less than 15 m deep, as much information was obtained from these boreholes as possible. Therefore test pumping was carried out in BGS4, BGS6, BGS7, BGS8, BGS10 and BGS12. Table 4 gives a summary of the test pumping.

A simple slug test was carried out in each borehole. These were undertaken using bailers, the water level recovery data obtained being analysed using both the Theis recovery method (Kruseman and de Ridder, 1990) and Barker's large diameter well method (Barker, 1989). Longer drawdown/recovery pumping tests using Whale pumps were carried out on BGS4, BGS6 and BGS12. Data obtained from these were analysed using Jacob's method and Theis recovery.

The best aquifer properties were recorded from borehole BGS6, which although shallow could be equipped with a handpump. Data produced from borehole BGS12 indicated good aquifer properties, sufficient for installation of a hand dug well. A break away was observed in the drawdown curve data from this borehole, however, possibly due to the de-watering of a fracture zone within the sandstone or the cone of depression encountering a mudstone unit. Data from borehole BGS4 also indicated aquifer properties insufficient for installation of a hand pump at that site. Test pumping at boreholes BGS7, BGS8 and BGS10 were hampered by sediment ingress. Data from borehole BGS7 suggest probable better aquifer properties than the test results produced.

Table 4. Summary of pumping tests carried out along the Ochingini traverse. (Annex 4 contains data and analysis).

Borehole and Test	Date	Casing height above ground	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m^2/d)
BGS4						
Bailer test	18/2/98	0 m	5.54	5:44	0.33	Barker: 0.88 Theis Rec: 0.6
Whale test	19/2/98	0 m	5.602	11 mins	0.326 (0-7) 0.12 (7-11)	Jacob: 1.8 Theis Rec: 0.8 Barker: 1.9
Whale test	20/2/98	0 m	5.66 m	31 mins	0.131 (0-25) 0.108 (25-31)	Jacob: 0.73 Theis Rec: 0.54
BGS 6						
Bailer test	19/2/98	0.25 m	5.19	10	0.3	Barker: 35 Theis Rec: 12.5
Whale test	18/2/98	0.25 m	5.08	260	0.325	Jacob: 13.9 Theis Rec: 18.3
BGS7						
Bailer test	19/2/98	0.22 m	4.04	2:50	0.2	Barker: 0.11
BGS8						
Bailer test	20/2/98	0.4 m	6.14	1:14	0.16	Barker: 0.68 Theis Rec: 0.43
BGS10						
Bailer test	20/2/98	0.1 m	2.118	2:16	0.33	Barker: 0.22 Theis Rec: 0.17
BGS12						
Bailer test	21/2/98	0.35 m	5.205	10	0.29	Barker: 1.9 Theis Rec: 1.6
Whale test	13/3/98	0.35 m	5.435	330	0.14	Jacob early: 1.1 Jacob late: 0.58 T Rec early: 1.6 T Rec late: 0.85

A water sample was obtained from each borehole for hydrochemical analysis. Those tested with the Whale pump were sampled during the test pumping. The other boreholes were sampled without prolonged pumping. Some field analysis was undertaken (see Table 5). Major, minor and trace element determinations undertaken at BGS Wallingford are detailed in Annex 5. None of the field measurements breach the WHO guidelines.

Table 5. Chemistry samples taken from the Ochingini traverse boreholes (Annex 5 contains data and analysis).

ID No	Sample No	date	Conductivity (µS/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	HCO3 titr (50ml 1.6M)	Comments
BGS4	212	21/02/98	410	189	7.2	28.9	95	taken after 2 hours pumping - strong odour
BGS6	211	18/02/98	1225	618	6.74	28.9	153	taken after 3 hours pumping
BGS7	230	31/03/98	545	273	7.14	29.4	128	taken from well 30 m away - rubber used
BGS8	229	31/03/98	399	200	7.09	29.4	89	shallow borehole - whale pump used to take sample
BGS10	228	31/03/98	553	276	6.64	28.6	128	shallow borehole; very silty - bailer used
BGS12	214	13/03/98	405	205	7.28	29.6	97	taken after 3 hours pumping

5. SUMMARY AND CONCLUSIONS

The Ochingini traverse was chosen as a site to test the effectiveness of EM34-3 surveys in locating sandstones. The nature of the Makurdi Sandstone and Upper Eze-Aku Formations were assessed. A long straight road passes through the village land and runs perpendicular to the main strike of the geology. The following work was undertaken at Ochingini:

- 8.2 km of EM34-3 surveys
- 8.2 km of magnetic profiling
- 3 resistivity VES
- 9 shallow boreholes were drilled and approximately 3 m of core taken from each borehole
- chip and core samples from each borehole were logged and analysed
- 6 boreholes, BGS4, BGS6, BGS7, BGS8, BGS10, BGS12, were screened and cased
- bailer tests were carried out on each screened borehole
- longer Whale tests were carried out on BGS4, BGS6 and BGS12
- water samples were taken from BGS4, BGS6, BGS7, BGS8, BGS10, BGS12.

The effectiveness of EM34-3 for identifying sandstones can be gauged by comparing Figure 4 and Figure 5. When the underlying rocks are primarily sandstone (e.g. BGS7, BGS10, BGS11 and BGS12) the measured electrical conductivity is between 10 and 20 mmhos/m. Conductivity values in excess of 30 mmhos/m were indicative of mainly mudstones (e.g. BGS8 and BGS10). In both these cases, the vertical and horizontal dipole readings were similar. Very high conductivity values (>80 mmhos/m) and a large disparity between horizontal and vertical dipole readings were found to the north-west of Ochingini around BGS6. These reading probably indicate a very high proportion of conductive clays in the shallow weathered zone. A large negative anomaly was noted around BGS5. The lithological logs indicated a high proportion of vein calcite, suggesting that the borehole was located on a fracture zone. However, when drilled the borehole was dry indicating that the mudstone was too soft to keep fractures open.

The limestones present in BGS6 and BGS8 contain significant amounts of groundwater. However, the limestone units are too thin to be found using any geophysical methods - therefore there is no way of knowing whether or not limestones are present without drilling or digging a well.

The magnetic profiling was generally quiet throughout Ochingini apart from noise from steel roofs. However several small anomalies unaccountable by noise were found at 2.5 and 2.9 km along OC4 (i.e. north-west of Ochingini). BGS4, which was close to one of these anomalies showed no indication of igneous intrusions. All three resistivity surveys carried out showed similar profiles: resistive surface layer, conductive middle layer (about 5-10 m thick) and resistive (>80 hm-m) bedrock. For the sandstones the middle layer had a resistivity of about 30 ohm-m; the mudstones had a resistivity of less than 10 ohm-m. This difference is due to the amount and conductivity of the clays present in the weathered zone of the mudstones and sandstones.

Several conclusions can be made from logging the rock and chip and core samples:

- The Upper Eze-Aku comprises mudstones with several significant sandstone layers and thin limestones.
- The boundary between the Makurdi Sandstone and Eze-Aku is indistinct
- The Makurdi sandstone here comprises interbedded fine-coarse grained sandstone and thin mudstones
- Fine sands can move through screens and block boreholes.
- The sandstones are commonly cross-bedded; load cast features are also present.
- The rocks are highly weathered over the first 10 – 12 m. Weathering in the mudstone produces thick clay sequences, within the sandstone a thin clay layer is present and kaolinised and discoloured sandstone is present beneath the clay.
- The intrinsic porosity and permeability of the sandstone is significant.
- The limestone layers were highly fractured and had calcite and pyrite deposited on fracture surfaces.

- The siltstone/ash observed in BGS10 is of uncertain origin

Test pumping of the boreholes indicated the best aquifer properties from the fractured limestone in BGS6. Good responses were gained from the sandstone boreholes, BGS12 and BGS4, although BGS12 showed a breakaway during the test that may have been due to a fracture dewatering or the cone of depression intersecting a mudstone layer. Testing from BGS7, BG8 and BGS10 were badly affected by silt and sands in the boreholes. However, all the sandstone locations would probably be able to support a hand dug well if it was dug to about 15 m.

REFERENCES

Kruseman G P and de Ridder N A 1990. Analysis and evaluation of pumping test data. IRLI publication 47, The Netherlands.

Barker J A 1989. Programs to simulate and analyse pumping tests in large diameter wells. British Geological Survey technical report WD/89/24.

Annex 1: Geophysics data

Ochinyini

OC1/2

GPS start: 7 00.873 8 23.284
Date and time: 2-3/12/96
Survey: (OC1) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OC2) Magnetic
From junction in village southeastward along dirt road

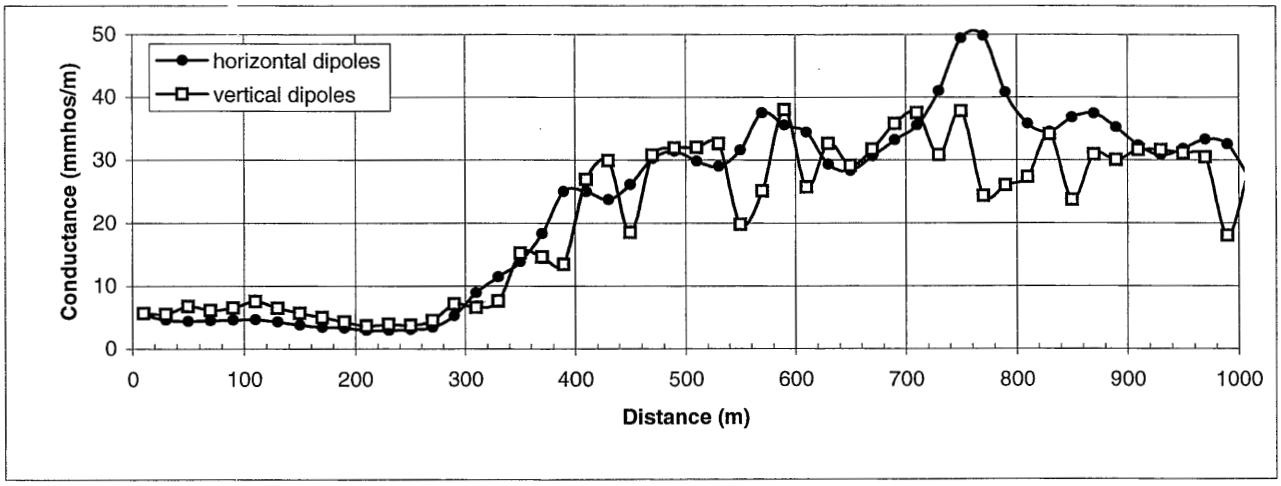
Strike:

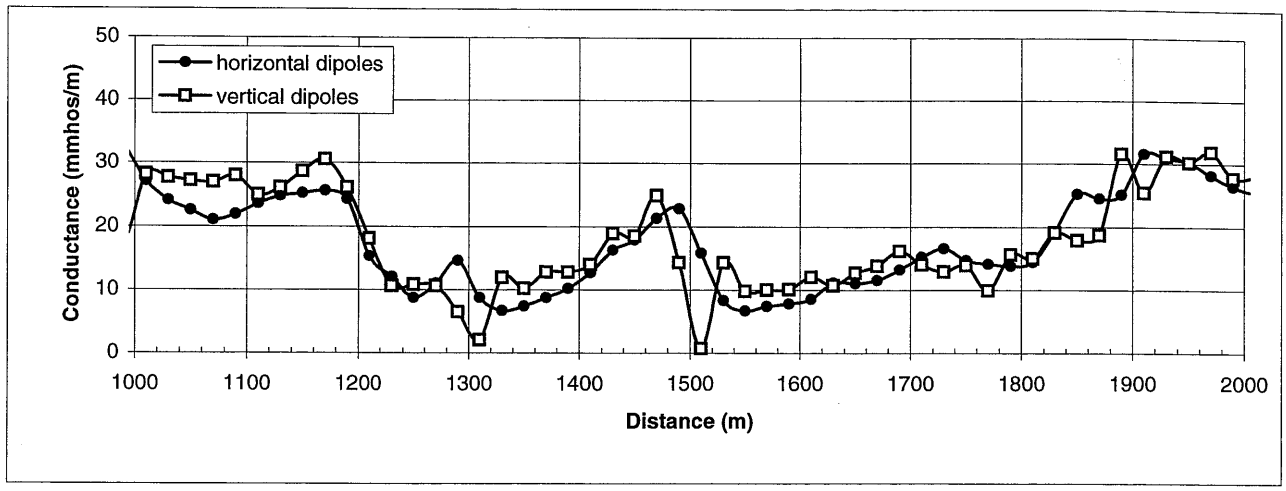
position (m)	strike (deg)
0	134
130	123
180	107
300	114
419	124
1380	114
1680	95
1890	96
2410	114
2510	126
2850	120
3330	95
3490	121
3630	116
4090	120
4650	128
4810	120
4870	107

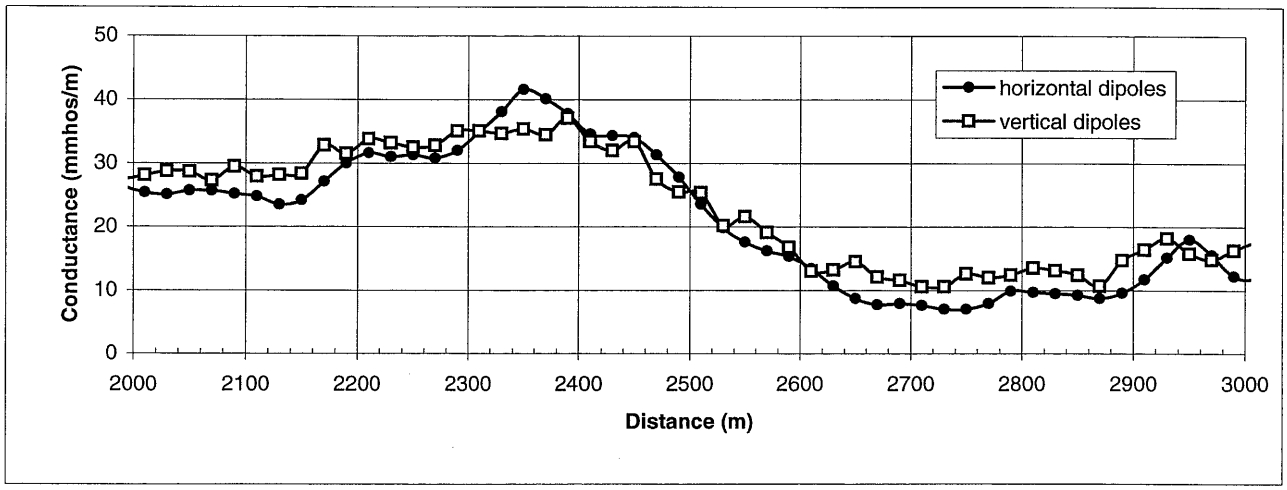
Comments:

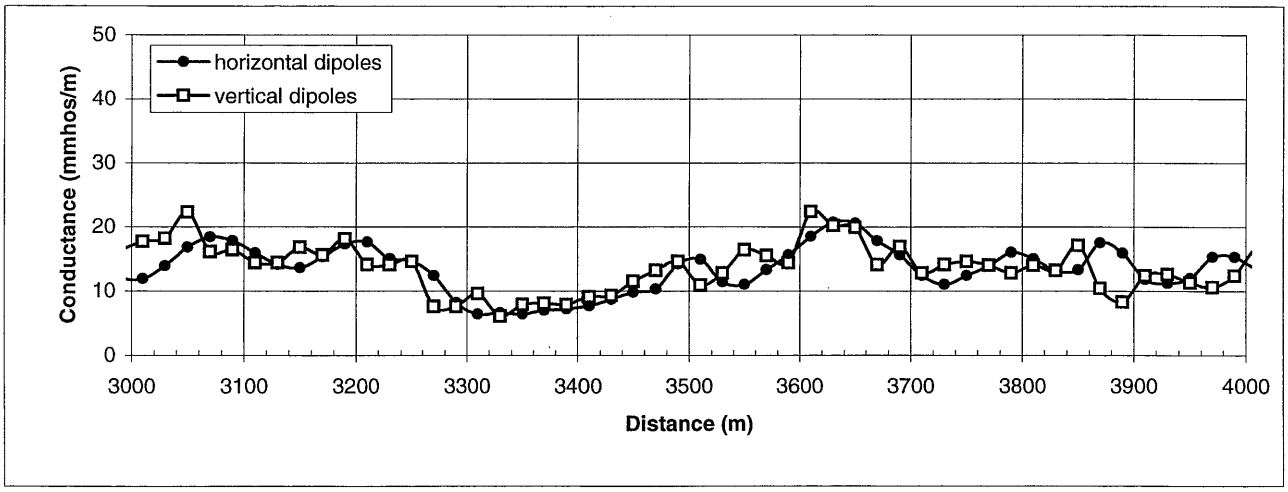
position (m)	comments
0	from small junction - no tin roofs
70	palm trees
110	roof 20 m SW
190	Basins 5 m away
300	leaving village and large trees
350	gradual downhill
760	concrete culvert
760 -	gradual up; sandy soil
1650	by wooden sign
1780	top of rise
2350	depression (dry) palm trees
2850	top of rise
2900	large tree
3130	depression - rice growing
3360	top of rise; school; mango trees
3450	church with metal roof
3970	rice fields; small culert
4100	large culvert - palm trees water
4200	exposed ferrecrete
4600	small culvert
4910	rice fields
4980	yam piles

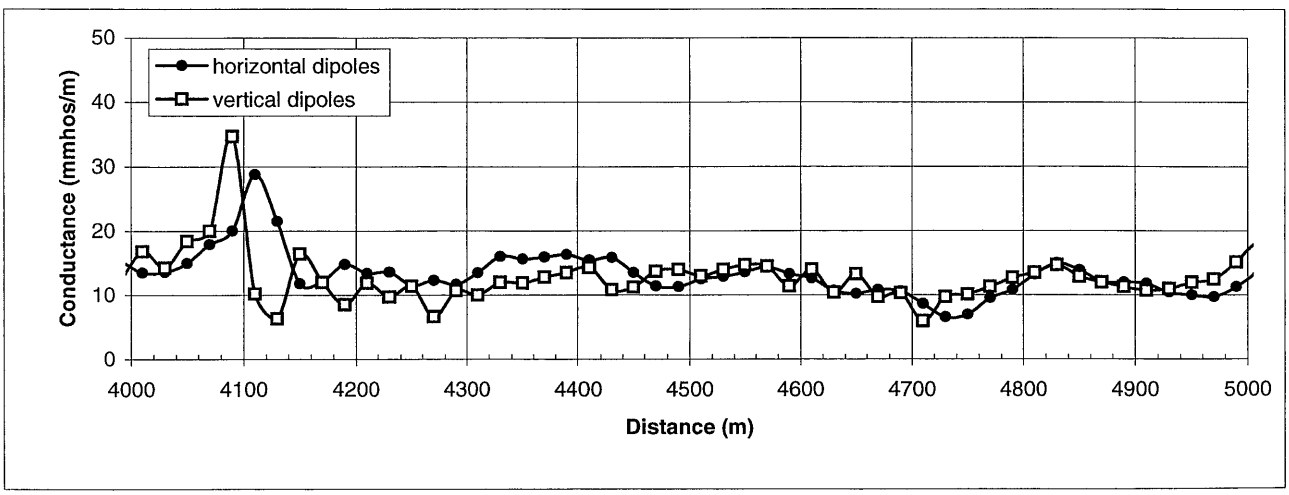
OC1 (EM34 20 m spacing):

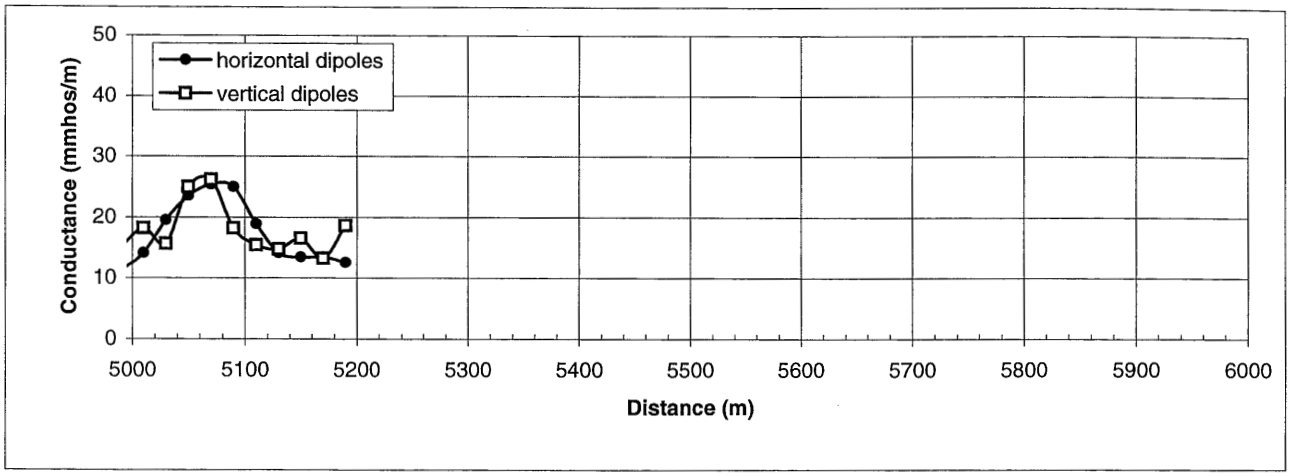



horizontal dipoles
vertical dipoles
Conductance (mmhos/m)
Distance (m)
0
10
20
30
40
50
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

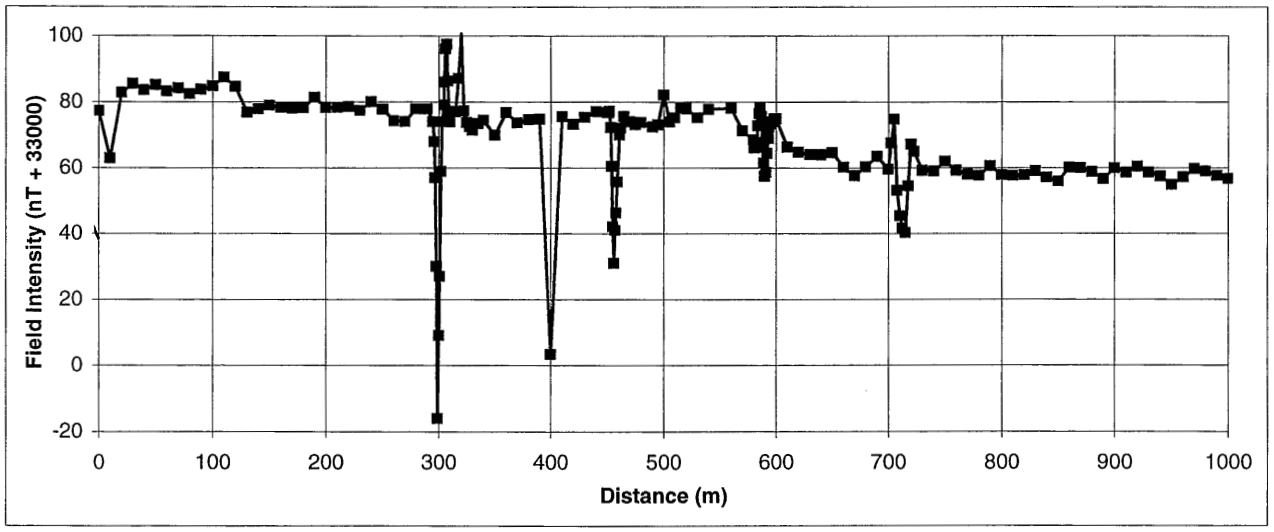

horizontal dipoles
vertical dipoles
Conductance (mmhos/m)
Distance (m)
0
10
20
30
40
50
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000

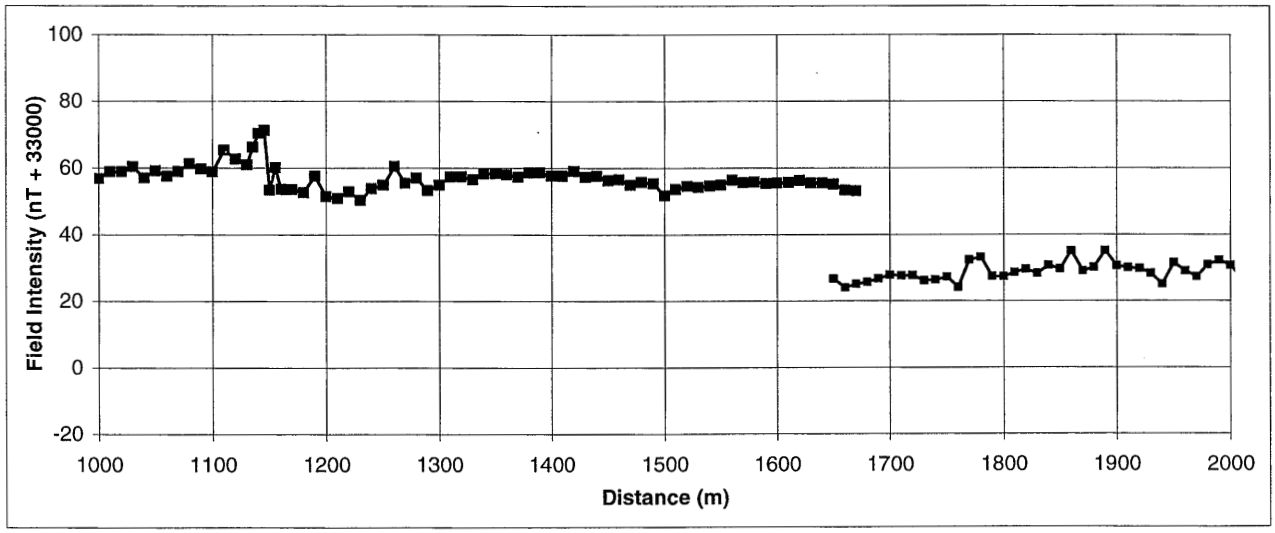

horizontal dipoles
vertical dipoles
Conductance (mmhos/m)
Distance (m)
0
10
20
30
40
50
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000

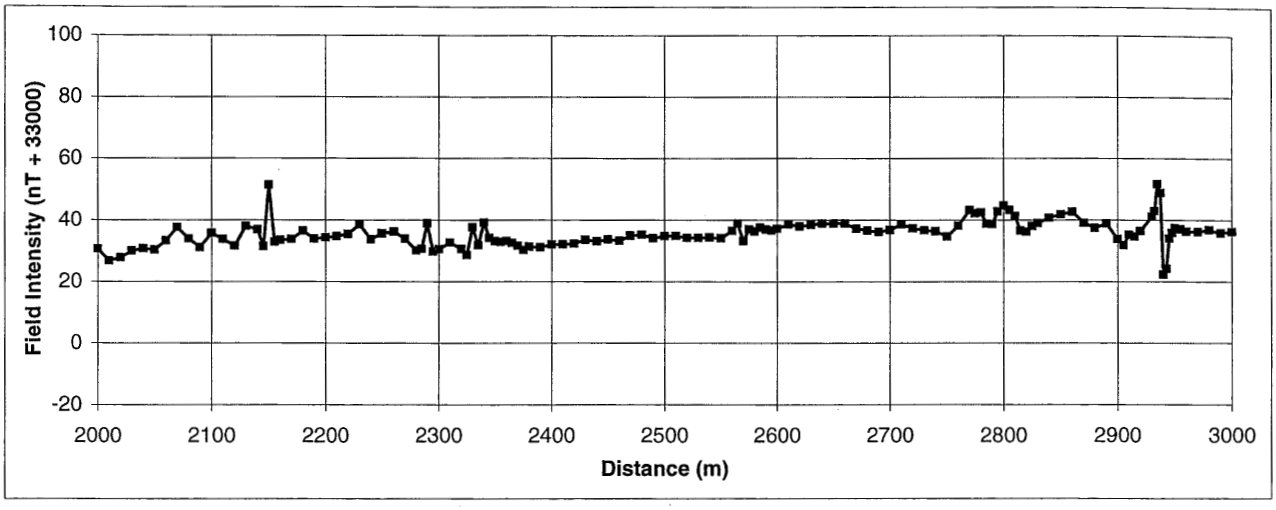

horizontal dipoles
vertical dipoles
Conductance (mmhos/m)
Distance (m)
0
10
20
30
40
50
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000

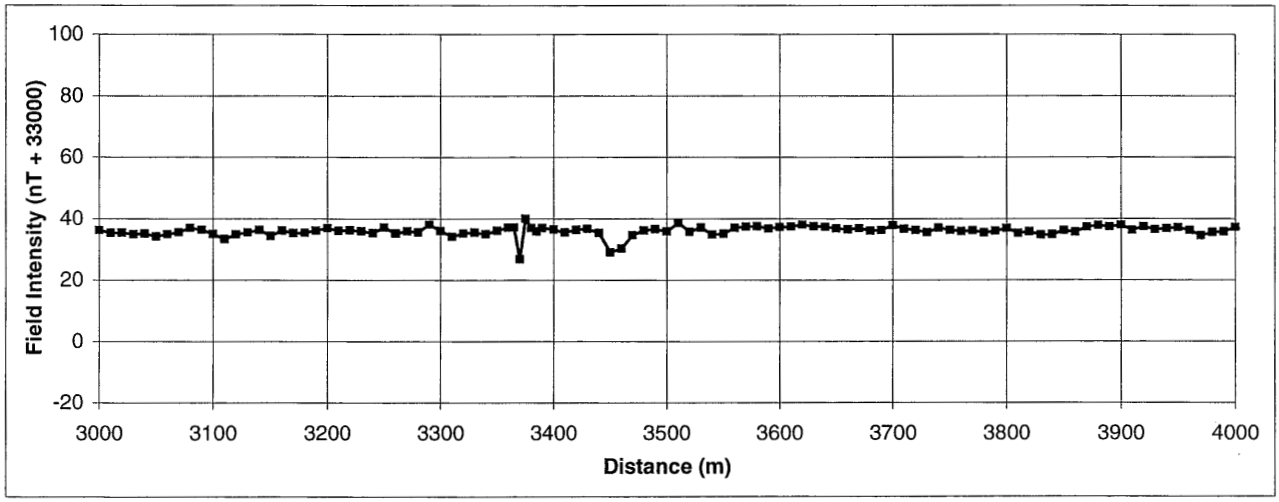


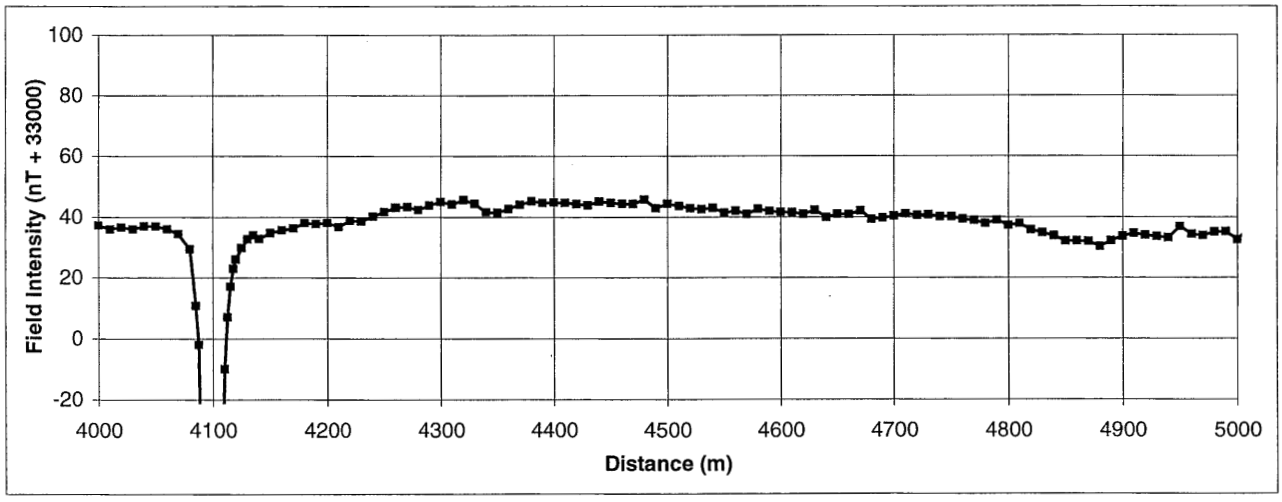
OC2 (magnetic):

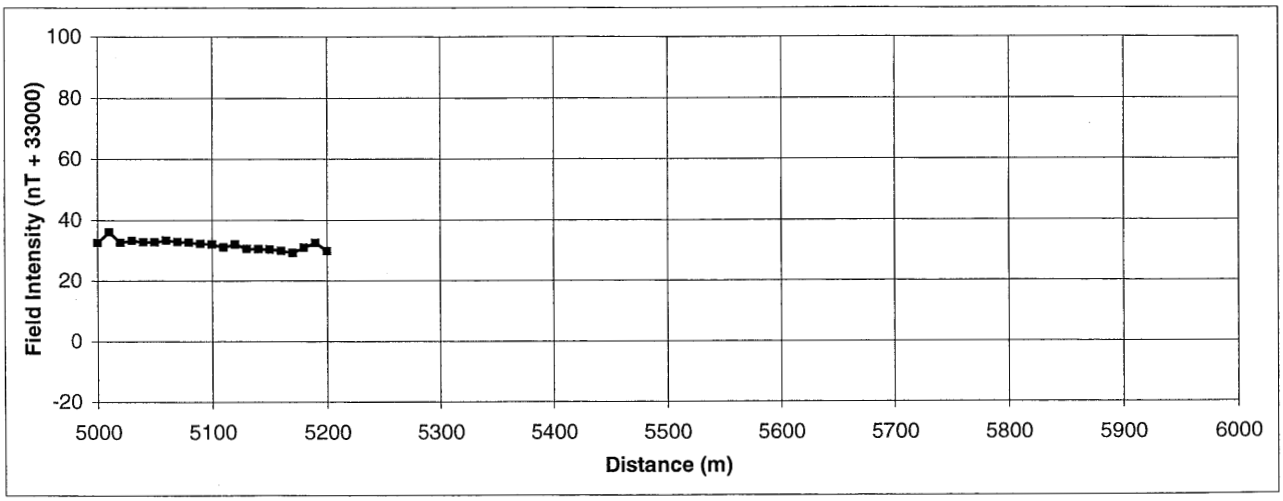





Field Intensity (nT + 33000)
100
80
60
40
20
0
-20
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
Distance (m)


Field Intensity (nT + 33000)
100
80
60
40
20
0
-20
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
Distance (m)


Field Intensity (nT + 33000)
100
80
60
40
20
0
-20
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
Distance (m)


Field Intensity (nT + 33000)
100
80
60
40
20
0
-20
5000
5100
5200
5300
5400
5500
5600
5700
5800
5900
6000
Distance (m)

Ochinyini

OC3/4

GPS start: 7 00.873 8 23.284
Date and time: 04/12/96 9:00-14:00
Survey: (OC3) EM34 with 20 m spacing; both horizontal and vertical dipoles
(OC4) Magnetic
From junction in village (same start as OC1/2) northwestward along dirt road

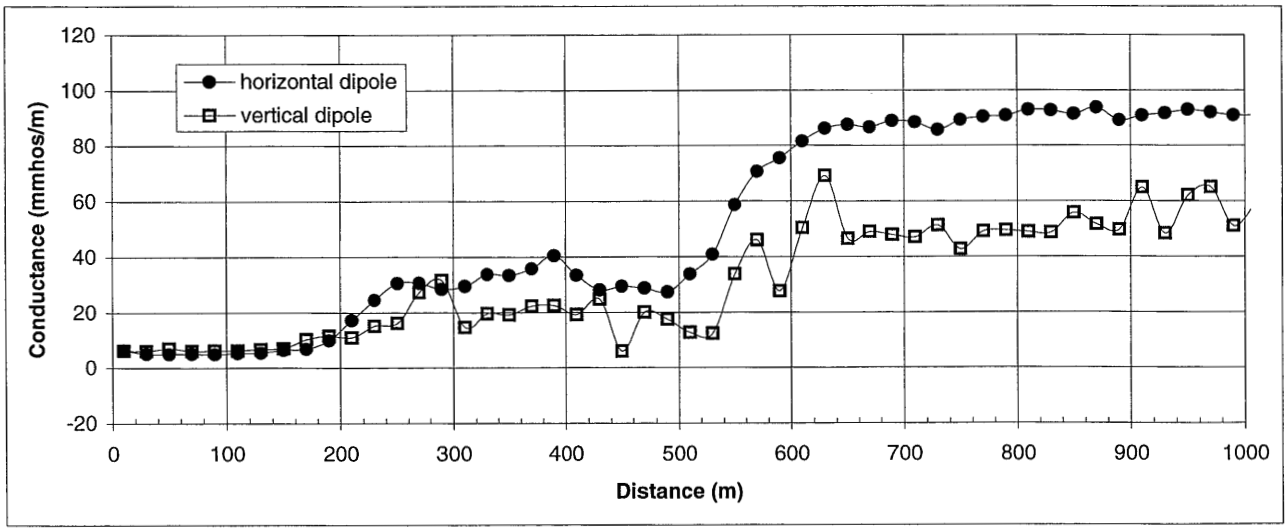
Strike:

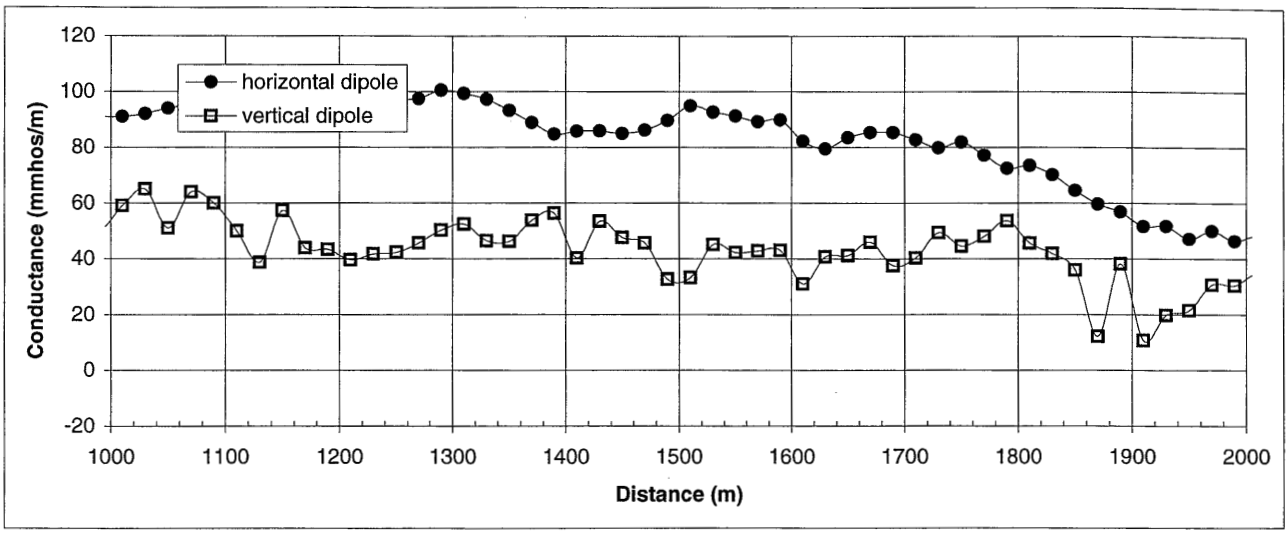
position (m)	strike (deg)
0	309

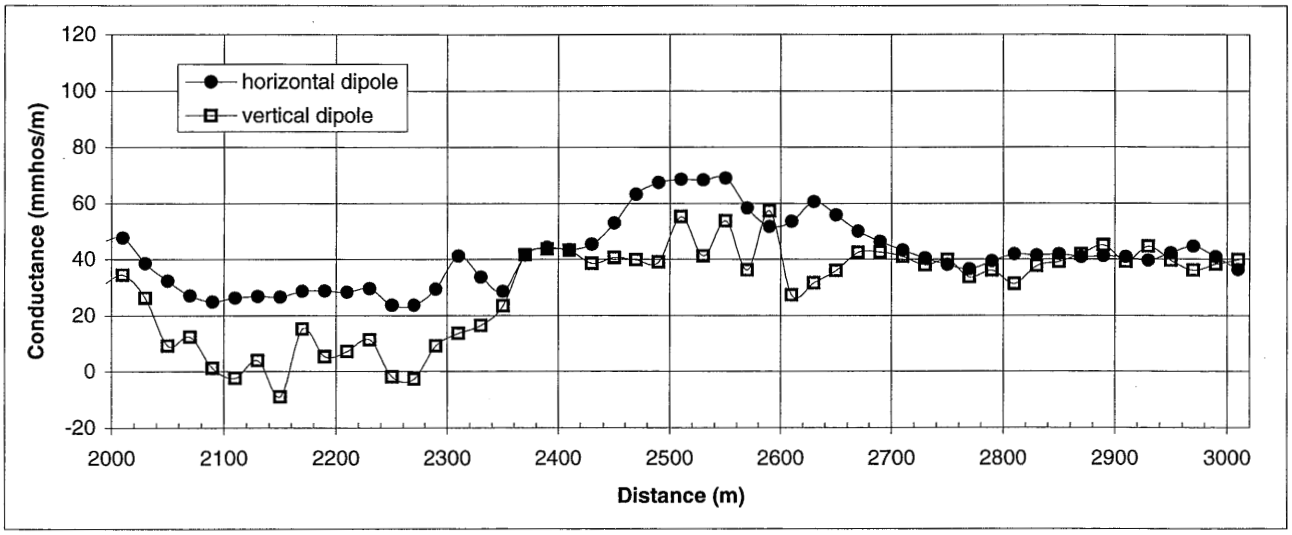
Comments:

position (m)	comments
0	within village - audience
	v sandy soil
130	some laterite nodules
180	basins
190	grass school
220	steel roof 30 m NE
240	roof 40 M NE
270	roof 20 m NE
280	roof 10 m NE
350	roof 20 m NE
390	soil less sandy
480	rice fields
550	hard clay rich soil
760	road junction
790	small culvert
1060	cracked clays
1430	ferecrete nodules
1590	small culvert
1670	silt and pisoliths
1740	culvert
1860	silt/dust
1900	rice
2170	small culvert
2350	metal bolt ???
2460	laterite nodules
2590	fine silt
2600	more lateriite

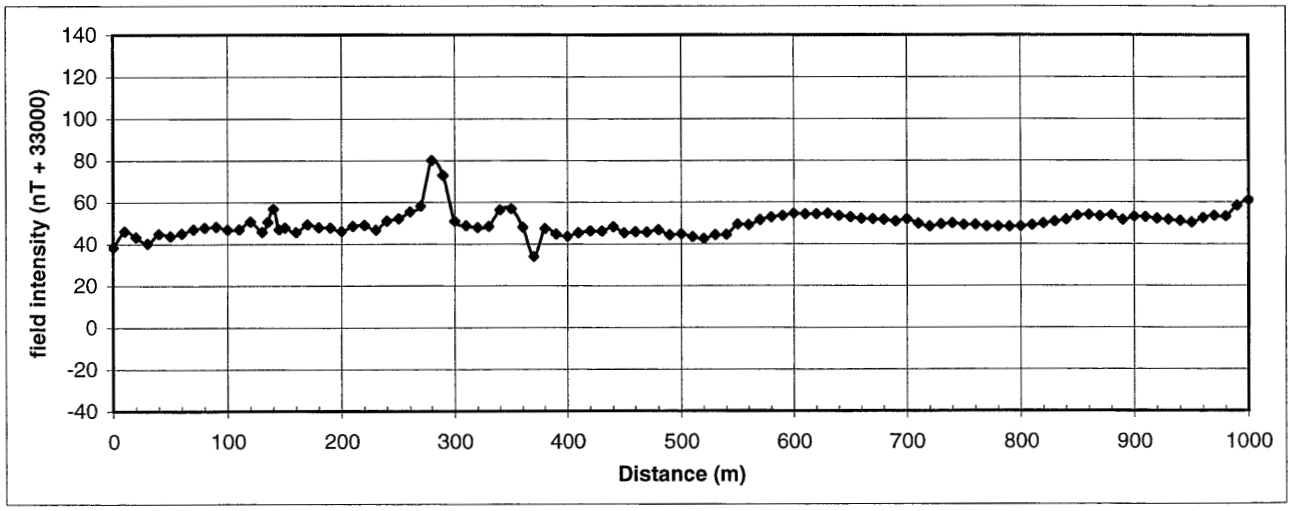
OC3 (EM34):

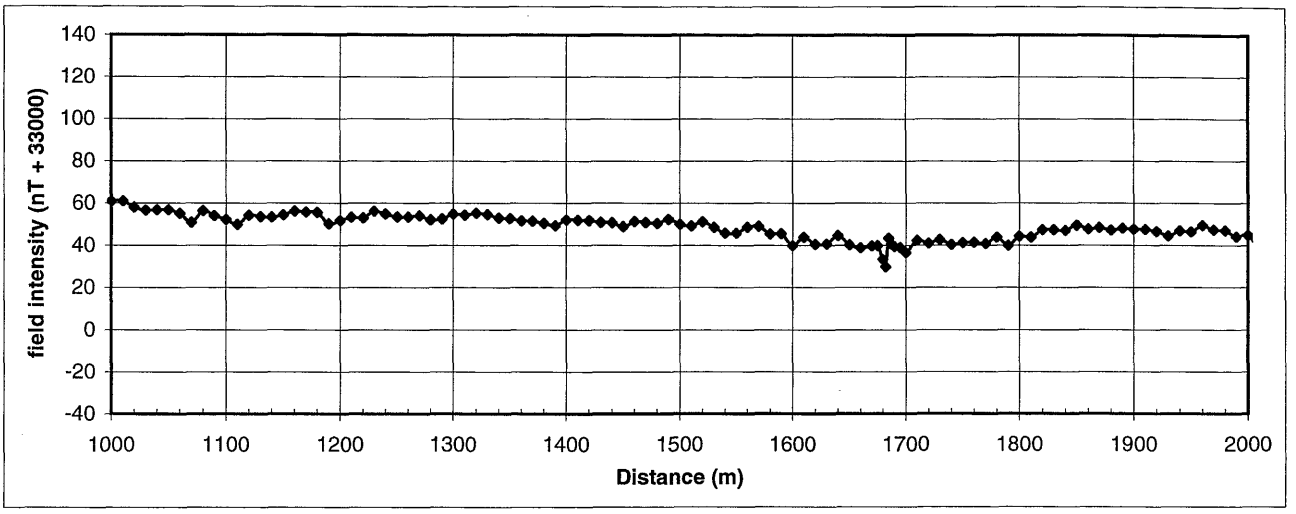


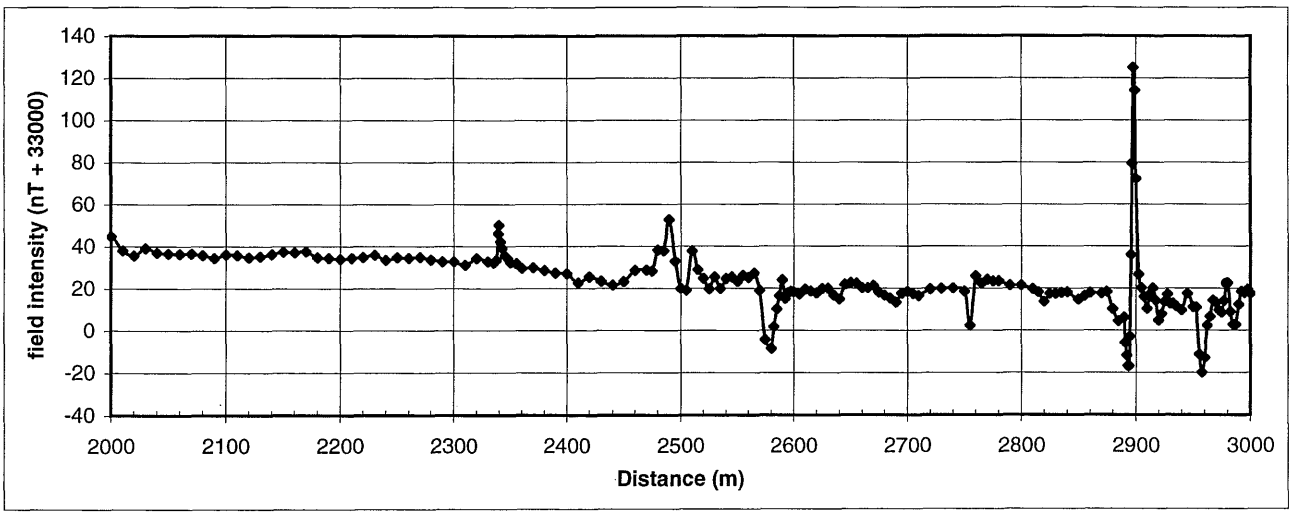




OC4 (Magnetic):



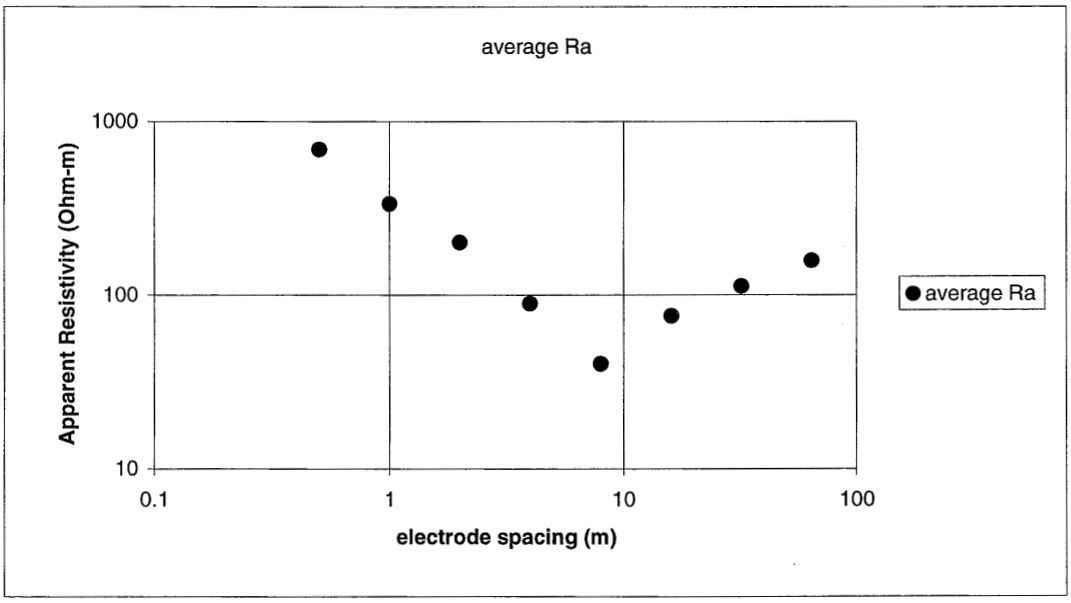

field intensity (nT + 33000)
140
120
100
80
60
40
20
0
-20
-40
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Distance (m)


field intensity (nT + 33000)
140
120
100
80
60
40
20
0
-20
-40
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
Distance (m)

Ochingini (OC5)

Resistivity Survey 1
Located at primary school, BGS 7 7 degs 0.754; 8 degs 23.313
Offset Wenner
Strike 130 degs
01/12/96

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5					689
1					333
2					200
4					89
8					40
16					75.5
32					112
64					157
125					257



DATA SET: OC5

CLIENT: WaterAid DATE: DEC 1996
LOCATION: Primary school (BGS7) SOUNDING: 2
COUNTY: OJU AZIMUTH: 0
PROJECT: OJU WATER AND SANITATION EQUIPMENT: SAS
ELEVATION: 3063.00
SOUNDING COORDINATES: X: 8.3940 Y: 7.0109

Offset Wenner Configuration

FITTING ERROR: 19.696 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			3063.0		
1	512.2	1.30	3061.6	0.00255	667.9
2	37.34	10.63	3051.0	0.284	397.0
3	351.7				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	396.640	512.263	715.604
	2	16.878	37.344	63.521
	3	213.488	351.742	971.739
THICK	1	0.944	1.304	1.710
	2	3.561	10.631	24.847
DEPTH	1	0.944	1.304	1.710
	2	5.238	11.935	26.040

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	689.0	497.2	27.82
2	1.00	333.5	428.3	-28.43
3	2.00	200.1	239.5	-19.69
4	4.00	89.30	73.84	17.30
5	8.00	40.11	46.95	-17.06
6	16.00	75.50	67.04	11.20

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	112.0	112.0	-0.0310
8	64.00	157.8	175.5	-11.23
9	125.0	257.0	242.7	5.54

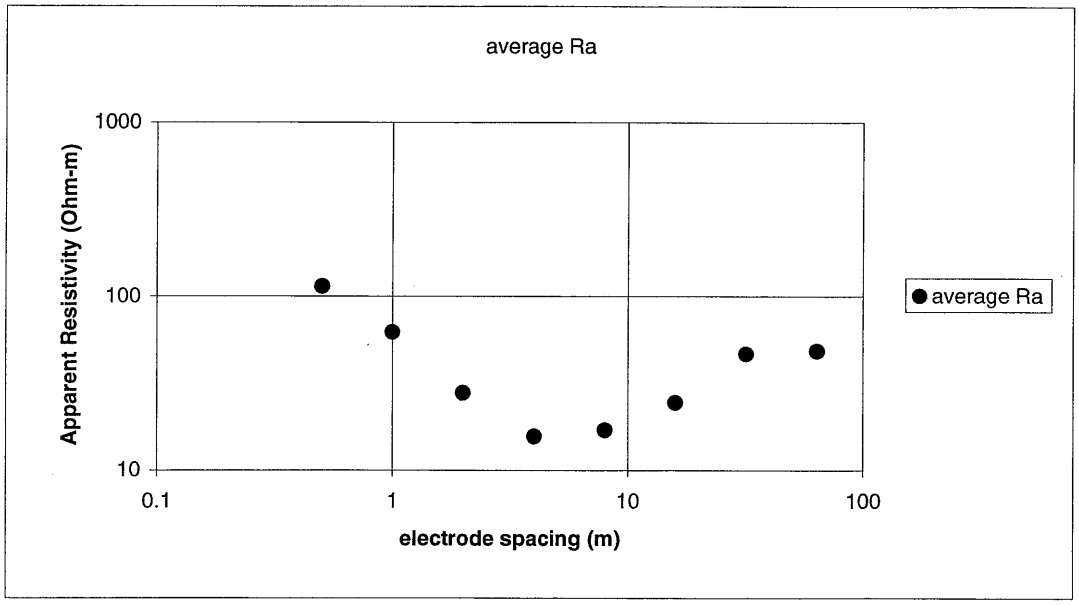
PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.99		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	-0.01	-0.01	0.00	0.99

Ochingini (OC6)

Resistivity Survey 2 7 degs 00.615; 8 degs 23.666
Located in depression (BGS8)
Offset Wenner
Strike 114 degs

spacing (n	left	right	Ra (left)	Ra (right)	average Ra
0.5					114
1					62
2					27.7
4					15.6
8					17
16					24.4
32					46.4
64					48.2



DATA SET: OC6

CLIENT: WaterAid DATE: DEC 1996
LOCATION: In depression (BGS8) SOUNDING: 2
COUNTY: OJU AZIMUTH: 0
PROJECT: OJU WATER AND SANITATION EQUIPMENT: SAS
ELEVATION: 3063.00
SOUNDING COORDINATES: X: 8.3787 Y: 7.0189

Offset Wenner Configuration

FITTING ERROR: 8.957 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			3063.0		
1	121.9	0.720	3062.2	0.00591	87.85
2	13.63	8.06	3054.2	0.591	110.0
3	69.57				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	103.933	121.971	148.654
	2	10.780	13.638	16.394
	3	53.780	69.578	101.131
THICK	1	0.600	0.720	0.851
	2	5.360	8.068	11.910
DEPTH	1	0.600	0.720	0.851
	2	6.173	8.788	12.580

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	114.0	107.0	6.09
2	1.00	62.00	68.31	-10.17
3	2.00	27.70	26.25	5.22
4	4.00	15.60	15.52	0.463
5	8.00	17.00	17.70	-4.17
6	16.00	24.40	26.18	-7.30

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	46.40	39.11	15.70
8	64.00	48.20	52.33	-8.58

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

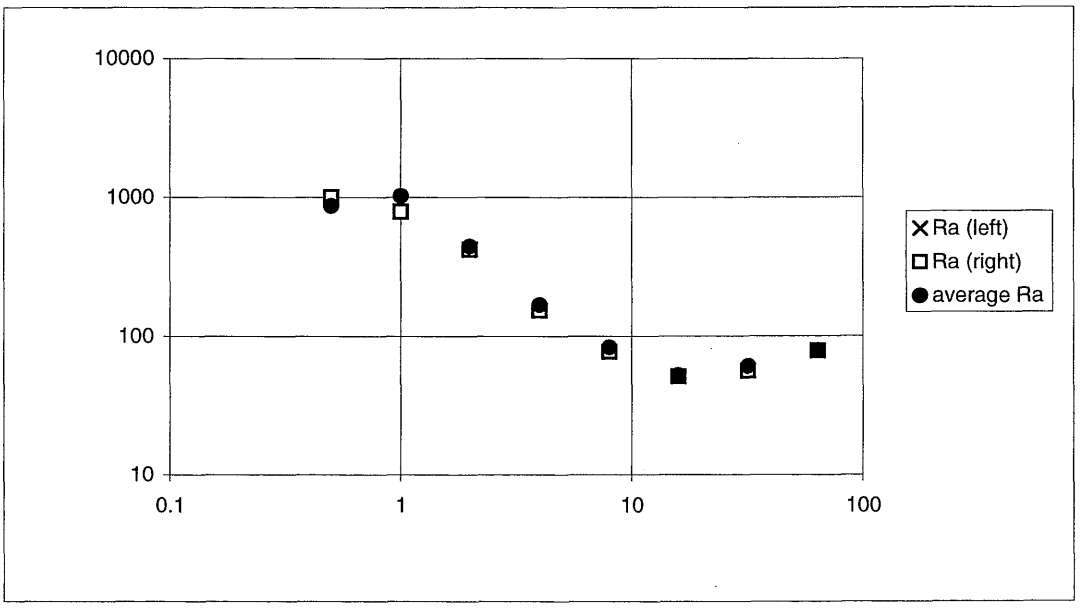
	P 1	P 2	P 3	T 1	T 2
P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	1.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	0.99

* BRITISH GEOLOGICAL SURVEY *

Ochingini (OC7)

Resistivity Survey 3
Loacted end traverse at BGS12
Offset Wenner 6 degs 59.958; 8 degs 25.499
293 degs
13/03/98

spacing (n	left	right	Ra (left)	Ra (right)	average Ra
0.5	234	319	734.76	1001.66	868.21
1	199.6	125.6	1253.488	788.768	1021.128
2	37.2	33.5	467.232	420.76	443.996
4	7.23	6.08	181.6176	152.7296	167.1736
8	1.774	1.532	89.12576	76.96768	83.04672
16	0.532	0.508	53.45536	51.04384	52.2496
32	0.324	0.279	65.11104	56.06784	60.58944
64	0.1962	0.1947	78.8567	78.25382	78.55526



DATA SET: OC7

CLIENT: WaterAid
LOCATION: End traverse BGS12
COUNTY: OJU
PROJECT: OJU WATER AND SANITATION
ELEVATION: 3063.00
SOUNDING COORDINATES: X: 8.3940 Y: 7.0109

DATE: 13/3/98
SOUNDING: 3
AZIMUTH: 293 degs
EQUIPMENT: SAS

Offset Wenner Configuration

FITTING ERROR: 8.880 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			3063.0		
1	1028.8	1.21	3061.7	0.00118	1246.1
2	117.7	5.10	3056.6	0.0433	600.7
3	31.60	11.99	3044.6	0.379	379.1
4	105.5				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	914.251	1028.835	1147.639
	2	80.214	117.736	151.970
	3	15.295	31.601	50.445
	4	77.950	105.553	144.606
THICK	1	1.059	1.211	1.420
	2	3.403	5.103	9.720
	3	4.658	11.999	31.347
DEPTH	1	1.059	1.211	1.420
	2	4.505	6.314	11.090
	3	12.091	18.313	36.781

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	868.0	994.8	-14.61
2	1.00	1021.0	845.3	17.20

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
3	2.00	444.0	470.7	-6.01
4	4.00	167.0	166.7	0.143
5	8.00	83.00	82.34	0.791
6	16.00	52.20	52.70	-0.976
7	32.00	60.60	60.04	0.923
8	64.00	78.60	78.85	-0.322

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	1.00						
P 2	0.00	0.98					
P 3	0.00	-0.04	0.83				
P 4	0.00	0.00	-0.03	0.98			
T 1	0.00	0.01	0.01	0.00	1.00		
T 2	0.00	0.03	0.11	0.01	-0.01	0.92	
T 3	0.00	-0.05	-0.24	-0.05	0.01	0.15	0.63

Annex 2: Drilling and borehole construction data

Depth of borehole on completion	16.5 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1 x 2.9 m x 125 mm casing
	2 x 5.8 m x 125 mm screen
Water Strike	11.1, 16.4 m
Total length of casing/screen	14.4 m
Casing above ground level	0.37 m
Rest water level below casing top	10.68 m

Borehole drilling/construction details: BGS8

Date drilling started	5/12/97
Date drilling completed	5/12/97
5/12/97 - Drilled with 6.5" tricone from	0.0 - 11.15 m
5/12/97 - Cored at 3" from 1	1.15 - 13.10 m

Depth of borehole on completion	13.1 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	2 x 2.9 m x 125 mm casing
	1 x 5.8 m x 125 mm screen
Yield while coring	0.3 l/s
Water Strike	10.6 (flowing) m
Total length of casing/screen	11.6 m
Casing above ground level	0. 4 m
Rest water level below casing top	6.3 m

Borehole drilling/construction details: BGS9

Date drilling started	6/12/97
Date drilling completed	6/12/97
6/12/97 - Drilled with 6.5" tricone from	0.0 - 2.6 m
6/12/97 - Cored at 3" from	2.6 - 5.8 m

Depth of borehole on completion	5.8 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	none

Borehole drilling/construction details: BGS10

Date drilling started	8/12/97
Date drilling completed	8/12/97
8/12/97 - Drilled with 6.5" tricone from	0.0 – 8.7 m
8/12/97 - Cored at 3" from	8.7 - 11.4 m
Depth of borehole on completion	11.4 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x2.9mx125mm screen
	1x5.8mx125mm screen
Water Strike	1 m (flowing), 2 m
Total length of casing/screen	8.7 m
Casing above ground level	0.1 m
Rest water level below casing top	0.6 m

Borehole drilling/construction details: BGS4

Date drilling started	30/11/97
Date drilling completed	1/12/97
30/11/97 - Drilled with 8.5" tricone from	0.0 - 8.6 m
30/11/97 - Cored at 3" from	8.6 - 11.0 m
1/12/97 - Cored at 3" from	11.0 - 12.7 m
Depths water struck -	8.4 (flowing)
Depth of borehole on completion	12.7mbgs
Borehole diameter	$8^1/_2$"
Casing erected in hole	1 x 2.9 m x 125 mm casing 1 x 5.8 m x 125 mm screen
Original top of casing above ground level	0.0 m
Total length of casing/screen	8.7 m
Amount of casing removed	0.0 m
Rest water level below casing top	2.10 m

Borehole drilling/construction details: BGS5

Date drilling started	1/12/97
Date drilling completed	2/12/97
1/12/97 - Drilled with 6.5" tricone from	0.0 - 17.6 m
2/12/97 - Drilled with 6.5" tricone from	17.6 - 20.6 m
2/12/97 - Cored at 3" from	20.6 - 23.4 m
Depth of borehole on completion	23.4 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	none

Borehole drilling/construction details: BGS6

Date drilling started	2/12/97
Date drilling completed	3/12/97
2/12/97 - Drilled with 6.5" tricone from	0.0 - 11.6 m
3/12/97 - Drilled with 6.5" tricone from	11.6 - 16.7 m
3/12/97 - Cored at 3" from	16.7 - 19.0 m
Depths water struck -	8.1, 8.6, 9.7 (flowing)
Depth of borehole on completion	19.0mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1 x 5.8 m x 125 mm casing 2 x 5.8 m x 125 mm screen
Original top of casing above ground level	0.65m
Total length of casing/screen	17.4 m
Amount of casing removed	0.40 m
Rest water level below casing top	5.05 m

Borehole drilling/construction details: BGS7

Date drilling started	4/12/97
Date drilling completed	4/12/97
4/12/97 - Drilled with 6.5" tricone from	0.0 - 14.6 m
4/12/97 - Cored at 3" from	14.6 - 16.5 m

Borehole drilling/construction details: BGS11

Date drilling started	9/12/97
Date drilling completed	9/12/97
9/12/97 - Drilled with 6.5" tricone from	0.0 - 3.1 m
9/12/97 - Cored at 3" from	3.1 - 6.05 m
Depth of borehole on completion	6.05 mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	none

Borehole drilling/construction details: BGS12

Date drilling started	10/12/97
Date drilling completed	10/12/97
10/2/98 - Drilled with 6.5" tricone from	0.0 - 11.9 m
10/2/97 - Cored at 3" from	11.9 - 15.7 m
Depth of borehole on completion	15.7mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	3 x 2.9 m x 125 mm casing 1 x 5.8 m x 125 mm screen
Water Strike	10.1 (flowing), 11.6 , 15 m
Yield while coring	0.12 l/s
Total length of casing/screen	12.25 m
Casing above ground level	0.35 m
Rest water level below casing top	8.03 m

Annex 3: Lithological Logs

Geological Log: BGS4

Soil/ferrecrete horizon	
0.0 - 0.6	Reddish brown 5YR4/3 loamy soil
0.6 - 1.1	Brown 7.5YR5/6 ferrisol
1.1 - 1.6	Yellowish red 5YR4/6 ferrisol
1.6 - 2.1	Dusky red 10R3/2 nodules up to 5 mm diameter within reddish yellow 7.5YR6/6 ferrisol
2.1 - 2.6	Dusky red 10R3/2 nodules with coating of red 2.5YR5/6 ferrisol with light greenish grey 10Y8/1 kaolinite nodules
Clayey very weathered horizon	
2.6 - 3.1	Red 2.5YR5/6 ferrisol soil with haematitic dusky red nodules with white kaolinite clay
3.1 - 3.6	Verigated red ferrisol and white kaolinite clay with some dusky red nodules
3.6 - 4.1	Weak red 10R5/4 ferrisol with much kaolinite
4.1 - 4.6	Reddish grey and white kaolinised weathered shales
4.6 - 5.1	Reddish grey and white weathered kaolinised shale
Weathered shales	
5.1 - 5.6	Light grey and white weathered shale, some kaolin
5.6 - 6.1	Light grey shales, soft with some white fragments
6.1 - 6.6	Darker grey shale with some white fragments, less weathered
Fairly weathered shales	
6.6 - 7.1	Dark grey shale, less weathered
7.1 - 7.6	Grey to dark grey shale, some white sandy layers
7.6 - 8.1	Grey to dark grey shales with white partings
Fine to medium grained sandstone - fairly weathered	
8.1 - 9.3	Dark orange brown fine to medium grained jointed to massive sandstone with coarser band at 9.15m
Weathered sandy mudstones	
9.3 - 10.8	Dark black grey massive to well laminated fine grained mudstone with thin white sandy bands sometime convoluted. High angle of cleavage noted. Softer clayey bands noted at 9.5m, 9.7-9.95m, 10.05-10.15m, 10.3-10.45m and 10.55-10.65m. Dark purple ferruginised ashy? band at 10.75m.
Hard medium grained sandstone - fairly weathered	
10.8 - 11.0	Dark red very dense and hard medium grained sandstone with haematite matrix, micaceous but no discernable bedding.
11.0 - 11.1	Red brown and light brown fine to medium sandstones, iron cemented, convoluted and balled load cast structures indicating deposition of sands onto fluid black carbonaceous muds
Interbedded shaley mudstones and fine to medium grained sandstones	
11.1 - 11.15	Black carbonaceous shaley mudstones interbedded with thin white to light brown fine sandstones
11.15 - 11.35	Mainly orange brown to light brown fine to medium sandstones with convoluted to balled loadcast structures interbedded with thin black carbonaceous shaley mudstones indicative of sands being deposited intermittently within a black carbonaceous mud environment
11.35 - 12.2	Black carbonaceous shaley mudstones intebedded with thin sheet to channel infill sandstone deposits, with convoluted loadcast structures
Faulted and very weathered shales	
11.75	Possible clay filled fault zone
12.2 - 12.23	Yellow and light blue grey laminated clayey zone - weathered zone or faulted horizon??
Medium to fine sandstones	
12.23 - 12.7	Dark brown well cemented medium to fine sandstone with black manganese oxide partings along joint planes

Geological log: BGS5

Soil/ferrecrete horizon	
0.0 - 0.6	Brown 7.5YR4/3 loamy soil
0.6 - 1.1	Yellowish red 5YR4/6 and reddish yellow ferrosol with many dusky red 7.5R
1.1 - 1.6	Red 2.5YR4/6 ferrosol with 2-3 mm thick light grey clay partings; some small red
1.6 - 2.1	Reddish Yellow 7.5YR6/6 clayey ferrosol with small (3 mm) red 10R5/6
2.1 - 2.6	Reddish Yellow 7.5YR6/6 clayey ferrosol with occasional light grey clay partings.
Clayey very weathered horizon	
2.6 - 3.1	Reddish Yellow 7.5YR6/6 clayey ferrosol with occasional light grey clay partings with some light red 2.5YR6/6 and yellow 10YR7/6 clay.
3.1 - 3.6	Light grey clay with some yellow 10YR7/6 clay.
3.6 - 4.1	Light grey and yellow clay with some red 10R4/6 clay. Harder.
4.1 - 4.6	Light grey and yellow clay with some red 10R4/6 clay. Harder.
4.6 - 5.1	Very pale brown 10YR7/4 silty clay with some light grey clay and mica.
5.1 - 5.6	Yellow 2.5Y7/6 silty clay with light grey and yellow 10YR7/6 partings; some
5.6 - 6.1	Light yellowish brown 2.5YR6/4 silty clay with light grey and yellow clay
6.1 - 6.6	Light yellowish brown 2.5YR6/4 silty clay with light grey and yellow clay
6.6 - 7.1	Light yellowish brown silty clay with light grey and yellow clay partings -
7.1 - 7.6	Light yellowish brown silty clay with light grey and yellow clay partings with occasional pieces of weathered grey fissile mudstone
Weathered mudstones	
7.6 - 8.1	Mottled light brown grey and light yellow brown very weathered mudstones, some light brown very fissile micaceous shales
8.1 - 8.6	Mottled light brown grey and light yellow brown to orange very weathered clayey mudstones
8.6 - 9.1	Mottled light brown grey and light yellow brown very weathered mudstones, odd micafragment
9.1 - 9.6	Mottled light green grey to light olive brown with partings of yellow brown and red brown very weathered mudstones
9.6 - 10.1	Mottled light grey, light olive brown and light yellow brown clayey weathered mudstones
10.1 - 10.6	Mottled light grey and light olive brown very weathered mudstones with red brown and dark grey black horizones, some kaolinitic clay layers
10.6 - 11.1	Mottled light ochre brown and light grey very weathered mudstones
11.1 - 11.6	Mottled light ochre brown to olive brown and light grey very weathered mudstone, with some gypsum?
11.6 - 12.1	Mottled light grey and olive brown weathered mudstones
Fairly weathered shaley mudstones	
12.1 - 12.6	Light and dark grey weathered shaley mudstones with orange and light olive brown and dark red weathered partings, some **calcite** veining
12.6 - 13.1	Mottled light and dark grey shaley mudstones, with orange and light olive brown partings
13.1 - 13.6	Mottled light grey and dark grey weathered mudstones with orange and dark red partings
13.6 - 14.1	Mottled ashy grey to dark grey, light olive brown and orange weathered shaley mudstones, some white **calcite**? partings
14.1 - 14.6	Mottled olive brown and grey weathered shaley mudstones with orange brown partings
14.6 - 15.1	Interlayered dark grey and olive brown weathered shaley mudstone
Non-weathered mudstones	
15.1 - 15.6	Dark ashy grey to dark grey black soft carbonaceous shaley mudstones
15.6 - 16.1	Dark grey very soft carbonaceous shaley mudstones
16.1 - 16.6	Dark grey very soft carbonaceous mudstones
16.6 - 17.1	Dark grey very soft carbonaceous mudstones
17.1 - 17.6	Dark grey very soft carbonaceous mudstones
17.6 - 18.1	Dark grey very soft very carbonaceous mudstones

Calcitic shaley mudstones	
18.1 - 18.6	Dark grey black to black soft very carbonaceous mudstones with thin shaley harder bands with calcitic limestone? partings.
18.6 - 19.1	Dark grey black to black soft very carbonaceous mudstones with thin shaley harder bands with calcitic? partings
19.1 - 19.6	Dark grey black to black soft very carbonaceous mudstones with thin shaley harder bands with calcitic? partings
19.6 - 20.1	Dark grey black to black soft very carbonaceous mudstones with thin shaley harder bands with calcitic? partings
20.1 - 20.6	Dark grey carbonaceous shaley mudstones with harder shaley bands, the latter with calcitic partings
20.60 - 23.40	about 25% core recovery, dark grey soft carbonaceous shaley mudstone, no hard bands, no obvious indications of fracturing.

Geological log: BGS6

Soil/ferrecrete horizon	
0.0 - 0.6	Brown 7.5YR4/4 and red 2.5YR5/8 clayey soil with hard well rounded blue
0.6 - 1.1	Red 2.5YR5/8 clay with many subrounded irregularly shaped nodules (< 10 mm)
1.1 - 1.6	Red 2.5YR5/8 clay with many subrounded irregularly shaped nodules (< 10 mm)
1.6 - 2.1	Red 2.5YR5/8 clay with many subrounded irregularly shaped nodules (< 10 mm) - clay more friable.
Clayey very weathered horizon	
2.1 - 2.6	Hard, dry red clay with much brownish yellow 10YR6/6 soft damp clay,
2.6 - 3.1	Olive yellow 2.5Y6/6 silty clay. Increased light grey clay. Some dark grey black
Very weathered mudstones	
3.1 - 3.6	Olive yellow weathered mudstone with much dark grey/black limestone with white
3.6 - 4.1	Olive yellow weathered mudstone with much dark grey/black limestone with white, light grey and reddish yellow clayey partings.
4.1 - 4.6	Grey - dark grey mudstone with reddish yellow staining along fractures
4.6 - 5.1	Grey - dark grey mudstone with reddish yellow staining along fractures with light grey and reddish yellow clayey partings.
5.1 - 5.6	Olive brown and grey mudstone with much light grey and reddish yellow calyey
5.6 - 6.1	Olive brown and dark grey mudstone with many yellowish brown soft clayey
6.1 - 6.6	Olive brown soft mudstone with light grey and yellowish brown soft clayey partings
6.6 - 7.1	Olive brown soft mudstone with yellowish brown soft clay and occasional light grey
7.1 - 7.6	Soft grey mudstone with light grey and yellowish brown clayey partings.
Weathered shaley mudstones	
7.6 - 8.1	Dark grey black noncalcareous carbonaceous shaley mudstones, very weathered with dark red, light yellow brown and light blue grey partings with hard fine grained siliceous dark grey and grey brown hard bands.
8.1 - 8.6	Dark grey black carbonaceous shaley mudstones weathered with ashy white and
8.6 - 9.1	Mottled grey, yellow brown 10YR5/6 and light olive brown 2.5Y6/4 partings weathered silty mudstones
9.1 - 9.6	Light olive brown 2.5Y6/4 weathered shaley mudstone, clayey
Muddy limestone some weathering	
9.6 - 10.1	Dark grey black limestone with vein **calcite** interbedded with noncalcareous light grey shaley mudstone with ligh brown iron stained partings
Silty mudstones, some weathering	
10.1 - 10.6	Grey non-calcareous silty mudstones, slightly weathered with much light brown iron oxide staining along partings
Thin muddy limestones and noncalcareous shaley mudstones, some weathering	
10.6 - 11.1	Dark grey large fragments of limestone interbedded with grey shaley non-calcareous mudstone with much light brown iron oxide staining on partings, water in blocky broken shales above limestones
Shaley mudstones	
11.1 - 11.6	Dark grey black carbonaceous non-calcareous shaley mudstones.
11.6 - 12.1	Dark grey black carbonaceous non-calcareous shaley mudstones
12.1 - 12.6	Dark grey black carbonaceous non-calcareous shaley mudstones with thin dark grey black limestone layers
12.6 - 13.1	Dark grey black carbonaceous non-calcareous shaley mudstones
13.1 - 13.6	Dark grey black carbonaceous non-calcareous shaley mudstones
Muddy limestone	
13.6 - 14.1	Dark grey black limestone with vein calcite interbedded with noncalcareous light grey shaley mudstone
Shaley mudstones	
14.1 - 14.6	Dark grey black carbonaceous non-calcareous shaley mudstones
14.6 - 15.1	Dark grey black carbonaceous non-calcareous shaley mudstones
15.1 - 15.6	Dark grey black carbonaceous non-calcareous shaley mudstones
15.6 - 16.1	Dark grey black carbonaceous non-calcareous shaley mudstones

Hard shelly limestone	
16.1 - 16.6	Hard black limestone with orange red faulted? partings
16.6 - 16.7	Hard black limestone with orange red faulted? parting, increased water flow to >0.5 l/sec
16.7 - 16.95	Dark grey and white shelly limestone
Shaley mudstones	
16.95 - 17.45	Grey black carbonaceous shaley mudstones
Hard muddy limestone, some pyrite	
17.45 - 17.50	Hard muddy limestone with vertical clacite filled fractures; some pyrite associated
Shaley to silty sometimes calcareous mudstone	
17.5 - 17.8	Dark grey shaly mudstone; some white discontinuous thin intercalations - react
17.8 - 18.28	Dark grey silty mudstone with cylical bedding.
Nodular limestone	
18.28 - 18.3	Thin nodular limestone with a large open fracture beneath.
Silty mudstone	
18.3 - 18.9	Dark grey silty mudstone with cyclical bedding; occasional thin gypsum.
Muddy limestone	
18.9 - 19.1	Dark grey black nodular muddy limestone with vertical fracture, vertical fracture

Geological log: BGS7

Soil/ferrecrete horizon	
0.0 - 1.1	Light brown 7.5YR6/4 sandy soil
1.1 - 1.6	Fine to medium well sorted sand (well rounded) reddish yellow 7.5YR6/6 with many 10-15 mm nodules (subrounded to rounded) can be broken with knife dark reddish brown 2.5YR3/3
1.6 - 2.1	Fine to medium well sorted sand (well rounded) reddish yellow 7.5YR6/6 with many 10-15 mm nodules (subrounded to rounded) dark reddish brown 2.5YR3/3 with some light grey and yellowish red mottles
Clayey very weathered horizon	
2.1 - 2.6	Sandy red clay 2.5YR5/8 with some light bluish grey 10B8/1 and yellow 10YR7/8 partings.
Very weathered fine to medium grained sandstone horizon	
2.6 - 3.1	Fine to medium well sorted sand with rounded grains and a little clay - white, orange and red grains.
3.1 - 3.6	Fine to medium well sorted sand with rounded grains and a little clay - white, orange and red grains, overall colour is very pale brown 10YR7/4
3.6 - 4.1	Fine to medium well sorted sand with rounded grains and a little clay - white, orange and red grains, overall colour is very pale brown 10YR7/4
4.1 - 4.6	Fine to medium well sorted sand with rounded grains and a little clay - white, orange and red grains, overall colour is very pale brown 10YR7/4, with some balls of white clay and pale yellow; very occasional hard red nodule.
4.6 - 5.1	Fine to medium well sorted sand with rounded grains and a little clay - white, orange and red grains, overall colour is very pale brown 10YR7/4, with some balls of white clay and pale yellow
5.1 - 5.6	Fine to medium well sorted sand with rounded grains and a little clay, overall colour is very pale brown 10YR7/4. Occassional balls of white and orange clay.
Weathered fine to medium dandstone horizon	
5.6 - 6.1	Very pale yellow 2.5YR8/2 poorly sorted fine to medium grained sandstone with some coarse grains. Much more white grains and some yellow grains.
6.1 - 6.6	Very pale brown 10YR8/3 fine to medium sand with some coarse grains and some balls of white clay.
6.6 - 7.1	Very pale brown 10YR8/3 fine to medium sand with some coarse grains and some balls of white and orange 7.5YR7/6 clay
7.1 - 7.6	Very pale brown 10YR8/3 fine to medium sand with some coarse grains and some balls of white and orange 7.5YR7/6 clay
7.6 - 8.1	Very pale brown 10YR7/6 and yellow and white damp clayey medium to fine sand
8.1 - 8.6	Very pale brown 10YR7/6 and yellow and white damp clayey medium to fine sand with lumps of white clay
8.6 - 9.1	Slightly clayey medium to fine whitish sand
9.1 - 9.6	Slightly clayey medium to fine whitish sand
9.6 - 10.1	Slightly clayey light yellowish brown 10YR6/4 medium to fine sand
10 .1 - 10.6	Slightly clayey light yellowish brown 10YR6/4 medium to fine sand with lumps of white and orange mottled clay
10.6 - 11.1	Slightly clayey light yellowish brown 10YR6/4 medium to fine sand with some lumps of white and orange mottled clay
11.1 - 14.6	Slightly clayey light yellowish brown 10YR6/4 medium to fine sand with lumps of brighter orange and yellow mottled clay
Hard siliceous fine to medium grained sandstone	
14.6 - 15.2	Sand from the top (collapsed from above)
15.2 - 15.34	Hard white, siliceous sandstone fine to medium grained
Fractured fine to medium sandstone with thin clay layers, fairly weathered	
15.34 - 15.4	Fracture with orange staining and dark red spots (up to 2 mm)
15.4 - 15.54	Orange and red bands dipping at about 10 degrees
Fine to medium sandstone, fairly weathered	
15.54 - 15.56	Very dark purple band with dark grey micaceous clayey band beneath a fracture, above purple band white for 5 mm, then into orange staining

15.56 - 15.63	More distinct banding, clay and fracture
15.63 - 15.68	Thin dark purple partings
15.68 - 15.70	Break along distinct dark purple and clay band
15.70 - 15.74	Dark red thin clay layer, fracture with small (2 mm) black spots
15.74 - 15.90	Very broken, thin clay layers associated with dark purple and orange bands
15.90 - 16.00	Orange and white banded fine to medium grained sandstone, white layers can be clayey - especially when next to darker bands. Large vertical fracture
16.00 - 16.10	Dark red fine to medium grained sandstone with orange staining Vertical fracture with small (1-2 mm) quartz vein
16.10 - 16.20	Broken, red-pink fine to medium grained sandstone with well rounded grains, some orange and grey partings, the grey being clayey

Geological log: BGS8

Soil/ferrecrete horizon	
0.0 - 0.6	Dark yellowish brown 10YR3/4 fine to medium sandy soil
0.6 - 1.1	Dark yellowish brown 10YR3/4 fine to medium sandy soil with some yellowish red 5YR5/8 clay with fine sand grains and occasional grey and orange partings
1.1 - 1.6	Yellowish red 5YR5/8 clay with fine sand grains and occasional grey and orange partings.
1.6 - 2.1	Yellowish red 5YR5/6 clay with some fine sand; with red 2.5YR5/6 and light grey partings. Occasional small purple black nodules.
2.1 - 2.6	Harder yellowish red 5YR5/6 clay with some fine sand; with red 2.5YR5/6 and light grey partings. Occasional small purple black nodules
Clayey very weathered horizon	
2.6 - 3.1	Red 2.5YR5/6 clay - with some fine sand - occasional small (5 mm) rounded purple/black nodules. White and orange clay partings.
3.1 - 3.6	Red 2.5YR5/6 clay - with some fine sand - occasional small (5 mm) rounded purple/black nodules. Red, white and orange clay partings
3.6 - 4.1	Red 2.5YR5/6 clay - with some fine sand - occasional small (5 mm) rounded purple/black nodules. Red, white and orange clay partings
4.1 - 4.6	Brownish yellow 10YR6/8 clay. Soft and plastic - sets very hard - very little silt fine sand
4.6 - 5.1	Yellow clay 2.5YR7/6 with some silt or fine sand occasional harder fragments. Some grey, red and orange partings.
5.1 - 5.6	Yellow clay 2.5YR7/6 with some silt or fine sand occasional harder fragments. Some red, orange, light grey clay and dark grey partings (1 - 2 mm across)
5.6 - 6.1	Yellow clay 2.5YR7/6 with some silt or fine sand occasional harder fragments. Some red, light grey and orange 10YR6/8 clay partings
6.1 - 6.6	Yellow clay 2.5YR7/6 with some silt or fine sand occasional harder fragments. Some light grey and orange 10YR6/8 clay partings, some hard light grey chips and fine sand and silt
6.6 - 7.1	Olive yellow 2.5YR6/6 clay with silt and increased light grey and orange partings.
7.1 - 7.6	Olive yellow 2.5YR6/6 clay with silt and increased light grey and orange partings, with dark grey/black and white limestone
7.6 - 8.1	Olive yellow 2.5Y6/6 silty clay, many light grey and orange 10YR6/8 partings, some red mottles and limestone chips
8.1 - 8.6	Olive yellow 2.5Y6/6 silty clay, many light grey and orange 10YR6/8 partings
8.6 - 9.1	Soft olive yellow clay with orange and light grey partings. Harder limestone chips
Weathered mudstones	
9.1 - 9.6	Olive green weathered mudstone very occasional calcareous chips
9.6 - 10.1	Olive green mudstone with some dark grey/black mudstone - occasional white and dark grey partings
Fairly weathered mudstones	
10.1 - 10.6	Dark grey/black mudstone - many orange and red layers along bedding
10.6 - 11.1	Dark grey/balck mudstone with red and orange layers along bedding, with hard black and white mudstone.
Hard shelly massive to broken limestone, some weathering	
11.1 - 11.2	Hard dark black limestone with white mottles - also red and orange chips
11.15 - 11.25	Black massive limestone with white swirls and orange staining
11.25 - 13.1	Broken limestone with much orange and olive brown staining.
12.2	3 mm thick calcite band with light grey clay sticking to the edges.
12.2 - 13.1	Broken Limestone with increased clay content.

Geological log: BGS9

Soil/ferrecrete horizon	
0.0 - 0.6	Fine to medium grained sandy soil. Reddish Yellow 7.5YR6/6
0.6 - 1.1	Fine to medium sand; reddish yellow 7.5YR6/8. Frequent hard subrounded - sub angular nodules up to 15 mm. Generally red 10R4/8 with black and reddish yellow 5YR6/8 mottles
1.1 - 1.6	Fine to medium sand; reddish yellow 7.5YR6/8. Frequent hard subrounded to rounded nodules up to 20 mm, dusky red 10R3/4 on the outside and black inside. Generally red 10R4/8 with black and reddish yellow 5YR6/8 mottles
Clayey very weathered sandstone horizon	
1.6 - 2.1	Fine to medium sand; reddish yellow 7.5YR6/8 - no nodules. Occasional small balls of yellowish red 5YR5/8 and light grey clay.
2.1 - 2.6	Fine to medium sand; reddish yellow 7.5YR6/8. Increased clay content. Chips of hard, well cemented fine - medum grained sandstone.
Weathered fine to medium sandstone	
2.6 - 3.45	Fine-medium well cemented sandstone. Buff coloured with orange and white grains, much mica. Black staining (often associated with 1 mm thick clay layers). Clay layers associated with black spots and orange partings. Bedding at about 17° - cleaves easily along the bedding. Bedding can vary in thickness.
3.45 - 3.7	More orange and black banding
3.7 - 4.0	Becoming more broken and more banded. Orange, white, red with grey clay. Sandstone has more black particles.
4.0	Bedding is more convoluted and varies in thickness (pretty indistinct).
4.0 - 4.3	Buff sandstone with orange staining and pink/red layers. Bedding varies in thickness.
4.3 - 4.9	Orange red and white banded fine- medium grained sandstone with orange and black grains. Some more micaceous layers with grey clay associated.
4.9 - 5.0	Broken core - as above with more clay associated with the mica.
5.0 - 5.2	Broken Sandstone with orange and red layers and grey clay within the sandstone.
5.2 - 5.8	Pale olive banded sandstone - deep red, orange and with grey clay layers, bedding indistinct and convoluted.

Geological log: BGS10

Soil/ferrecrete horizon	
0.0- 0.7	Fine to medium clayey sand; brown 7.5YR4/3. Some light grey and orange clayey partings.
0.7 - 1.2	Fine to medium sand; yellowish red 5YR5/6. Many well cemented sandy nodules (about 20 mm) and broken pieces mainly red with some orange and black.
1.2 - 1.7	Broken pieces of multicoloured nodular sandstone. Some small rounded dark nodules. Some light grey partings within the nodular sandstone.
1.7 - 2.2	Broken pieces of multicoloured nodular sandstone, some light grey partings within the nodular sandstone
Clayey very weathered fine to medium nodular sandstones	
2.2 - 2.7	Broken pieces of multicoloured nodular sandstone, some light grey partings within the nodular sandstone with increased clay.
2.7 - 3.2	Less clay, but more fine to medium sand. Nodular multicoloured sandstone probably from above.
3.2 - 3.7	Nodular multicoloured fine to medium sandstone with lumps of clay with grey and orange partings.
3.7 - 4.2	Nodular multicoloured fine to medium sandstone with lumps of clay with grey and orange partings and dark grey mudstone chips.
4.2 - 4.7	no samples
Weathered clayey shaley mudstones	
4.7 - 5.2	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding.
5.2 - 5.7	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding
5.7 - 6.2	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding
6.2 - 6.7	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding
6.7 - 7.2	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding
7.2 - 7.7	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding with maybe some silt
7.7 - 8.2	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding
8.2 - 8.5	Dark greenish grey 10YR4/- clayey mudstone. Shaley with light blue grey partings and mottles. Some iron staning on the bedding with silt.
Weathered siltstones to fine grained sandstones with clay	
8.5 - 8.6	Yellow, fine grained sandstone/siltstone with some thin layers (0.5 mm) of dark grey clay. Bedding is convoluted.
Weathered clayey silty mudstones	
8.6 - 9.0	Pale olive 5Y6/3 siltstone/mudstone with dark grey purple clay along fracture surfaces with some light grey and orange staining.
9.0 - 9.8	Pale olive 5Y6/3 siltstone/mudstone with dark grey purple clay along fracture surfaces with some light grey and orange staining. Light grey partings at all angles with fractures along them.
9.8 - 10.0	Some coarser grained layers up to 10 mm with complex sedimentary structure.
10.0 - 10.5	Grey silty mudstone with light grey along fractures and some orange staining. Occasionally some lighter complex structures of fine sands and silts. Some show cross bedding and others are small and rounder. Increased orange and red staining with grey clay fracture surfaces. Purple/black spots on the grey clay.
10.5 - 10.7	More silts loaded into the mudstone
10.7 - 11.4	Dark Grey massive mudstone with little sand or silt. Some light grey fractures with orange, red and black staining.

Geological log: BGS11

Soil/ferrecrete horizon	
0.0 - 0.9	Reddish Yellow 7.5YR6/6 fine to medium grained sandy soil, few small dark nodules.
0.9 - 1.4	Strong Brown 7.5YR5/6 fine to medium grained sand, many hard sandy dusky red 10R3/4 and black nodules (< 20 mm)
Clayey very weathered nodular sands	
1.4 - 1.9	Yellowish red 5YR5/8 clayey sand. Clay occurs as light grey and yellowish red and red partings. Many hard sandy reddish brown nodules 2.5YR4/4 and occasional dark hard well rounded nodule (<3 mm)
1.9 - 2.4	Reddish yellow 7.5YR6/8 clayey sand with much light grey and yellowish red clay partings, and a few reddish brown nodules.
Weathered fine to medium grained sandstones, some clay	
2.4 - 2.9	Yellowish 10YR8/4 fine to medium sand with some mica, some light grey clay.
Fine to medium grained sandstone, fairly weathered	
2.9 - 3.1	Pale brown consolidated sandstone.
3.1 - 4.1	Pale brown fine to medium grained cross bedded sandstone with white clayey cement, thin black micaceous and carbonaceous partings and light grey clay
4.1 - 4.7	Pale brown fine to medium grained cross bedded sandstone with white calcareous cement, thin black micaceous and carbonaceous partings and light grey clay and increased orange brown and brownish yellow staining.
4.7 - 5.0	Pale brown fine to medium grained cross bedded sandstone with white clayey cement, thin black micaceous and carbonaceous partings and light grey clay
5.0 - 5.1	Much sand - no core recovery
5.1 - 5.7	Hard fine grained well cemented sandstone with white calcareous cement.

Geological log: BGS12

Soil/ferrecrete horizon	
0.6 - 1.1	Yellowish red 5YR5/8 sandy clay.
1.1 - 1.6	Yellowish red sandy clay with occasional light grey and red partings
1.6 - 2.1	Yellowish red sandy clay with light grey clay and red partings; some dark purple/black nodules (8 mm)
2.1 - 2.6	Yellowish red sandy clay with light grey clay and red partings; some dark purple/black and red nodules (8 mm)
Clayey very weathered sandstones	
2.6 - 3.1	Mottled clay with little sand: light grey, yellow 10YR7/8 and red 2.5YR5/8 mottles.
3.1 - 3.6	Soft brownish yellow clay 10YR6/8 with a little sand and a few light grey and red mottles.
3.6 - 4.1	Soft brownish yellow clay 10YR6/8 with a little sand and a few light grey and red mottles with more light grey clay and less red clay.
4.1 - 4.6	Soft and damp brownish yellow 10YR6/8 clay with little sand and some light grey partings
4.6 - 5.1	Soft and damp brownish yellow 10YR6/8 more friable clay with little sand and some light grey partings.
Weathered sandstones	
5.1 - 5.6	Sandy clay: brownish yellow and light grey clay - occasional piece of consolidated clayey sandstone
5.6 - 6.1	Light yellowish brown 2.5Y6/4 fine to medium grained sand with some coarse grains. Occasional piece of consolidated sandstone.
6.1 - 6.6	Light yellowish brown 2.5Y6/4 fine to medium grained sand with some coarse grains. Occasional piece of consolidated sandstone. Some chips of dark grey mudstone with light grey clay and reddish yellow clay staining.
6.6 - 7.1	Light yellowish brown 2.5Y6/4 fine to medium grained sand with some coarse grains. Occasional piece of consolidated sandstone. Some chips of dark grey mudstone with light grey clay and reddish yellow clay staining
7.1 - 7.6	Light yellowish brown 2.5Y6/4 fine to medium grained sand with some coarse grains. Occasional piece of consolidated sandstone. Some chips of dark grey mudstone with light grey clay and reddish yellow clay staining
Fairly weathered shaley mudstones and fine grained sandstones	
7.6 - 8.1	Light olive brown 2.5Y5.4 fine grained well cemented sandstone and dark grey mudstone with light grey clay and reddish yellow staining.
8.1 - 8.6	Dark grey soft shaley mudstone with reddish yellow and black staining along bedding.
8.6 - 9.1	Olive grey fine to meduim grained sandstone; with dark grey shaly mudstone and some siltstone
9.1 - 9.6	Dark grey shaly mudstone (some reddish yellow and black staining) with some fine grained sandstone chips
Shaley to silty mudstones	
9.6 - 10.1	Dark grey shaly mudstone with olive grey 5Y5/2 siltstone and fine sandstone
10.1 - 10.6	Dark grey silty mudstone - some reddish yellow and black staining along fractures and bedding - damp
10.6 - 11.1	Dark grey silty mudstone - some reddish yellow and black staining along fractures and bedding - damp increasingly hard
Interbedded fine to medium sandstones and silty mudstones	
11.1 - 11.6	Dark grey silty mudstone with yellowish/reddish brown staining; some olive brown fine - medium grained sandstone
11.6 - 11.9	Fine to medium grained well cemented olive brown sandstone - some red clay; with some dark grey shaly mudstone
Fine to medium grained sandstone	
11.9 - 12.2	Pale yellow 5Y8/2 fine to medium grained well cemented sandstone. Black and orange staining along fractures.

Interbedded fine to medium grained sandstone and fissile to shaley mudstones

12.2 - 13.7	Dark grey fissile mudstone interbedded with fine to medium grained well cemented white sandstone. Sandstone layers generally 1 - 4 mm thick - many load features. Some of the sandstone shows cross bedding. Hairline fractures in the sandstone have reddish yellow staining on the surfaces. Thin black silty, micaceous stringers. Also mica on some fracture surfaces
13.7 - 14.3	Light olive grey fine to medium grained well cemented siliceous sandstone with some cross bedding. Very ocassional thin (< 1 mm) grey fissile mudstone layer.
14.3 - 14.4	Dark grey silty mudstone interbedded with Light olive grey fine to medium grained well cemented siliceous sandstone with some cross bedding. Very ocassional thin (< 1 mm) grey fissile mudstone layer - many load feature
14.4 - 14.6	Dark grey silty mudstone interbedded with Light olive grey fine to medium grained well cemented siliceous sandstone with some cross bedding, ocassional thin (< 1 mm) grey fissile mudstone layer - many load feature with increased sandstone. Very broken with red staining on fracture surfaces.
14.6 - 14.75	Interbedded shale and sandstone - sandstone cross bedded
14.75 - 15.0	Fine - medium grained well cemented white/pale olive green sandstone with occasional thin dark grey mudstone
15.0 - 15.2	Fine - medium grained well cemented white/pale olive green sandstone with increased thin dark grey mudstone (<4 mm) about 20% of total. Red staining along fractures

Fine to medium grained sandstone

15.2 - 15.7	Fine to medium grained well cemented cross bedded white sandstone with slightly calcareous cement. Very occasional thin (<1mm) mudstone band.

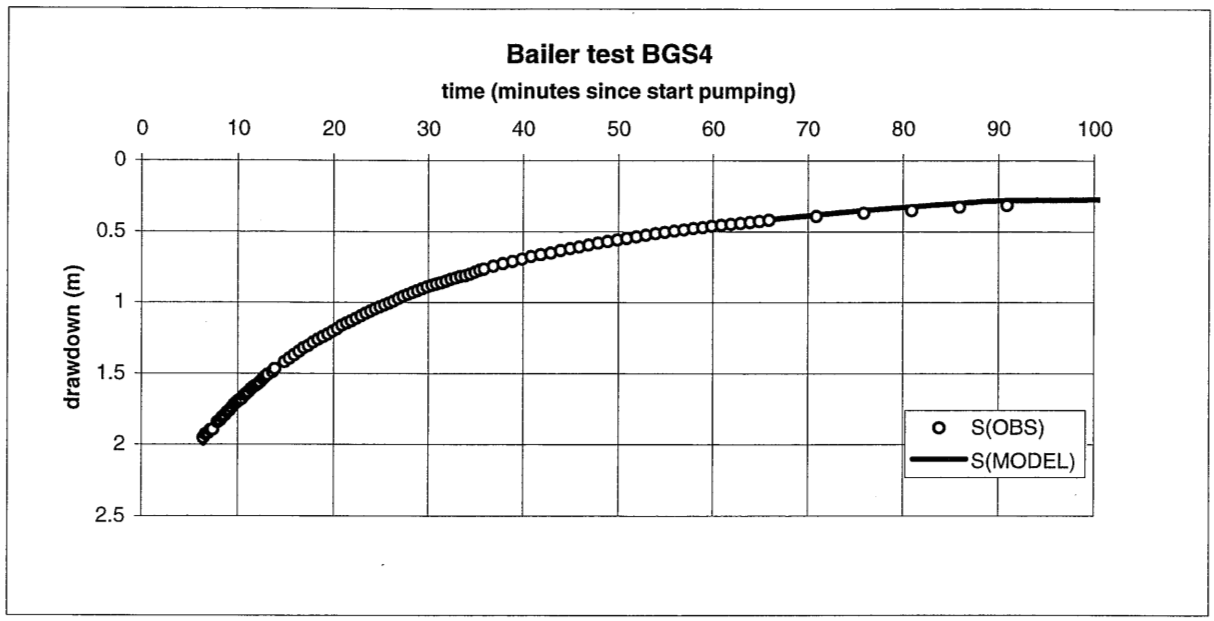
Annex 4: Test Pump data

BGS4: Bailer tests

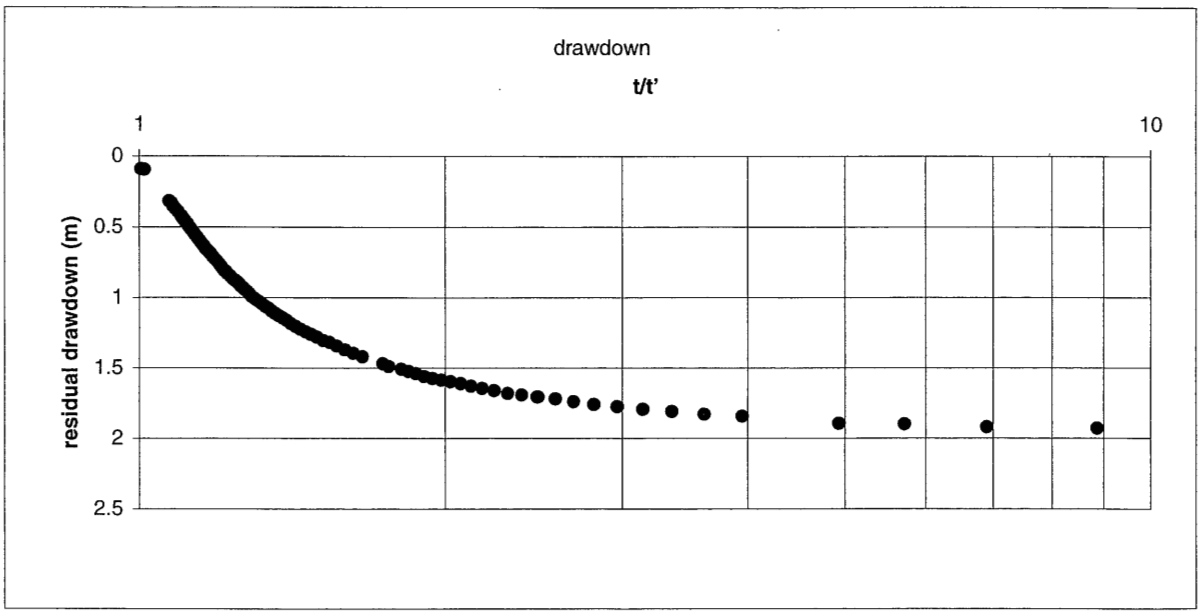
Bailer Test

date:	18/2/98		
rwl:	5.54 m btc		
casing	0 m agl		
length of pumping		5:44 mins	
No of bails		25	= average p-rate 0.33 l/s

Barker Analyis
T = 0.88 m2/d
S = 0.02
radius = 0.11m



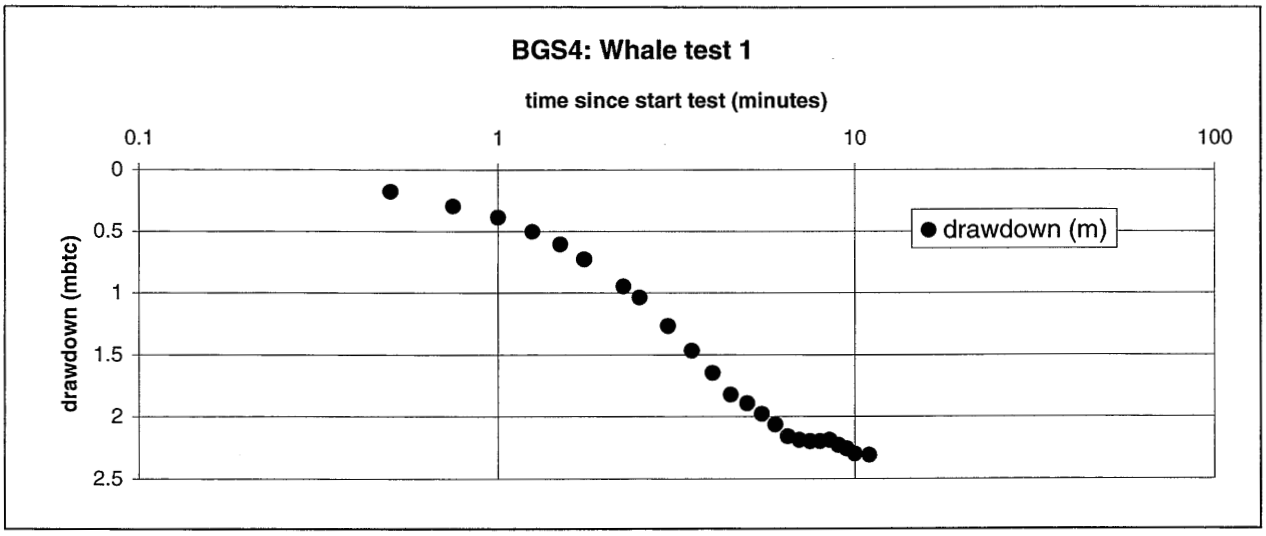
Theis recovery
T = 0.6 m^2/d

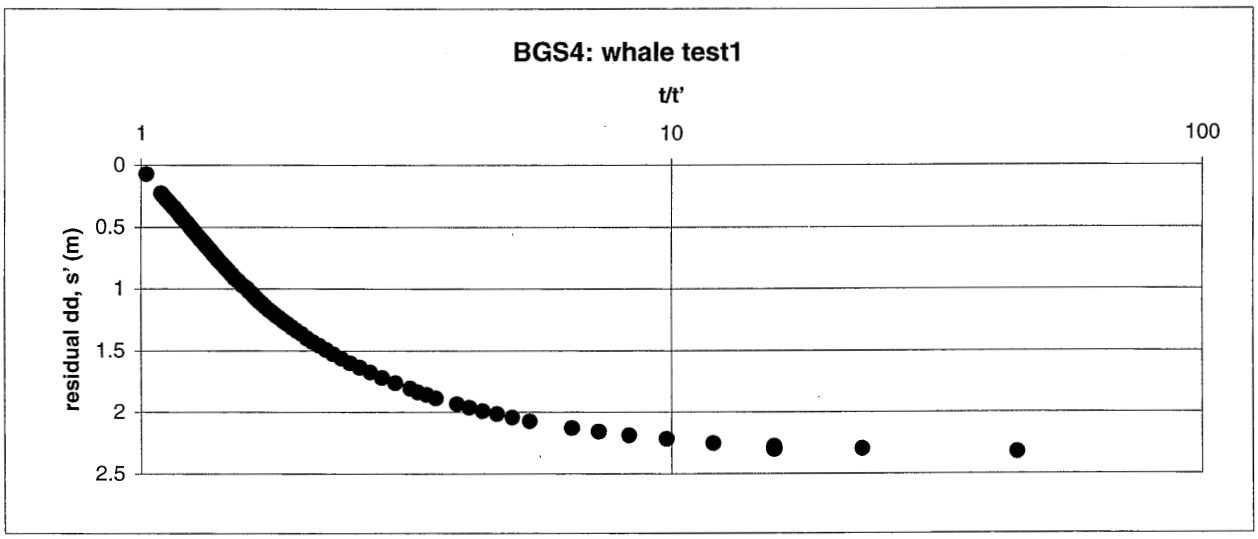


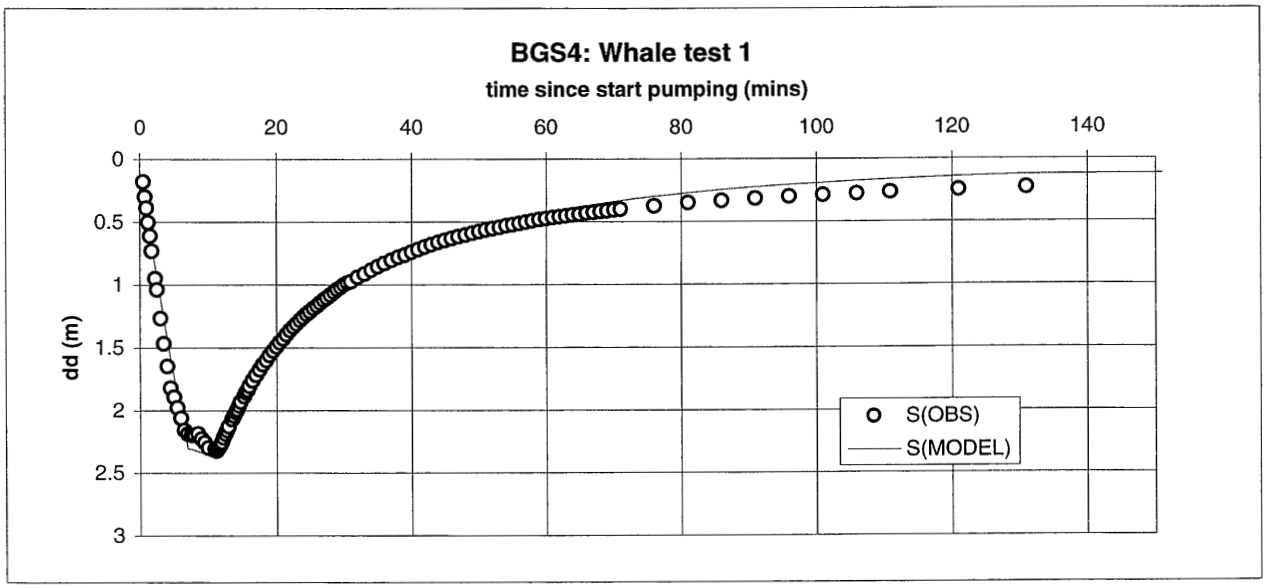
BGS4: Whale test 1

date:	19/2/98	
rwl	5.602 mbtc	mbc
casing	0 m btc	
using both whale pumps		
pumped for 11 minutes		
puming rate	0.326 l/s	7 minutes
	0.12 l/s	7-11 minutes

T = 1.8 m^2/d from dd
T = 0.84 m^2/d from recovery
T = 1.9 m^2/d from Barker



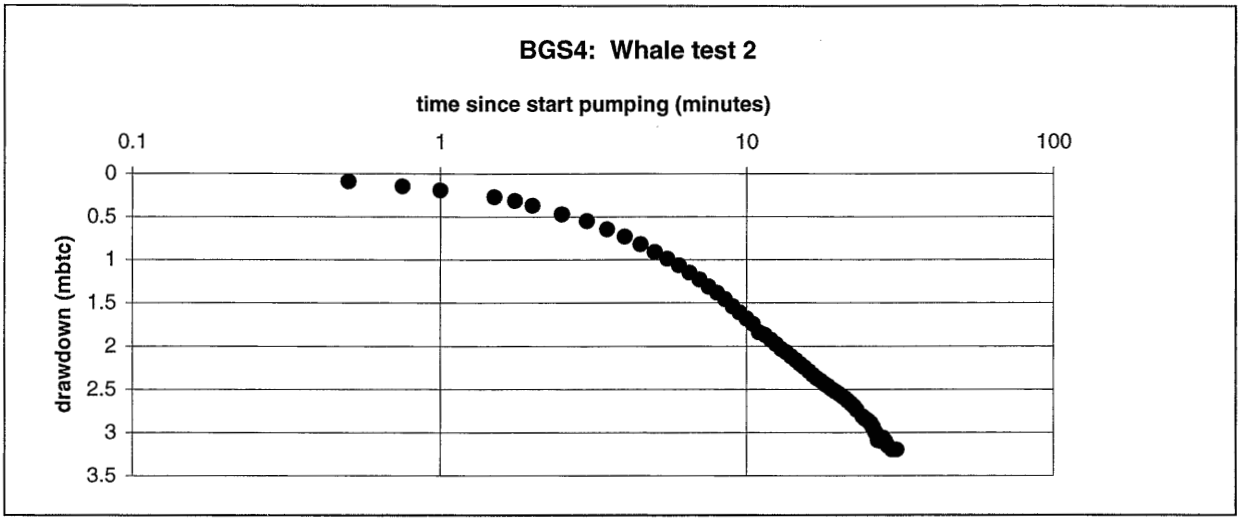


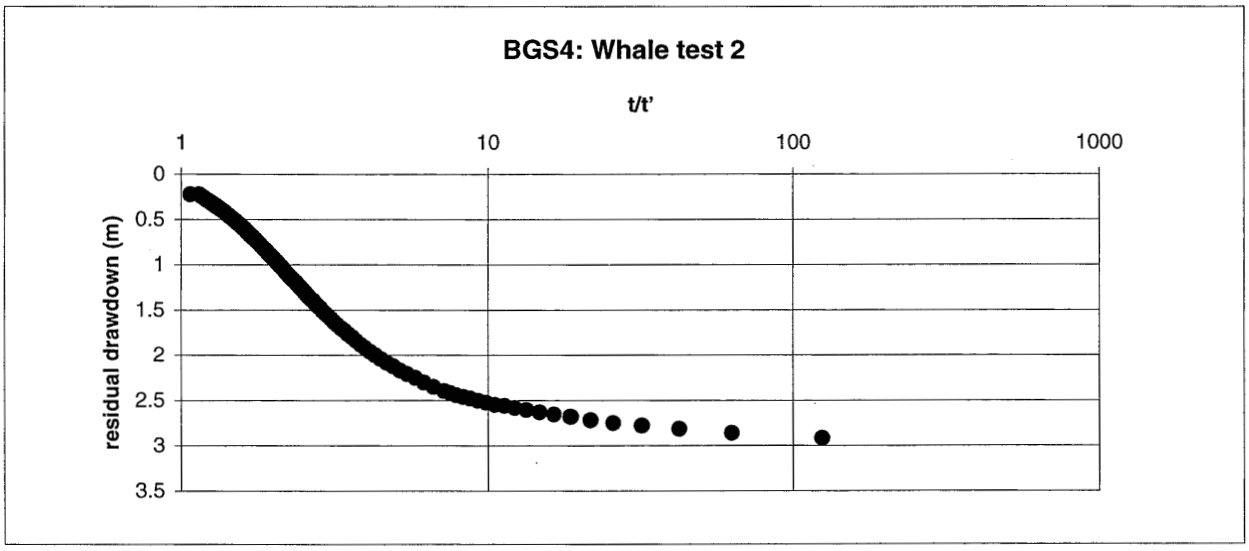


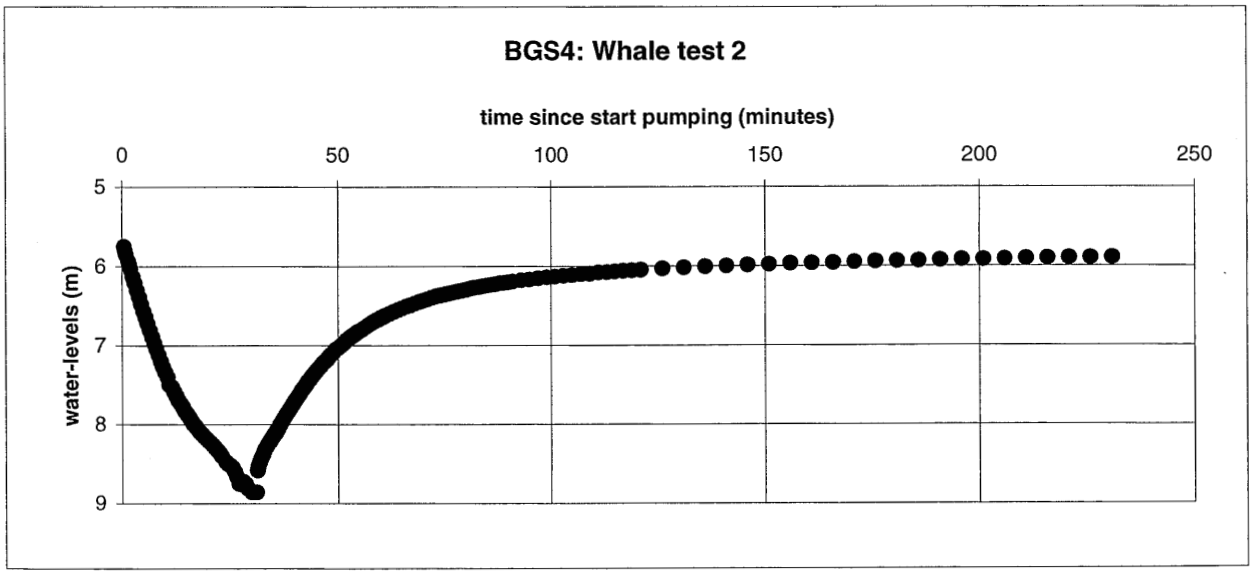
BGS4: Whale test 2

T from drawdown = 0.73 m^2/d
T from recovery = 0.54 m^2/d

date: 20/2/98
rwl 5.66 mbtc mbc
casing 0 m btc
using one throttled back whale pump
pumped for 31 minutes
puming rate 0.131 25 mins
0.108 25-31 mins
average rate 0.127 l/s







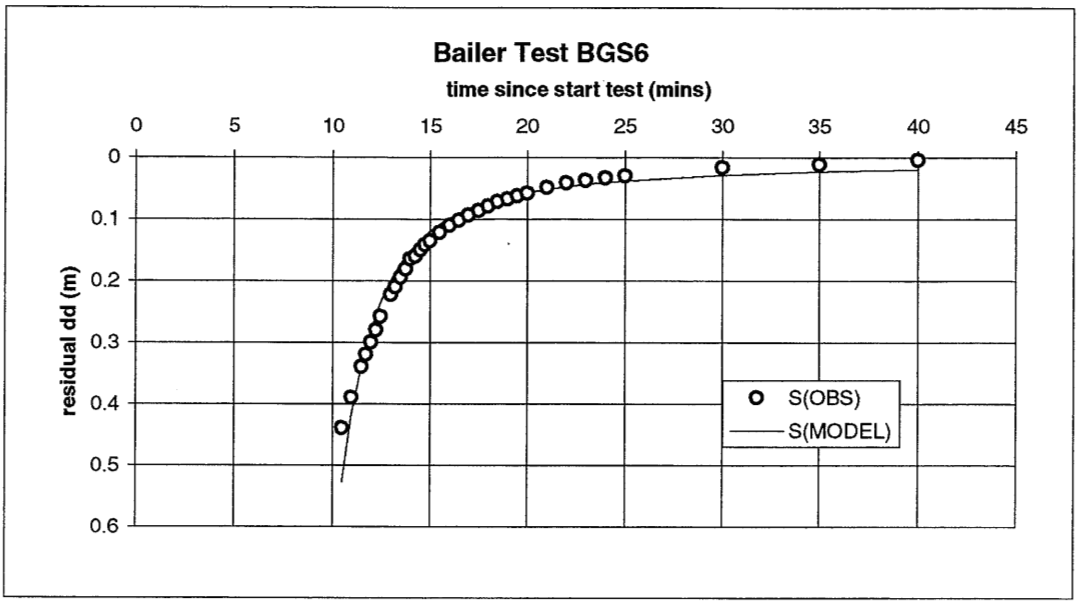
BGS6: Bailer Tests

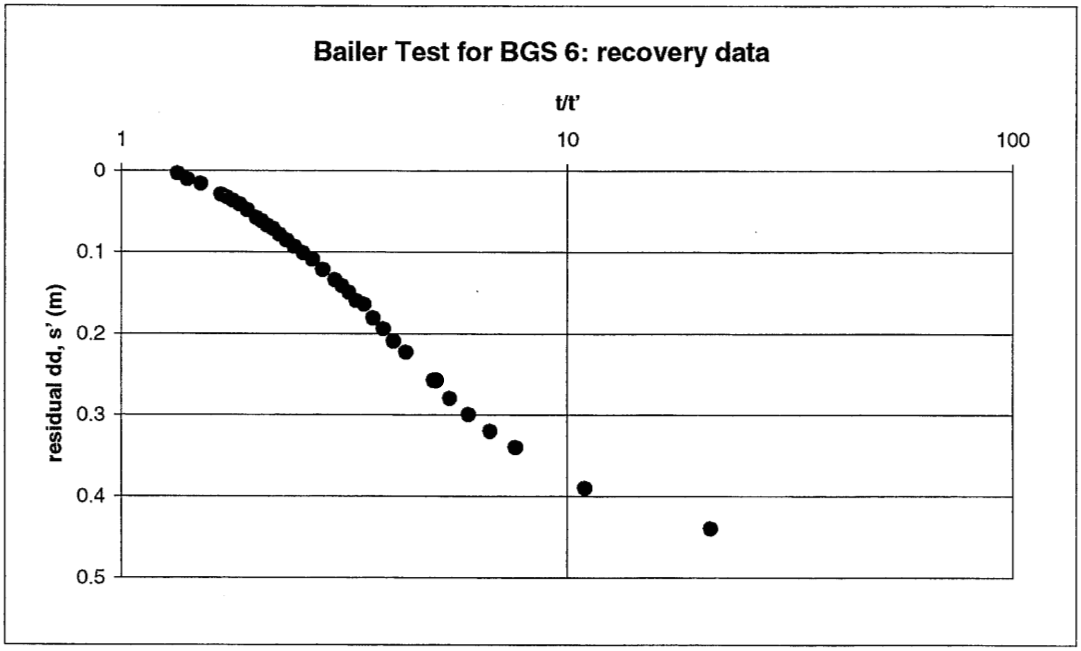
date: 19/2/98
40 bails in 10 mins
=0.3 l/s
casing: 0.25 m agl
rwl = 5.19 mbtc

Barker Analyis
T = 35 m^2/d
S = 0.00025
radius = 0.12m

Theis Recovery

T = 12.5 m^2/d

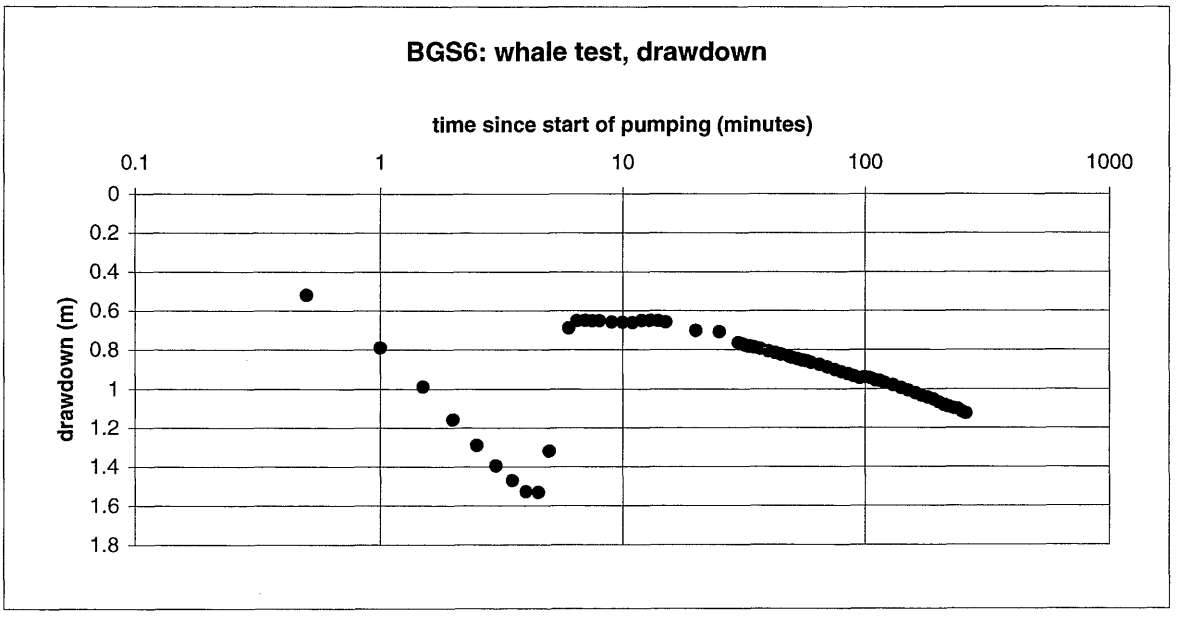


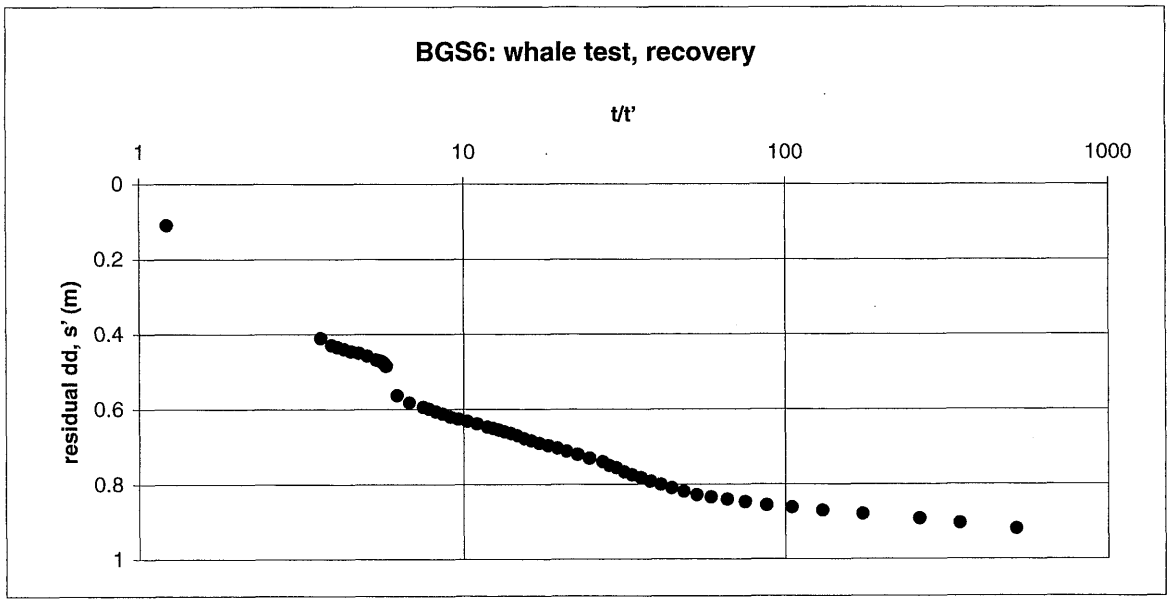


BGS 6: whale test

date: 18/2/98
using two whale pumps
Casing 0.25 m
rwl: 5.08 mbtc
length of pumping 260 mins
yield 0.325 l/s

T = 13.9 m^2/d from drawdown
T = 18.3 m^2/d from recovery

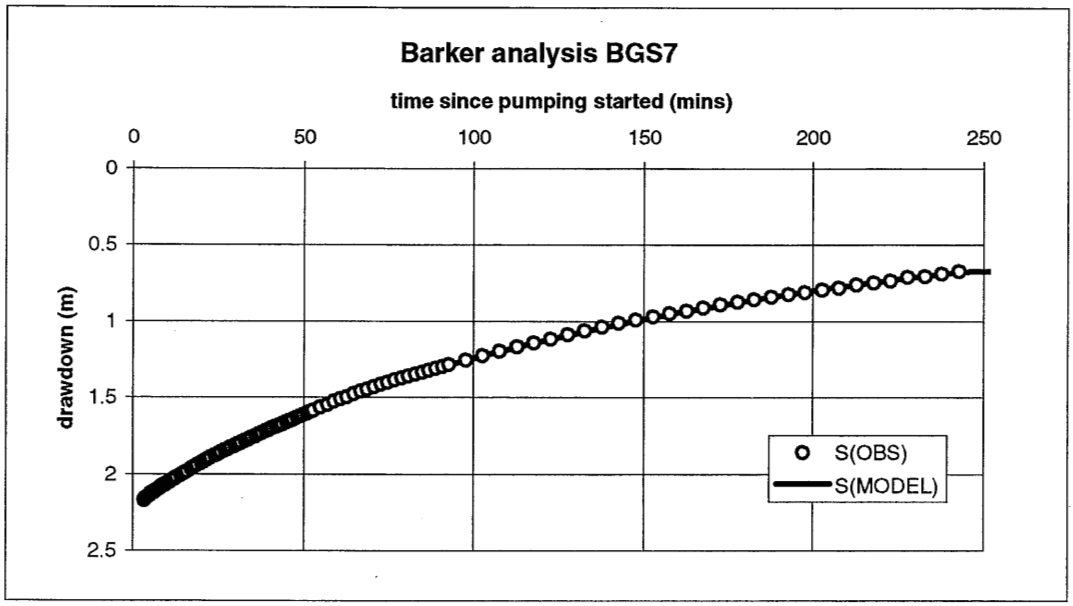


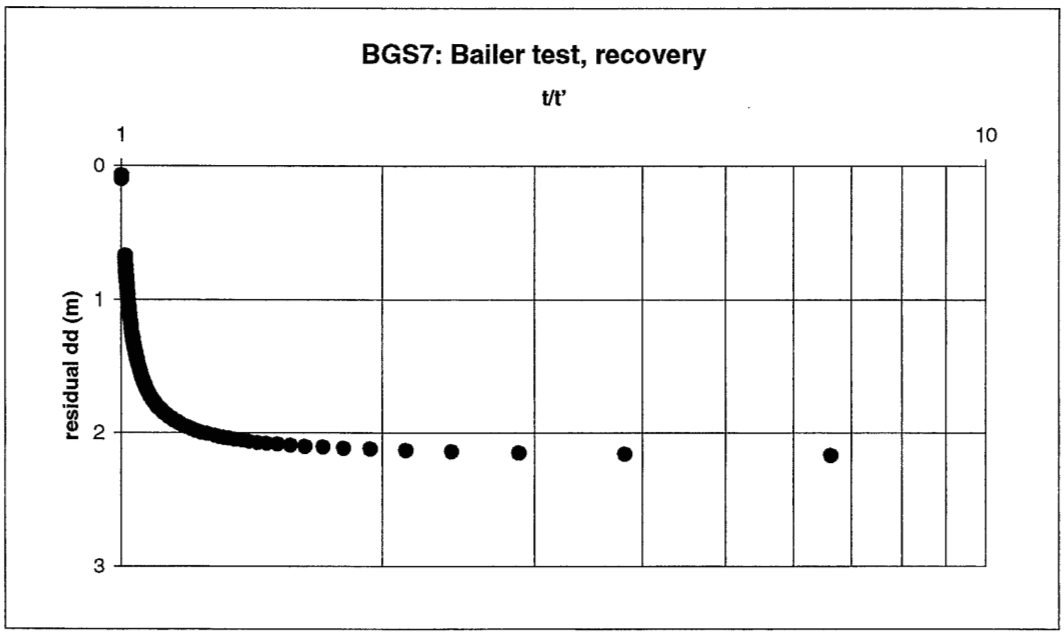


BGS7: test pump analysis

date: 19/2/98
using bailers
Casing 22 m agl
rwl: 4.04 m
No of bails 12 (10?)
time 02:50 minutes = prate 0.28 l/s

Barker analysis
T = 0.111 m2/d
S = 0.0017
radius = 0.088m



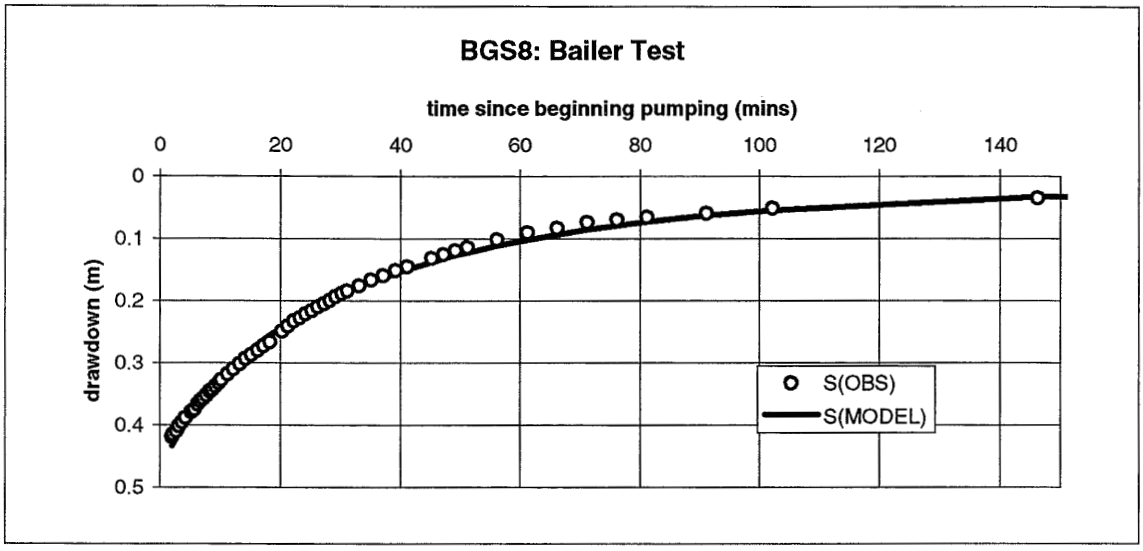


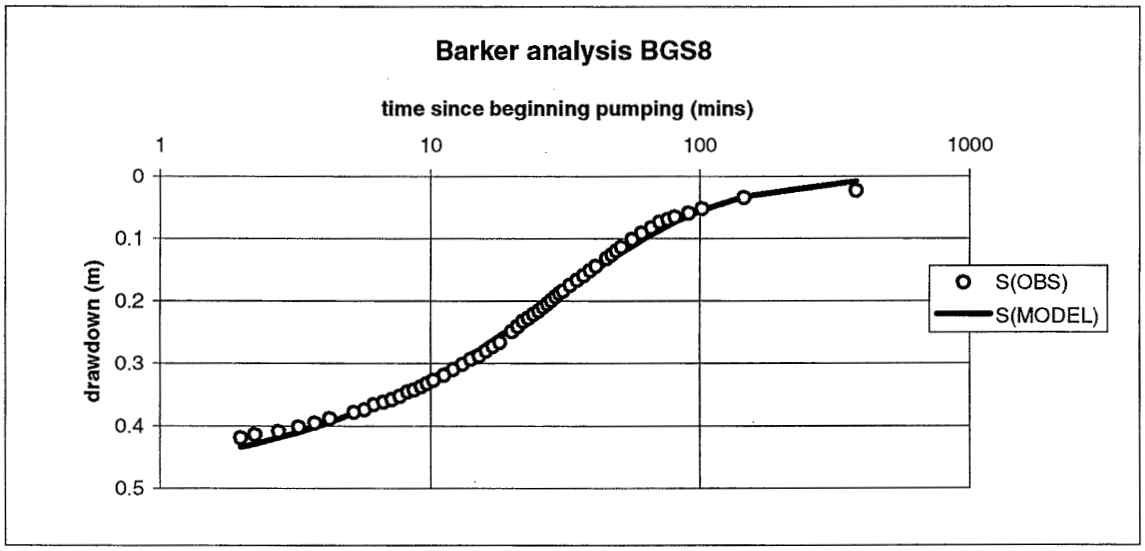
BGS8: Bailer Test

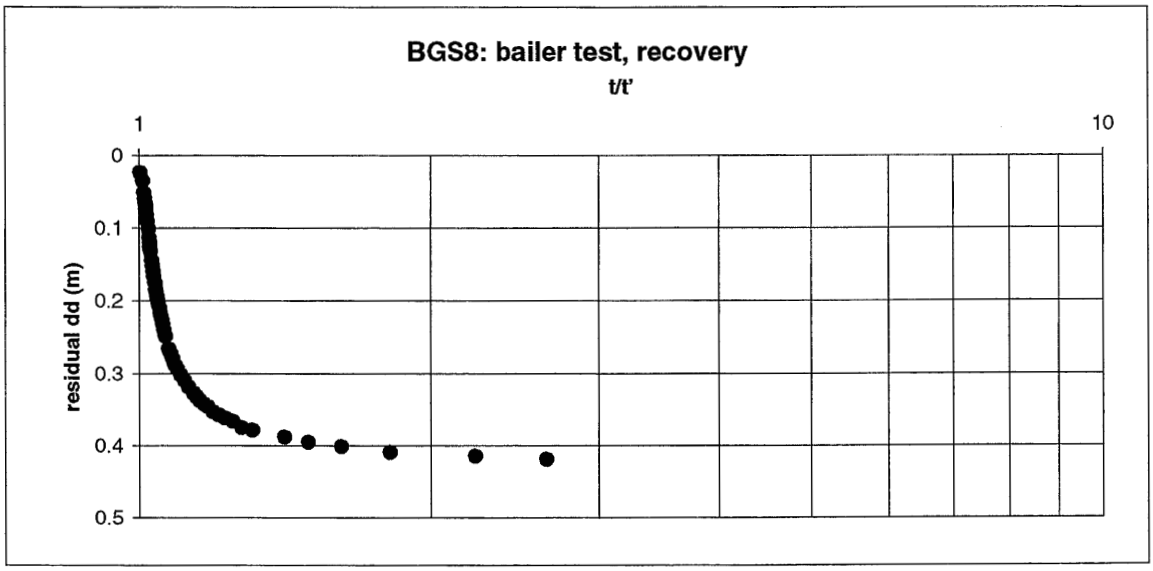
date:	20/2/98
using bailers	
casing	0.4 m agl
rwl:	6.14 m
length of pumping	1:14mins = prate 0.16 l/s
No of bails	3

Theis recovery
T = 0.43 m^2/d

Barker Analyis
T = 0.68 m2/d
S = 0.006
radius = 0.1m





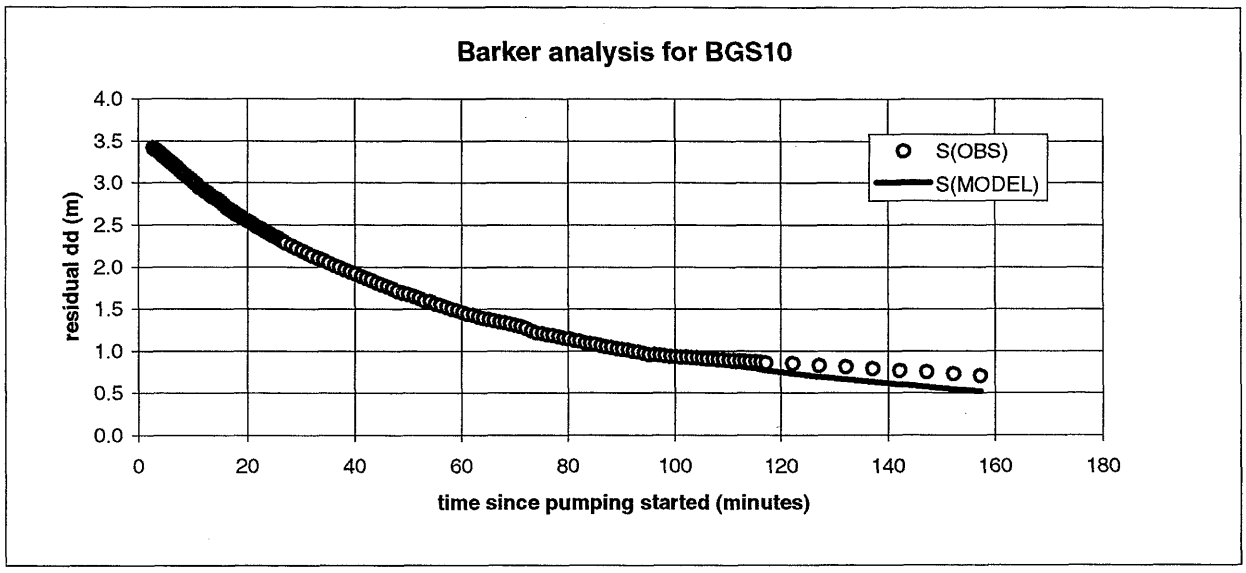


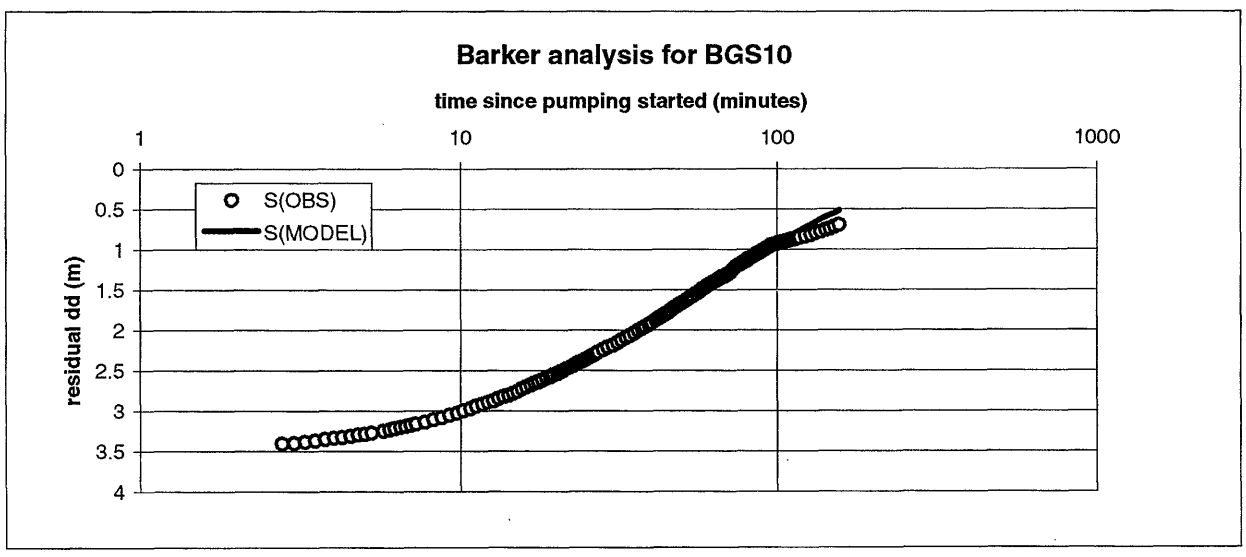
BGS10: bailer test

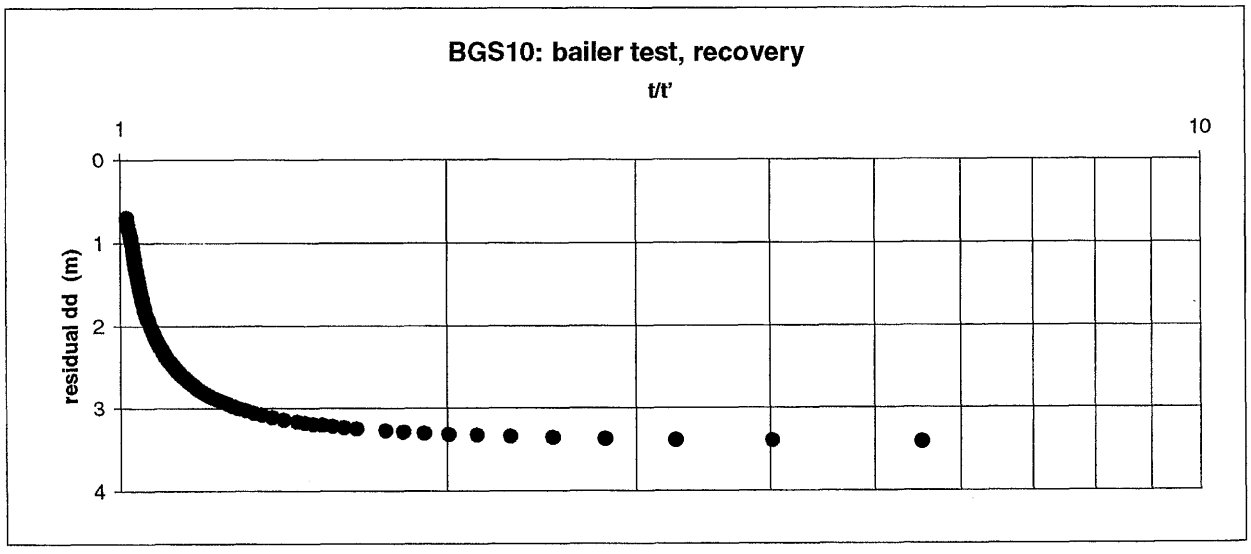
date:	20/2/98	
casing	0.1 m agl	
rwl:	2.118 m	
length of pumping	02:16	mins
No of bails	10	= p-rate - 33 l/s

Theis Recovery
0.17 m^2/d

Barker Analyis
T = 0.221 m2/d
S = 0.00011
radius = 0.064m







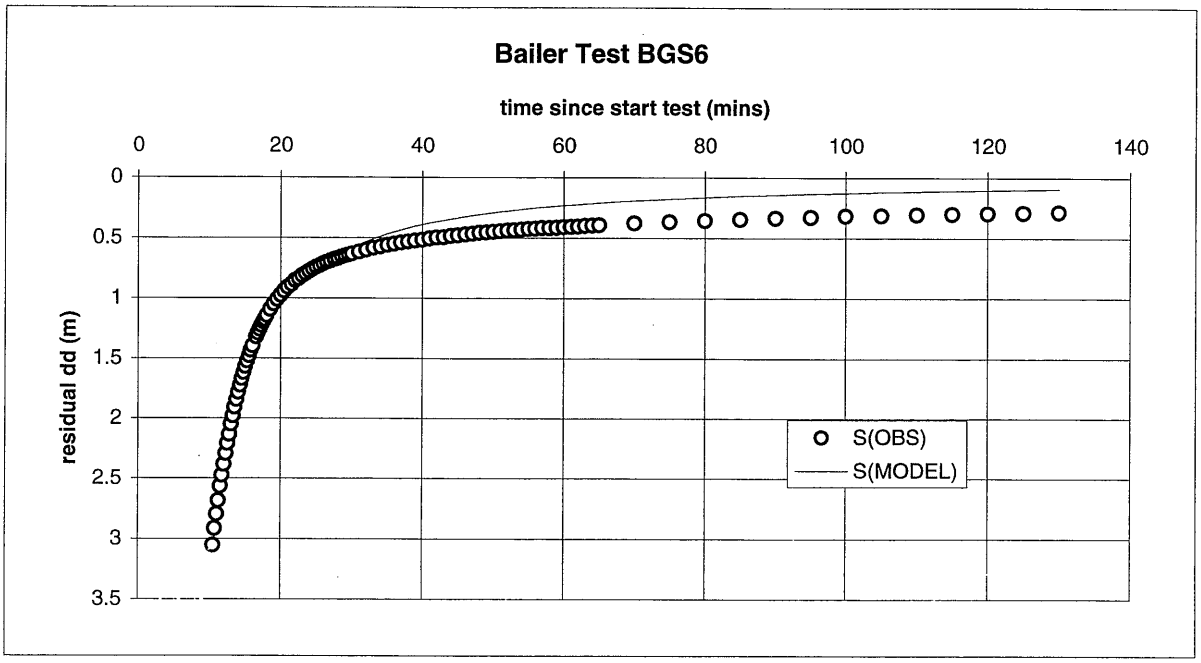
BGS12: Bailer test

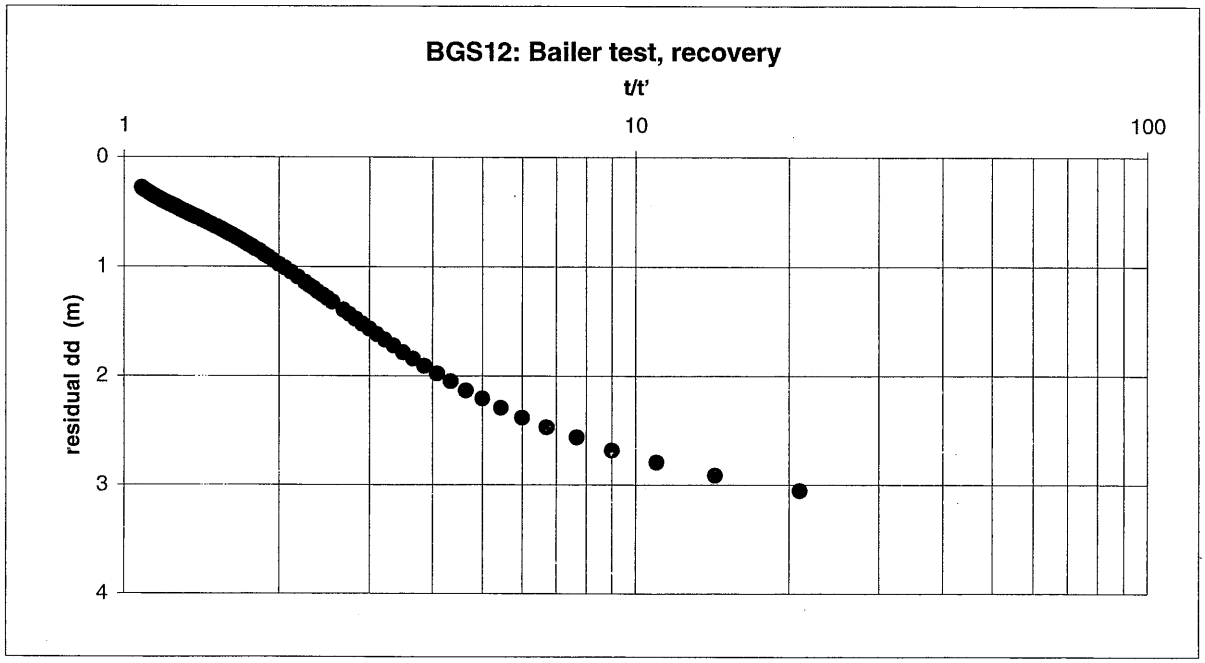
date: 21/2/98
39 bails in 10 mins
= 0.29 l/s
rwl = 5.205 mbtc
casing = 0.35 m agl

Barker Analyis
T = 1.9 m^2/d
S = 0.1 HIGH
radius = 0.074m

Theis Recovery

T = 1.6 m^2/d



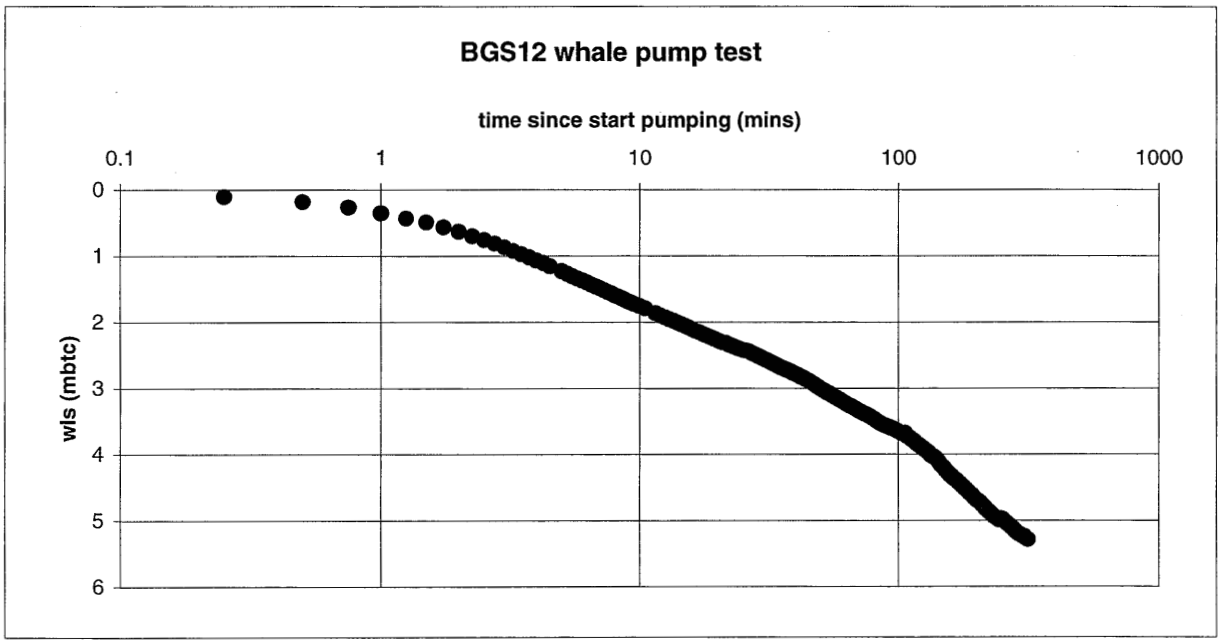


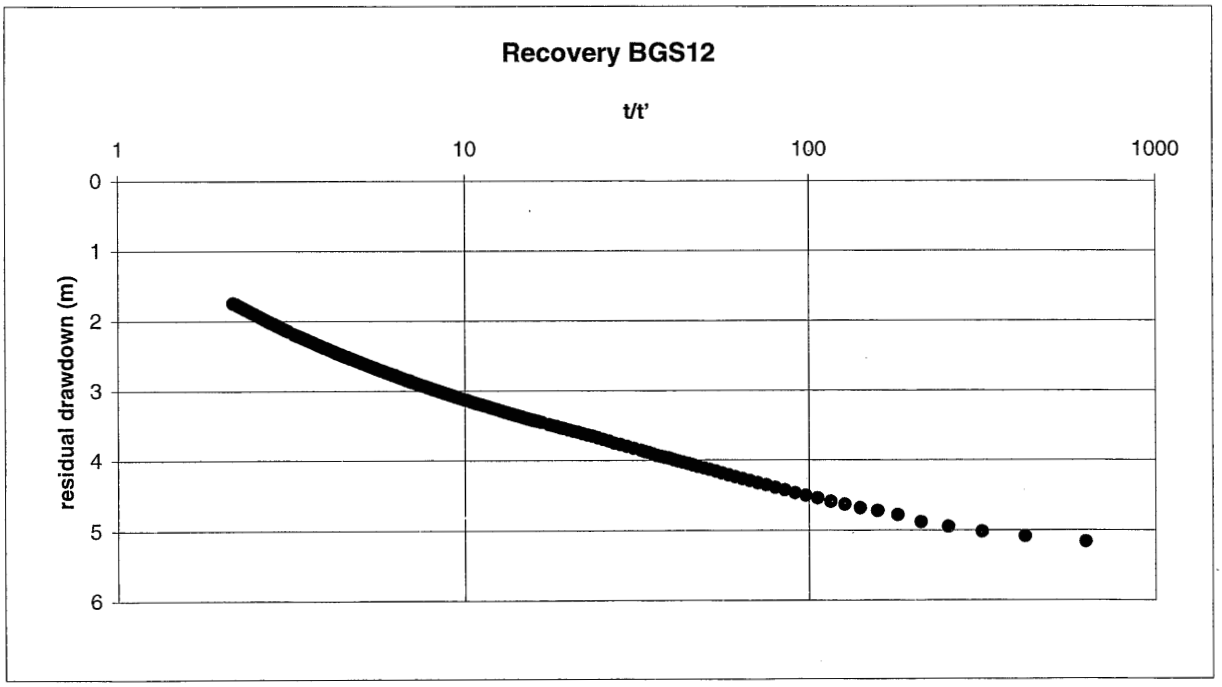
BGS 12: Whale test

date 13/3/98
casing 0.35 m agl
using one whale pump
rwl: 5.435 m btc
length of pumping 330 mins
yield 0.14 l/s

Recovery
early = 1.6 m^2/d
late = 0.85 m^2/d

Drawdown
early dd = 1.1 m^2/d
late dd = 0.58 m^2/d





Annex 5: Water quality data

Ochingini

Jan-Apr 1998

Easting	Northing	Site ID No	Bh No	pH	Temp deg C	Cond microS/cm	HCO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l
8.380783	7.018217	211	BGS6	6.74	28.9	1225	373	97.2	2.8	142	32.4	367	
8.3637	7.028333	212	BGS4	7.2	28.9	410	232	21.6	1.9	31.7	16	2.1	
8.424983	6.999283	214	BGS12	7.28	29.6	405	236	49.8	2.4	24.5	11.6	2.9	
8.407283	7.00735	228	BGS10	6.64	28.6	553	312	87.1	2.6	19.8	11.5	5.7	
8.394433	7.01025	229	BGS8	7.09	29.4	399	217	6	0.5	78.6	1	1.4	

Site ID No	NO3-N mg/l	Si mg/l	Sr mg/l	Ba mg/l	Li mg/l	B mg/l	Fe Total mg/l	Mn mg/l	I mg/l	F mg/l	Br mg/l
211		10.5	1.85	0.025	0.067	0.16	0.37	0.286	0.0084		
212		33.3	0.225	0.157	0.013	-0.03	0.12	1.56	0.0037		
214		14.3	0.451	0.555	0.021	-0.03	0.1	0.525	0.0022		
228		7.8	0.212	0.164	-0.007	0.05	2.41	1.49	0.0237		
229		11.8	0.157	0.058	-0.007	-0.03	0.58	0.059	0.0022		