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TECHNICAL REPORT WC/98/52
Overseas Geology Series

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

J Davies and A M MacDonald





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Children helping with geophysical fieldwork in Obi.

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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 groundwater potential of the Awgu Shales in North Obi was investigated along a traverse from Ijegwu to Ameka. Testing was carried out between February and March 1998. EM34-3 and magnetic surveys were carried out over a 12 km traverse and ten resistivity soundings carried out. Ten boreholes were drilled to an average depth of 23 m and core samples taken from the last 3 m. Chip and core samples were analysed and logged. Three boreholes (BGS26, BGS27 and BGS30) were completed with screen and casing. Test pumping and water quality analysis was carried out on these three boreholes. The following conclusions can be made from the test traverse.

- The Awgu Shales comprise very soft shallow marine mudstone with negligible permeability and few open fractures. They have a very low potential for groundwater development.
- The weathered zone within the Awgu Shale is 8-15 m thick. Much secondary gypsum was deposited within the weathered zone either in nodules or veins.
- Where groundwater exists within the Awgu Shales, the quality is very poor and not suitable for human consumption.
- Occasional siltstone and limestone layers are present, possibly relating to the Agbani Sandstone marked on the geology map – these had little groundwater potential
- A thicker sandstone unit is present at Ameka, beyond the Agbani Sandstone outcrop marked on the geology map. This sandstone is likely to be the true Agbani Sandstone and may form an important aquifer - however no drilling could be carried out because of access problems.
- EM34-3 survey results indicate that the electrical conductivity of the Awgu Shales is very high (vertical coil ~100 mmhos/m). There are two reasons for the high conductivity: (1) the saline water within the mudstone; and (2) the high proportion of clay present within the soft mudstone.
- Vertical dipole (horizontal coil) results were always less than those from the horizontal dipole (vertical coil). This indicates that the conductivity reduces with depth, probably correlated with the reduction of mudstone weathering with depth.
- At Ameka geophysical signals were similar (both horizontal and vertical readings equal and less than 40 mmhos/m), probably due to the presence of thicker sandstone layers within the Agbani Sandstone. No drilling could be done to substantiate these results.
- The resistivity surveys all gave very similar results: a surface layer of moderate resistivity followed by a thick very low resistivity layer (about 6 ohm-metres).
- An alluvial deposit was identified from the EM34-3 survey within the flood plain of the River Obi. Drilling proved the presence of fine sand interbedded with swelling clays. Groundwater quality was good and in sufficient quantities for a hand dug well.
- No igneous intrusions were identified from the magnetic survey or drilling.

1. BACKGROUND INFORMATION

A 10 km long traverse was undertaken across the Awgu Shales in north Obi. The traverse ran eastward from the tarmac road at Ijegwu to Ameka. The purpose of this traverse was to study the hydrogeological characteristics of the Awgu Shales and test the appropriateness of various geophysical methods for siting boreholes. The Awgu Shales are composed of compact black to dark grey carbonaceous shaley mudstones with subordinate dark grey siltstones and thin hard dark grey muddy limestones. These sediments were deposited in shallow marine conditions containing a fauna of shallow-water marine macro-fossils. The geological map indicated that the traverse should also cut across the Agbani Sandstone formation. The traverse passed through five villages, Ijegwu Uhye Ito, Ijegwu Eji Ito, Orikpe Ameka, Ameka Ipinu and Okpaga Odiapa. The locations of Ijegwu and Ameka are shown in Figure 1.

Access along this traverse line is only possible in the dry season. Even then some of the bridges had to be bypassed by the drilling rig. The final bridge before Ameka Ipinu could not be crossed, therefore, no drilling was possible beyond this point. There are few wells or boreholes in this part of Obi. The majority of people walk long distances in the dry season to obtain water from small seepages or streams. However, within Ameka Ipinu at the end of the traverse, the ground is sandy and small wells are successful long into the dry season. A borehole drilled within the Ameka has high yields but there are frequent problems with corrosion of the rising main due to the high salt content of the water.

Figure 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 north Obi. Along the traverse line the ground is generally flat, cut by several valleys. The area is characterised by grassland with well spaced trees.

Table 1. Available map information for north Obi traverse.

Data type	Source
Aerial Photographs	Sheet 270, run 11, 46-53
Topographic maps	Sheet 270, run 12, 230-238
Geology map	Sheet 270, run 13, 13-16
	1:50,000 Sheet 270SE Oturkpo SE
	1:50,000 Sheet 270SW Oturkpo SW
	Makurdi Area, Map No. 64, Scale 1:250,000

2. GEOPHYSICS

Various geophysical surveys were carried out at along the north Obi traverse. The main traverse was an EM34-3 survey from Ameka to Ijegwu. According to the available maps (see Figure 2) this should have crossed both the Agbani Sandstone and two small igneous intrusions. A magnetic survey was also carried out over the last part of the traverse to try and identify the intrusions. Table 2 gives a summary of the various traverses and soundings. The data are presented in Appendix 1.

The EM34-3 data indicate that the electrical conductivity of the rock is fairly high (see Figure 4). Generally, the horizontal dipole (vertical coil) has conductivity values in excess of 80 mmhos/m and the vertical dipole (horizontal coil) conductivity values between 40 and 60 mmhos/m. There are several points of interest along the traverse:

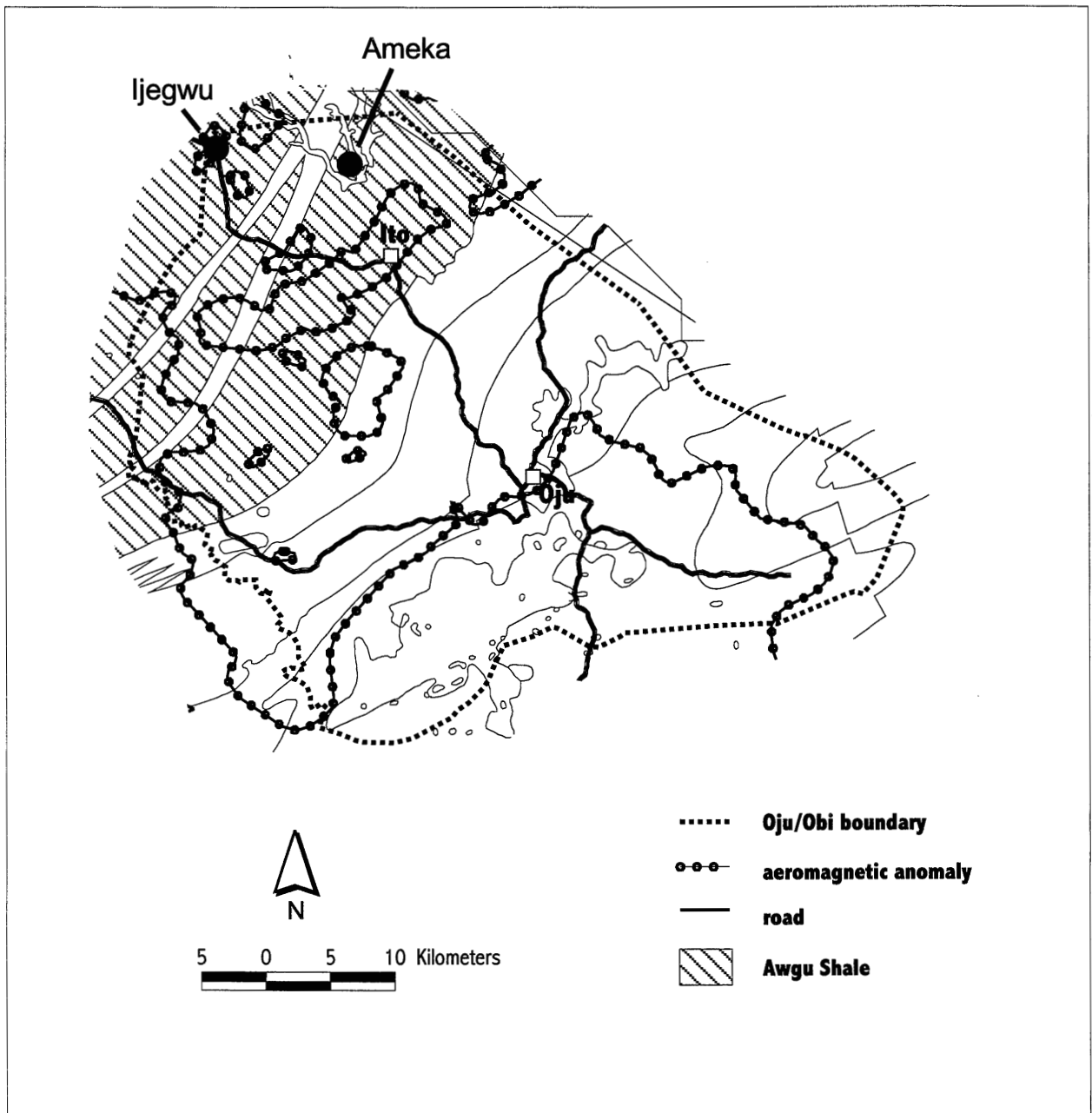


Figure 1. The location of the north Obi traverse and the outcrop of Awgu Shale.

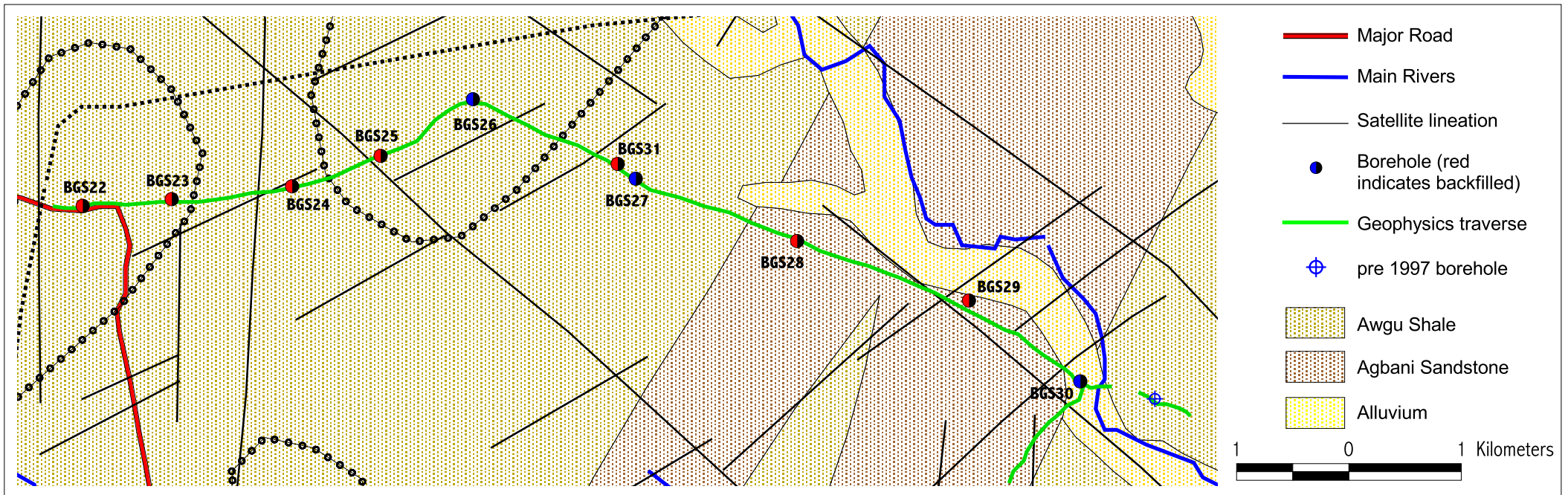


Figure 2. Available map information for north Obi and location of boreholes and geophysics traverses.

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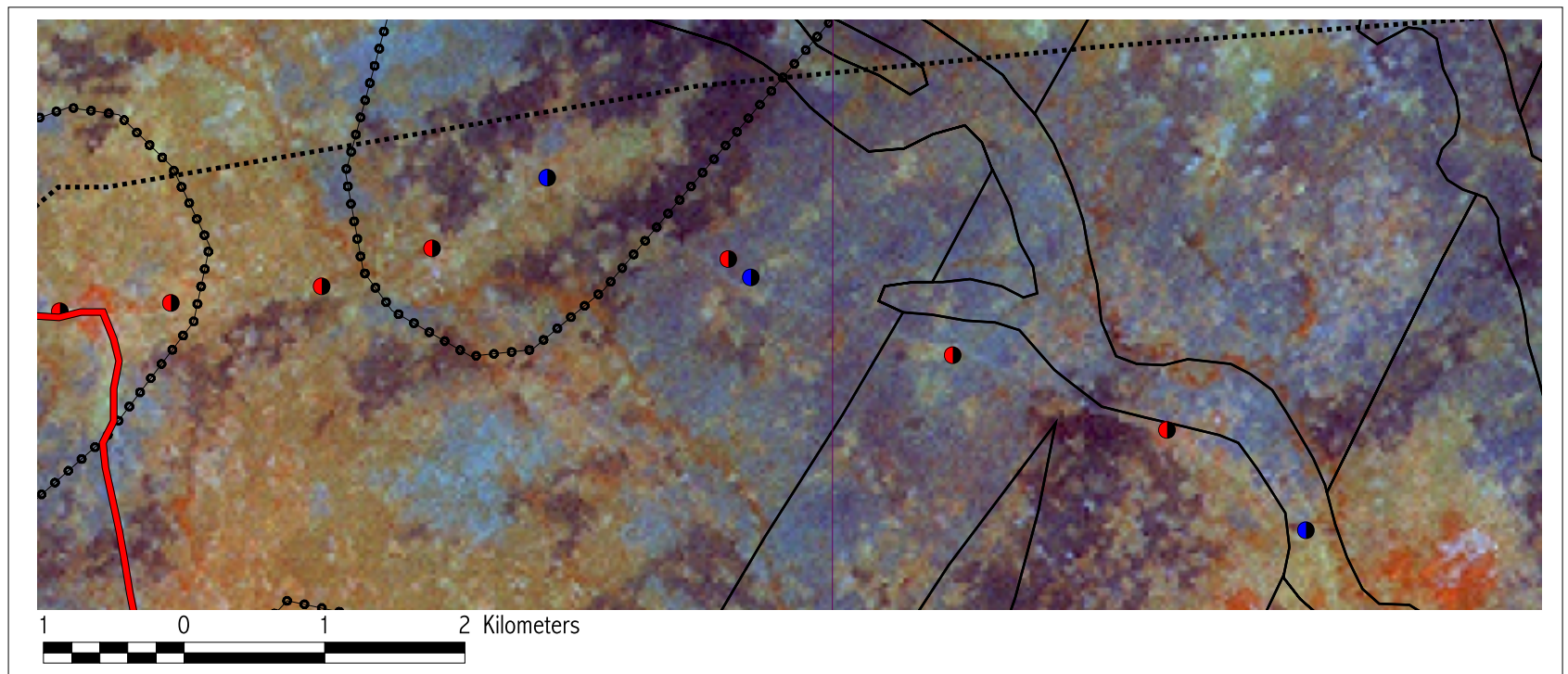


Figure 3. Satellite image for north Obi.

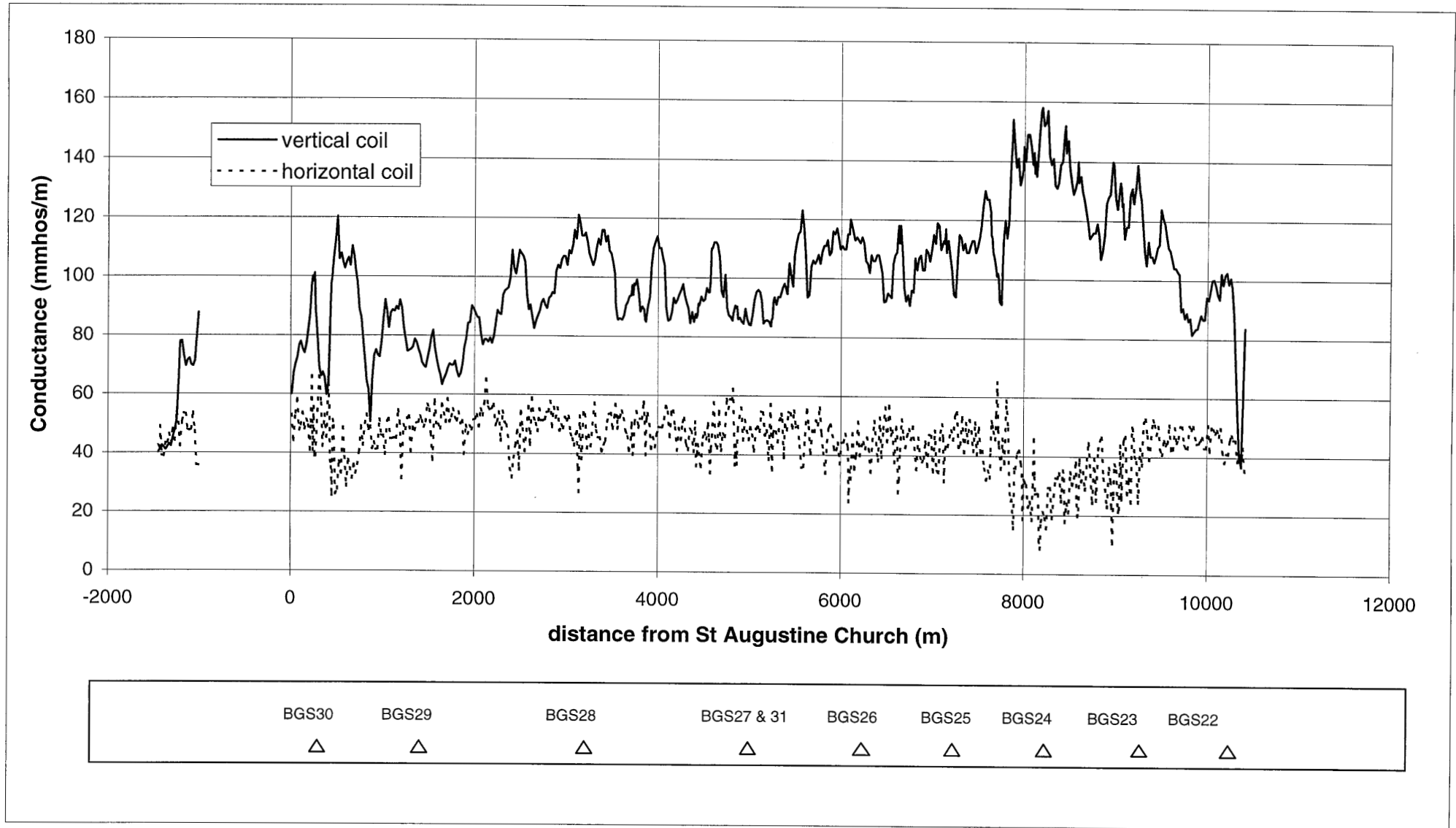


Figure 4. EM34-3 traverse across north Obi. Ameka is approximately -1000 m and Ijegwu 10 000 m. See Annex 1 for data.

- (i) Conductivity values are generally very high with horizontal dipole twice the conductivity of the vertical dipole.
- (ii) Between 8000 m and 9000 m conductivity is anomalously high (>120 mmhos/m) for the horizontal dipole and low (< 40 mmhos/m) for the vertical dipole.
- (iii) Between 0 and 2000 m there are many incidences where the horizontal and vertical conductivity are the same (approximately 60 mmhos/m).
- (iv) Within Ameka village between -1500 m and -1300 m the conductivity reduces and stabilises at 40 mmhos for both the vertical and horizontal dipole measurements.

Ten resistivity soundings were carried out along the traverse. They were located on type sections of the EM34-3 traverse. However, although the EM data varied significantly from sounding to sounding, the resistivity soundings all gave very similar results. They all indicated a surface layer (usually several metres thick) of a few hundred ohm-metres followed by thick very low resistivity layer of about 6 ohm-metres. In some of the traverse, the resistivity increased slightly at depth.

The magnetic traverse from 5000 m to 10000 m was very noisy. The diurnal variation was very high and there were many smaller short-term fluctuations. No ground anomalies were observed, even where the aeromagnetic map indicated regional anomalies were present. Maybe if the magnetic survey was repeated when atmospheric conditions were quieter, and the survey expanded within the areas marked as having aeromagnetic anomalies then some igneous intrusions could be found.

Table 2. Main Geophysical Surveys carried out along the north Obi traverse (data in Annex 1)

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
AM1	7° 5.409' 8° 17.04'	11 km	20 m	EM34-3 (20 m)	From St Augustine catholic Church Ameka to tarred road at Ijegwu; also backwards to Ameka borehole
AM2	7° 6.456' 8° 14.542'	5 km	10 m	Magnetic	From 5 –10 km along AM1.
AM3	7° 5.476' 8° 16.790'	1 km	20 m	EM34-3 (20 m)	From Okpaga village (well site 1) to Y junction (400 m along AM1)
AM4	7° 05.822' 8° 16.291'		0.5 – 64 m	Offset Wenner	On BGS29
AM5	7° 05.433' 8° 16.830'		0.5 – 64 m	Offset Wenner	On BGS30
AM6	7° 5.306' 8° 17.303'		0.5 – 64 m	Offset Wenner	Within Ameka village (-1340 along AM1)
AM7	7° 6.302' 8° 12.007'		0.5 – 64 m	Offset Wenner	Catholic Church Ijegwu BGS22
AM8	7° 6.313' 8° 12.488'		0.5 – 64 m	Offset Wenner	Fig tree BGS23
AM9	7° 6.399' 8° 13.00'		0.5 – 64 m	Offset Wenner	In depression BGS24
AM10	7° 6.535' 8° 13.486'		0.5 – 64 m	Offset Wenner	In village next to Primary school BGS25
AM11	7° 6.789' 8° 13.902'		0.5 – 64 m	Offset Wenner	BGS26
AM12	7° 6.449' 8° 14.557'		0.5 – 64 m	Offset Wenner	BGS27 and BGS31
AM13	7° 06.142' 8° 15.497'		0.5 – 64 m	Offset Wenner	In depression BGS28

From the geophysics surveys, nine sites were identified for test drilling. The nine sites identified were:

- BGS22: 10020 m along AM1, next to Catholic Church in Ijegwu
- BGS23: 9150 m along AM1, next to fig tree
- BGS24: 8180 m along AM1, located in side of depression
- BGS25: 7230 m along AM1, located in village next to primary school
- BGS26: 6200 m along AM1
- BGS27 and BGS31: 5000 m along AM1
- BGS28: 3140 m along AM1, on side of depression
- BGS29: 1650 m along AM1, in palm forest within village
- BGS30: 920 m along AM2, in flood plain.

Unfortunately, a large bridge at 300 m along AM1 was in poor condition and the drilling rig could neither get over or around it. Therefore, one of the most striking geophysical anomalies (where both the vertical and horizontal readings dropped to 40 mmhos/m) could not be tested. However, the success of a DIFFRI borehole there and the presence of many shallow hand-dug wells within Ameka village, suggests that this particular geophysical signature is associated with sandstone - probably the Agbani Sandstone.

3. DRILLING

Ten boreholes were drilled along the north Obi traverse. They were drilled to about 23 m with the last few metres cored. The majority of the boreholes were dry - only three contained sufficient water to put in screen and casing. The boreholes were spaced at approximately 1 km intervals along the traverse - their precise location was defined by the geophysics. As stated above, the poor conditions of some of the bridges meant that the first 300 m of the traverse (i.e. into Ameka village) could not be drilled. Summary information on the boreholes is given in Table 3. More details on construction etc. 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.

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
BGS22	7° 06.277' 8° 12.009'	19/2/98	23 m	165 mm	20.5 – 23.0 m	10 m (damp)	none	Backfilled – wl rose to 17.6 m
BGS23	7° 06.311' 8° 12.439'	20/2/98	23 m	165 mm	20.5 – 23.0 m	15.5 m (damp)	none	Backfilled – wl rose to 22 m
BGS24	7° 06.373' 8° 13.022'	20/2/98	23 m	215 mm	20.5 – 23.0 m	14.5 m (damp)	none	Backfilled
BGS25	7° 06.520' 8° 13.449'	24/2/98	21.3 m	215 mm	20.5 – 21.3 m	none	none	Backfilled
BGS26	7° 06.794' 8° 13.895'	25/2/98	23.4 m	165 mm	20.5 – 23.4 m	21.4 m (flowing)	0.6 m	Screened and cased.
BGS27	7° 06.395' 8° 14.567'	26/2/98	23.35 m	165 mm	20.5 – 23.35 m	unknown	0.6 m	Screened and cased.
BGS28	7° 06.110' 8° 15.462'	27/2/98	23.4 m	165 mm	20.5 – 23.4 m	dry	none	Backfilled
BGS29	7° 05.822' 8° 16.291'	3/3/98	23.0 m	165 mm	20.5 – 23.0 m	damp	none	Backfilled
BGS30	7° 05.433' 8° 16.830'	4/3/98	23.5 m	165 mm	20.5 – 23.5 m	4 m (flowing)	0.3 m	Much running sand and swelling clay
BGS31	7° 06.395' 8° 14.567'	5/3/98	14.5 m	165 m	5.5 – 14.5 m	damp	none	Backfilled – next to BGS27

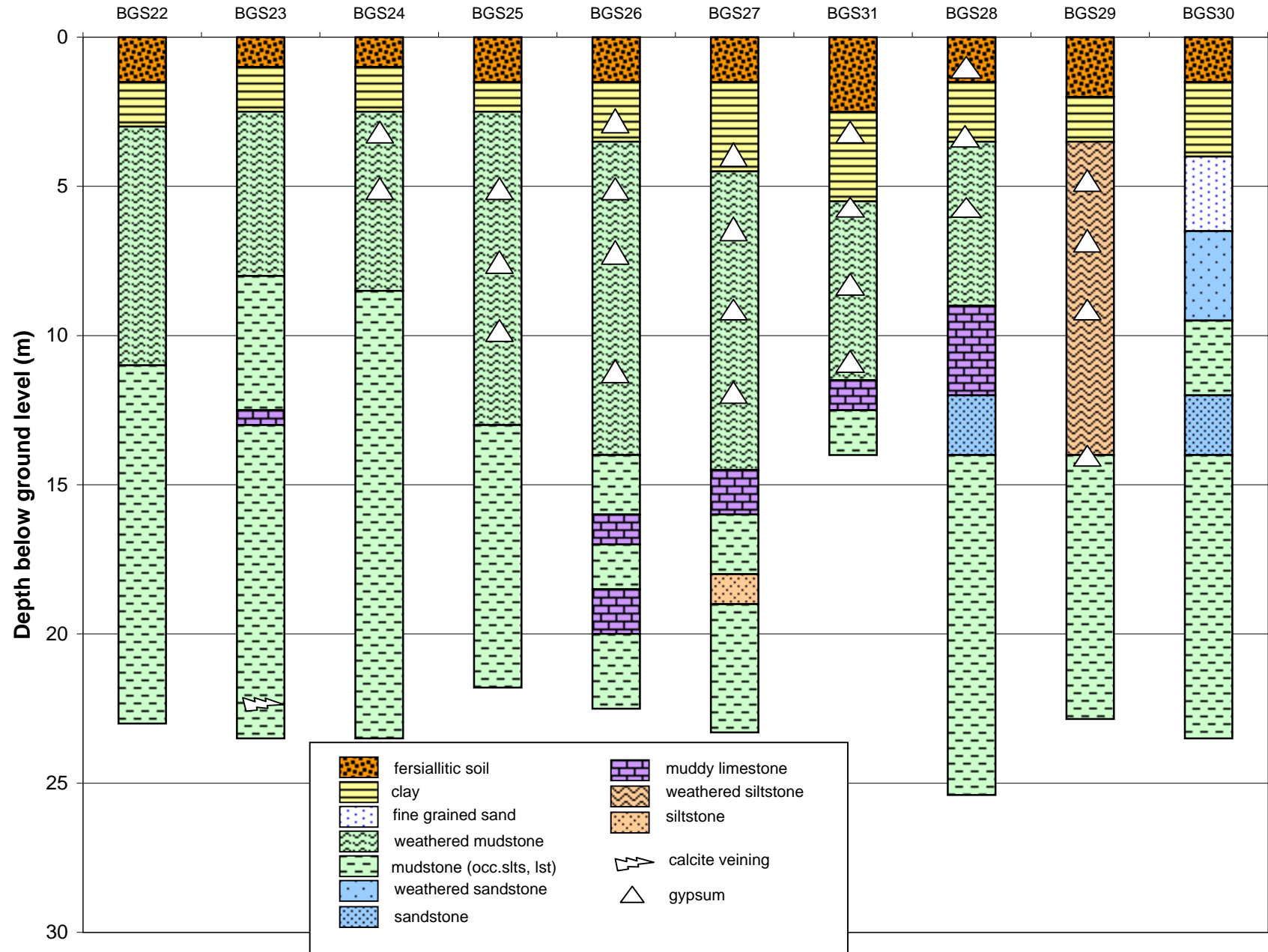


Figure 5. Simplified lithological logs for the north Obi traverse (horizontal axis not to scale). Details in Annex 3.

Summary lithological log: BGS22

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 3.0	Clayey very weathered horizon
3.0 - 6.0	Very weathered shaley mudstone with clay
6.0 - 8.0	Weathered mudstone
8.0 - 11.0	Fairly weathered mudstone
11.0 - 21.08	Shaley carbonaceous mudstone
21.08 - 21.36	Interbedded muddy limestone, mudstone, siltstone and fine grained sandstone
21.36 - 21.67	Carbonaceous shaley and silty mudstone
21.67 - 22.00	Interbedded shaley mudstone, muddy siltstone and fine-grained sandstone
22.00 - 22.19	Shaley mudstone and siltstone, fractured
22.19 - 22.46	Medium to fine grained glauconitic sandstone with muddy siltstone and mudstone
22.46 - 22.49	Carbonaceous mudstone
22.49 - 22.54	Fine grained sandstone, siltstone and mudstone
22.54 - 22.95	Carbonaceous shaley mudstone and siltstone

Summary lithological log: BGS23

0.0 - 1.0	Soil/ferricrete horizon
1.0 - 2.5	Clayey very weathered horizon
2.5 - 8.0	Weathered mudstones with much gypsum
8.0 - 10.5	Compact carbonaceous mudstone
10.5 - 12.5	Soft carbonaceous mudstone
12.5 - 13.0	Hard muddy limestone
13.0 - 20.5	Soft carbonaceous mudstone
20.50 - 21.60	Shaley mudstone
21.60 - 21.70	Shaley siltstone and medium to fine grained glauconitic sandstone
21.70 - 22.30	Shaley mudstone
22.30 - 22.39	Fractured shaley mudstone
22.39 - 22.91	Shaley mudstone
22.91 - 22.94	Fractured muddy calcite vein
22.94 - 23.50	Shaley mudstone

Summary lithological log: BGS24

0.0 - 1.0	Soil/ferricrete horizon
1.0 - 2.5	Clayey very weathered horizon
2.5 - 4.0	Weathered clayey shaley mudstones
4.0 - 8.5	Weathered shaley mudstones with much gypsum
8.5 - 9.0	Carbonaceous shaley mudstone
9.0 - 9.5	Carbonaceous shaley mudstone and thin limestone
9.5 - 13.0	Carbonaceous shaley mudstone
13.0 - 13.5	Shaley mudstone with thin ash band
13.5 - 15.0	Carbonaceous shaley mudstone
15.0 - 17.0	Carbonaceous shaley mudstone with thin hard bands
17.0 - 17.5	Carbonaceous shaley mudstone with ash layer
17.5 - 18.5	Carbonaceous shaley mudstone
18.5 - 19.0	Carbonaceous shaley mudstone with ash layer

19.0 - 20.5	Carbonaceous shaley mudstone
20.5 - 22.0	No samples
22.00 - 22.10	Sandy mudstone
22.10 - 22.66	Shaley mudstone
22.66 - 22.71	Sandy silty shale
22.71 - 22.80	Sandy shale and muddy fine to medium grained sandstone
22.80 - 23.00	Shaley mudstone
23.00 - 23.50	Fractured sandy mudstone with calcite

Summary lithological log: BGS25

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 2.5	Clayey very weathered horizon
2.5 - 5.5	Very weathered clayey mudstone
5.5 - 6.5	Weathered shaley mudstone
6.5 - 13.0	Weathered shaley mudstone with much gypsum
13.0 - 20.5	Carbonaceous shaley mudstone
20.50 - 20.75	Sandy and shaley siltstone
20.75 - 21.12	Shaley mudstone
21.12 - 21.26	Shaley siltstone and fine grained sandstone
21.26 - 21.70	Sandy shaley siltstone
21.70 - 21.80	Shaley mudstone

Summary lithological log: BGS26

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 3.5	Clayey very weathered horizon
3.5 - 5.5	Very weathered clayey mudstones
5.5 - 10.0	Weathered mudstones with much gypsum
10.0 - 14.0	Fairly weathered carbonaceous shaley mudstone with gypsum along oxidised partings
14.0 - 16.0	Carbonaceous mudstone
16.0 - 17.0	Carbonaceous mudstone and hard limestone, some siltstone
17.0 - 18.5	Carbonaceous mudstone
18.5 - 20.0	Carbonaceous mudstones and hard thin limestone
20.0 - 21.3	Carbonaceous shaley mudstones
21.30 - 21.52	Muddy and sandy limestone
21.52 - 23.30	Shaley mudstones
23.30 - 23.50	Silty mudstone

Summary lithological log: BGS27

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 4.5	Clayey very weathered horizon
4.5 - 6.5	Weathered mudstone
6.5 - 11.5	Weathered mudstones with much gypsum
11.5 - 12.5	Fairly weathered muddy limestone and mudstone
12.5 - 14.5	Fairly weathered mudstone with gypsum along oxidised partings
14.5 - 16.0	Muddy limestone with mudstone
16.0 - 18.0	Carbonaceous blocky and shaley mudstones

18.0 - 19.0	Muddy siltstones and fine grained sandstones with some carbonaceous mudstones
19.0 - 20.5	Carbonaceous silty mudstone, some fine grained sandstone and limestone
20.50 - 22.38	Shaley to blocky mudstone, some pyrite and gypsum
22.38 - 22.52	Sandy mudstone
22.52 - 22.98	Blocky to shaley mudstones, some gypsum
22.98 - 23.35	Blocky mudstones some pyrite

Summary lithological log: BGS28

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 3.5	Clayey very weathered horizon
3.5 - 4.0	Weathered shales and hard limestone
4.0 - 6.5	Weathered shaley mudstones with gypsum
6.5 - 9.0	Fairly weathered carbonaceous mudstone with gypsum
9.0 - 12.0	Muddy limestone with carbonaceous shaley mudstone
12.0 - 14.0	Compact fine grained sandstone or limestone with mudstone
14.0 - 16.5	Carbonaceous shaley mudstone and siltstone
16.5 - 18.0	Carbonaceous shaley mudstone and nodular limestone
18.0 - 19.5	Carbonaceous shaley mudstone with siltstone bands
19.5 - 20.0	Carbonaceous shaley mudstone with hard thin limestone
20.0 - 21.90	Carbonaceous shaley mudstone, fine grained sandstone and siltstone
21.90 - 23.40	Carbonaceous shaley and sandy siltstone and mudstone

Summary lithological log: BGS29

0.0 - 2.0	Soil/ferricrete horizon
2.0 - 3.5	Clayey very weathered horizon
3.5 - 5.5	Very weathered sandy clay
5.5 - 7.5	Weathered siltstone
7.5 - 12.0	Fairly weathered siltstone with gypsum
12.0 - 14.0	Fairly weathered siltstone
14.0 - 16.5	Carbonaceous shaley mudstones with gypsum along oxidised bands
16.5 - 20.5	Carbonaceous shaley mudstones
20.57 - 21.11	Silty and sandy mudstones
21.11 - 22.70	Shaley and silty mudstones
22.70 - 22.85	Muddy fine grained sandstone

Summary lithological log: BGS30

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 4.0	Clayey very weathered fine grained sands
4.0 - 6.5	Soft collapsing weathered fine grained sand
6.5 - 9.0	Weathered fine grained sandstone and clay
9.0 - 9.5	Weathered fine grained sandstone and weathered shales
9.5 - 10.0	Weathered silty shaley mudstones and fine grained sandstone
10.0 - 12.0	Fairly weathered carbonaceous mudstones with interbedded thin limestone or sandstone bands
12.0 - 13.0	Fine grained sandstone with carbonaceous shaley mudstones
13.0 - 14.0	Fine grained sandstone, siltstone and carbonaceous mudstone

14.0 - 14.5	Carbonaceous shaley mudstone
14.5 - 17.0	Shaley silty mudstones with thin limestone or sandstone bands
17.0 - 17.5	Carbonaceous shaley mudstones
17.5 - 19.5	Carbonaceous shaley mudstones and siltstones with thin limestone or sandstone bands
19.5 - 20.0	Carbonaceous shaley mudstones with thin limestone bands
20.0 - 20.88	Carbonaceous shaley mudstones
20.88 - 21.14	Sandy to silty mudstones
21.14 - 22.00	Shaley mudstones
22.00 - 23.24	Silty and shaley fractured mudstones
23.24 - 23.50	Shaley mudstones

Summary lithological log: BGS31

0.0 - 2.5	Soil/ferricrete horizon
2.5 - 4.0	Clayey very weathered horizon
4.0 - 5.5	Weathered clayey mudstones
5.5 - 7.28	Weathered silty mudstones and fine grained sandstone with layered gypsum
7.28 - 9.67	Weathered clayey mudstones with gypsum bands
9.67 - 9.74	Fairly weathered mudstones with gypsum bands
9.74 - 10.0	Fairly weathered mudstones with gypsum nodules
10.00 - 11.50	Clayey weathered mudstones with nodular gypsum
11.50 - 12.17	No samples
12.17 - 12.47	Weathered calcareous mudstones with gypsum
12.47 - 13.14	Weathered muddy limestones and calcareous mudstones with gypsum bands
13.14 - 14.41	Fairly weathered mudstones with prominent gypsum bands and nodules
14.41 - 15.00	Non-weathered shaley carbonaceous mudstones

4. TEST PUMPING

The majority of the boreholes drilled along the north Obi traverse were dry. Only three boreholes had sufficient water for screen and casing to be installed: BGS26, BGS27 and BGS 30. Of these, BGS26 and 27 had very low yields and could only be tested with the bailer. Although BGS30 had higher yields, fine sand running through the screen clogged up the borehole, and no long-term pumping test could be undertaken. Table 4 gives a summary of the test pumping; the data are given in Annex 4.

Table 4. Summary of pumping tests carried out along the north Obi traverse. (Annex 4 contains data and analyses).

Borehole and Test	Date	Casing height above ground	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m ² /d)
BGS26 Bailer test	6/3/98	0.6 m	14.71	7	0.14	Barker: 0.024
BGS27 Bailer test	6/3/98	0.6 m	10.096	9:53	0.152	Barker: 0.08 Theis Rec: 0.05
BGS30						

Only simple slug tests were carried out in each borehole. These were undertaken using bailers and analysed using both the Theis recovery method (Kruseman and de Ridder, 1990) and Barker's large diameter well method (Barker, 1989). The best aquifer properties were found in BGS30. The drawdown curve, however, suggests complex behaviour within the aquifer, probably associated with the dewatering of thin water-bearing layers. The fine sand within BGS30 rapidly clogged up the borehole making any further testing impossible. A borehole would not be recommended at this site, but a properly constructed hand-dug well would be successful. Any hand-dug well would have to be constructed carefully to avoid problems with the running sand and swelling clays.

Both BGS26 and BGS27 had very poor aquifer properties – neither would support a borehole. BGS27 might be able to support a very deep hand-dug well – but this would be marginal.

A water sample was taken for hydrochemical analysis from each of the boreholes. These were obtained using the whale pump. The very low yields meant that the BGS26 and BGS27 could not be pumped prior to taking a sample. Some field hydrochemical analyses were undertaken (see Table 5). Major, minor and trace element determinations undertaken at BGS Wallingford are detailed in Annex 5. The quality of groundwater produced from BGS30 conforms to WHO standards; most of the water is probably recently recharged. Highly saline waters were obtained from BGS26 and BGS27, with chemical contents well in excess of the WHO standards. The poor chemistry is probably associated with the gypsum found in the chip samples, and reflects the lack of recharge and low permeability.

Table 5. Chemistry samples taken from the north Obi 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
BGS27	215	17/03/98	7160	3620	7.03	29.8	315	Took sample with Whale pump very low yield
BGS26	216	17/03/98	10080	5040	7.38	30	256	Took sample with Whale pump - very low yield
BGS30	218	17/03/98	201	104	6.22	29.2	46	Sample taken with Whale pumps one hour after end test

5. SUMMARY AND CONCLUSIONS

The groundwater development potential of the Awgu Shales in North Obi was investigated along a traverse from Ijegwu to Ameka. A series of boreholes were drilled and some test pumped. The following work was undertaken in North Obi:

- 12 km of EM34-3 surveys
- 5 km of magnetic profiling
- 10 resistivity VES
- 10 boreholes were drilled and approximately 3 m of core taken from each borehole
- 9 m of core were obtained from BGS31 to study the occurrence of gypsum in the weathered zone

- chip and core samples from each borehole were logged and analysed
- 3 boreholes, BGS26, BGS27, BGS30 were screened and cased
- bailer tests were carried out on each screened borehole
- water samples were taken from BGS26, BGS27, BGS30.

The EM34-3 data was interpreted in light of the drilling and water quality analysis.

- Conductivity values are generally very high. There are two reasons for the high conductivity: (1) the saline water within the mudstone; and (2) the high proportion of clay present within the weathered mudstone.
- The conductivity values decrease towards Ameka; this can be attributed to the increasing amount of sand and silt.
- Vertical dipole (horizontal coil) results were always less than those from the horizontal dipole (vertical coil). This indicates that the conductivity reduces with depth, probably correlated with the reduction of weathering with depth.
- A marked geophysical signal (both horizontal and vertical readings equal and less than 40 mmhos/m) was given within Ameka and is probably due to thicker sandstone layers within the Agbani Sandstone. This is similar to results at Udegi which is also thought to be on the Agbani Sandstone. No drilling could be done at either site to substantiate these results.

The resistivity surveys were all very similar. All indicated a surface layer (usually several metres thick) of a few hundred ohm-metres followed by thick very low resistivity layer of about 6 ohm-metres. In some of the traverse, the resistivity increased slightly at depth. The similarity is probably due to the shallow clay layers. Any changes with depth would be masked by the high conductivity of the clays.

The magnetic traverse from 5000 m to 10000 m was very noisy. The diurnal variation was very high and there were many smaller short-term fluctuations. No ground anomalies were observed, even where the aeromagnetic map indicated regional anomalies were present. Maybe if the magnetic survey was repeated when atmospheric conditions were quieter, and the survey expanded within the areas marked as having aeromagnetic anomalies then some igneous intrusions could be found.

Several conclusions can be made from the rock and chip samples.

- The Awgu Shale generally comprises soft black to dark grey compact to shaley carbonaceous mudstones
- Gypsum has been deposited in veins or nodules within the weathered zone,
- Thin silt and limestone layers are common in the east but are not hydrogeological significant.
- The geology map shows an outcrop of Agbani Sandstone crossing the traverse. No significant sandstone was found where the outcrop is marked, however, the thin limestone and siltstone may comprise the Agbani Sandstone here.

- A thicker sandstone unit is present at Ameka, beyond the Agbani Sandstone outcrop marked on the map. This sandstone is likely to be the true Agbani Sandstone. This sandstone may form an important aquifer, however, no drilling could be carried out within it.
- A significant alluvium deposit was found beneath the flood-plain of the river Obi. This comprised fine running sand that contained groundwater.

The groundwater potential along the north Obi traverse is very low. Only three boreholes out of the ten drilled had sufficient water to be tested. There was only enough water to carry out bailer test - no longer-term tests could be carried out. The permeability within the Awgu Shale is very low. There is negligible primary permeability, and any fractures that exist are quickly closed because of the soft nature of the mudstone. There is insufficient water for boreholes or hand dug wells. Test pumping within the alluvium was more promising. The alluvium has sufficient water for a hand dug well, although any hand-dug well would have to be constructed carefully to avoid problems with the running sand and swelling clays.

The Agbani sandstone within Ameka could not be tested as there was no access for the drilling rig. However, there has been a successful borehole within the village for the last seven years and many shallow hand dug wells. Rock samples obtained from these wells indicate that they have been constructed within sandstone. Drilling within the Agbani Sandstone would help understand the nature of this aquifer.

Water quality within the Awgu Shales is very poor. The salinity was very high (>3000 mg/l) and therefore is well above the WHO recommended limits. Water quality within the alluvium and Agbani Sandstone is much better.

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

Amaka - Ijegwu

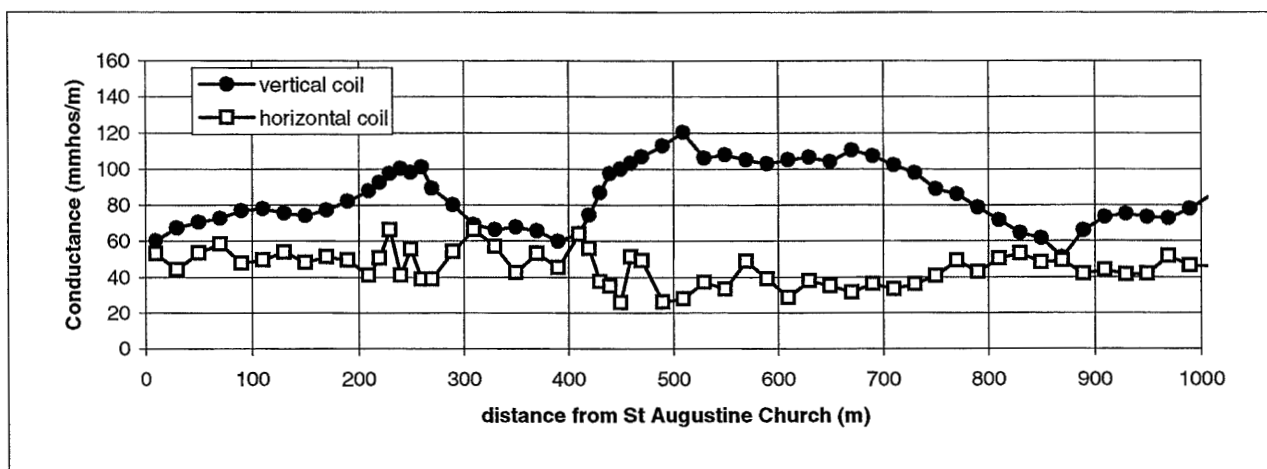
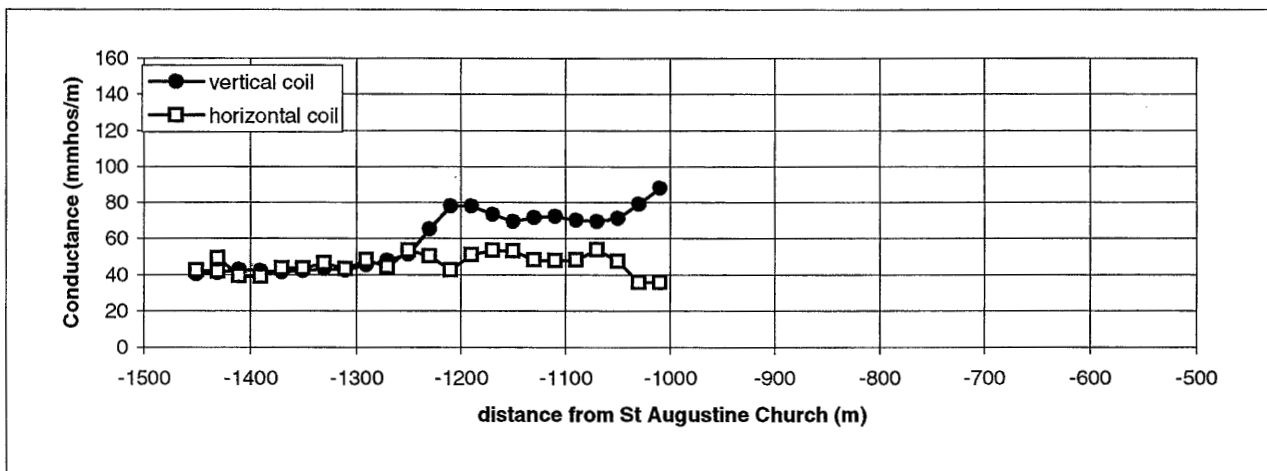
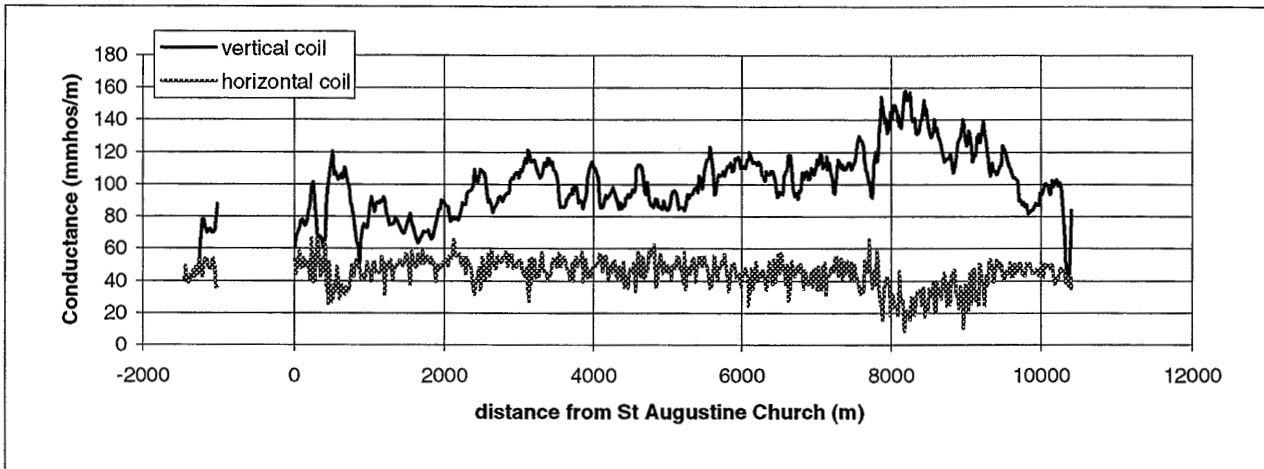
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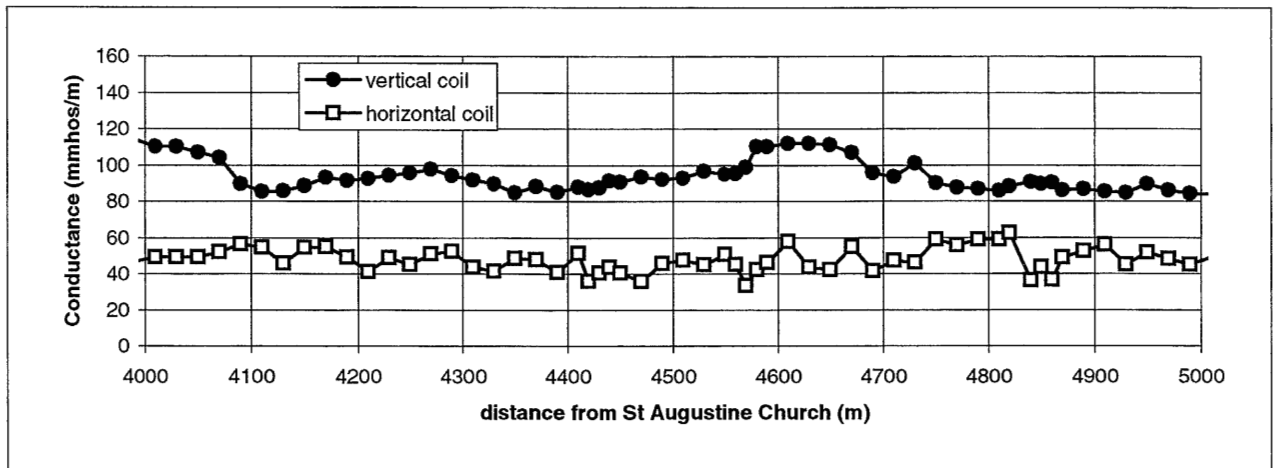
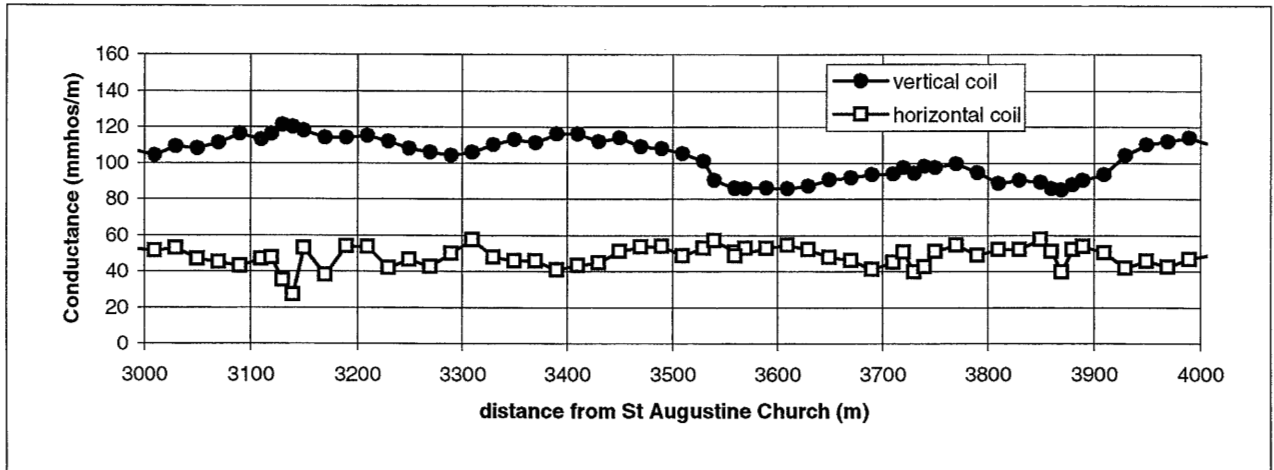
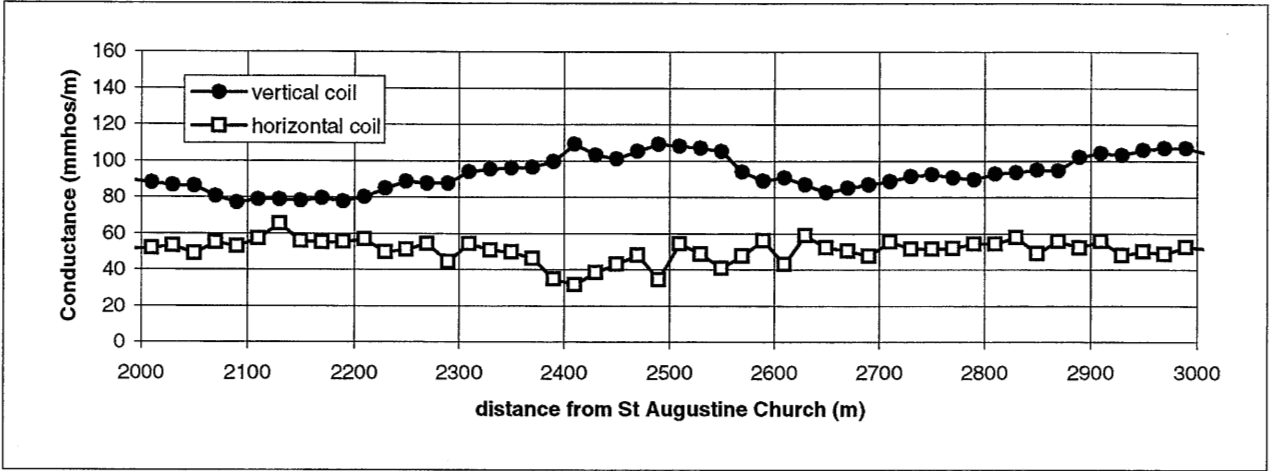
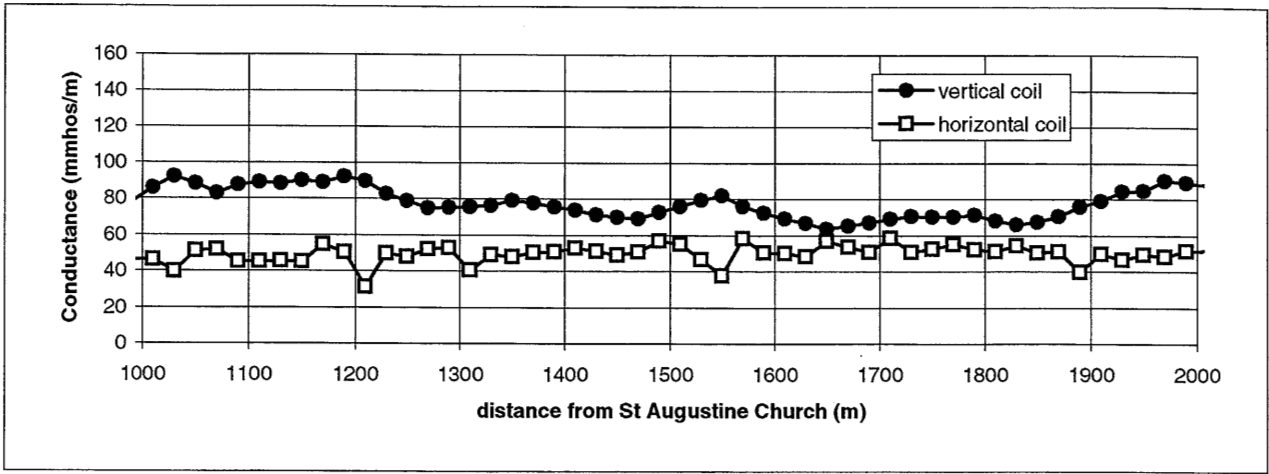
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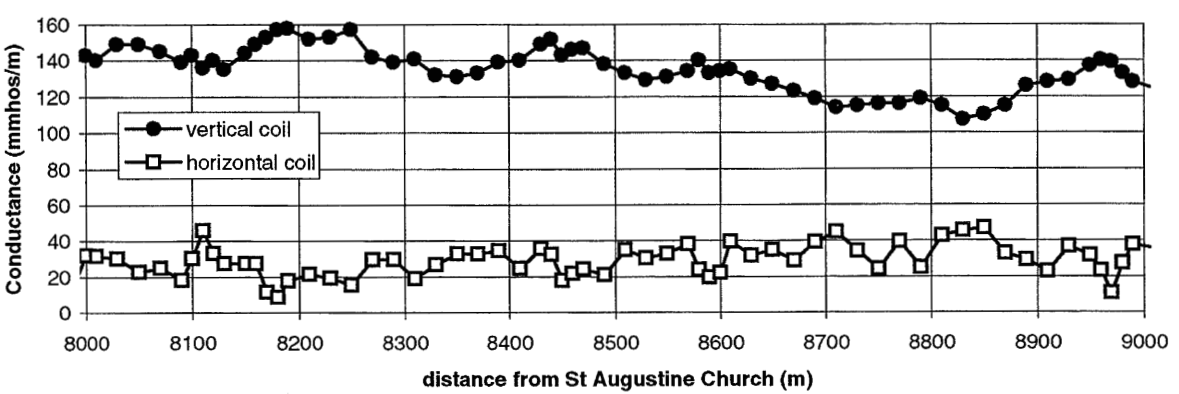
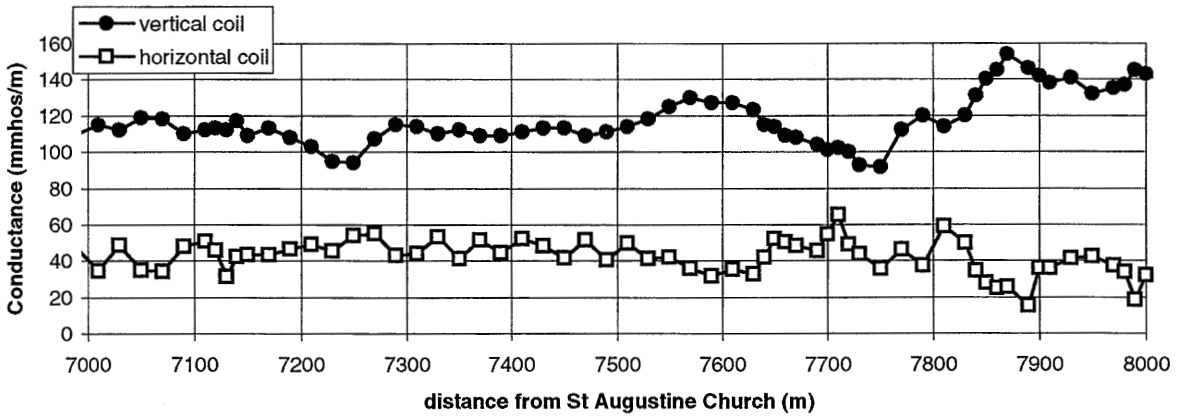
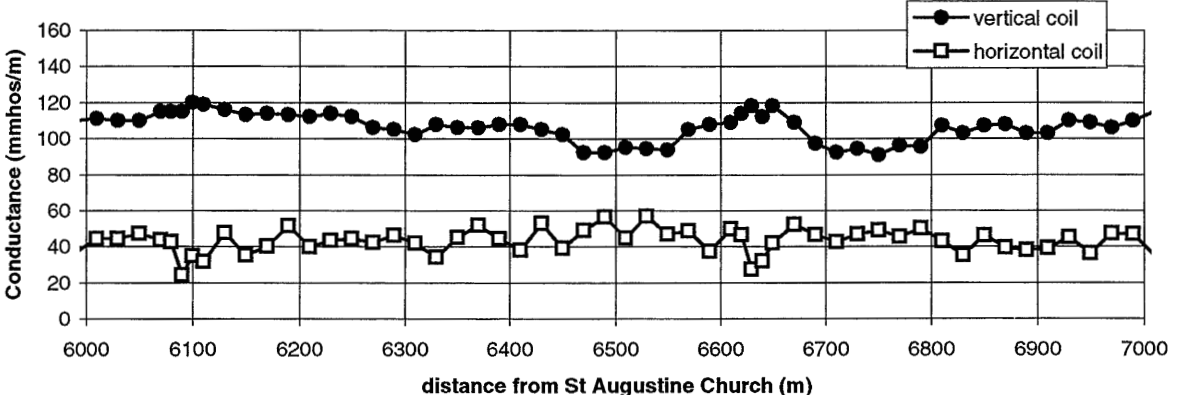
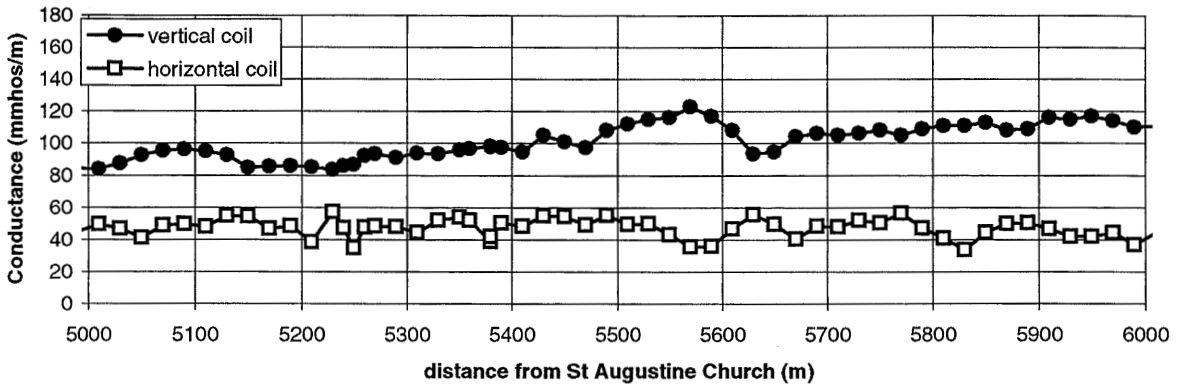
GPS finish

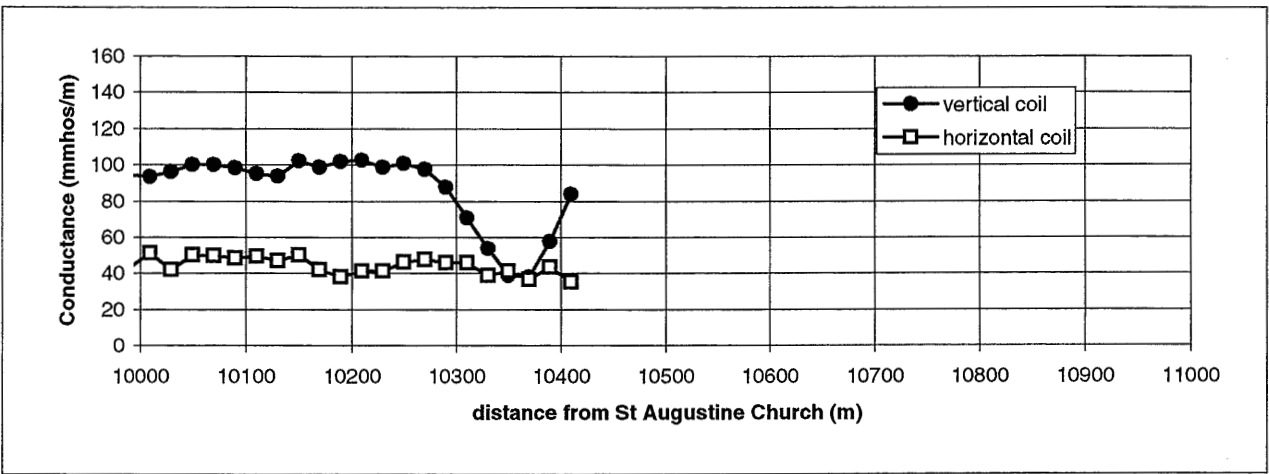
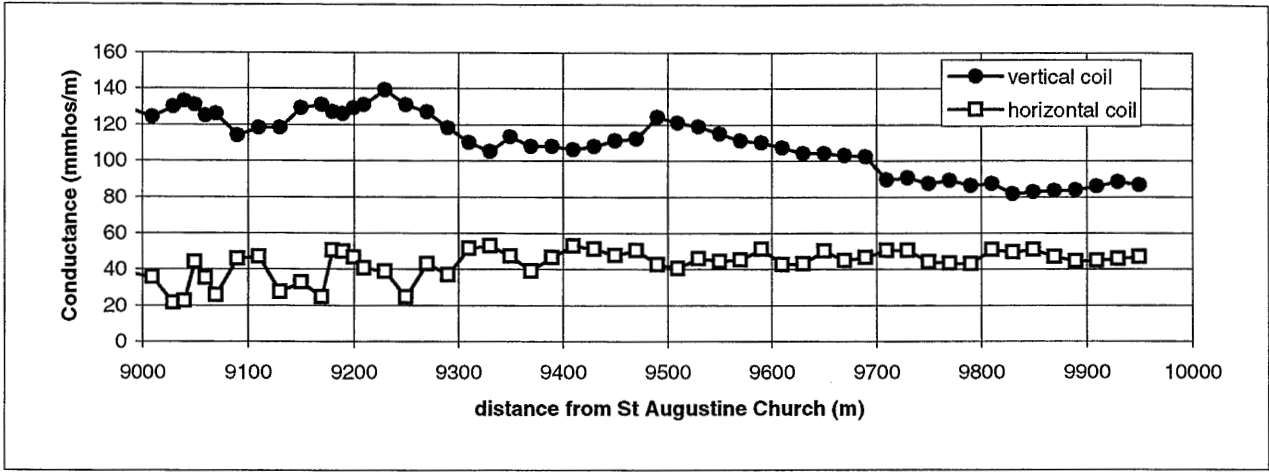
Date and time: 6-7, 11-12/2/98

Survey: AM1 From St Augustine Catholic church Amaka to tarred road at Ijegwu
EM34.3 at 20m spacings









Amaka - Ijegwu

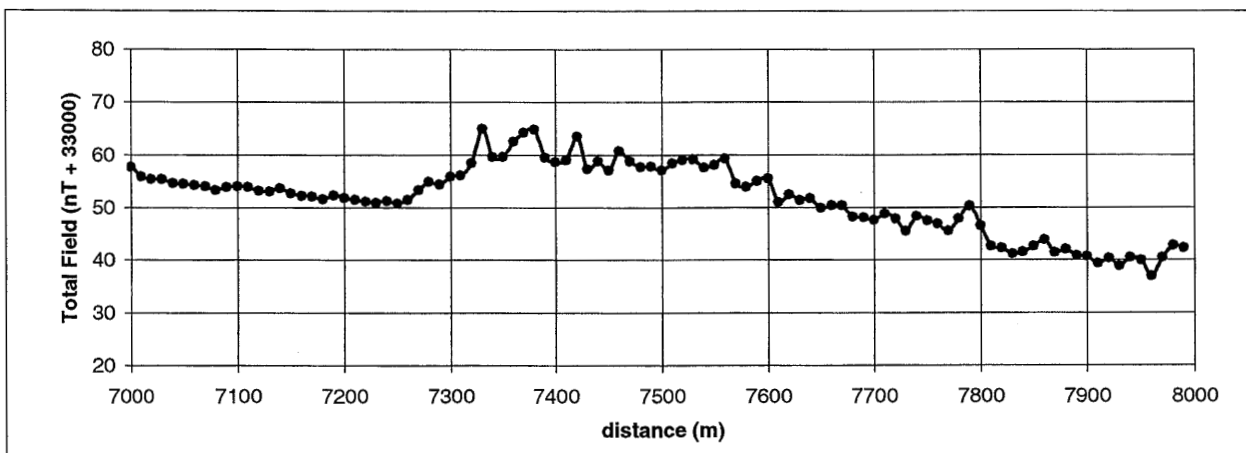
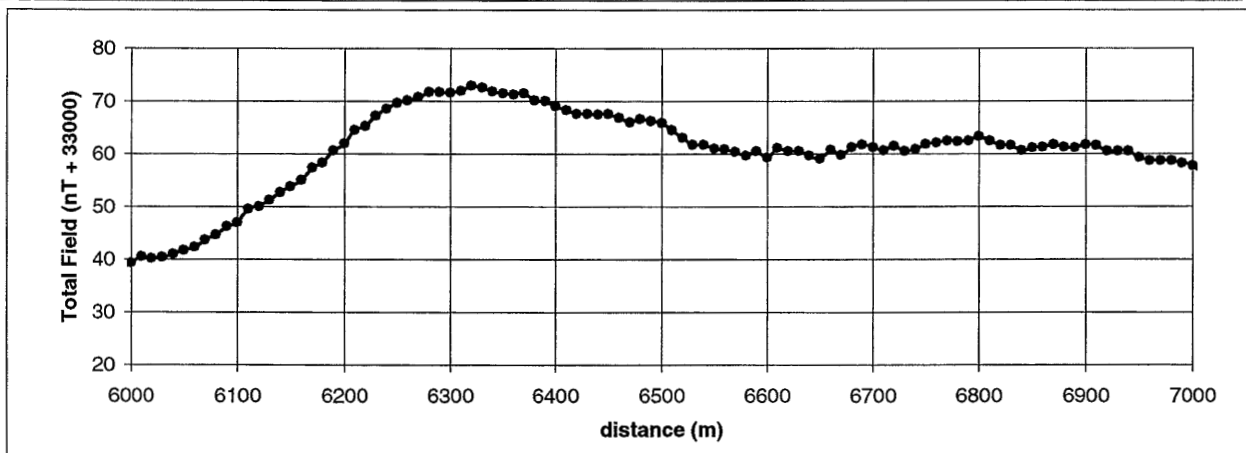
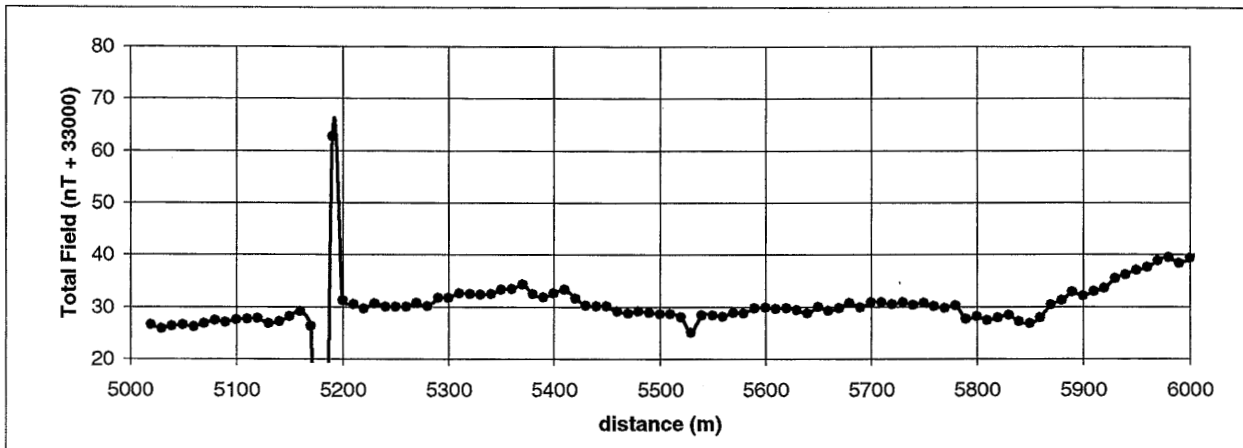
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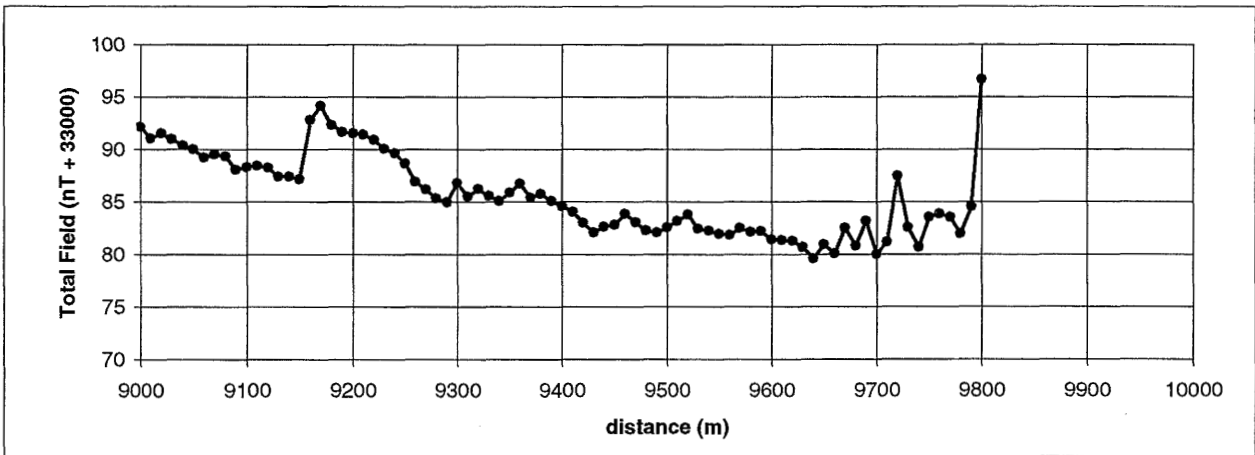
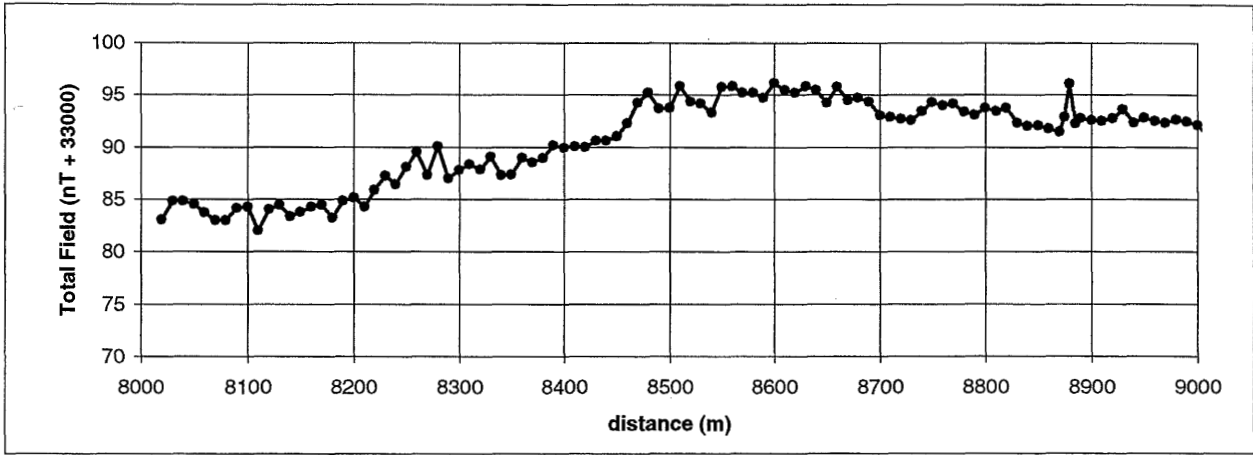
GPS start:

GPS finish

Date and time: 11-12/2/98 day1 = 5000 - 8000; day 2 = 8000 - 10000

Survey: AM2 As AM1 starting at 5000 m
EM34.3 at 20m spacings





Amaka - Ijegwu

AM3

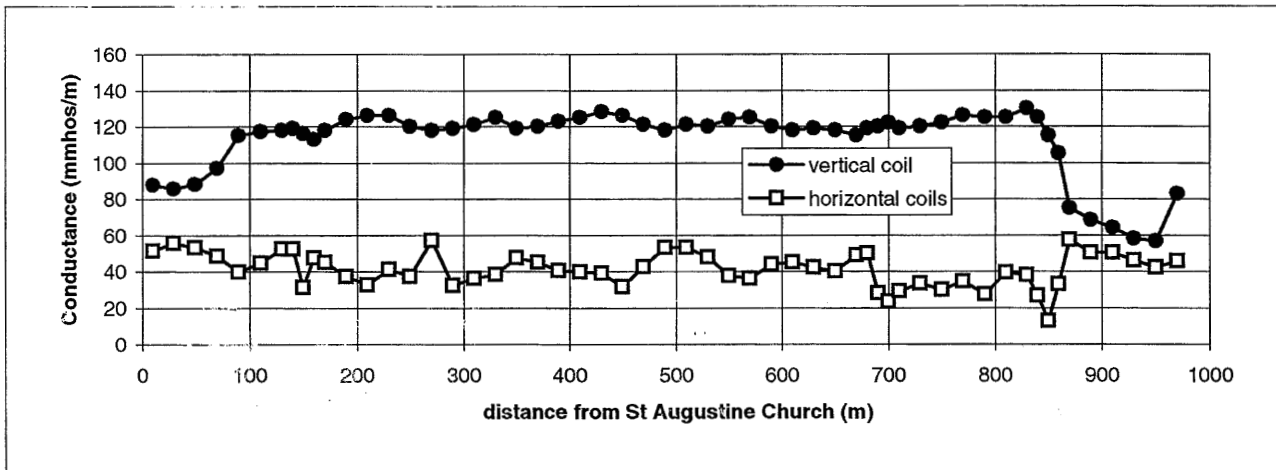
GPS start:

GPS finish 7 degs 5.476; 8 degs 16.790

Date and time: 12/02/98

Survey: AM3 From new well in Okpaga to Y junction AM1
EM34.3 at 20m spacings

position (m)	strike (deg)	position (m)	comments
	50		20 hut right
100	16		40 new well
160	38		60 wild pinapples left
220	24		100 mid compound oranges
260	14		140 x roads
420	40		160 malina tree
670	36		200 path left
740	48		280 church
800	42		380 path left - mango tree
920	4		420 malina left
940	335		520 dead tree left
960	332		680 locust bean tree
			820 dead tree left with anthill
			860 small tree left
			980 y junction with ameka (400 m along AM1)



Amaka

AM4

Resistivity Survey 1

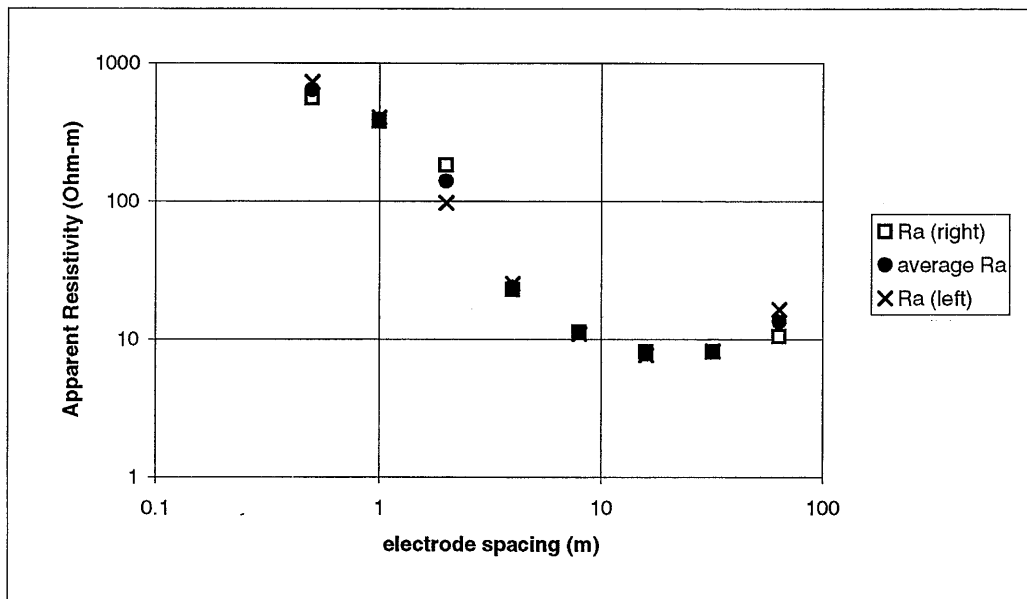
Located in village 1650 m along AM1 BGS29

Offset Wenner right to Amaka

Strike 288 degs

24/02/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	231	177.1	725.34	556.094	640.717
1	64	59.8	401.92	375.544	388.732
2	7.74	14.5	97.2144	182.12	139.6672
4	0.995	0.904	24.9944	22.70848	23.85144
8	0.217	0.225	10.90208	11.304	11.10304
16	0.076	0.08	7.63648	8.0384	7.83744
32	0.0405	0.04	8.13888	8.0384	8.08864
64	0.0408	0.026	16.39834	10.44992	13.42413

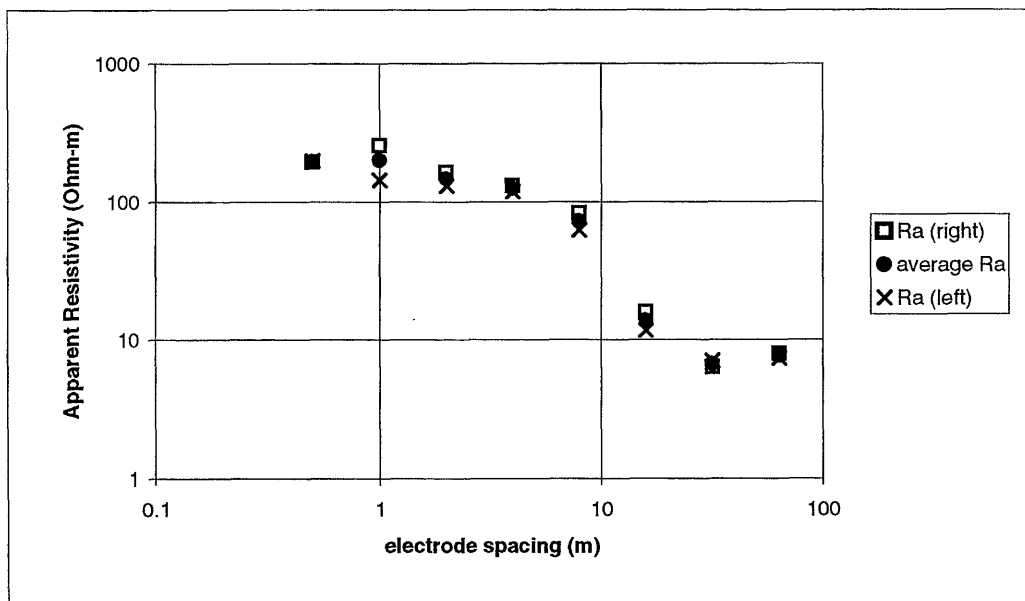


Amaka

AM5

Resistivity Survey 2
920 m along AM2 BGS30
Offset Wenner right to Amaka
Strike 219 degs
24/02/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	63	61.8	197.82	194.052	195.936
1	22.7	40.6	142.556	254.968	198.762
2	10.41	13	130.7496	163.28	147.0148
4	4.71	5.2	118.3152	130.624	124.4696
8	1.243	1.631	62.44832	81.94144	72.19488
16	0.116	0.158	11.65568	15.87584	13.76576
32	0.035	0.0314	7.0336	6.310144	6.671872
64	0.0184	0.0197	7.395328	7.917824	7.656576



DATA SET: AM5

CLIENT: WaterAid
 LOCATION: Oju
 COUNTY: Ameka BGS29
 PROJECT: Water and sanitation
 ELEVATION: 0.00
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: Feb 1998
 SOUNDING: 2
 AZIMUTH: 288 degs
 EQUIPMENT: bgs128

Offset Wenner Configuration

FITTING ERROR: 9.519 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m ²)
1	178.0	4.79	0.0	0.0269	854.3
2	6.09	86.86	-4.79	14.24	529.7
3	296.2		-91.66		

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO			
1	163.797	178.018	193.533
2	5.068	6.099	7.421
3	18.513	296.216	4739.455
THICK			
1	4.429	4.799	5.184
2	52.774	86.863	188.817
DEPTH			
1	4.429	4.799	5.184
2	57.755	91.662	193.437

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
1	0.500	196.0	177.8	9.26
2	1.00	199.0	176.9	11.08
3	2.00	147.0	170.8	-16.25
4	4.00	124.5	140.7	-13.02
5	8.00	72.20	67.30	6.77
6	16.00	13.80	14.02	-1.63

* BRITISH GEOLOGICAL SURVEY *

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
7	32.00	6.70	6.67	0.383
8	64.00	7.60	7.59	0.0751

PARAMETER RESOLUTION MATRIX:
 "F" INDICATES FIXED PARAMETER

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	-0.01	-0.03	0.00	0.97
	P 1	P 2	P 3	T 1	T 2

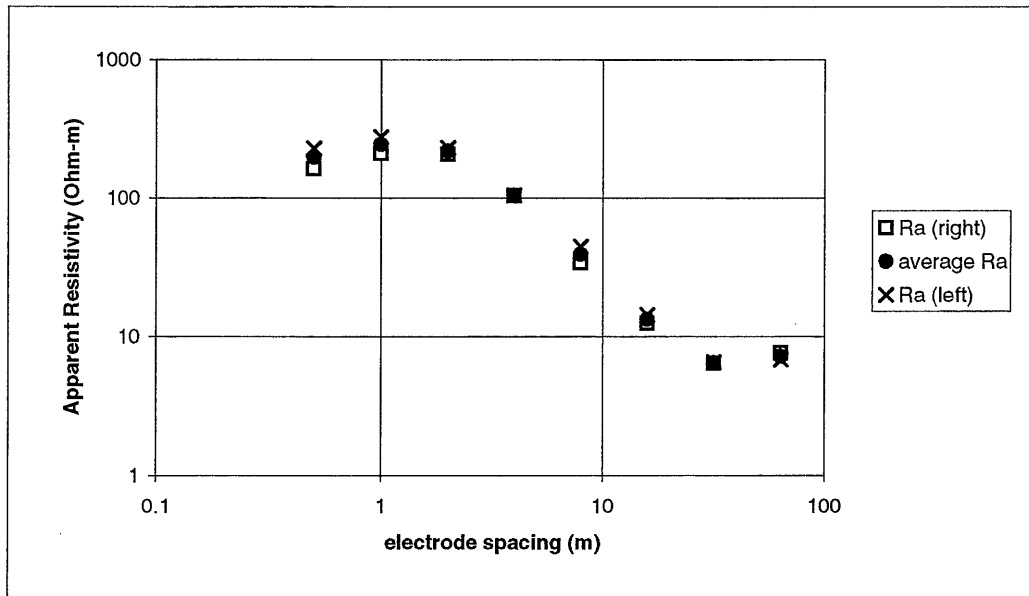
* BRITISH GEOLOGICAL SURVEY *

Amaka

AM6

Resistivity Survey 3
within ameka village -1340 m along AM1
Offset Wenner left to borehole
Strike 248 degs
24/02/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	72.5	51.2	227.65	160.768	194.209
1	43.6	33.3	273.808	209.124	241.466
2	18.33	16.31	230.2248	204.8536	217.5392
4	4.15	4.1	104.248	102.992	103.62
8	0.882	0.673	44.31168	33.81152	39.0616
16	0.142	0.123	14.26816	12.35904	13.3136
32	0.0327	0.032	6.571392	6.43072	6.501056
64	0.017	0.019	6.83264	7.63648	7.23456



DATA SET: AM6

CLIENT: WaterAid
 LOCATION: Oju
 COUNTY: Ameka village
 PROJECT: Water and sanitation
 ELEVATION: 0.00
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: Feb 1998
 SOUNDING: 3
 AZIMUTH: 11.5 Deg N-NE
 EQUIPMENT: bgs128

Offset Wenner Configuration

FITTING ERROR: 4.496 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m ²)
			0.0		
1	148.6	0.443	-0.443	0.00299	65.97
2	965.4	0.381	-0.825	3.950E-04	368.1
3	58.64	5.27	-6.09	0.0898	309.2
4	6.58				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO			
1	103.386	148.611	185.661
2	457.418	965.410	3791.818
3	46.336	58.649	73.797
4	6.182	6.588	7.006
THICK			
1	0.240	0.444	0.640
2	0.093	0.381	0.829
3	4.700	5.272	5.956
DEPTH			
1	0.240	0.444	0.640
2	0.608	0.825	1.237
3	5.478	6.098	6.843

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
1	0.500	194.0	194.0	-0.0216
2	1.00	241.0	243.6	-1.09

* BRITISH GEOLOGICAL SURVEY *

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
3	2.00	217.0	212.8	1.90
4	4.00	104.0	105.0	-1.00
5	8.00	39.00	39.19	-0.502
6	16.00	13.00	12.75	1.84
7	32.00	6.50	7.11	-9.52
8	64.00	7.23	6.68	7.58

PARAMETER RESOLUTION MATRIX:
 "F" INDICATES FIXED PARAMETER

P 1	0.98							
P 2	0.00	0.52						
P 3	0.01	-0.01	0.99					
P 4	0.00	0.00	0.00	1.00				
T 1	-0.03	-0.05	0.01	0.00	0.94			
T 2	0.01	0.50	0.01	0.00	0.06	0.49		
T 3	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
	P 1	P 2	P 3	P 4	T 1	T 2	T 3	

* BRITISH GEOLOGICAL SURVEY *

Amaka

AM7

Resistivity Survey 4

7 degs 06.302; 8 degs 12.007 (8 bars)

At Catholic Church BGS22

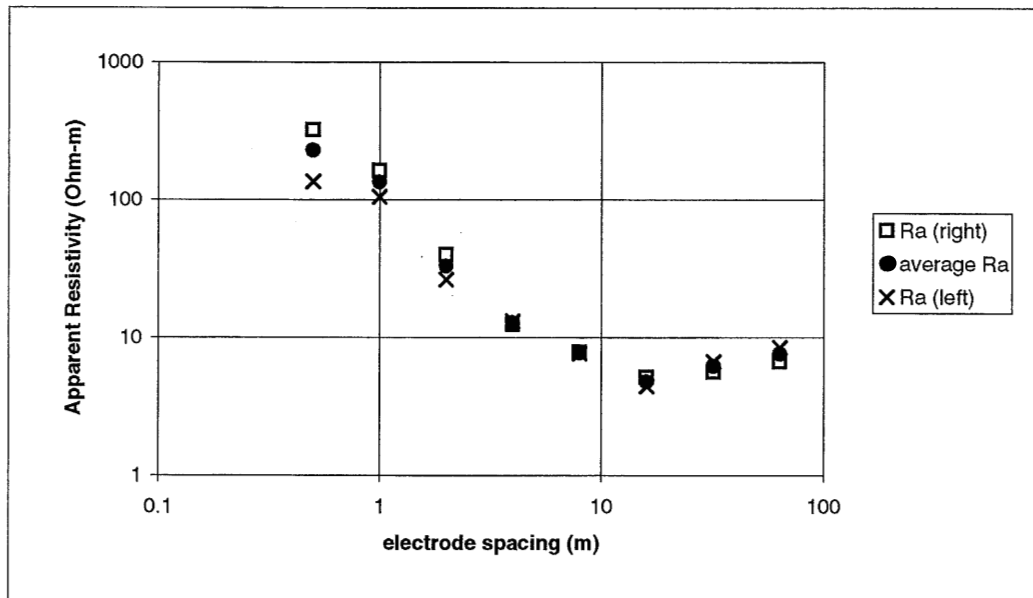
Offset Wenner

Left to Ijegwu

Strike 90 degs

04/03/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	42.8	101.8	134.392	319.652	227.022
1	16.6	25.9	104.248	162.652	133.45
2	2.09	3.16	26.2504	39.6896	32.97
4	0.52	0.495	13.0624	12.4344	12.7484
8	0.153	0.155	7.68672	7.7872	7.73696
16	0.044	0.051	4.42112	5.12448	4.7728
32	0.0333	0.028	6.691968	5.62688	6.159424
64	0.021	0.0165	8.44032	6.63168	7.536



Amaka

AM8

Resistivity Survey 5

7 degs 6.313; 8 degs 12.488 (7 bars)

At Fig tree BGS23

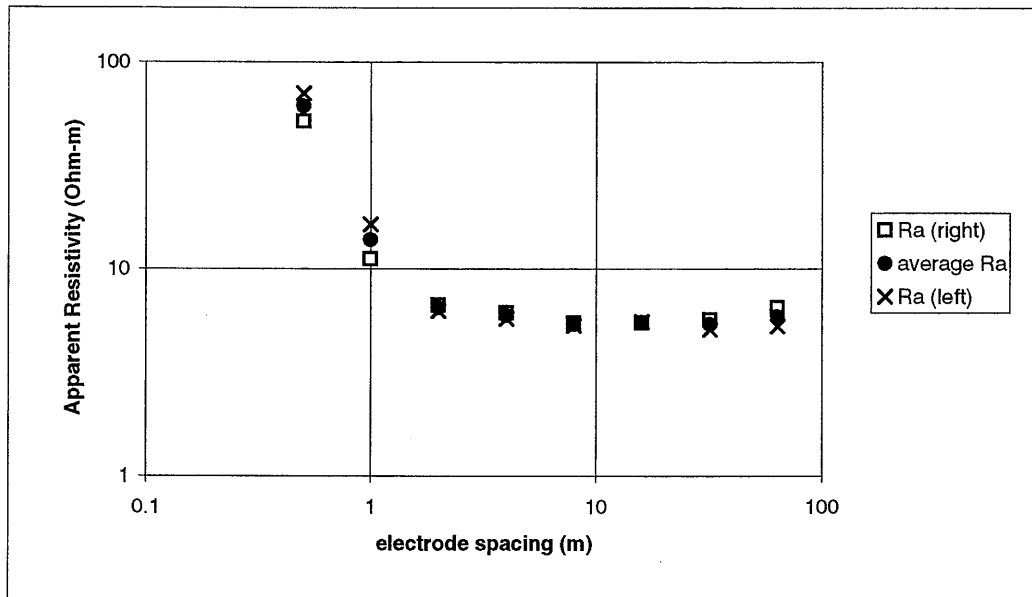
Offset Wenner

Left to Ijegwu

Strike 266 degs

04/03/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	22.4	16.38	70.336	51.4332	60.8846
1	2.6	1.77	16.328	11.1156	13.7218
2	0.495	0.528	6.2172	6.63168	6.42444
4	0.227	0.243	5.70224	6.10416	5.9032
8	0.105	0.108	5.2752	5.42592	5.35056
16	0.055	0.054	5.5264	5.42592	5.47616
32	0.0252	0.0281	5.064192	5.646976	5.355584
64	0.013	0.016	5.22496	6.43072	5.82784



DATA SET: AM8

CLIENT: WaterAid
 LOCATION: Oju
 COUNTY: Ameka BGS23
 PROJECT: Water and sanitation
 ELEVATION: 0.00
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: March 98
 SOUNDING: 5
 AZIMUTH: 0
 EQUIPMENT: bgs128

Offset Wenner Configuration

FITTING ERROR: 2.843 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m ²)
			0.0		
1	156.5	0.301	-0.301	0.00193	47.25
2	6.47	1.21	-1.52	0.188	7.88
3	5.49				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO			
1	133.770	156.504	190.558
2	5.620	6.472	7.937
3	5.262	5.499	5.727
THICK			
1	0.276	0.302	0.324
2	0.406	1.218	2.888
DEPTH			
1	0.276	0.302	0.324
2	0.695	1.520	3.200

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
1	0.500	60.90	60.91	-0.0168
2	1.00	13.70	13.69	0.0397
3	2.00	6.40	6.42	-0.376
4	4.00	5.90	5.78	1.95
5	8.00	5.35	5.57	-4.19
6	16.00	5.48	5.51	-0.676

* BRITISH GEOLOGICAL SURVEY *

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
7	32.00	5.35	5.50	-2.73
8	64.00	5.83	5.49	5.67

PARAMETER RESOLUTION MATRIX:
 "F" INDICATES FIXED PARAMETER

P 1	0.99				
P 2	-0.01	0.98			
P 3	0.00	0.00	1.00		
T 1	0.00	0.01	0.00	1.00	
T 2	0.03	0.09	0.01	-0.02	0.41
	P 1	P 2	P 3	T 1	T 2

* BRITISH GEOLOGICAL SURVEY *

Amaka

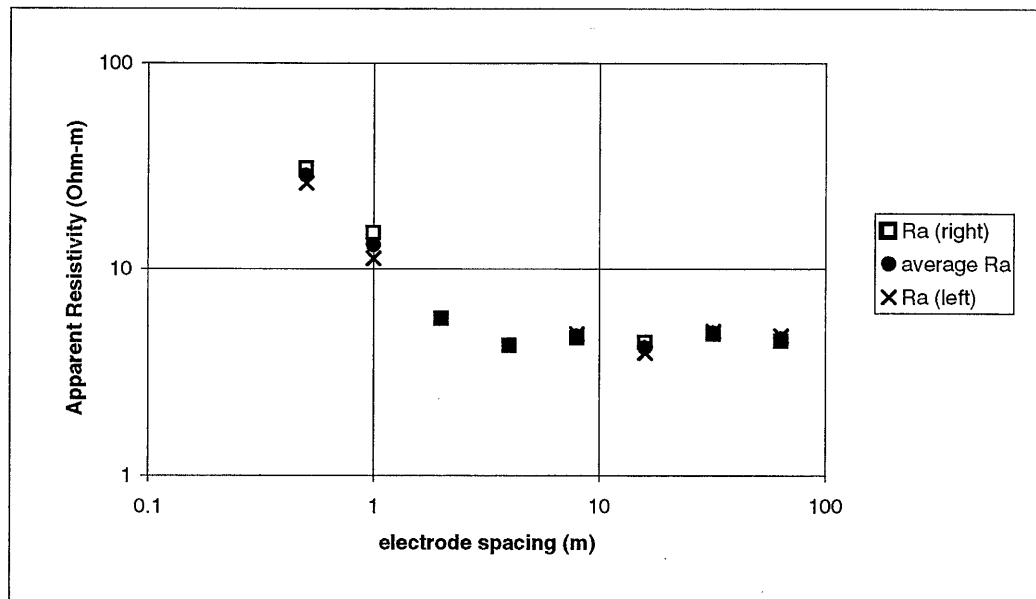
AM9

Resistivity Survey 6
At depression BGS24
Offset Wenner
Strike 266 degs
04/03/98

7 degs 06.399; 8 degs 13.00 (7 bars)

Left to Amaka

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	8.26	9.76	25.9364	30.6464	28.2914
1	1.784	2.36	11.20352	14.8208	13.01216
2		0.453		5.68968	5.68968
4		0.168		4.22016	4.22016
8	0.096	0.092	4.82304	4.62208	4.72256
16	0.039	0.0435	3.91872	4.37088	4.1448
32	0.0246	0.024	4.943616	4.82304	4.883328
64	0.0117	0.0111	4.702464	4.461312	4.581888



PARAMETER RESOLUTION MATRIX:
 "F" INDICATES FIXED PARAMETER
 P 1 1.00
 P 2 0.00 1.00
 T 1 0.00 0.00 1.00
 P 1 P 2 T 1

DATA SET: AM9

CLIENT: WaterAid
 LOCATION: Oju
 COUNTY: Ameka BGS24
 PROJECT: Water and sanitation
 ELEVATION: 0.00
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: March 98
 SOUNDING: 6
 AZIMUTH: 266 degs
 EQUIPMENT: bgs128

Offset Wenner Configuration

FITTING ERROR: 5.751 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m ²)
			0.0		
1	38.67	0.485	-0.485	0.0125	18.78
2	4.48				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO	1 31.820	38.678	48.268
	2 4.241	4.487	4.748
THICK	1 0.425	0.486	0.555
DEPTH	1 0.425	0.486	0.555

No.	SPACING (m)	RHO-A (ohm-m) DATA	RHO-A (ohm-m) SYNTHETIC	DIFFERENCE (percent)
1	0.500	28.30	28.12	0.623
2	1.00	13.00	13.16	-1.29
3	2.00	5.70	5.54	2.63
4	4.00	4.22	4.61	-9.37
5	8.00	4.72	4.51	4.37
6	16.00	4.14	4.49	-8.39
7	32.00	4.88	4.48	8.09
8	64.00	4.58	4.48	2.08

Amaka

AM10

Resistivity Survey 7

7 degs 06.535; 8 degs 13.486

BGS25

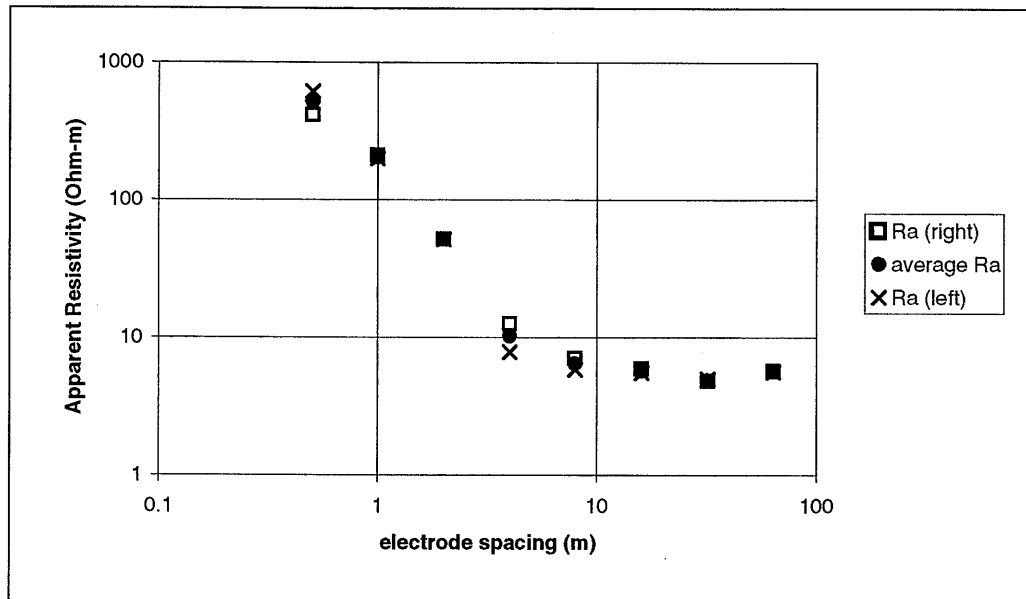
Offset Wenner

Left to Ijegwu

strike 244 degs

05/03/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	195.1	131.5	612.614	412.91	512.762
1	31.5	33.4	197.82	209.752	203.786
2	4.09	4.1	51.3704	51.496	51.4332
4	0.312	0.499	7.83744	12.53488	10.18616
8	0.116	0.14	5.82784	7.0336	6.43072
16	0.055	0.059	5.5264	5.92832	5.72736
32	0.0248	0.024	4.983808	4.82304	4.903424
64	0.014	0.0141	5.62688	5.667072	5.646976



Amaka

AM11

Resistivity Survey 8

7 degs 06.789; 8 degs 13.902

BGS26

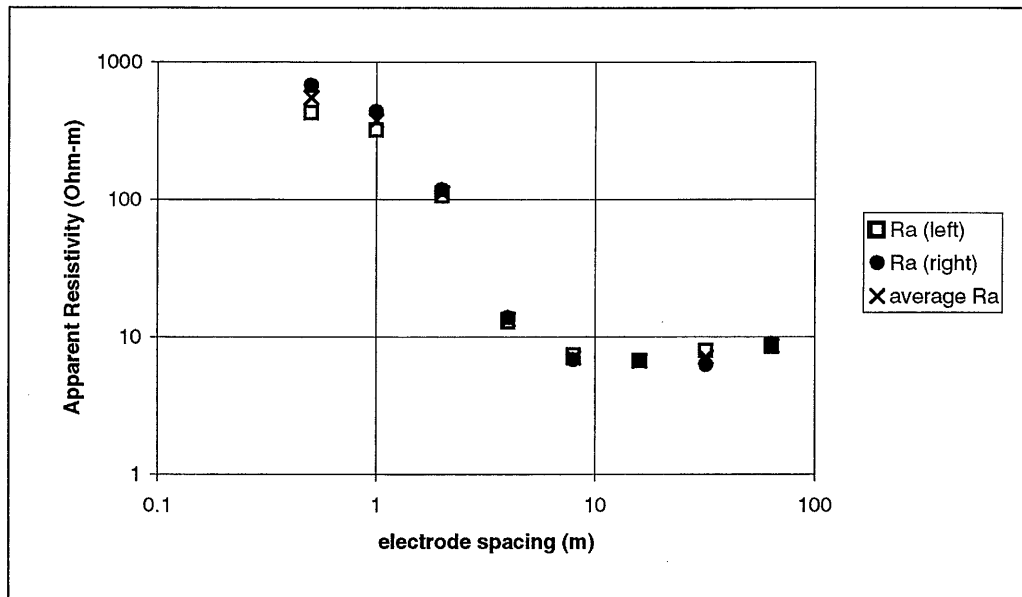
Offset Wenner

Left to Ijegwu

strike 109 degs

05/03/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	135.5	215	425.47	675.1	550.285
1	50.4	68.7	316.512	431.436	373.974
2	8.4	9.3	105.504	116.808	111.156
4	0.511	0.551	12.83632	13.84112	13.33872
8	0.146	0.135	7.33504	6.7824	7.05872
16	0.066	0.066	6.63168	6.63168	6.63168
32	0.0394	0.031	7.917824	6.22976	7.073792
64	0.021	0.022	8.44032	8.84224	8.64128



Amaka

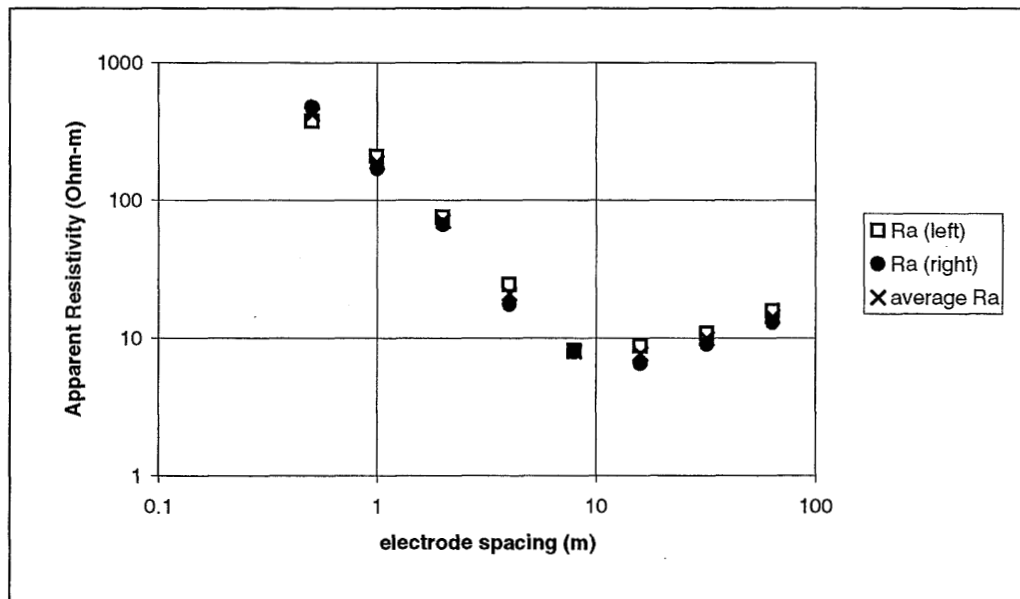
AM12

Resistivity Survey 9
BGS27 and BGS31
Offset Wenner
strike 309 degs
06/03/98

7 degs 06.449; 8 degs 14.557

Left to Ijegwu

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	118.4	150.1	371.776	471.314	421.545
1	32.9	26.9	206.612	168.932	187.772
2	5.98	5.25	75.1088	65.94	70.5244
4	0.972	0.697	24.41664	17.50864	20.96264
8	0.161	0.158	8.08864	7.93792	8.01328
16	0.087	0.065	8.74176	6.5312	7.63648
32	0.0535	0.0447	10.75136	8.982912	9.867136
64	0.039	0.0321	15.67488	12.90163	14.28826



Amaka

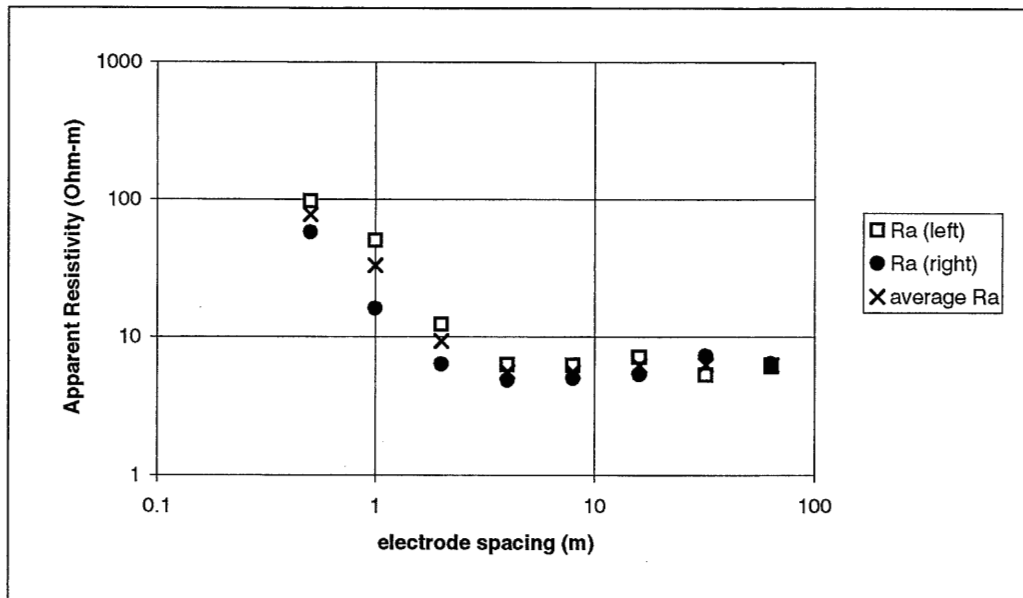
AM13

Resistivity Survey 10
 BGS28
 Offset Wenner
 strike 117 degs
 05/03/97

7 degs 06.142; 8 degs 15.497

Left to Ijegwu

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	30.8	18.2	96.712	57.148	76.93
1	7.93	2.54	49.8004	15.9512	32.8758
2	0.98	0.5	12.3088	6.28	9.2944
4	0.248	0.193	6.22976	4.84816	5.53896
8	0.123	0.099	6.17952	4.97376	5.57664
16	0.0704	0.053	7.073792	5.32544	6.199616
32	0.0263	0.0361	5.285248	7.254656	6.269952
64	0.015	0.0159	6.0288	6.390528	6.209664

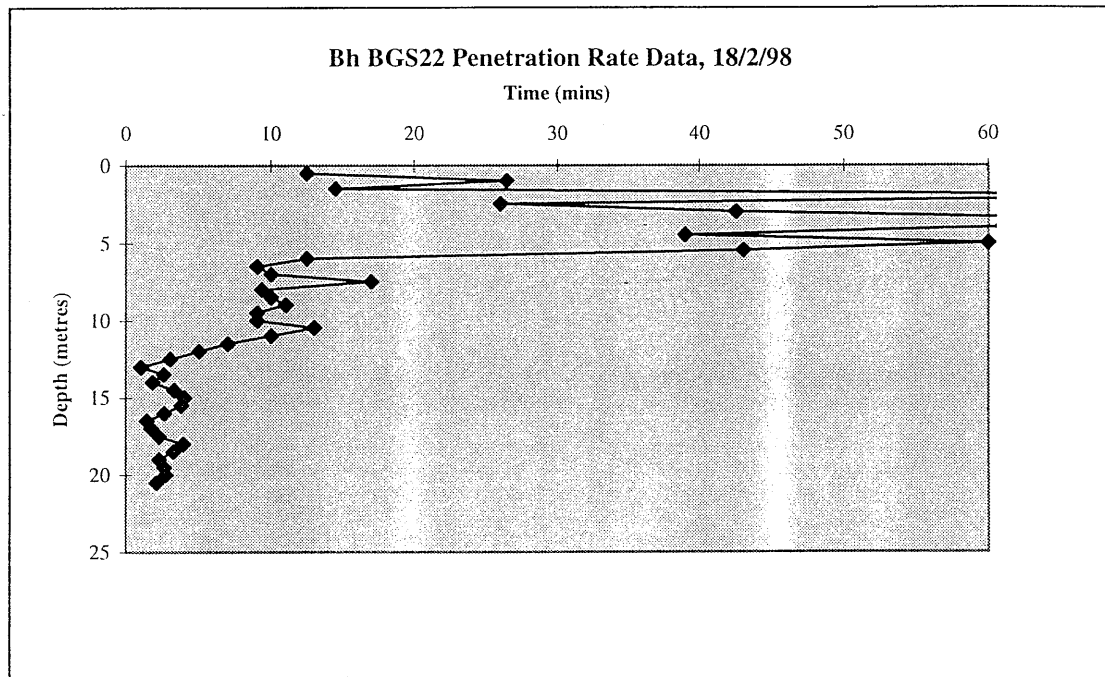


Annex 2: Drilling and Borehole Construction Data

Borehole BGS22

Borehole Drilling/Construction Details

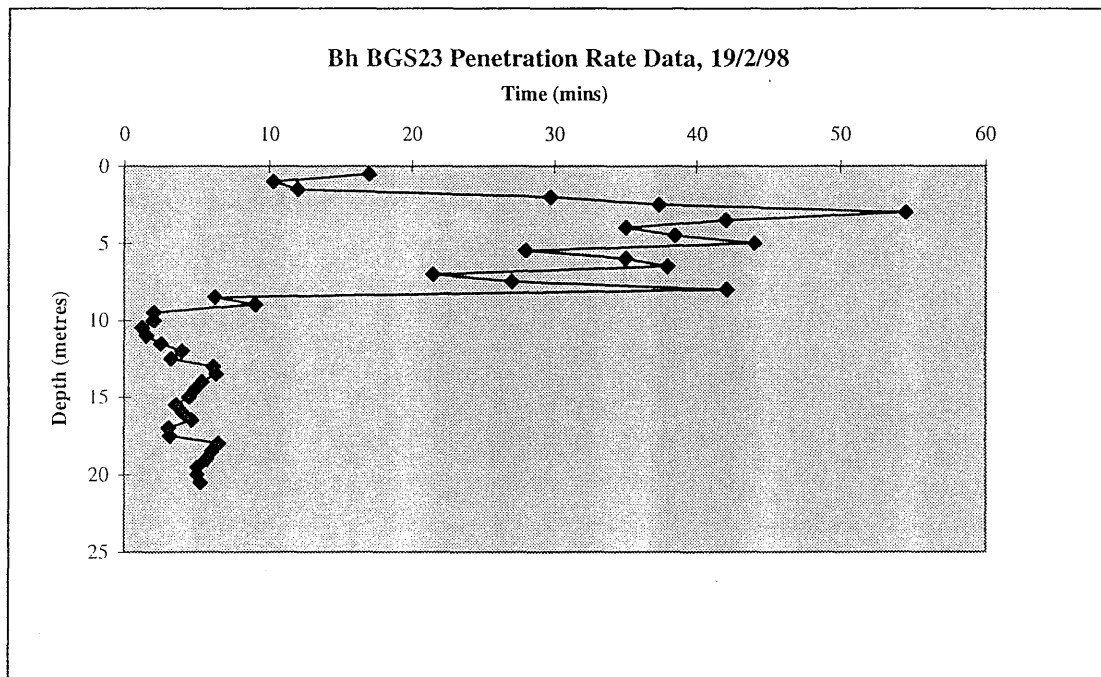
Date drilling started	18/2/98
Date drilling completed	19/2/98
18/2/98 - Drilled with 8.5" tricone	0.00 - 5.5m
18/2/98 - Drilled with 6.5" hammer	5.5 - 20.5m
19/2/98 - Cored at 3"	20.5 - 23.0m
Depths water struck	10m (very damp)
Depth of borehole on completion	23.0m bgs
Borehole diameter	6 1/2"
Casing erected in hole	none
Rest water level below casing top	17.60m



Borehole BGS23

Borehole Drilling/Construction Details

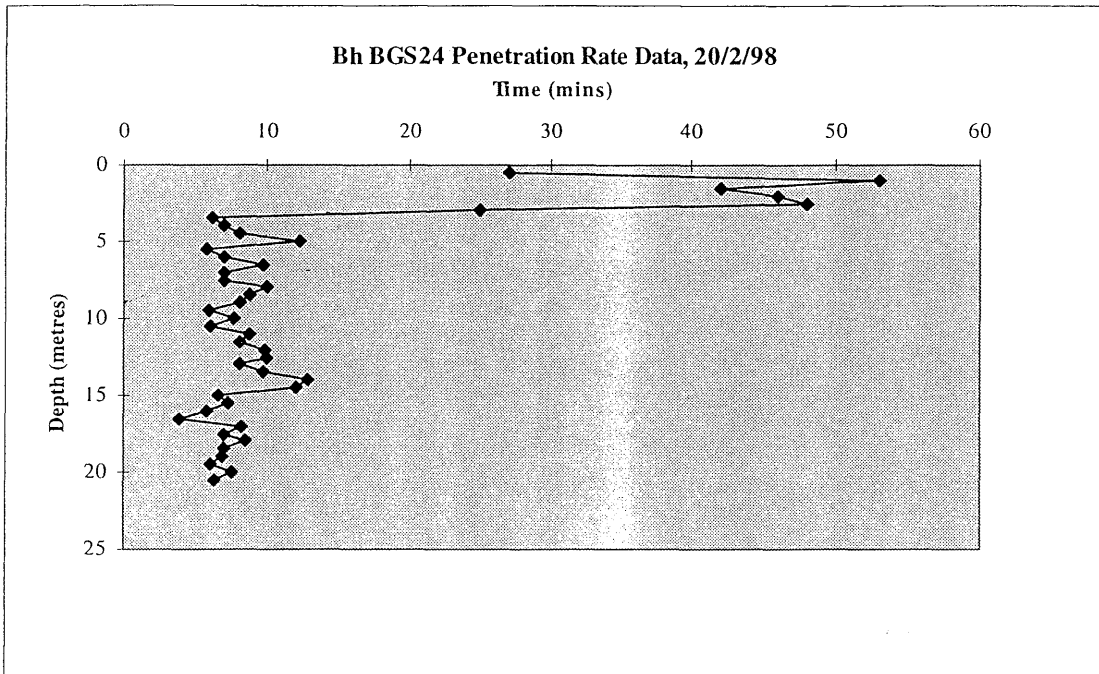
Date drilling started	19/2/98
Date drilling completed	20/2/98
19/2/98 - Drilled with 8.5" tricone	0.00 - 8.0m
19/2/98 - Drilled with 6.5" hammer	8.0 - 12.5m
20/2/98 - Drilled with 6.5" hammer	12.5 - 20.5m
20/2/98 - Cored at 3"	20.5 - 23.0m
Depths water struck	15 (damp), 15.5m
Depth of borehole on completion	23.5mbgs
Borehole diameter	6 ¹ / ₂ "
Casing erected in hole	none
Rest water level below casing top	22.00m



Borehole BGS24

Borehole Drilling/Construction Details

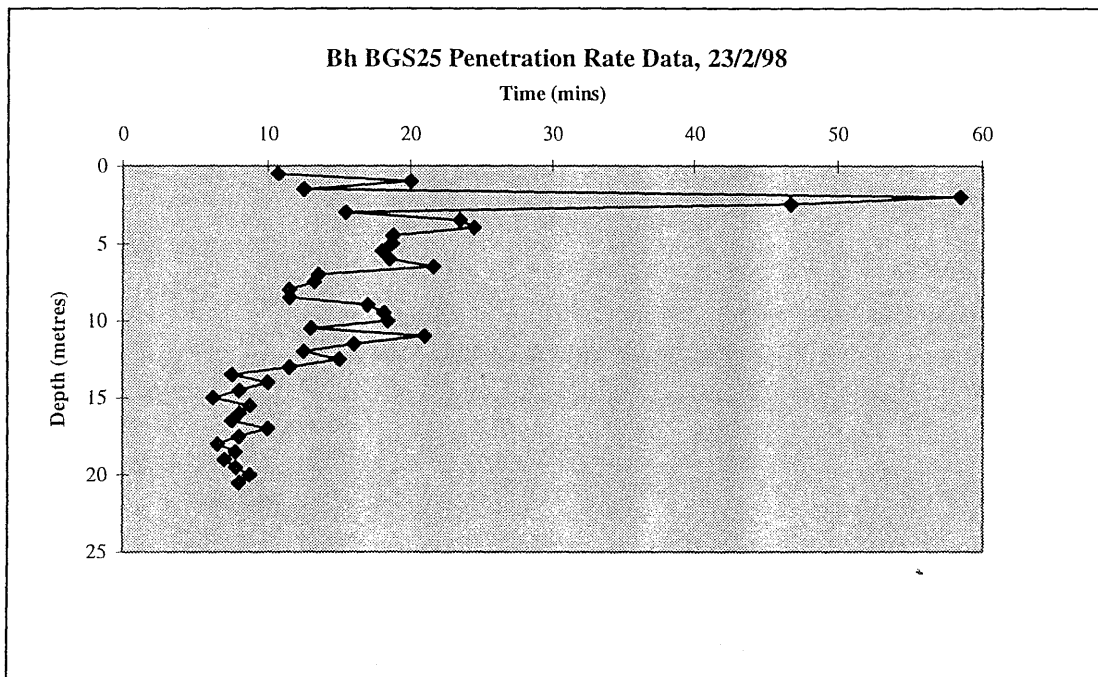
Date drilling started	20/2/98
Date drilling completed	20/2/98
20/2/98 - Drilled with 8.5" tricone	0.00 - 20.5m
20/2/98 - Cored at 3"	20.5 - 23.0m
Depths water struck	14.5 (damp)
Depth of borehole on completion	23.0mbgs
Borehole diameter	6 ¹ / ₂ "
Casing erected in hole	none
Rest water level below casing top	dry



Borehole BGS25

Borehole Drilling/Construction Details

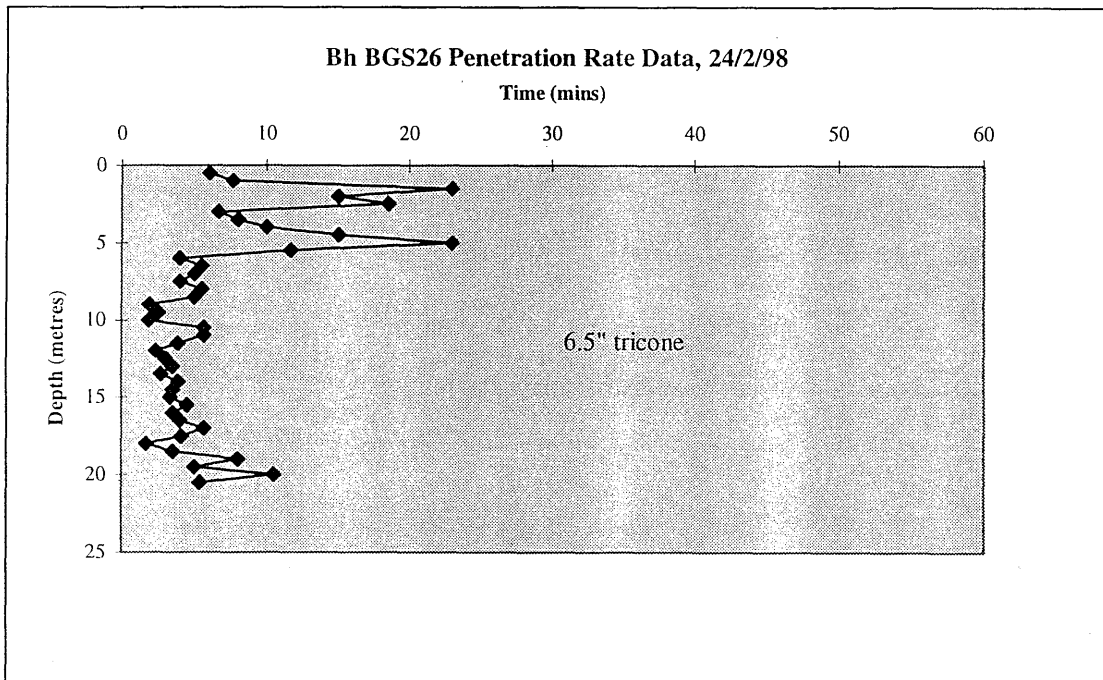
Date drilling started	23/2/98
Date drilling completed	24/2/98
23/2/98 - Drilled with 8.5" tricone	0.00 - 20.5m
24/2/98 - Cored at 3"	20.5 - 21.3m
Depth of borehole on completion	21.3mbgs
Borehole diameter	6 1/2"
Casing erected in hole	none
Rest water level below casing top	dry



Borehole BGS26

Borehole Drilling/Construction Details

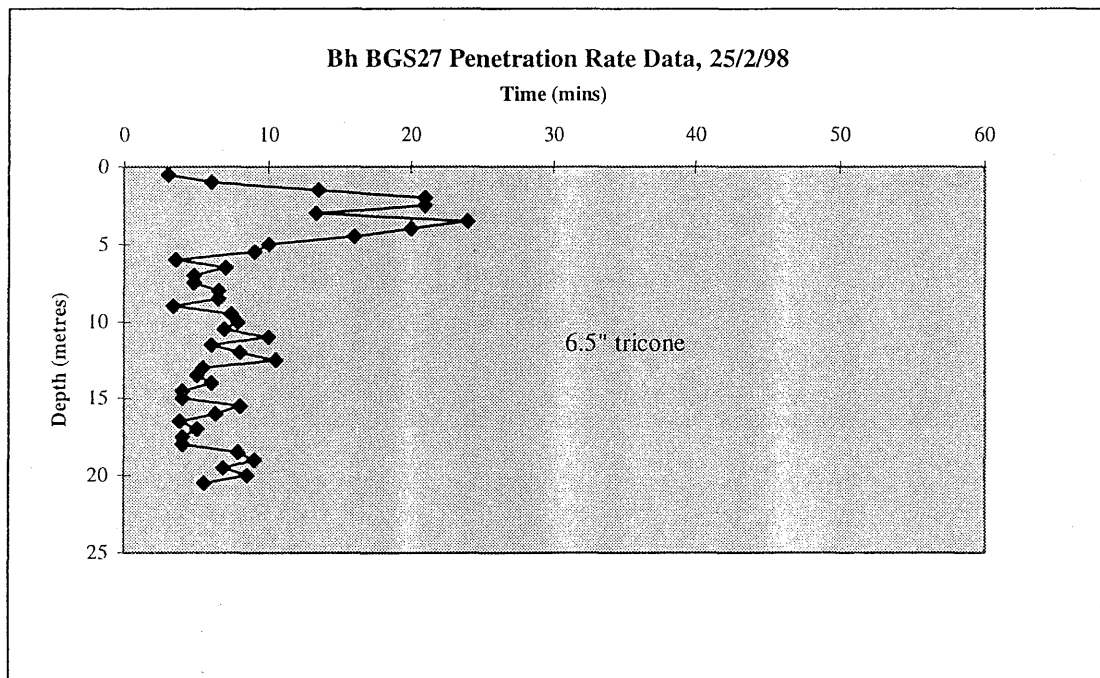
Date drilling started	24/2/98
Date drilling completed	25/2/98
24/2/98 - Drilled with 6.5" tricone	0.00 - 20.5m
25/2/98 - Cored at 3"	20.5 - 23.4m
Depth water struck	21.40m (flowing)
Depth of borehole on completion	23.4mbgs
Borehole diameter	6 1/2"
Casing erected in hole	3x5.8mx125mm casing 1x2.9mx125mm casing 1x2.9mx125mm screen
Original top of casing above ground level	2.40m
Total length of casing/screen	22.90m
Amount of casing removed	1.80m
Top of casing above ground level	0.60m
Rest water level below ground surface	7.915m



Borehole BGS27

Borehole Drilling/Construction Details

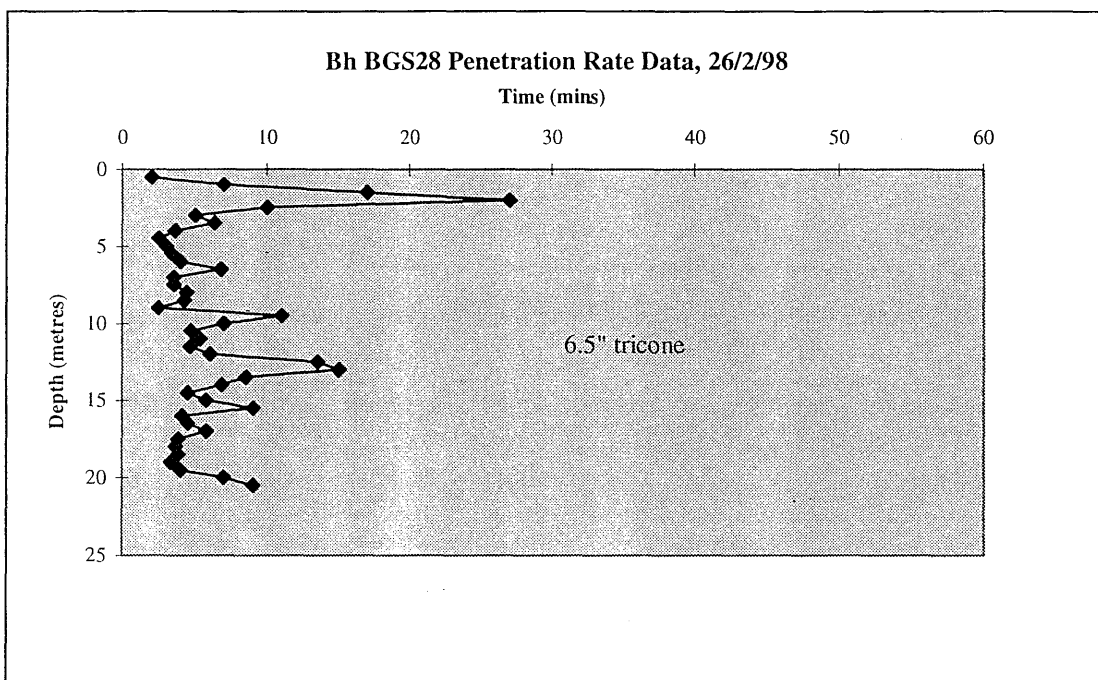
Date drilling started	25/2/98
Date drilling completed	26/2/98
25/2/98 - Drilled with 6.5" tricone	0.00 - 20.5m
25/2/98 - Cored at 3"	20.5 - 23.35m
Depth of borehole on completion	23.35mbgs
Borehole diameter	6 1/2"
Casing erected in hole	3x5.8mx125mm casing 1x5.8mx125mm screen
Original top of casing above ground level	2.25m
Total length of casing/screen	22.96m
Amount of casing removed	1.62m
Rest water level below casing top	10.19m



Borehole BGS28

Borehole Drilling/Construction Details

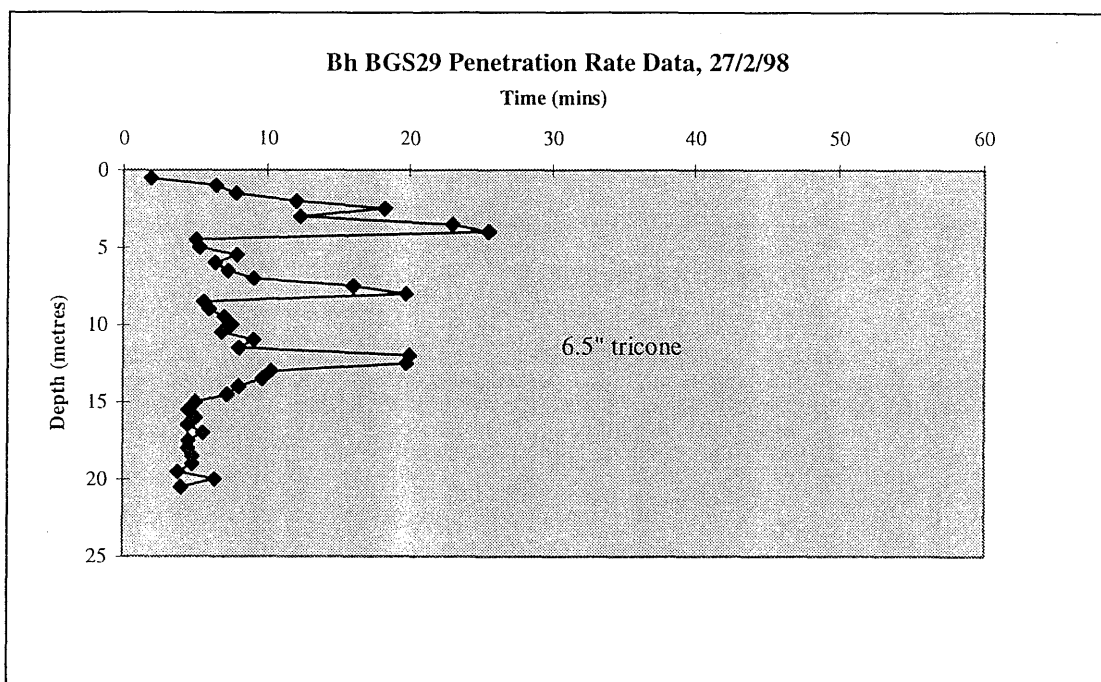
Date drilling started	26/2/98
Date drilling completed	27/2/98
26/2/98 - Drilled with 6.5" tricone	0.00 - 20.5m
26/2/98 - Cored at 3"	20.5 - 23.4m
Depth of borehole on completion	23.4mbgs
Borehole diameter	6 $\frac{1}{2}$ "
Casing erected in hole	none
Rest water level below casing top	dry



Borehole BGS29

Borehole Drilling/Construction Details

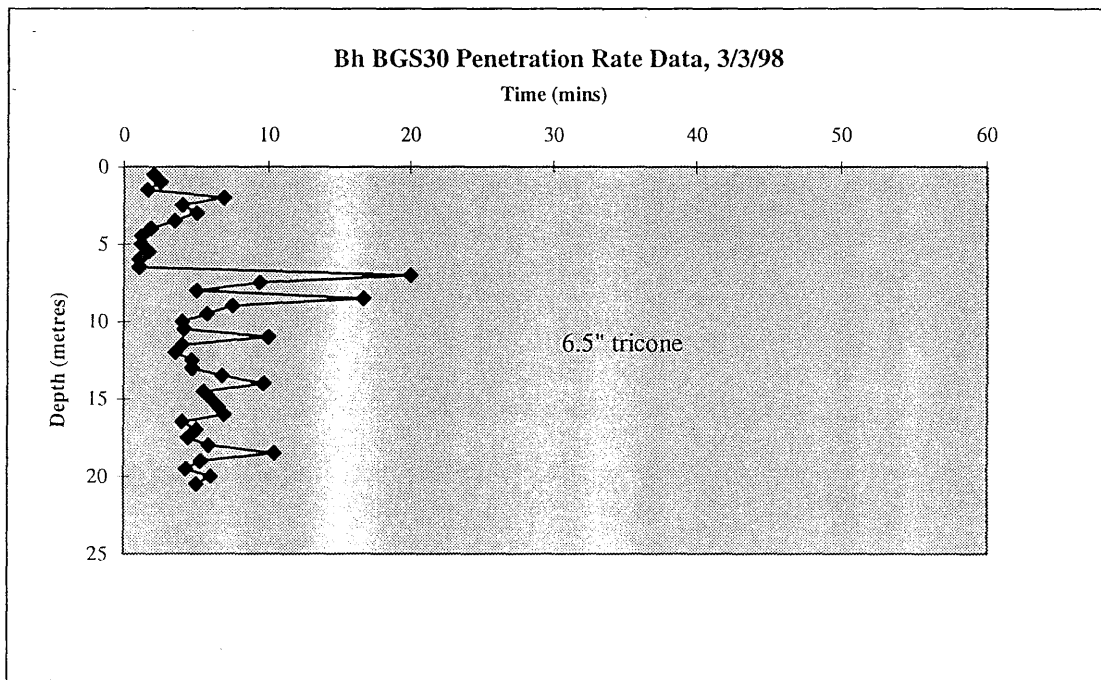
Date drilling started	27/2/98
Date drilling completed	3/3/98
27/2/98 - Drilled with 6.5" tricone	0.00 - 20.5m
27/2/98 - Cored at 3"	20.5 - 23.0m
Depth of borehole on completion	23.6mbgs
Borehole diameter	6 1/2"
Casing erected in hole	none
Rest water level below casing top	22.41m



Borehole BGS30

Borehole Drilling/Construction Details

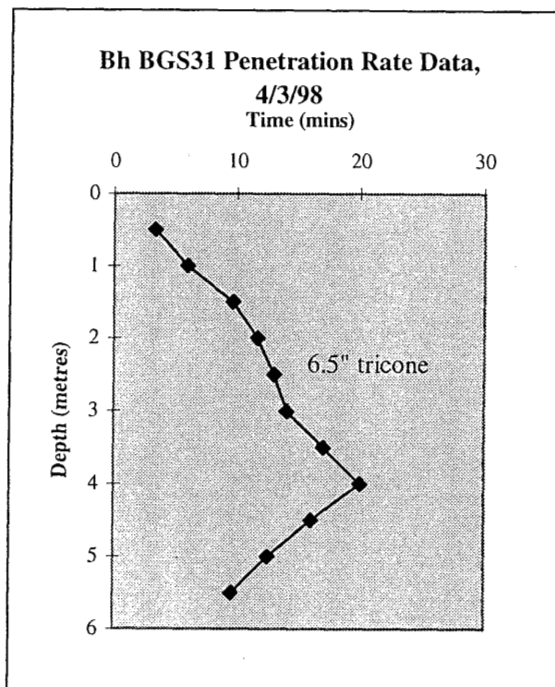
Date drilling started	3/3/98
Date drilling completed	4/3/98
3/3/98 - Drilled with 6.5" tricone	0.00 - 20.5m
3/3/98 - Cored at 3"	20.5 - 23.5m
4/3/98 - reamed out at 8.5" with tricone	0.00 - 11.5m
Depths water struck	4.0m
Depth of borehole on completion	23.5mbgs
Borehole diameter	6 1/2"
Casing erected in hole	2x2.9mx125mm casing 1x2.9mx125mm screen 1x1.6mx125mm casing
Original top of casing above ground level	0.30m
Total length of casing/screen	10.2m
Amount of casing removed	0.00m
Rest water level below casing top	11.51m



Borehole BGS31

Borehole Drilling/Construction Details

Date drilling started	4/3/98
Date drilling completed	5/3/98
4/3/98 - Drilled with 6.5" tricone	0.00 - 5.5m
5/3/98 - Cored at 3"	5.5 - 14.5m
Depth of borehole on completion	14.5mbgs
Borehole diameter	6 ¹ / ₂ "
Casing erected in hole	none



Annex 3: Lithological Logs

Lithological Log: BGS22

Soil/ferrecrete horizon

0.0 - 0.5	Yellowish brown 10YR5/4 silty clayey soil
0.5 - 1.0	Red 10R5/8 lateritic soil, bright red with some light blue grey kaolin clay
1.0 - 1.5	Dark red purple ferrecrete nodules with red lateritic soil and light blue grey and bright orange clays

Clayey very weathered horizon

1.5 - 2.0	Red lateritic soil with light blue grey kaolin clay, no nodules, slightly damp
2.0 - 2.5	Purple red 10R6/4 and light blue clays, damp
2.5 - 3.0	Dark orange red and white grey clays, much kaolin

Very weathered shaley mudstone with clay

3.0 - 3.5	Pale red to ochre, with orange partings very weathered shaley mudstones
3.5 - 4.0	Pale red and white with olive green mottled weathered mudstones
4.0 - 4.5	Olive green to light olive green weathered shaley siltstone
4.5 - 5.0	Brown, ochre brown and light olive green weathered muddy siltstone
5.0 - 5.5	Light orange olive green weathered silty mudstones, some light bluish grey kaolin
5.5 - 6.0	Weathered olive green to brown mudstones with some light bluish grey kaolin clay

Weathered mudstone

6.0 - 6.5	Fairly hard brown thinly layered mudstones above weathered grey mudstones, some orange partings, damp
6.5 - 7.0	Weathered grey mudstones and light grey sandstones, some orange weathered partings
7.0 - 7.5	Red brown, olive green and grey weathered mudstones
7.5 - 8.0	Red brown, olive green and grey weathered mudstones

Fairly weathered mudstone

8.0 - 8.5	Dark grey weathered mudstones with some black organic partings, with olive brown and yellowish brown partings
8.5 - 9.0	Soft weathered grey to light grey mudstones, mottled with orange partings
9.0 - 9.5	Dark grey mudstones and light green, brown and olive siltstones, soft and damp
9.5 - 10.0	No returns - stuck to side of borehole
10.0 - 10.5	Poor returns - ochre mudstones
10.5 - 11.0	Poor returns - olive mudstone

Shaley carbonaceous mudstone

11.0 - 11.5	Blue grey shaley mudstones
11.5 - 12.0	Dark grey carbonaceous shaley mudstones
12.0 - 12.5	Dark grey carbonaceous shaley mudstones
12.5 - 13.0	Dark grey carbonaceous shaley mudstones
13.0 - 13.5	Soft black grey carbonaceous shaley mudstones
13.5 - 14.0	Soft black grey carbonaceous shaley mudstones
14.0 - 14.5	Black to dark grey very carbonaceous shaley mudstones
14.5 - 15.0	Black to dark grey very carbonaceous shaley mudstones
15.0 - 15.5	Black to dark grey very carbonaceous shaley mudstones
15.5 - 16.0	Black to dark grey very carbonaceous shaley mudstones
16.0 - 16.5	Black grey carbonaceous shaley mudstones
16.5 - 17.0	Black to dark grey carbonaceous shaley mudstones, finer grained
17.0 - 17.5	Hard thin layer, limestone?, within black carbonaceous shaley mudstones
17.5 - 18.0	Black very carbonaceous shaley mudstones
18.0 - 18.5	Black very carbonaceous shaley mudstones
18.5 - 19.0	Dark grey black carbonaceous shaley mudstones
19.0 - 19.5	Dark grey black carbonaceous shaley mudstones
19.5 - 20.0	No returns
20.0 - 20.5	No returns
20.50 - 20.62	Black fine grained blocky very carbonaceous mudstones, some small cubes of iron pyrite
20.62 - 20.71	Black fine grained very carbonaceous to silty mudstones, occasional thin gypsum/calcite bands along bedding planes
20.71 - 20.89	Black very carbonaceous and silty fine sandstones with thin interbedded mudstones

20.89 - 21.08 Black very carbonaceous finely grained and bedded mudstones. Some **gypsum** along bedding planes.

Interbedded muddy limestone, mudstone, siltstone and fine grained sandstone

21.08 - 21.19 White and dark grey very muddy bioturbated limestone and interbedded mudstone

21.19 - 21.36 Black carbonaceous silty blocky well bedded mudstones to siltstones with fine sandstone and thin white limestone bands

Carbonaceous shaley and silty mudstone

21.36 - 21.48 Massive blocky black very carbonaceous fine grained mudstone with light grey clayey flattened nodules at 40m - seem to have been dropped into mud

21.48 - 21.52 Black blocky fine grained carbonaceous mudstones, some iron **pyrite** and thin **gypsum** along bedding planes

21.52 - 21.61 Dark grey to grey fine grained mudstones, shaley. thinly laminated

21.61 - 21.67 Dark grey to grey finely laminated shaley mudstone with silty mudstones

Interbedded shaley mudstone, muddy siltstone and fine grained sandstone

21.67 - 21.75 Dark grey shaley mudstone interbedded with light grey muddy siltstones and odd thin grey fine sandstone band, some interbedded thin calcite lenses along bedding planes

21.75 - 21.87 Interbedded thin beds of dark grey shaley mudstones, light grey siltstones and grey fine grained sandstones

21.87 - 22.00 Dark grey mudstones and light grey siltstone, thinly bedded with interbedded thin grey fine sandstone bands, some calcite in thin intermittent lenses along bedding planes

Shaley mudstone and siltstone, fractured

22.00 - 22.08 Dark grey thinly bedded shaley mudstones with thin green siltstones

22.08 - 22.13 Broken rock

22.13 - 22.19 Dark grey muddy shaley siltstone

Medium to fine grained glauconitic sandstone with muddy siltstone and mudstone

22.19 - 22.26 Dark grey muddy shaley siltstone with thin discontinuous fine grained sandstone layers

22.26 - 22.41 Green medium to fine grained glauconitic sandstones with black muddy partings, bioturbated

22.41 - 22.46 Thinly bedded green medium to fine grained glauconitic sandstone with interbedded black mudstones, slump structures common above more competent light brown intermittent fine grained sandstone bands

Carbonaceous mudstone

22.46 - 22.49 Black to dark grey carbonaceous mudstones

Fine grained sandstone, siltstone and mudstone

22.49 - 22.54 Light grey fine sandstone grading downward into grey siltstone and dark grey mudstones

Carbonaceous shaley mudstone and siltstone

22.54 - 22.64 Black carbonaceous to dark grey mudstones, bivalves present including oyster and lamp shells at 22.61

22.64 - 22.68 Black carbonaceous to dark grey shaley mudstones, some black organic carbon remains

22.68 - 22.78 Black carbonaceous to dark grey shaley mudstones, some bivalve remains

22.78 - 22.87 Black carbonaceous to dark grey shaley mudstones with thin grey siltstone bands

22.87 - 22.91 Black carbonaceous to dark grey shaley mudstones with grey siltstones, some ribbed bivalves

22.91 - 22.95 Black carbonaceous and dark grey mudstones to grey siltstones, some ribbed bivalves

Lithological Log: BGS23

Soil/ferrecrete horizon

0.0 - 0.5	Light brown 7.5YR6/4 loamy soil, thick tree root
0.5 - 1.0	Red brown to orange brown and grey brown silty soil, tree root

Clayey very weathered horizon

1.0 - 1.5	Pale red to orange brown silty and sticky clay
1.5 - 2.0	Pale red and pale orange red to light grey red silty clays, some white kaolin
2.0 - 2.5	Pale red to reddish white silty clays, some white kaolin

Weathered mudstones with much gypsum

2.5 - 3.0	Pale red and yellow brown very weathered mudstones with white gypsum crystals
3.0 - 3.5	Light olive green to brown weathered mudstones, much crystalline gypsum
3.5 - 4.0	Ochre yellow to olive green very weathered mudstones, some grey partings
4.0 - 4.5	Olive green weathered shaley mudstones, with crystalline gypsum
4.5 - 5.0	Olive green weathered silty mudstones much fibrous sellanite gypsum
5.0 - 5.5	Olive green 2.5YR6/4 weathered mudstones, much gypsum
5.5 - 6.0	Light yellowish brown 10YR6/4 weathered silty mudstones, clayey with crystalline gypsum
6.0 - 6.5	Yellow brown 10YR5/4 weathered mudstones, little gypsum
6.5 - 7.0	Light grey and yellow brown less weathered mudstones, some crystalline gypsum
7.0 - 7.5	Light orange brown, olive green and grey weathered mudstones, some gypsum
7.5 - 8.0	Dark grey black mudstone, weathered light brown, some gypsum

Compact carbonaceous mudstone

8.0 - 8.5	Dark grey carbonaceous mudstones - damp
8.5 - 9.0	Dark grey carbonaceous mudstones
9.0 - 9.5	Dark grey carbonaceous mudstones
9.5 - 10.0	Compact hard blocky carbonaceous black mudstone
10.0 - 10.5	Compact hard blocky carbonaceous black mudstone

Soft carbonaceous mudstone

10.5 - 11.0	Soft blocky carbonaceous black mudstone
11.0 - 11.5	Soft blocky carbonaceous black mudstone
11.5 - 12.0	Soft blocky carbonaceous black mudstone
12.0 - 12.5	Soft blocky carbonaceous black mudstone

Hard muddy limestone

12.5 - 13.0	Hard compact light grey muddy limestone
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Soft carbonaceous mudstone

13.0 - 13.5	Soft dark grey carbonaceous mudstones
13.5 - 14.0	Soft dark grey carbonaceous earthy mudstones
14.0 - 14.5	Soft dark grey carbonaceous mudstones
14.5 - 15.0	Soft dark grey carbonaceous mudstones
15.0 - 15.5	Soft dark grey carbonaceous mudstones
15.5 - 16.0	Soft dark grey carbonaceous mudstones
16.0 - 16.5	Soft dark grey carbonaceous mudstones
16.5 - 17.0	Soft dark grey carbonaceous mudstones
17.0 - 17.5	Soft dark grey carbonaceous mudstones
17.5 - 18.0	Soft dark grey carbonaceous mudstones
18.0 - 18.5	Soft dark grey carbonaceous mudstones
18.5 - 19.0	Soft dark grey carbonaceous mudstones
19.0 - 19.5	Soft dark grey carbonaceous mudstones
19.5 - 20.0	Soft dark grey carbonaceous mudstones
20.0 - 20.5	Soft dark grey carbonaceous mudstones

Shaley mudstone

20.50 - 21.60	Grey splitting shaley mudstones, very fossiliferous with coarse and fine ribbed bivalves, spiral gastropods and elongate scaphopods?
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Shaley siltstone and medium to fine grained glauconitic sandstone

21.60 - 21.70	Dark grey shaley siltstone, some bands of medium to fine greenish grey glauconitic sandstone, only the odd gastropod - few fossils
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Shaley mudstone

21.70 - 22.30 Grey shaley non-fossiliferous mudstones

Fractured shaley mudstone

22.30 - 22.39 Sheared black and dark grey lustrous fractured shaley mudstones (possible minor fracture zone)

Shaley mudstone

22.39 - 22.91 Grey shaley mudstones, very fossiliferous, mainly microfossils with macro-fossils in the lower half including fine ribbed bivalves

Fractured muddy calcite vein

22.91 - 22.94 Fractured muddy calcite vein

Shaley mudstone

22.94 - 23.50 Grey very fossiliferous shaley mudstones, mainly microfossils with bivalves and gastropods

Lithological Log: BGS24

Soil/ferrecrete horizon

- 0.0 - 0.5 Yellow brown 10YR5/6 clayey soil
0.5 - 1.0 Brown 7.5YR5/4 clayey soil
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Clayey very weathered horizon

- 1.0 - 1.5 Yellow red 5YR5/8 to brown 7.5YR5/6 clayey soil, some light grey kaolin
1.5 - 2.0 Olive yellow 2.5Y6/8 silty clay, damp
2.0 - 2.5 Olive yellow 2.5Y6/6 clay
-

Weathered clayey shaley mudstones

- 2.5 - 3.0 Olive brown 2.5Y4/4 to dark olive brown 2.5Y4/2 clayey weathered shaley mudstones
3.0 - 3.5 Blue grey and orange mottled weathered shaley mudstones
3.5 - 4.0 Yellow 2.5Y7/6 to light blue grey weathered shaley mudstones, some light grey carbonaceous shale
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Weathered shaley mudstones with much gypsum

- 4.0 - 4.5 Slightly weathered dark grey shaley mudstones with orange partings, some **gypsum** veins
4.5 - 5.0 Weathered black to dark grey carbonaceous shaley mudstones with some **gypsum**
5.0 - 5.5 Black carbonaceous shaley mudstones with **gypsum**
5.5 - 6.0 Soft black carbonaceous shaley mudstones with weathered orange partings, some **gypsum**
6.0 - 6.5 Dark grey carbonaceous shaley mudstones with light grey and orange weathered partings some **gypsum**
6.5 - 7.0 Light grey to light brown weathered shaley mudstones with fibrous and platy **gypsum**
7.0 - 7.5 Soft and clayey dark grey carbonaceous shaley mudstones with light brown and orange weathered partings, some fibrous and platy **gypsum**
7.5 - 8.0 Weathered dark grey shaley mudstones with light brown and green brown partings some **gypsum**
8.0 - 8.5 Interbedded dark grey carbonaceous shaley mudstones with very weathered light brown, green and orange clayey shaley mudstones, some **gypsum**
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Carbonaceous shaley mudstone

- 8.5 - 9.0 Dark grey carbonaceous shaley mudstones, unweathered - base of weathered zone
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Carbonaceous shaley mudstone and thin limestone

- 9.0 - 9.5 Thinly bedded black carbonaceous shaley mudstones, very soft, some thin limestone bands
-

Carbonaceous shaley mudstone

- 9.5 - 10.0 Thinly bedded black carbonaceous shaley mudstones
10.0 - 10.5 Thinly bedded black carbonaceous shaley mudstones, some ribbed bivalves
10.5 - 11.0 Thinly bedded black carbonaceous shaley mudstones, very soft, some ribbed bivalves, odd gypsum fragment
11.0 - 11.5 Thinly bedded black carbonaceous shaley mudstones
11.5 - 12.0 Thinly bedded black carbonaceous shaley mudstones
12.0 - 12.5 Thinly bedded black carbonaceous shaley mudstones
12.5 - 13.0 Thinly bedded black carbonaceous shaley mudstones with plant remains
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Shaley mudstone with thin ash band

- 13.0 - 13.5 Thinly bedded dark grey shaley mudstone, possible light grey thin ash layer
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Carbonaceous shaley mudstone

- 13.5 - 14.0 Soft black carbonaceous shaley mudstones
14.0 - 14.5 Soft black very carbonaceous shaley mudstones, damp
14.5 - 15.0 Soft black dark grey carbonaceous shaley mudstones
-

Carbonaceous shaley mudstone with thin hard bands

- 15.0 - 15.5 Soft black carbonaceous shaley mudstones, with thin hard bands
15.5 - 16.0 Soft black carbonaceous shaley mudstones, with thin hard bands
16.0 - 16.5 Soft black carbonaceous shaley mudstones, with thin hard bands
16.5 - 17.0 Soft black carbonaceous shaley mudstones
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Carbonaceous shaley mudstone with ash layer	
17.0 - 17.5	Thinly laminated black carbonaceous shaley mudstones, odd thin band of light grey fine grained ash or siltstone
Carbonaceous shaley mudstone	
17.5 - 18.0	Thinly laminated black carbonaceous shaley mudstones
18.0 - 18.5	Thinly laminated black very carbonaceous shaley mudstones
Carbonaceous shaley mudstone with ash layer	
18.5 - 19.0	Thinly laminated black very carbonaceous shaley mudstones, odd thin band of light grey fine grained ash or siltstone
Carbonaceous shaley mudstone	
19.0 - 19.5	Thinly bedded black very carbonaceous shaley mudstones
19.5 - 20.0	Dark grey to black carbonaceous shaley mudstones
20.0 - 20.5	Dark grey to black carbonaceous shaley mudstones
20.5 - 22.00	No core
Sandy mudstone	
22.00 - 22.10	Grey broken sandy mudstone
Shaley mudstone	
22.10 - 22.66	Grey shaley mudstones, blocky to subconcoidal fracture, generally non-fossiliferous
Sandy silty shale	
22.66 - 22.71	Grey silty shale, some sandy bands, fairly fossiliferous, some crab? remains
Sandy shale and muddy fine to medium grained sandstone	
22.71 - 22.80	Grey sandy shale with light grey muddy fine to medium grained sandstones, thinly bedded
Shaley mudstone	
22.80 - 23.00	Grey shaley mudstone, fossiliferous with sponge spines and plates as well as bivalves and microfossils
Fractured sandy mudstone with calcite	
23.00 - 23.50	Broken grey sandy mudstones with prominent 1 cm thick vein of fibrous beef calcite, fracture zone

Lithological Log: BGS25

Soil/ferrecrete horizon

0.0 - 0.5	Light brown (7.5YR6/4) fine grained soil with red (2.5YR5/8) partings
0.5 - 1.0	Red (10R5/8) lateritic clay with some light grey kaolin clay
1.0 - 1.5	Red (10R5/8) lateritic clay with nodules of purple red hematite and black manganese oxide with some light grey kaolin clay

Clayey very weathered horizon

1.5 - 2.0	Red (10R5/6) lateritic clay, increased light grey and off white/pink kaolin clay
2.0 - 2.5	Yellowish red (7.5YR6/6) smectitic clay

Very weathered clayey mudstone

2.5 - 3.0	Light grey green (7/10Y) and reddish yellow (5YR6/6) mottled clay of weathered shaley mudstones
3.0 - 3.5	Light grey green (7/10Y) and reddish yellow (5YR6/6) mottled clay of weathered shaley mudstones
3.5 - 4.0	Light brown, light grey green (7/10Y) and reddish yellow (5YR6/6) mottled clay of weathered shaley mudstones
4.0 - 4.5	Light greenish grey (7/5GY) and dark yellowish brown (10YR4/6) very weathered clayey mudstones
4.5 - 5.0	Light greenish grey (7/5GY) and yellow brown (7.5YR6/6) very weathered clayey shaley mudstones
5.0 - 5.5	Brownish yellow (10YR6/6) to olive yellow (2.5Y6/6) weathered light grey mudstones

Weathered shaley mudstone

5.5 - 6.0	Olive yellow (2.5Y6/8) weathered shaley mudstones
6.0 - 6.5	Light olive brown (2.5Y5/4) weathered shaley mudstones

Weathered shaley mudstone with much gypsum

6.5 - 7.0	Dark olive green to dark grey weathered shaley mudstones, some gypsum crystals
7.0 - 7.5	Dark olive green to dark grey weathered shaley mudstones, increased gypsum crystals
7.5 - 8.0	Mottled orange and light grey weathered shaley mudstones, much gypsum - damp
8.0 - 8.5	Yellowish red (7.5YR6/8), dark bluish grey (3/5PB) and light blue grey clayey weathered mudstones
8.5 - 9.0	Dark olive green to dark grey weathered shaley mudstones, some gypsum
9.0 - 9.5	Yellowish brown and dark grey weathered shaley mudstones, little gypsum
9.5 - 10.0	Mottled grey and orange weathered shaley mudstones
10.0 - 10.5	Olive green weathered shaley mudstones, some gypsum
10.5 - 11.0	Brown (7.5YR5/4) and olive brown (2.5YR4/4) weathered shaley mudstones, some gypsum
11.0 - 11.5	Brown (7.5YR5/4) and light olive brown (2.5YR5/4) weathered shaley mudstones, some gypsum
11.5 - 12.0	Olive green to dark grey weathered shaley mudstones with gypsum
12.0 - 12.5	Olive green to dark grey weathered shaley mudstones with gypsum
12.5 - 13.0	Slightly weathered dark grey carbonaceous shaley mudstones, some gypsum

Carbonaceous shaley mudstone

13.0 - 13.5	Dark blue grey weathered shaley mudstones
13.5 - 14.0	Dark blue grey shaley mudstones weathered olive brown to yellow in parts
14.0 - 14.5	Dark blue grey shaley mudstones weathered olive brown to yellow in parts
14.5 - 15.0	Dark blue grey carbonaceous shaley mudstones weathered brown in parts
15.0 - 15.5	Dark grey to black carbonaceous shaley mudstones
15.5 - 16.0	Dark grey to black carbonaceous shaley mudstones, some shell fragments
16.0 - 16.5	Dark grey to black carbonaceous shaley mudstones
16.5 - 17.0	Dark grey to black carbonaceous shaley mudstones
17.0 - 17.5	Dark grey to black carbonaceous shaley mudstones
17.5 - 18.0	Dark grey to black carbonaceous shaley mudstones
18.0 - 18.5	Dark grey carbonaceous shaley mudstones
18.5 - 19.0	Dark grey carbonaceous shaley mudstones
19.0 - 19.5	Dark grey carbonaceous shaley mudstones

19.5 - 20.0	Dark grey carbonaceous shaley mudstones
20.0 - 20.5	Dark grey carbonaceous shaley mudstones
Sandy and shaley siltstone	
20.50 - 20.75	Grey sandy and shaley siltstones, soft non-fossiliferous
Shaley mudstone	
20.75 - 20.94	Grey shaley mudstones, non-fossiliferous, uneven fracture
20.94 - 21.12	Fractured grey non-fossiliferous shaley mudstone
Shaley siltstone and fine grained sandstone	
21.12 - 21.19	Grey shaley sandy siltstones, non-fossiliferous
21.19 - 21.26	Very muddy greenish grey shaley fine grained sandstones
Sandy shaley siltstone	
21.26 - 21.40	Grey sandy shaley siltstones
21.40 - 21.70	Grey fractured sandy shaley siltstones
Shaley mudstone	
21.70 - 21.80	Dark grey black shaley mudstones, some fine ribbed bivalves

Lithological Log: BGS26

Soil/ferrecrete horizon

0.0 - 0.5	Light brown (7.5YR6/4) fine grained soil
0.5 - 1.0	Light brown (7.5YR5/4) fine grained soil with red (10R5/6) partings
1.0 - 1.5	Red (10R5/6) lateritic clay

Clayey very weathered horizon

1.5 - 2.0	Reddish yellow (7.5YR6/6) and light red (2.5YR6/6) clays
2.0 - 2.5	Reddish yellow (7.5YR6/6) and light greenish grey (7/5GY) kaolin clays
2.5 - 3.0	Light greenish grey (7/10Y) kaolin clay with red (7.5YR4/8) and reddish yellow (7.5YR6/6 to 6/8) clays
3.0 - 3.5	Mainly reddish yellow (7.5YR6/6 to 6/8) clays with some light greenish grey (7/10Y) and light olive brown (2.5Y6/6) clays

Very weathered clayey mudstones

3.5 - 4.0	Mottled light yellowish brown (2.5Y6/4) to brownish yellow (10YR6/6 to 6/8) and light greenish grey clayey weathered mudstones
4.0 - 4.5	Yellowish brown (10YR5/8) to light yellowish brown (2.5Y6/4) weathered mudstones with light blue grey kaolin clay
4.5 - 5.0	Light brownish grey (2.5Y6/2) to light yellowish brown (2.5Y6/3) and olive yellow (2.5Y6/6 to 6/8) weathered clayey mudstones
5.0 - 5.5	Brownish yellow (10YR6/8), strong brown (7.5YR4/6) and light greenish grey (7/5GY) clays

Weathered mudstones with much gypsum

5.5 - 6.0	Light olive brown (2.5Y5/4) weathered mudstones
6.0 - 6.5	Greyish brown (2.5Y5/2) and olive (5Y5/4) weathered mudstones with some gypsum
6.5 - 7.0	Mottled light greenish grey and brown weathered carbonaceous mudstones with light yellow sulphurous partings, some gypsum
7.0 - 7.5	Dark olive green to dark olive grey weathered shaley mudstones with much gypsum
7.5 - 8.0	Yellow brown, brown and olive green weathered mudstones some gypsum
8.0 - 8.5	Olive, yellow brown and light greenish grey weathered mudstones little gypsum
8.5 - 9.0	Slightly weathered well laminated black to dark grey carbonaceous shaley mudstones
9.0 - 9.5	Olive green weathered mudstones, prominent bright red band with gypsum
9.5 - 10.0	Yellow brown to olive green to yellow weathered mudstones with much gypsum

Fairly weathered carbonaceous shaley mudstone with gypsum along oxidised partings

10.0 - 10.5	Dark grey to black carbonaceous shaley mudstones with olive green and yellow brown weathered partings, much fibrous gypsum
10.5 - 11.0	Soft light grey to yellow very weathered mudstones
11.0 - 11.5	Black carbonaceous shaley mudstones, light brown weathered partings, thick gypsum band
11.5 - 12.0	Weathered black and dark grey finely laminated shaley mudstones, orange partings with gypsum
12.0 - 12.5	Dark purple grey to dark brown grey weathered carbonaceous mudstones some gypsum
12.5 - 13.0	Black to dark grey very carbonaceous slightly weathered mudstones
13.0 - 13.5	Dark grey black very carbonaceous mudstones, much gypsum
13.5 - 14.0	Dark blue grey very carbonaceous shaley mudstones weathered, some gypsum

Carbonaceous mudstone

14.0 - 14.5	Black to dark grey mudstones with yellow partings
14.5 - 15.0	Dark grey black carbonaceous mudstones
15.0 - 15.5	Dark grey black carbonaceous mudstones
15.5 - 16.0	Dark grey black carbonaceous mudstones

Carbonaceous mudstone and hard limestone, some siltstone

16.0 - 16.5	Dark grey black carbonaceous mudstones with thin bands of hard nodular limestone
16.5 - 17.0	Dark grey black carbonaceous mudstones thin grey limestone and siltstone layers

Carbonaceous mudstone

17.0 - 17.5	Thinly laminated dark grey black carbonaceous shaley mudstones
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17.5 - 18.0	Dark grey black carbonaceous mudstones
18.0 - 18.5	Soft blocky black carbonaceous mudstones
Carbonaceous mudstones and hard thin limestone	
18.5 - 19.0	Soft black carbonaceous mudstones with interbedded thin hard grey limestone bands
19.0 - 19.5	Soft blocky black carbonaceous mudstones
19.5 - 20.0	Dark grey mudstones and siltstones with interbedded thin grey hard limestones
Carbonaceous shaley mudstones	
20.0 - 20.5	Black carbonaceous shaley mudstones
20.50 - 20.60	Grey shaley mudstones with microfossils and some bivalves and gastropods
20.60 - 21.20	Grey shaley mudstone, very few fossils, odd fine ribbed shallow water bivalve and lingulids
21.20 - 21.30	Fossiliferous grey shaley mudstones with numerous bivalve fragments
Muddy and sandy limestone	
21.30 - 21.52	Very muddy and sandy grey and white limestones
Shaley mudstones	
21.52 - 21.91	Grey shaley mudstones generally non-fossiliferous, odd lingula
21.91 - 22.00	Grey shaley mudstones, some microfossils and bivalves
22.00 - 22.06	Dark grey silty shaley mudstones, non-fossiliferous
22.06 - 22.85	Grey shaley mudstones, non-fossiliferous
22.85 - 23.30	Grey shaley mudstones with numerous lingula, some gastropods and microfossils, odd pyrite nodule
Silty mudstone	
23.30 - 23.50	Grey silty fissile mudstones, non-fossiliferous

Lithological Log: BGS27

Soil/ferrecrete horizon

- 0.0 - 0.5 Pale brown (10YR6/3) fine grained soil
0.5 - 1.0 Brown (10YR5/3) and strong brown (7.5YR5/6) mottled clayey soil
1.0 - 1.5 Light reddish brown (5YR6/4) and dark red (2.5YR3/6) mottled lateritic clay with odd hematitic ferricrete nodule

Clayey very weathered horizon

- 1.5 - 2.0 Red (2.5YR5/8) lateritic clay
2.0 - 2.5 Red (2.5YR4/8), yellowish red (5YR5/8) and brownish yellow (10YR6/6) mottled clays passing downward into yellow smectite
2.5 - 3.0 Pale yellow (2.5Y7/4) and brownish yellow (10YR6/8) to yellow (10YR7/6) mottled clays
3.0 - 3.5 Yellow (2.5Y7/6) and pale yellow (5Y7/3) mottled clays
3.5 - 4.0 Brownish yellow (10YR6/6) and light yellow brown (2.5Y6/4) mottled clays
4.0 - 4.5 Reddish grey (2.5YR6/1), brownish yellow (10YR6/8) and olive yellow mottled clays
- weathered mudstones

Weathered mudstone

- 4.5 - 5.0 Greenish grey (6/10BG), brownish yellow (10YR6/8) and light olive brown (2.5Y5/6)
mottled clayey weathered mudstones with some red (10R4/8) partings
5.0 - 5.5 Light olive brown (2.5Y5/4) clayey weathered mudstones with some light greenish grey (7/10BG) clay
5.5 - 6.0 Dark yellowish brown (10YR4/4), brown yellow (10YR6/8) and light greenish grey (7/10GY) mottled weathered mudstones
6.0 - 6.5 Dark yellowish brown (10YR4/4), brown yellow (10YR6/8) and light greenish grey (7/10GY) mottled weathered mudstones

Weathered mudstones with much gypsum

- 6.5 - 7.0 Light olive brown (2.5Y5/6) weathered mudstones with **gypsum**
7.0 - 7.5 Light olive brown (2.5Y5/4) weathered mudstones with much **gypsum**
7.5 - 8.0 Olive (5Y5/4) and yellowish brown (10YR5/4) mottled clayey weathered black grey carbonaceous shaley mudstones with no gypsum
8.0 - 8.5 Dark olive to dark grey weathered carbonaceous mudstones, some **gypsum**
8.5 - 9.0 Light olive green weathered shaley mudstones with much **gypsum**
9.0 - 9.5 Dark grey to olive green very weathered mudstones with orange partings and much **gypsum**
9.5 - 10.0 Grey and red laminated clayey weathered shaley mudstones with orange partings, some **gypsum**
10.0 - 10.5 Mottled grey and orange clayey weathered mudstones, some **gypsum** the result of weathering
10.5 - 11.0 Mottled grey and orange weathered carbonaceous mudstones little **gypsum**
11.0 - 11.5 Light grey to grey soft weathered shaley mudstones with orange partings, no gypsum

Fairly weathered muddy limestone and mudstone

- 11.5 - 12.0 Weathered orange Brown shaley mudstones above grey limestone
12.0 - 12.5 Grey muddy limestones with orange weathered partings, damp

Fairly weathered mudstone with gypsum along oxidised partings

- 12.5 - 13.0 Dark grey and red weathered carbonaceous mudstone, some dark purple clay and some **gypsum** formation, damp
13.0 - 13.5 Soft dark grey to black weathered mudstones with bright red partings, some **gypsum** formation, damp
13.5 - 14.0 Dark grey to black slightly weathered mudstones, some thick **gypsum** bands
14.0 - 14.5 Dark grey black soft shaley mudstones, unweathered, no gypsum

Muddy limestone with mudstone

- 14.5 - 15.0 Light grey hard limestone bands with light brown weathered margins within black mudstones
15.0 - 15.5 Grey muddy limestones with dark grey mudstones partings
15.5 - 16.0 Dark grey to black carbonaceous mudstones, some thin limestones
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Carbonaceous blocky and shaley mudstones

16.0 - 16.5	Soft dark grey black carbonaceous mudstones
16.5 - 17.0	Black soft carbonaceous shaley mudstones
17.0 - 17.5	Black to dark grey carbonaceous shaley mudstones
17.5 - 18.0	Black blocky carbonaceous shaley mudstones, little water

Muddy siltstones and fine grained sandstones with some carbonaceous mudstones

18.0 - 18.5	Hard bands of dark grey carbonaceous siltstones and shales within blocky mudstones
18.5 - 19.0	Dark grey muddy siltstones and fine grained sandstones with some black carbonaceous mudstones

Carbonaceous silty mudstone, some fine grained sandstone and limestone

19.0 - 19.5	Dark grey to black carbonaceous silty mudstones with thin fine sandstones
19.5 - 20.0	Dark grey to black carbonaceous silty mudstones and thin dark grey friable limestones
20.0 - 20.5	Dark grey to black carbonaceous shaley soft mudstones

Shaley to blocky mudstone, some pyrite and gypsum

20.50 - 22.00	Blocky grey to dark grey shaley mudstone spotted white with white radiating rosetts of gypsum crystals about 1mm diameter along bedding planes, subvertical slickenslide at 21.10 - 21.55, pyritized bivalve at 21.95 otherwise non-fossiliferous
22.00 - 22.38	Grey to dark grey white spotted blocky to shaley mudstones, earthy texture, spots formed by radiating rosetts of gypsum crystals 1mm in diameter, fine ribbed bivalve at 22.30

Sandy mudstone

22.38 - 22.52	Greenish dark grey very sandy mudstone, soft very uneven fracture, no fossils
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Blocky to shaley mudstones, some gypsum

22.52 - 22.98	Grey to dark grey silty blocky to shaley mudstones, spotted white with numerous 1mm rosetts of gypsum crystals on bedding planes, elongate plant remains at 22.98
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Blocky mudstones some pyrite

22.98 - 23.35	Dark grey blocky fine grained mudstones, numerous bivalves, NO white gypsum spots, many bivalve casts frequently pyritised , some elongate plant remains
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Lithological Log: BGS28

Soil/ferrecrete horizon

0.0 - 0.5	Light brown (7.5YR6/4) fine grained sandy soil
0.5 - 1.0	Strong brown 7.5YR4/6 lateritic soil
1.0 - 1.5	Yellowish red 5YR5/6 to red 2.5YR5/6 lateritic clay

Clayey very weathered horizon

1.5 - 2.0	Red 2.5YR5/6 and olive yellow 2.5Y6/6 clayey weathered mudstones
2.0 - 2.5	Brownish yellow 10YR6/6 to dark grey clay and siltstone
2.5 - 3.0	Olive yellow 2.5Y6/6 and light bluish grey 6/10B mottled clays
3.0 - 3.5	Yellow 10YR7/8 and light bluish grey 6/10B mottled clays

Weathered shales and hard limestone

3.5 - 4.0	Dark grey weathered shales with hard grey limestones
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Weathered shaley mudstones with gypsum

4.0 - 4.5	Light grey weathered shaley mudstones
4.5 - 5.0	Dark grey weathered shaley mudstones with white gypsum bands and orange clayey partings
5.0 - 5.5	Weathered dark grey carbonaceous shaley mudstones with yellow, orange and olive brown partings, much white gypsum
5.5 - 6.0	Dark yellowish brown 10YR3/6 to dark grey and olive yellow weathered mudstones
6.0 - 6.5	Brownish yellow 10YR6/6 to dark grey weathered mudstones

Fairly weathered carbonaceous mudstone with gypsum

6.5 - 7.0	Dark grey black weathered carbonaceous mudstone with orange partings, some gypsum
7.0 - 7.5	Olive 5Y5/4 weathered grey to black carbonaceous shaley mudstones, some gypsum
7.5 - 8.0	Olive to black weathered carbonaceous mudstones
8.0 - 8.5	Slightly weathered black carbonaceous shaley mudstones, some orange and dark brown partings, some gypsum
8.5 - 9.0	Dark grey brown to black carbonaceous mudstones with orange partings, with gypsum

Muddy limestone with carbonaceous shaley mudstone

9.0 - 9.5	Light grey muddy limestones
9.5 - 10.0	Light grey limestone passing downward into black soft carbonaceous shaley mudstones
10.0 - 10.5	Soft black carbonaceous shaley mudstones
10.5 - 11.0	Black carbonaceous shaley mudstones with dark grey and white muddy limestones, thin but hard
11.0 - 11.5	Dark grey shaley mudstones
11.5 - 12.0	Dark grey muddy limestones with shaley mudstones

Compact fine grained sandstone or limestone with mudstone

12.0 - 12.5	Grey friable sandstone or limestone
12.5 - 13.0	Grey fine grained compact sandstone or limestone
13.0 - 13.5	Dark grey fine grained compact sandstone to siltstone to mudstone
13.5 - 14.0	Black to dark grey carbonaceous shaley mudstones with thin hard light grey sandstone or limestone

Carbonaceous shaley mudstone and siltstone

14.0 - 14.5	Soft black carbonaceous shaley mudstone
14.5 - 15.0	Soft dark grey carbonaceous mudstones and siltstones
15.0 - 15.5	Grey to dark grey fine grained sandstones and siltstones, some limestones
15.5 - 16.0	Soft black dark grey carbonaceous shaley mudstones to siltstones
16.0 - 16.5	Dark grey fine grained sandstones, siltstones and mudstones

Carbonaceous shaley mudstone and nodular limestone

16.5 - 17.0	Dark grey carbonaceous mudstones with thin grey limestones
17.0 - 17.5	Soft dark grey black carbonaceous shaley mudstones
17.5 - 18.0	Dark grey black carbonaceous shaley mudstones with thin dark grey nodular limestones

Carbonaceous shaley mudstone with siltstone bands

18.0 - 18.5	Soft black to dark grey carbonaceous shaley mudstones
18.5 - 19.0	Dark grey to black carbonaceous mudstones, some harder siltstone bands
19.0 - 19.5	Soft black very carbonaceous shaley mudstones

Carbonaceous shaley mudstone with hard thin limestone

19.5 - 20.0	Black carbonaceous shaley mudstones with hard thin fine grained limestones
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Carbonaceous shaley mudstone, fine grained sandstone and siltstone

20.0 - 20.4	Light grey fine grained sandstones, siltstones and dark grey shaley mudstones
20.40 - 20.60	Dark grey carbonaceous silty mudstone, many microfossils, some fine ribbed bivalves
20.60 - 20.95	Dark grey very carbonaceous shaley mudstones with sandy intercalations e.g. worm burrow infills, some fine ribbed bivalves, odd spiral gastropod and few microfossils
20.95 - 21.45	Grey to dark grey interbedded silty mudstones and dark grey muddy fine sandstones, some fossils, some slickenslides and odd iron pyrite nodule
21.45 - 21.90	Soft friable greenish dark grey to grey carbonaceous muddy shaley fine grained sandstones, few bivalve impressions

Carbonaceous shaley and sandy siltstone and mudstone

21.90 - 22.10	Dark grey carbonaceous shaley very muddy siltstones, numerous bivalve impressions
22.10 - 22.35	Dark grey carbonaceous sandy siltstone, soft with earthy fracture, some fine ribbed shallow water bivalves, mudcracks, organic remains leaves?, some pyrite nodules, tarry looking sediments
22.35 - 22.67	Dark grey sandy shaley siltstones and shaley mudstones, few bivalve impressions, some dark greenish grey silty sandstones, tarry looking sediments, some mica
22.67 - 22.94	Dark grey carbonaceous sandy siltstone, very few fossil impressions - odd bivalve, earthy tarry texture, fairly compact splits unevenly
22.94 - 23.10	Dark grey silty mudstones, some small cherty nodules 5mm long, sub-vertical slickenslide, few impressions of shallow water fine ribbed bivalves
23.10 - 23.40	Dark grey carbonaceous sandy very muddy siltstones, some iron pyrite (marcasite?) and cherty nodules, sandier partings are greenish dark grey. Very few shallow water fine ribbed bivalve impressions, little mica.

Lithological log: BGS29

Soil/ferrecrete horizon

0.0 - 0.5	Brown 7.5YR5/4 fine grained sandy soil
0.5 - 1.0	Mottled dark red 10R4/8, brown 7.5YR5/2 and grey sandy soil
1.0 - 1.5	Mottled pinkish grey 7.5YR6/2 and dark red 2.5YR4/8 clayey sandy soil, some red haematitic ferrecrete nodules
1.5 - 2.0	Mottled grey 7.5YR6/1, reddish yellow 7.5YR6/8, red 2.5YR4/8 and red 10R4/8 clay with purple red hematitic ferrecrete nodules

Clayey very weathered horizon

2.0 - 2.5	Mottled yellowish red 5YR5/6 and reddish yellow 5YR5/6 clays, some dark red 10R3/6 and grey partings
2.5 - 3.0	Mottled strong brown 7.5YR6/8 and light bluish grey 8/5PB clay, bit balling up with clays
3.0 - 3.5	Mottled strong brown 7.5YR5/6, yellow 2.5Y7.6, reddish yellow 7.5YR6/8 to 7/8, and light bluish grey clays

Very weathered sandy clay

3.5 - 4.0	Mottled brownish yellow 10YR6/8 and light bluish grey weathered sandy clay
4.0 - 4.5	Mottled brownish yellow 10YR6/8 and increased light bluish grey weathered sandy clay
4.5 - 5.0	Mottled grey 10YR6/1, red 10R4/8, orange and pale grey to pale yellow 2.5Y7/2 - 7/3 sandy clays
5.0 - 5.5	Olive yellow 2.5Y6/6 fine grained clayey sands with grey and red partings

Weathered siltstone

5.5 - 6.0	Mottled pale yellow 2.5Y7/3, reddish yellow 7.5YR6/8 and strong brown 7.5YR4/6 weathered siltstone
6.0 - 6.5	Mottled grey 7.5YR6/1 and strong brown 7.5YR5/8 weathered siltstone
6.5 - 7.0	Mottled grey 7.5YR5/1, brownish yellow 10YR6/8 and olive brown 2.5Y4/3 weathered grey siltstone with pale yellow 2.5Y8/3 partings
7.0 - 7.5	Mottled grey 7.5YR5/1, brownish yellow 10YR6/8, brown 10YR4/3 and olive brown 2.5Y4/3 weathered grey siltstone with pale yellow 2.5Y8/3 partings, damp

Fairly weathered siltstone with gypsum

7.5 - 8.0	Mottled brown 10YR4/3 and olive brown 2.5YR4/3 above light olive brown 2.5YR5/6 with bands of soft gypsum weathered shaley siltstones with orange partings
8.0 - 8.5	Mottled grey with black streaks, yellow 2.5Y7/8 and olive brown 2.5Y5/6 weathered siltstones with much gypsum
8.5 - 9.0	Mottled bluish grey 5/5PB and strong brown 7.5YR5/8 clayey weathered siltstones, some gypsum
9.0 - 9.5	Mottled reddish grey 10R5/1, dark red 10R3/6 and reddish yellow 7.5YR6/8 weathered siltstones
9.5 - 10.0	Mottled grey, reddish grey, bright dark red, light olive green and orange weathered siltstones with little gypsum
10.0 - 10.5	Mottled light grey, grey reddish grey, dark red and orange clayey weathered grey siltstones
10.5 - 11.0	Soft light grey with gypsum and grey with carbonaceous streaks weathered shaley siltstones with dark red, reddish brown and orange partings
11.0 - 11.5	Light grey, dark red and reddish yellow weathered siltstones with white gypsum
11.5 - 12.0	Soft grey and brown weathered siltstones with some clayey pale yellow and orange partings

Fairly weathered siltstone

12.0 - 12.5	Olive green and grey weathered siltstones, clayey above
12.5 - 13.0	Olive green, grey brown and yellow brown weathered siltstone
13.0 - 13.5	Dark grey muddy siltstone, carbonaceous in parts, weathered reddish yellow, brown and reddish grey
13.5 - 14.0	Dark grey, brown and light brown weathered siltstones with some gypsum

Carbonaceous shaley mudstones with gypsum along oxidised bands

14.0 - 14.5	Very dark grey to black weathered silty mudstones, much fibrous gypsum
14.5 - 15.0	Black carbonaceous shaley mudstones with weathered red and orange partings, some gypsum
15.0 - 15.5	Dark red and black carbonaceous shaley mudstones, some gypsum in red oxidised beds
15.5 - 16.0	Dark grey carbonaceous shaley siltstones, with weathered bright red gypsiferous partings
16.0 - 16.5	Dark grey carbonaceous shaley siltstones, reduced red partings

Carbonaceous shaley mudstones

16.5 - 17.0	Black to dark grey carbonaceous shaley mudstones, silty in parts, some red weathered partings
17.0 - 17.5	Blocky black carbonaceous mudstones
17.5 - 18.0	Black soft carbonaceous shaley mudstones
18.0 - 18.5	Black soft carbonaceous shaley mudstones
18.5 - 19.0	Black soft carbonaceous shaley mudstones
19.0 - 19.5	Black very soft very carbonaceous shaley to blocky mudstones
19.5 - 20.0	Dark grey carbonaceous shaley mudstones, some bands of harder dark grey siltstones
20.0 - 20.5	Dark grey fairly carbonaceous mudstones

Silty and sandy mudstones

20.57 - 20.76	Dark grey silty to sandy mudstones, many microfossils, some bivalves and plant remains
20.76 - 20.93	Dark grey sandy mudstones fairly fossiliferous with small banks of bivalve fragments and fine sands
20.93 - 21.11	Dark grey sandy to silty shaley mudstones, few fossils

Shaley and silty mudstones

21.11 - 21.38	Soft dark grey carbonaceous shaley mudstones, many microfossils, a very fragmented layer
21.38 - 21.76	Dark grey silty mudstones very fossiliferous, many microfossils, some small gastropods and bivalves as well as echinoderm spines
21.76 - 21.92	Dark grey shaley mudstone, earthy texture, uneven fracture, some squashed crustacea otherwise no fossils
21.92 - 22.70	Dark grey fine grained shaley thinly bedded mudstones, odd bivalve otherwise no fossils

Muddy fine grained sandstone

22.70 - 22.85	Dark grey very muddy non-fossiliferous fine grained sandstone
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Lithological Log; BGS30

Soil/ferrecrete horizon	
0.0 - 0.5	Light brown (7.5YR6/4) fine grained soil
0.5 - 1.0	Brown 7.5YR5/4 soil with black nodules
1.0 - 1.5	Mottled reddish brown 7.5YR6/8 and light grey 7.5YR7/1 clayey soil
Clayey very weathered fine grained sands	
1.5 - 2.0	Mottled reddish brown 7.5YR6/6 to 6/8 and light grey 7.5YR7/1 clayey damp sand
2.0 - 2.5	Mottled reddish brown 7.5YR6/6 and light grey 7.5YR7/1 sand and clay
2.5 - 3.0	Reddish yellow 5YR6/6 clayey sand
3.0 - 3.5	Mottled reddish yellow 7.5YR6/6 and light grey 7.5YR7/1 damp fine to medium sand and some clay
3.5 - 4.0	Brownish yellow 10YR6/8 and yellow grey clayey sand
Soft collapsing weathered fine grained sand	
4.0 - 4.5	Soft yellow 10YR6/6 sand
4.5 - 5.0	Soft yellow 10YR6/6 sand
5.0 - 5.5	Soft yellow 10YR6/6 sand
5.5 - 6.0	Pinkish grey 7.5YR6/2 and reddish yellow 7.5YR6/8 mottled soft fine grained sands, some grey clay
6.0 - 6.5	Strong brown 7.5YR5/6 to yellow and grey damp fine to medium orange sands with clay collapsing sands
Weathered fine grained sandstone and clay	
6.5 - 7.0	Mottled light grey 7.5YR7/1, light yellow brown 10YR6/4 and strong brown 7.5YR5/6 fine sands with some grey clays, very soft
7.0 - 7.5	Light yellowish brown 10YR6/4 fine sand with some grey clay with strong brown to reddish brown mottles
7.5 - 8.0	Mottled light yellowish brown 10YR6/4 and strong brown 10YR6/4 clayey fine grained sand with grey clay
8.0 - 8.5	Mottled light pinkish grey 7.5YR6/2 and reddish yellow 7.5YR6/8 to 10YR6/3 pale brown fine grained sand and clay
8.5 - 9.0	Light yellow 2.5Y6/4 and brown clayey fine sand
Weathered fine grained sandstone and weathered shales	
9.0 - 9.5	Light yellow brown fine sand and dark grey weathered shales with red partings
Weathered silty shaley mudstones and fine grained sandstone	
9.5 - 10.0	Weathered dark grey to grey silty shaley mudstones with olive green fine grained sands
Fairly weathered carbonaceous mudstones with interbedded thin limestone or sandstone bands	
10.0 - 10.5	Dark grey weathered shaley carbonaceous mudstone
10.5 - 11.0	Dark grey carbonaceous shaley mudstones with hard thin bands of limestone or sandstone
11.0 - 11.5	Soft dark grey to black carbonaceous mudstones
11.5 - 12.0	Soft dark grey to black carbonaceous mudstones with thin sandstones
Fine grained sandstone with carbonaceous shaley mudstones	
12.0 - 12.5	Light brown to strong brown hard banded fine grained sandstones with some black carbonaceous shaley mudstones
12.5 - 13.0	Black carbonaceous shaley mudstones with some hard damp fine grained sandstones
Fine grained sandstone, siltstone and carbonaceous mudstone	
13.0 - 13.5	Dark grey fine grained sandstones to siltstones, shaley and fairly hard. Some olive green soft damp weathered fine grained sandstones
13.5 - 14.0	Olive green sandstones above dark grey to black carbonaceous shaley mudstones
Carbonaceous shaley mudstone	
14.0 - 14.5	Black carbonaceous shaley mudstones
Shaley silty mudstones with thin limestone or sandstone bands	
14.5 - 15.0	Dark grey silty and shaley mudstones with hard thin bands of grey fine grained limestone or sandstone
15.0 - 15.5	Dark grey silty shaley mudstones with thin hard bands of fine grained sandstone or limestone

15.5 - 16.0	Grey to dark grey shaley siltstones to mudstones with thin hard bands of fine grained sandstone or limestone
16.0 - 16.5	Dark grey to black carbonaceous shaley mudstones with thin hard bands of fine grained sandstone or limestone
16.5 - 17.0	Dark grey black carbonaceous mudstones interbedded with orange brown weathered thin sandstone bands

Carbonaceous shaley mudstones

17.0 - 17.5	Dark grey to black carbonaceous shaley mudstones
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Carbonaceous shaley mudstones and siltstones with thin limestone or sandstone bands

17.5 - 18.0	Dark grey to grey carbonaceous mudstones to siltstones with thin hard bands of fine grained sandstone or limestone
18.0 - 18.5	Dark grey to grey thinly bedded shaley limestone to siltstone or unweathered fine grained sandstones
18.5 - 19.0	Dark grey carbonaceous shaley siltstones to mudstones, with thin hard bands of fine grained sandstone or limestone
19.0 - 19.5	Dark grey to black carbonaceous mudstones with a few thin hard bands of fine grained sandstone

Carbonaceous shaley mudstones with thin limestone bands

19.5 - 20.0	Dark grey to black carbonaceous shaley mudstones with few thin limestone bands
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Carbonaceous shaley mudstones

20.0 - 20.5	Black carbonaceous shaley mudstones
20.50 - 20.65	Grey shaley mudstones, silty to sandy in parts, numerous fine ribbed bivalves and some echinoid plates
20.65 - 20.88	Dark grey carbonaceous shaley mudstones with occasional bivalves, some thin carbonaceous fine sand partings

Sandy to silty mudstones

20.88 - 21.05	Dark grey sandy to silty mudstones, some bivalve fragments especially lingulla
21.05 - 21.14	Dark grey thinly bedded, uneven fracture, earthy texture, shaley mudstone, fairly silty

Shaley mudstones

21.14 - 22.00	Dark grey fine grained shaley very thinly bedded mudstones, earthy fracture, no fossils
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Silty and shaley fractured mudstones

22.00 - 22.44	Dark grey silty shaley mudstone, uneven fracture, no fossils, slickenslides at 22.22-22.26 and 22.40-22.44
22.44 - 23.24	Dark grey silty mudstones, very uneven fracture, earthy texture, no fossils

Shaley mudstones

23.24 - 23.50	Dark grey shaley fine grained thinly bedded mudstones, no fossils
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Lithological Log: BGS31

Soil/ferrecrete horizon

0.0 - 0.5	Light brown 7.5YR6/3 soil
0.5 - 1.0	Pinkish grey 7.5YR6/2 clayey soil
1.0 - 1.5	Red 10R4/8 to 7.5R4/8 and reddish grey 7.5R6/1 mottled lateritic clay
1.5 - 2.0	Red 10R5/6 lateritic clay some ferrecrete nodules
2.0 - 2.5	Red 10R4/6 lateritic clay above strong brown 7.5YR5/6 clay

Clayey very weathered horizon

2.5 - 3.0	Mottled reddish yellow 7.5YR6/8, yellow 2.5Y7/6, brownish yellow 10YR6/6 and light grey 5Y7/2 clays
3.0 - 3.5	Yellow 10YR7/8 clay with some 8/10GY light greenish grey clay
3.5 - 4.0	Mottled brownish yellow 10YR6/6, yellow 2.5Y7/6 and light bluish clay 8/10B clays

Weathered clayey mudstones

4.0 - 4.5	Variegated brownish yellow 10YR6/6, light yellowish brown 10YR6/4 and light olive grey weathered clayey mudstones
4.5 - 5.0	Light olive brown 2.5Y5/6, olive yellow 2.5Y6/6 and light grey 2.5Y7/1 weathered clayey mudstones
5.0 - 5.5	Yellow 10YR7/8, light greenish grey 7/10GY and olive yellow 2.5Y6/6 weathered clayey mudstones, some gypsum

Weathered silty mudstones and fine grained sandstone with layered gypsum

5.5 - 7.00	broken during drilling - mottled grey 5Y6/1, olive yellow 2.5Y6/6 and some brownish yellow 10YR6/8 weathered silty mudstones with odd fibrous bands of gypsum , much black manganese oxide along joints
7.00 - 7.21	Variegated pale yellow 5Y7/4, grey 5Y6/1 and brownish yellow 10YR6/8 silty clay with much brownish yellow 10YR6/8 along joints, gypsum band at 7.20
7.21 - 7.28	Thin gypsum bands (at 7.23 and 7.26) within very pale brown 10YR7/4 silty fine sandstone

Weathered clayey mudstones with gypsum bands

7.28 - 7.38	Pale brown and grey 10YR7/4 weathered mudstones with gypsum bands at 7.28, 7.32 and 7.33
7.38 - 7.45	Variegated light yellowish brown 2.5Y6/3, yellow 2.5Y6/3 and some brownish red 10YR6/8 with increasing red with depth weathered mudstones with gypsum bands at 7.39 and 7.45
7.45 - 7.50	Brownish yellow 10YR6/8 and olive yellow 2.5Y6/6 weathered shaley mudstones with some gypsum at 7.45 and numerous black spots of manganese oxide
7.50 - 7.54	Light olive brown 2.5Y5/4 and grey streaked weathered clayey mudstones with some interbedded black manganese oxide and white gypsum
7.54 - 7.90	Pale olive 5Y6/3 to olive 5Y5/3 weathered mudstones with gypsum bands
7.90 - 8.02	Olive 5Y5/3 weathered silty mudstones with some dark yellow brown 10YR4/4 weathered mudstone and white gypsum layers
8.02 - 8.13	Variegated light olive brown 2.5Y5/3, pale yellow 2.5Y7/4 and yellow 2.5Y7/6 clayey weathered mudstones with gypsum rich partings
8.13 - 8.21	Light olive brown 2.5Y5/4, yellow 2.5Y7/8 and light brownish grey 2.5Y6/2 variegated clayey weathered mudstones
8.21 - 8.26	Light yellowish brown 2.5Y6/4, yellow 2.5Y7/8 and grey 2.5Y6/1 variegated clayey weathered mudstone
8.26 - 8.33	Light yellowish brown 2.5Y6/3, olive yellow 2.5Y6/8 and grey 2.5Y6/1 variegated clayey weathered mudstones with gypsum bands at 8.32m
8.33 - 8.50	Olive 5Y2/3, yellow 2.5Y7/8 and grey 2.5Y6/1 variegated clayey mudstones with gypsum layer at 8.36m and thin gypsum layers at 8.41 and 8.50m
8.50 - 9.28	Light grey 2.5YR7/1 clayey mudstone with pale yellow 2.5YR7/4 partings, gypsum layer at 9.28m
9.28 - 9.47	Brownish yellow 10YR6/8, light yellowish brown 10YR6/4, light yellowish brown 2.5YR6/4 and olive yellow 2.5Y6/6 variegated weathered clayey mudstones with thick band of gypsum at 9.43m
9.47 - 9.67	Brownish yellow 10YR6/8, some pale olive 5Y6/3 and pale grey 5Y7/1 variegated clayey weathered mudstone with gypsum at 9.48-9.49 (nodules), 9.58 (larger

nodules) and 9.67 (layer)

Fairly weathered mudstones with gypsum bands

- 9.67 - 9.69 Pale olive weathered mudstone with **gypsum** band (9.67)
9.69 - 9.74 Pale grey 5Y7/1 weathered mudstones with brownish yellow (orange) 10YR6/8 streaks interbedded with pale olive 5Y6/3 weathered mudstones

Fairly weathered mudstones with gypsum nodules

- 9.74 - 9.83 Pale olive 5Y6/3 weathered mudstones with nodular **gypsum** layer at 9.76m
9.83 - 9.87 Pale olive 5Y6/3, pale grey 5Y7/1 and brownish yellow 10YR6/8 variegated and streaked weathered mudstones with nodular **gypsum** between 9.83-9.85m
9.87 - 10.00 Pale olive 5Y6/3 weathered mudstones with thin pale grey 5Y7/1 clay layers and nodules of **gypsum** at 9.90-9.92 and 9.96m

Clayey weathered mudstones with nodular gypsum

- 10.00 - 10.23 Pale olive clayey weathered mudstones, some pale grey and orange clay streaks, numerous small **gypsum** nodules at 10.03-10.18m
10.23 - 10.47 Variegated pale olive, pale grey and some brownish yellow clayey weathered mudstones with **gypsum** nodules at 10.44m
10.47 - 10.64 Mainly pale olive clayey weathered mudstones with numerous **gypsum** nodules, some pale grey and orange clay streaks
10.64 - 10.92 Mainly pale grey clayey weathered mudstones with pale grey and orange clay streaks, **gypsum nodules** associated with olive beds at 10.87m
10.92 - 11.11 Mainly pale olive clayey weathered mudstones with orange and pale grey clay streaks, latter increasing with depth, **gypsum** nodules in pale olive beds at 11.00 and 11.07m
11.11 - 11.30 Mainly very pale grey clayey mudstones with some olive partings and orange grey streaks, **gypsum** at 11.25m in olive band
11.30 - 11.50 Pale olive weathered mudstones with some **gypsum** at 11.33m

No samples

- 11.50 - 12.17 no core

Weathered calcareous mudstones with gypsum

- 12.17 - 12.47 Mainly pale yellow 2.5Y7/3 weathered calcareous mudstones with some light grey partings, **gypsum** layer at 12.19, thin bands of **gypsum** nodules at 12.24-12.33m

Weathered muddy limestones and calcareous mudstones with gypsum bands

- 12.47 - 12.64 Dark grey with orange yellow weathered partings very muddy limestones, rubblely with no coherent core. Odd bivalve impressions
12.64 - 12.73 Light yellow grey to white weathered mudstones
12.73 - 12.93 Broken rubblely dark grey very muddy limestones very weathered yellow brown partings
12.93 - 13.09 Yellow grey calcareous weathered mudstones with prominent **gypsum** bands at 13.03-13.09m
13.09 - 13.14 Light grey very muddy weathered limestone with prominent **gypsum** band at 13.14m

Fairly weathered mudstones with prominent gypsum bands and nodules

- 13.14 - 13.32 Yellow grey and grey weathered mudstones with prominent **gypsum** bands at 13.19-13.20, 13.26-13.27 and 13.28-13.30m
13.32 - 13.61 Light grey weathered mudstones with **gypsum** bands with prominent red and orange weathered margins at 13.39-13.42, 13.48, 13.53-13.56, and 13.62m
13.61 - 13.93 Grey slightly weathered carbonaceous shaley mudstones, gypsum band with orange yellow weathering at 13.72m, thin **gypsum** band with yellow weathering at 13.88m
13.93 - 14.14 Light grey weathered shaley mudstones with numerous orange and red partings. **Gypsum** occurs as bands or as associated with orange and red oxidation bands
14.14 - 14.23 Dark grey fairly weathered shaley carbonaceous mudstones, some **gypsum** nodules
14.23 - 14.26 Olive yellow to pale grey weathered shaley mudstones with some **gypsum**
14.26 - 14.35 Dark grey carbonaceous shaley mudstones slightly weathered, some very small **gypsum** nodules
14.35 - 14.41 Weathered grey carbonaceous mudstones with **gypsum** development along oxidised olive and orange coloured bands

Non-weathered shaley carbonaceous mudstones

- 14.41 - 15.00 Black to dark grey shaley carbonaceous mudstones
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Annex 4: Test Pump data

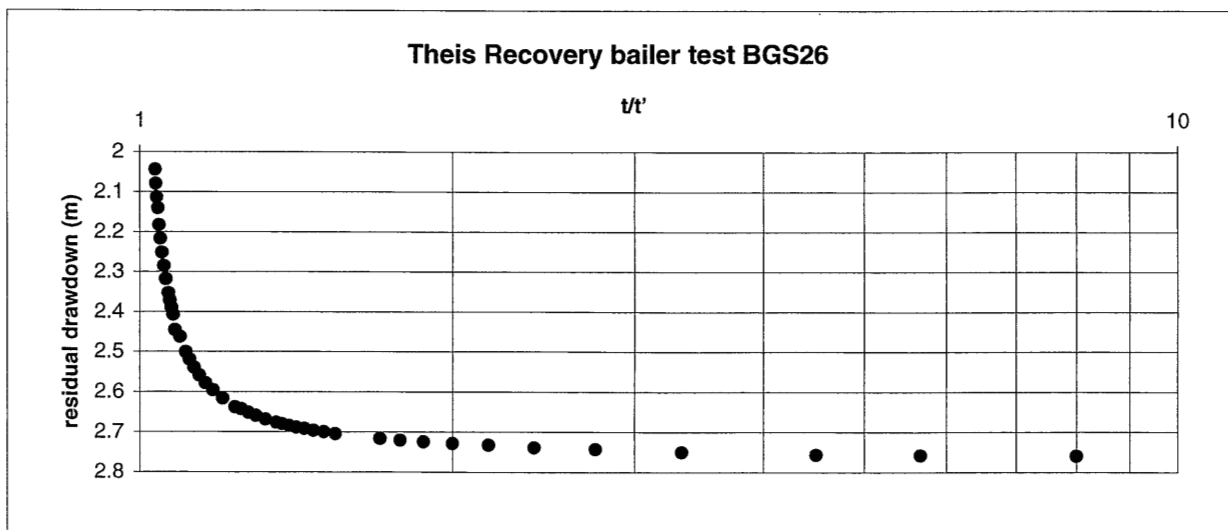
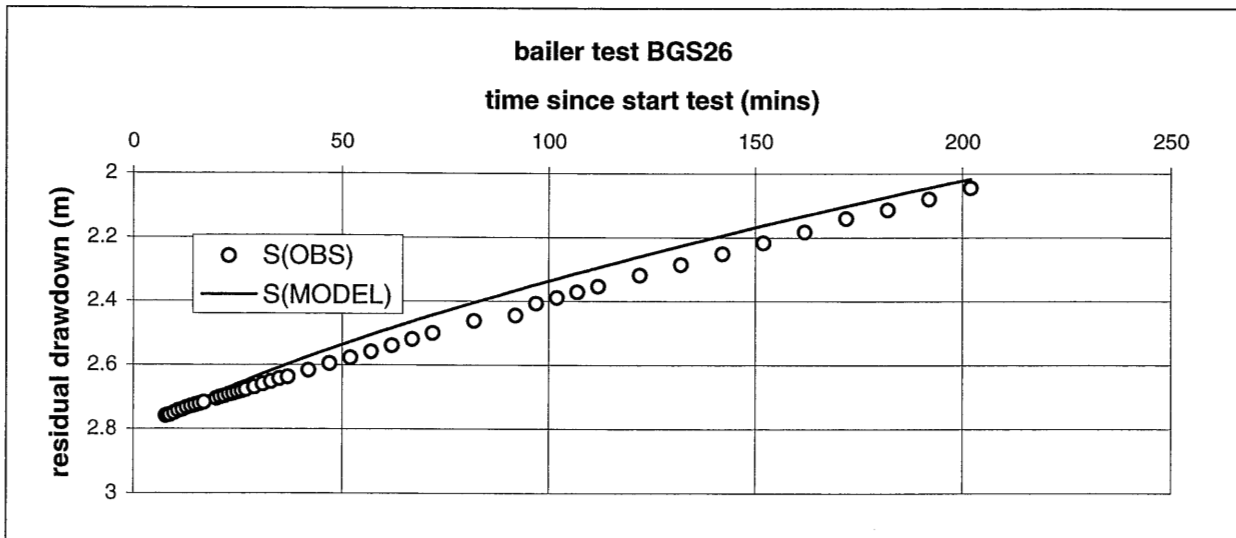
BGS26

Bailer Test

date: 06/03/98
 rwl: 14.71 mbtc
 length of pumping 07:00
 No of bails 13 = average p-rate 0.14 l/s

Barker analysis

$T = 0.024 \text{ m}^2/\text{d}$
 $S = 0.0015$
 $RC = 0.082\text{m}$

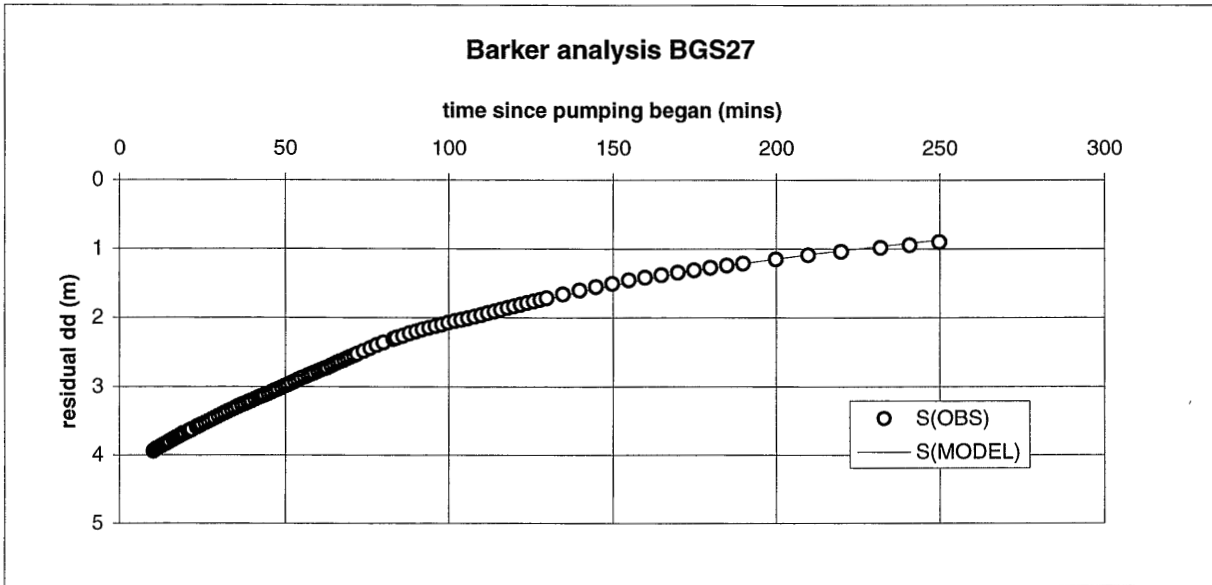


BGS27: test pump analysis

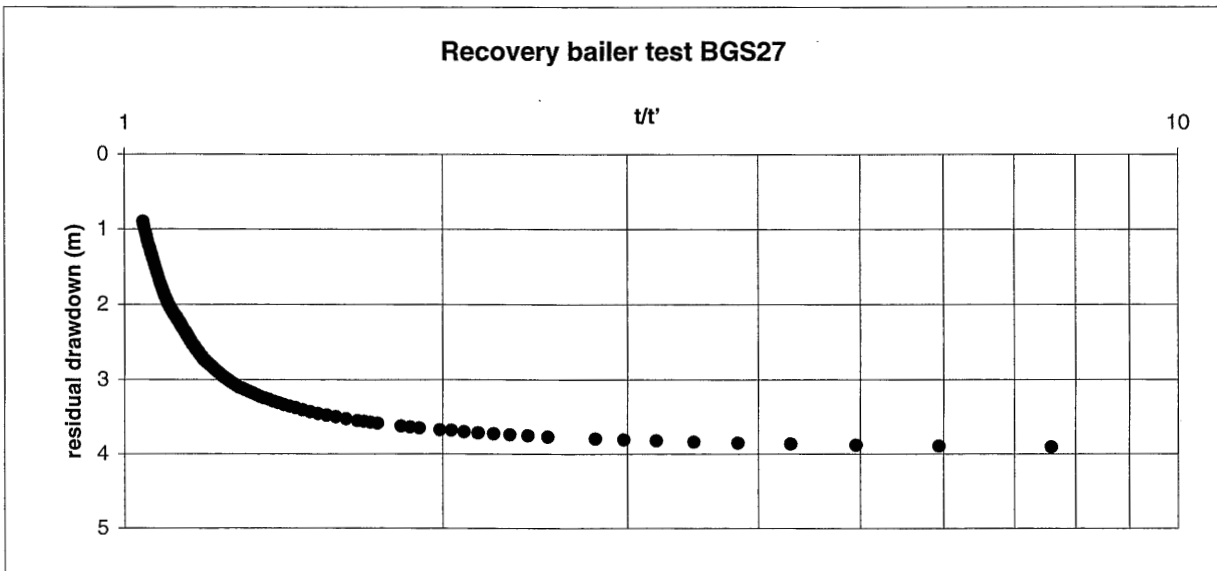
Bailer Test

date: 06/03/98
 casing 0.6 m agl
 rwl: 10.0096 mbtc
 length of pumping 09:53
 No of bails 20 = average p-rate 0.152 l/s

Barker analysis
 $T = 0.08 \text{ m}^2/\text{d}$
 $S = 0.0004$
 $RC = 0.082\text{m}$



Theis recovery
 $T = 0.05 \text{ m}^2/\text{d}$



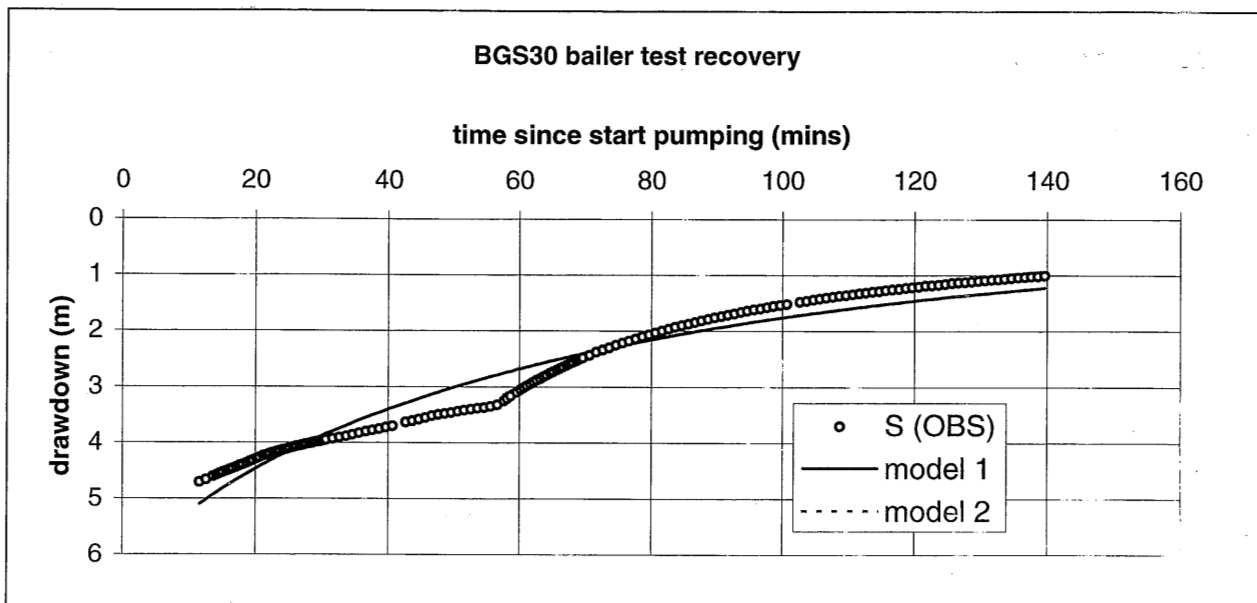
BGS30: test pump analysis

Bailer Test

date: 05/03/98
 casing: 0.33agl
 rwl: 3.238 mbtc
 length of pumping: 09:40 minutes
 No of bails: 40 = average p-rate 0.31 l/s

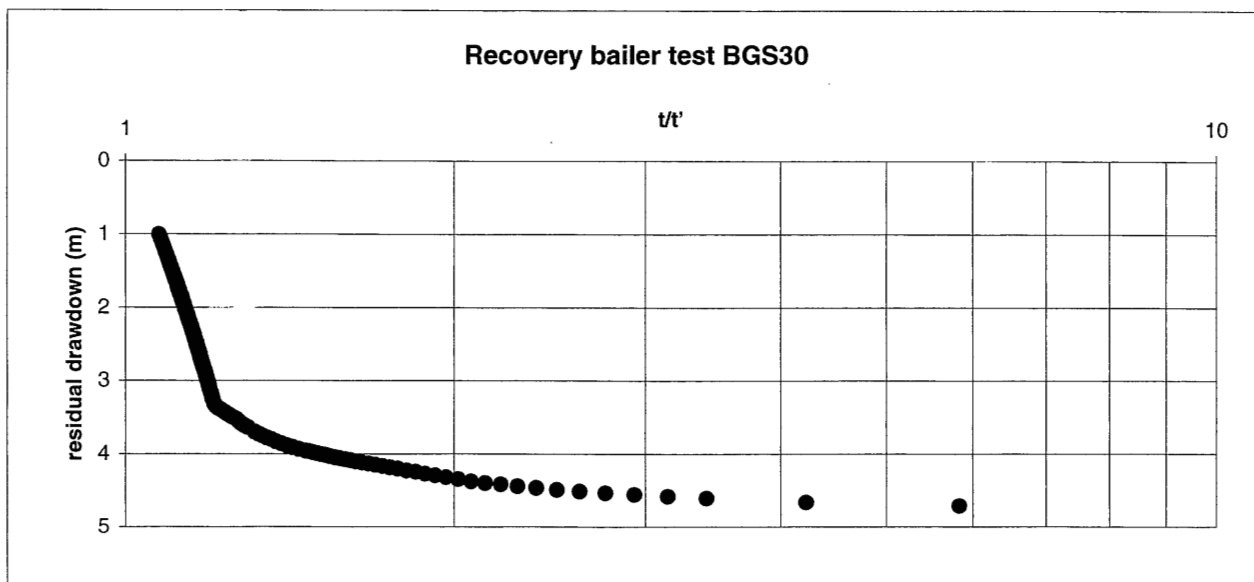
Barker analysis

model 1:	model 2:
$T = 0.36\text{m}^2/\text{d}$	$T = 0.36\text{m}^2/\text{d}$
$S = 0.0017$	$S = 0.0017$
$RC = 0.099\text{m}$	$RC = 0.069\text{m}$



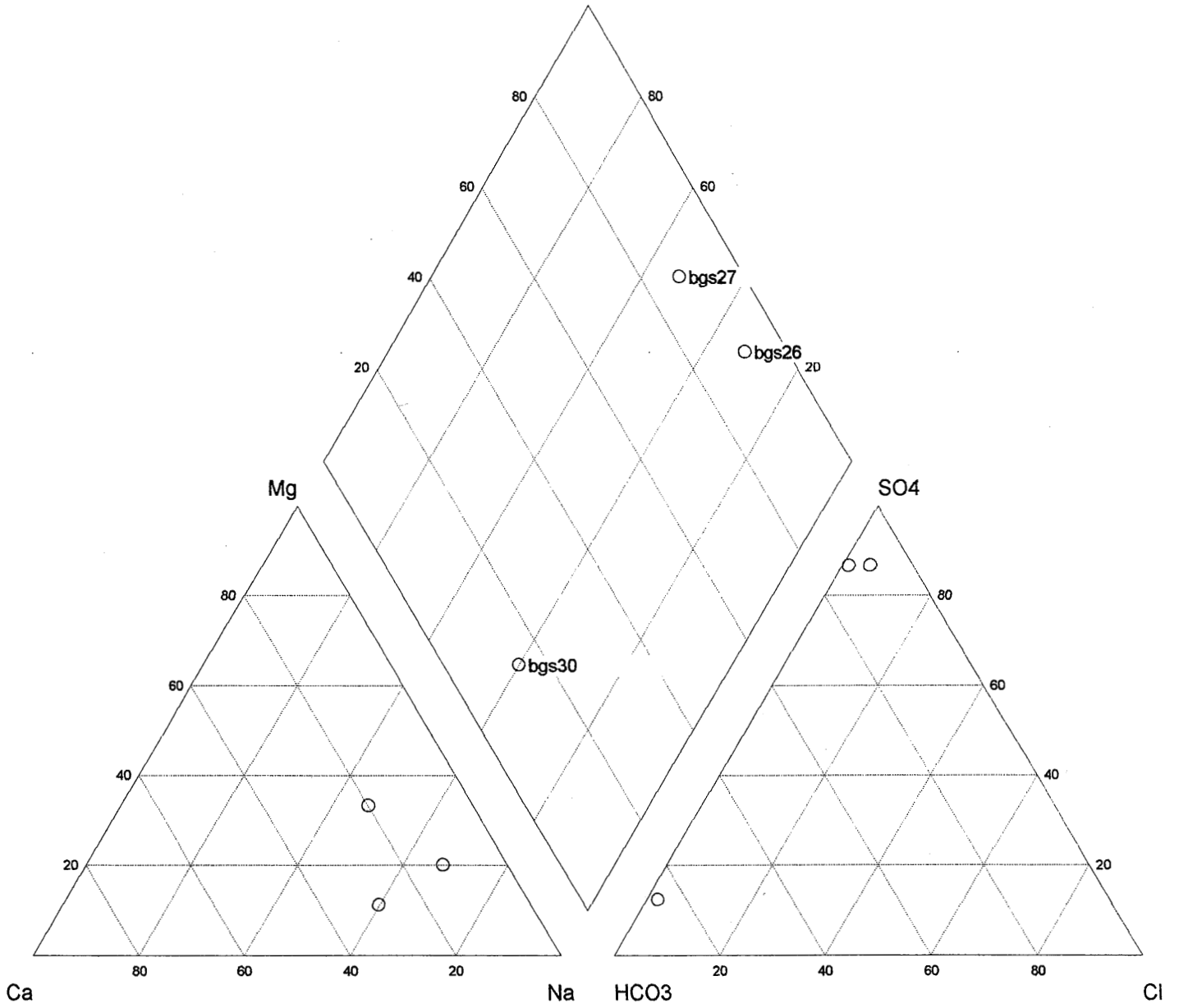
Theis Recovery

$T = 0.11\text{m}^2/\text{d}$



Annex 5: Water quality data

Groundwater Hydrochemistry - North Obi Traverse



North Obi traverse

Jan-Apr 1998

Easting	Northing	sample ID No	Bh No	pH	Temp DegC	Cond microS/cm	HCO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l
8.242783	7.106583	215	BGS27	7.03	29.8	7160	768	1150	10.7	426	433	4330	
8.231583	7.113233	216	BGS26	7.38	30	10080	624	1950	13.1	310	307	5290	
8.2805	7.09055	218	BGS30	6.22	29.2	201	112	27.2	0.9	11.5	2.7	12.8	

sample 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
215		9.2	7.31	0.018	0.36	1.81	0.16	0.497	0.0406		
216		6.5	8.26	0.014	0.314	2.98	0.43	0.38	0.42		
218		21.2	0.086	0.087	0.011	0.04	3.64	0.38	0.009		