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## **The hydrogeology of the Oju/Obi area, eastern Nigeria: Odaleko Adiko area data report**

J Davies and A M MacDonald





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Drilling borehole BGS13 at Odaleko Adiko.

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## **PREFACE**

Oju is a remote part of southeastern 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 development potential of the Makurdi Sandstone and Upper Eze-Aku Shale was investigated at Odaleko Adiko. Geophysical surveys, drilling and test pumping were carried out between November and March 1998. Over three kilometres of EM34-3 and magnetic surveys and three resistivity soundings were undertaken. Four boreholes were drilled: two deep exploration boreholes and two shallow cored observation boreholes. Rock chip and core samples obtained during drilling were analysed and logged. Two boreholes (BGS13 and BGS13a) were completed with screen and casing. Test pumping and water quality analysis was carried out on these two boreholes. The following conclusions can be made from the test site.

- The Eze-Aku Shale comprises black carbonaceous shallow water marine mudstones interbedded with siltstones, fine sandstones and shelly to muddy limestones. Where fractured the limestones contain some groundwater but not enough to for a developable resource.
- The top 10-15 m of the Eze Aku shale has been weathered to a smectite to illite-smectite rich clay.
- The Makurdi Sandstone comprises fine to coarse grained well cemented feldspathic sandstones. The sandstones generally have low intrinsic permeability. No fractures were encountered during the drilling – their presence would have significantly enhanced permeability.
- The Makurdi Sandstone remains the best option for groundwater in this area. Large diameter wells would be the best method of groundwater development, where seepage area and storage capacity could be optimised.
- Commonly, the top few metres of sandstone are weathered: feldspar crystals and cement have been removed; within the 5-10 m depth interval very hard silcretised sandstone bands have formed. Hand dug wells need to be excavated to depths below this hard band to realise success.
- Groundwater found at depth within the Makurdi Sandstone is saline and unsuitable for consumption; shallow groundwater met all the WHO guidelines for drinking water.
- The EM34-3 can be used to distinguish mudstone from sandstone. The mudstone has an electrical conductivity of greater than 30 mmhos/m (using 20 or 40 m intercoil spacing); in contrast, sandstone had conductivities of less than 15 mmhos/m.
- Resistivity surveys can also be used to distinguish mudstone from sandstone. However, it is the resistivity of the weathered material, rather than the bedrock that gives the largest contrast.

## 1. BACKGROUND INFORMATION

The groundwater potential of the Makurdi Sandstone and Upper Eze-Aku Shale was investigated at Odaleko Adiko. The village is located on a small ridge in eastern Obi (see Figure 1). There are no wells within the village. During the wet season, rainwater is collected as roof runoff. With cessation of the rains, women collect water from a spring about 1 km away from the village. This spring diminishes markedly to a series of small seepages as the dry season progresses, so that women need to walk much further to find water. These dry season sources are located outside their community grounds, which can cause conflicts. There are many orange and mango trees within the village, thick woodland lying to the north of the village.

The geology map shows that the village is on the border between the Eze-Aku Shale and the Makurdi Sandstone. The uppermost part of the Makurdi Sandstone is composed of a thick cross bedded sequence of fluvial medium to coarse grained sandstones that crop out as a prominent north-east – south-west trending ridge. The village is located on the northern side of this ridge, as indicated by the very sandy soil found throughout the village. Cross-bedded Makurdi Sandstone is seen to crop out in the bed of an ephemeral river about a kilometre to the east of the village. Eze Aku Shales underlie the lower land to the north of the ridge. These are composed of black carbonaceous blocky to shaly shallow marine mudstones interbedded with thin sandstones and shelly to muddy limestones. Vertical fractures occur within these limestones, providing an element of secondary permeability. Figure 2 and 3 show the available map data for the area and also the location of the geophysics surveys and test boreholes. Table 1 shows the appropriate maps and aerial photographs for Odaleko Adiko. Interestingly, a geophysics team visited the village about twenty years ago and hammered a steel peg in the ground to indicate where a borehole should be drilled. An orange tree was planted on the spot and is now fully grown. The proposed borehole was not drilled.

**Table 1. Available map information for Odaleko Adiko.**

Data type	Source
Aerial Photographs	Sheet 289, run 1, 96-99
Topographic maps	1:50,000 Sheet 289NE Ejekwe NE
Geology map	Ogoja Area, Map No. 73, Scale 1:250,000

## 2. GEOPHYSICS

Two to three kilometres of EM34-3 surveys were carried out within Odaleko Adiko village. These surveys were short, following the main paths through the village. Several coil spacings were used along some of the traverses; both horizontal and vertical dipole measurements were taken. One magnetic field survey and three vertical electric soundings (VES) were carried out. Table 2 lists the traverses and soundings. Detailed survey data are presented in Annex 1.

Several observations can be made from analysis of the geophysical data:

1. The EM34-3 surveys show that electrical conductivity varies from 10 to 80 mmhos/m. A typical EM34-3 survey is shown in Figure 4.
2. Plotting all the geophysics data on one diagram shows that one part of the village is underlain by high conductivity rock, and the other by low conductivity rocks (Figure 5).



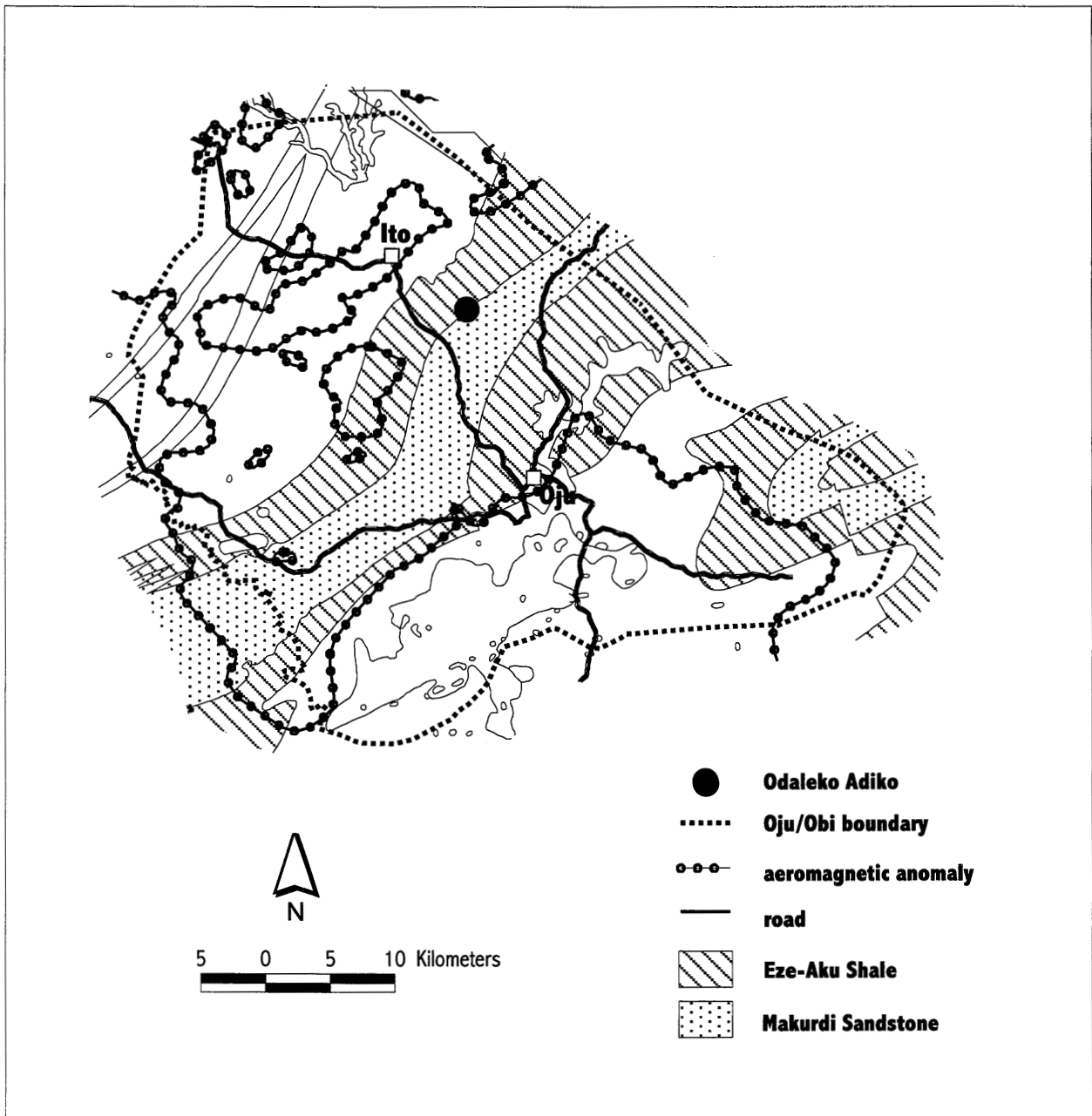


Figure 1. The location of Odaleko Adiko and the outcrops of Makurdi Sandstone and Eze-Aku Shale.

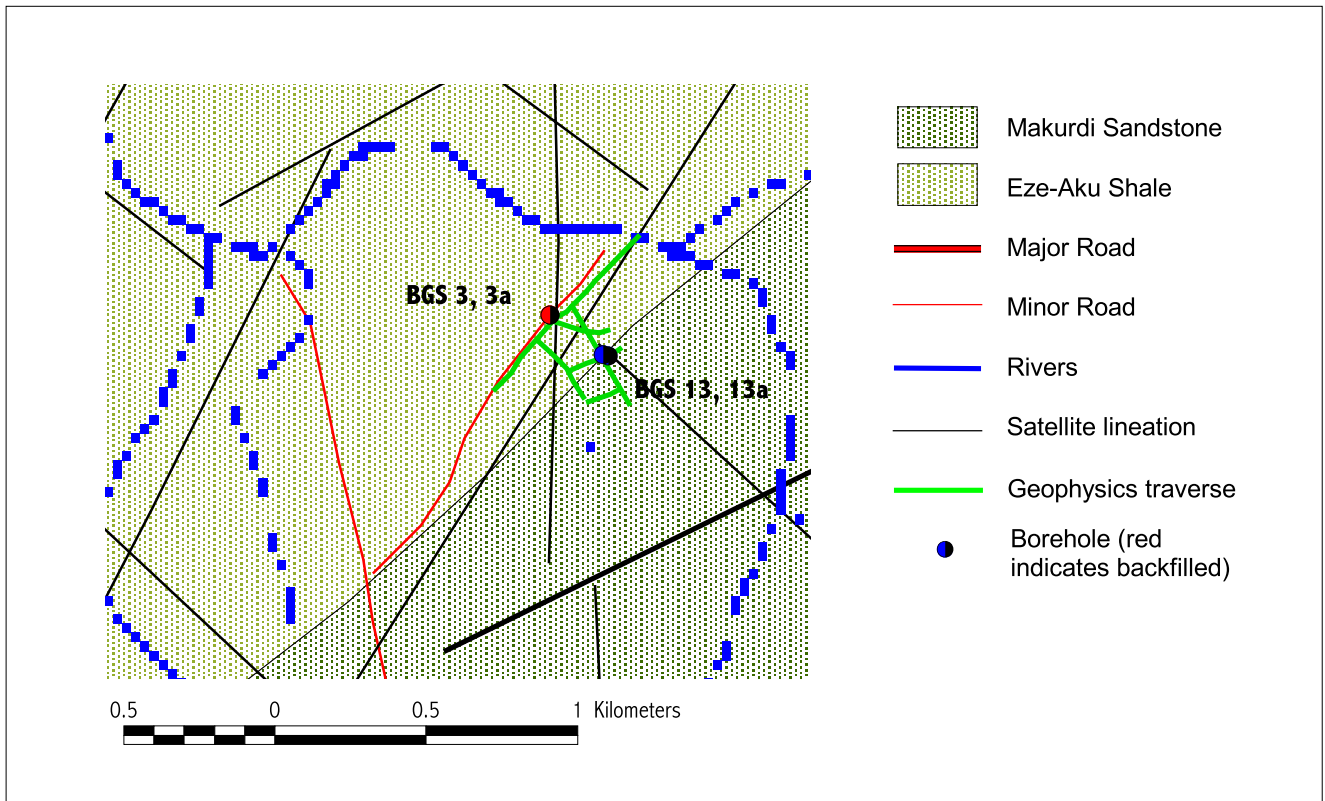


Figure 2. Available map information for Odaleko Adiko and location of boreholes and geophysics traverses. Geological boundary marked on the map is approximate.

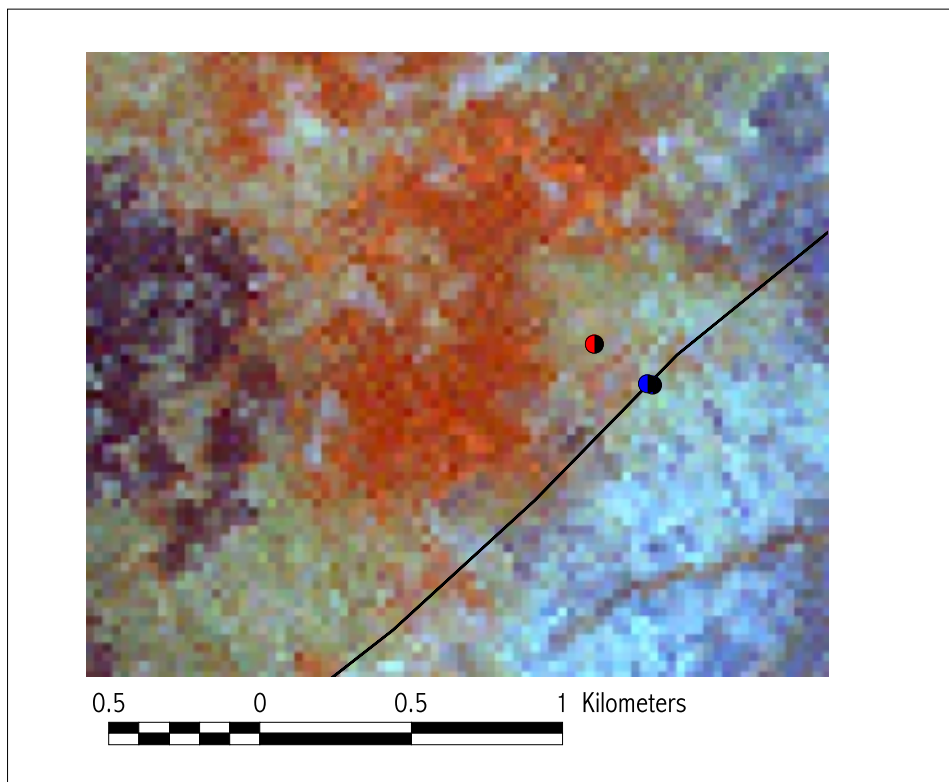


Figure 3. Satellite image for Odaleko Adiko.

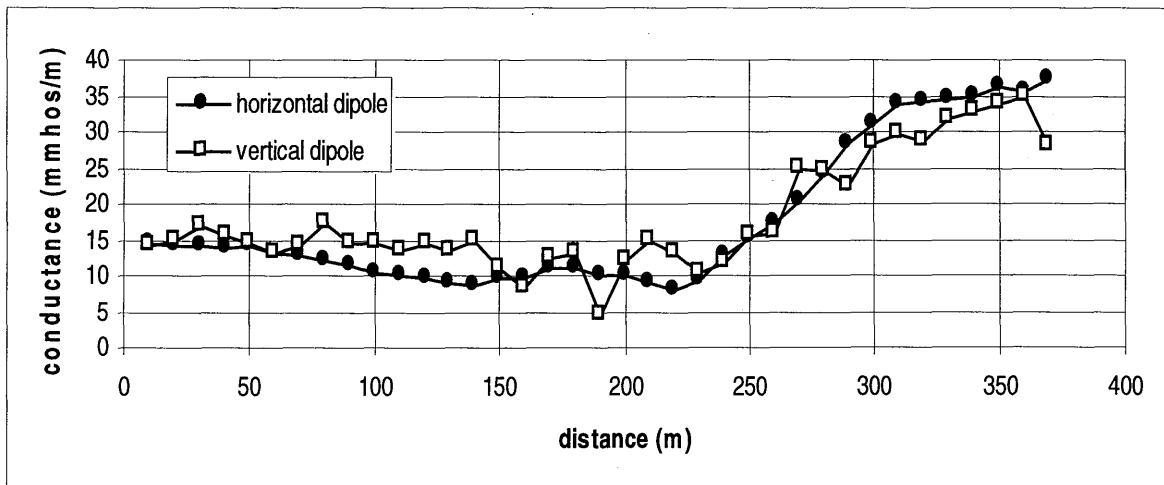


Figure 4. Conductivity measurements along OA 10 using EM34-3 with 20 m intercoil spacing.

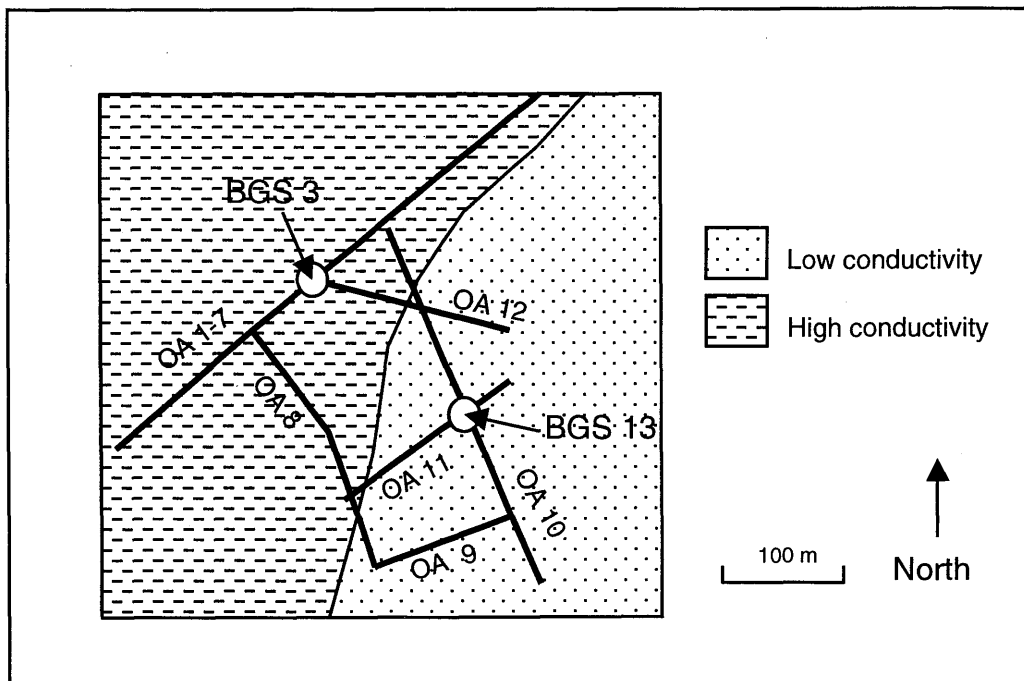


Figure 5. Approximate boundary between high and low conductivity areas at Odaleko Adiko as implied by the EM34-3 surveys. The location of the boreholes is also shown .

3. Within the high conductivity area, three different coil spacings were used (10, 20 and 40 m). The vertical coil (horizontal dipole) measurements became greater with increasing coil separation; however, the horizontal coil (vertical dipole) measurements were roughly the same (30-50 mmhos/m) for each inter-coil separation. This could be interpreted as a high conductivity layer from about 5 – 15 m.
4. Within the low conductivity area, vertical and horizontal coil readings were similar – 10-15 mmhos/m.
5. No natural magnetic anomalies were present in the area – only those caused by steel roofs.
6. Three resistivity soundings were carried out – two in the high conductivity area and one in the low conductivity area. The soundings in the high conductivity area showed similar profiles: moderately resistive soil overlying a low resistive (5-15 ohm-m) layer approximately 10 m thick, followed by 30-50 ohm-m bedrock. The sounding in the low conductivity area showed a moderate resistive soil overlying a 1-2 m thick high resistivity (> 4000 ohm-m) layer, followed by 90 ohm-m bedrock.

**Table 2. Main Geophysical Surveys carried out at Odaleko Adiko (data in Annex 1)**

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
OA1	6° 59.195' 8° 22.312'	0.5 km	20 m	EM34-3 (20 m)	From malina tree at junction in village to river
OA2	6° 59.195' 8° 22.312'	0.2 km	20 m	EM34-3 (20 m)	From malina tree at junction in village back to mango tree
OA4	6° 59.195' 8° 22.312'	0.2 km	10 m	EM34-3 (20 m)	Infilling part of OA 1 and 2.
OA5	6° 59.195' 8° 22.312'	0.6 km	20 m	EM34-3 (40 m)	From mango tree past Malina to river – 40 m coil spacing
OA6	6° 59.195' 8° 22.312'	0.6 km	10 m	magnetic	As OA5 – major anomaly caused by steel roof.
OA7	6° 59.195' 8° 22.312'	0.6 km	10 m	EM34-3 (10 m)	As OA5 – 10 m intercoil spacing
OA8	6° 59.195' 8° 22.312'	0.27 km	20 m	EM34-3 (20 m)	From malina tree at junction – through village up hill
OA9		0.13 km	20 m	EM34-3 (20 m)	From end OA 8 through fields to palm tree
OA10		0.4 km	20 m	EM34-3 (20 m)	From end OA 9 down hill past large mango tree
OA11		0.2 km	10 m	EM34-3 (20 m)	Along path along top of village to large mango tree
OA12		0.2 km	10 m	EM34-3 (20 m)	From BGS 3 crossing OA 10 to first hut
OA13	6° 59.18' 8° 22.399'		0.5 – 64 m	Offset Wenner	Large mango tree – BGS 13
OA14			0.5 – 64 m	Offset Wenner	45 m towards village from malina tree
OA15			0.5 – 64 m	Offset Wenner	At junction of small path (BGS 3)

Following the geophysical surveys, two sites were identified for drilling. BGS3 was located about 100 m along OA1 in a high conductivity zone. BGS13 was drilled at the large mango tree 150 m along OA 11.

### 3. DRILLING

Four boreholes were drilled at two sites in Odaleko Adiko. Two deep production boreholes were drilled using tricone bits through the weathered zone and down the hole hammer through the non-weathered horizons (BGS3 and BGS13); core samples were taken from the bottom of these boreholes. Shallow cored observation boreholes were drilled next to the main exploration boreholes. Summary borehole information is listed in Table 3. Details of borehole construction and drilling are presented in Annex 2.

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

Borehole ID	Location	Date completed	Total depth	Drilled diameter	Section cored	Main water strikes	Casing above gl	Comments
BGS 3	6° 59.195' 8° 22.312'	26/11/97	60.7 m	165 mm	No core	damp	none	Damp – very little water
BGS 3a	6° 59.195' 8° 22.312'	29/11/97	16 m	100 mm	0 – 16 m	damp	None	
BGS 13	6° 59.180' 8° 22.399'	24/1/98	87.5 m	165 mm	84.5 – 87.5 m	77.5 m	0.2 m	Artesian flow – salty water
BGS 13a	6° 59.180' 8° 22.399'	27/1/98	8.3m	165 mm	0 – 8.3 m	damp	0.2 m	

Summary of the lithological logs of boreholes drilled at Odaleko Adiko are presented below. Detailed lithological logs are presented in Annex 3. Figure 6 shows a schematic of the borehole logs drilled.

#### Summary lithological log: BGS3

0.0 - 3.7	Soil/ferricrete zone
3.7 - 5.7	Clayey very weathered zone
5.7 - 9.7	Weathered micaceous siltstones
9.7 - 14.7	Non-weathered massive silty shales and shaley mudstones
14.7 - 18.7	Fairly weathered shaley mudstones
18.7 - 19.7	Limestone
19.7 - 24.7	Non-weathered zone
24.7 - 25.7	Muddy limestones
25.7 - 27.7	Massive shaley mudstones with calcite veining
27.7 - 29.7	Muddy limestones
29.7 - 35.7	Massive shaley mudstones with calcite veining
35.7 - 37.7	Calcite veined zone - water producing zone
37.7 - 41.7	Massive shaley mudstones
41.7 - 44.7	Muddy limestones with calcite veining
44.7 - 46.7	Massive shaley mudstones
46.7 - 50.7	Muddy limestones with calcite veining
50.7 - 53.7	Calcareous mudstones with calcite veining
53.7 - 59.7	Calcite veined zone - water producing zone
59.7 - 60.7	Massive shaley mudstone

#### Summary lithological log: BGS3A

0.00 - 3.40	Soil/ferricrete zone
3.40 - 5.00	Clayey very weathered zone
5.00 - 7.90	Weathered micaceous clayey siltstones and fine grained sandstones
7.90 - 8.05	Limestone
8.05 - 9.35	Fairly weathered micaceous shaley siltstones
9.35 - 9.75	Massive micaceous fine grained sandstones
9.75 - 12.55	Massive silty and shaley mudstones
12.55 - 12.65	Limestone
12.65 - 14.70	Massive siltstones and shaley mudstones
14.70 - 15.15	Muddy limestone
15.15 - 16.00	Shaley siltstones and mudstones

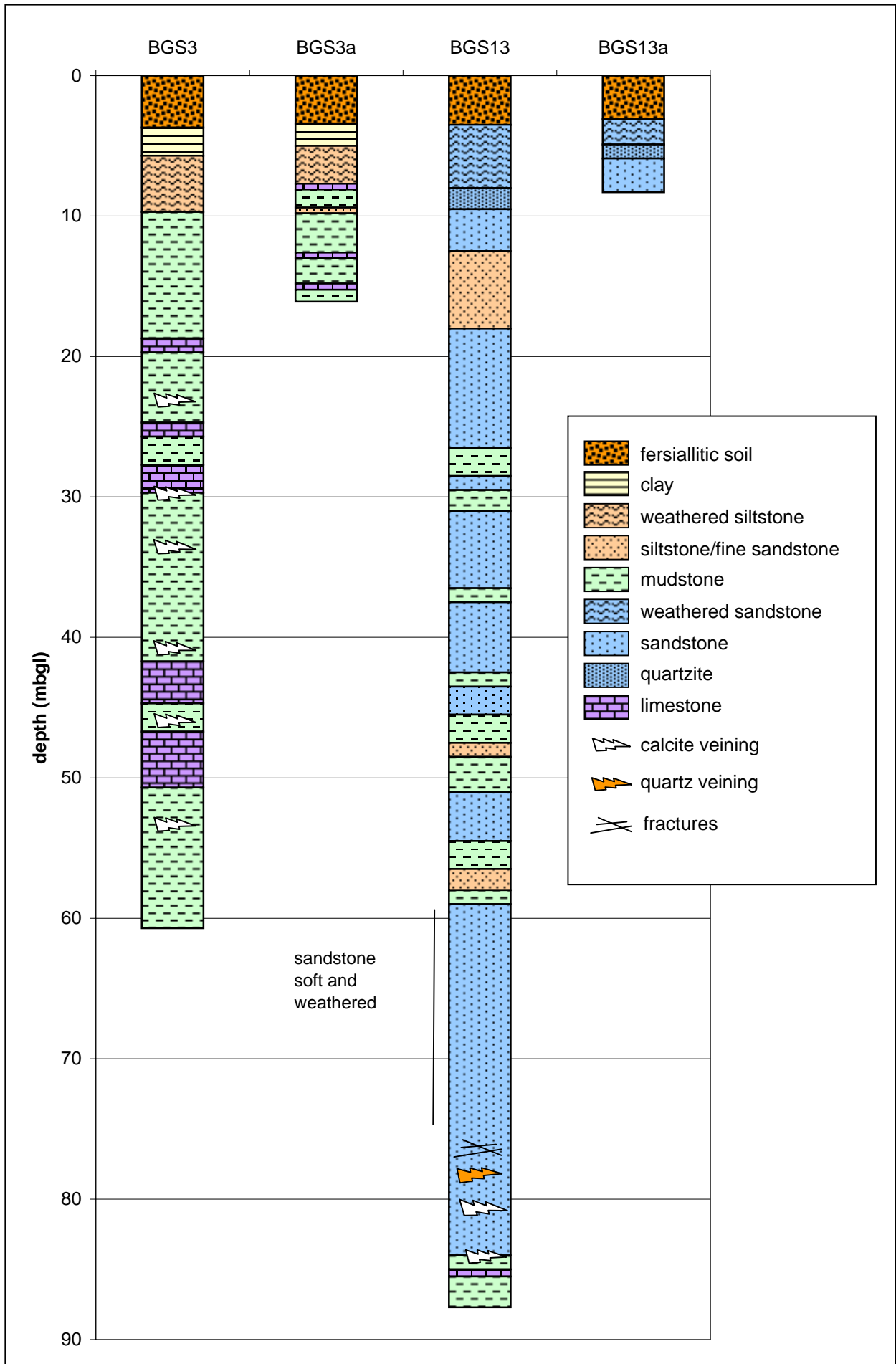


Figure 6. Simplified lithological logs for Odaleko Adiko (horizontal axis not to scale).

## Summary lithological log: BGS13

0.0 - 3.5	Soil/ferricrete horizon
3.5 - 5.5	Clayey very weathered fine to medium sandstone
5.5 - 8.0	Weathered friable fine to medium sandstone with kaolin cement
8.0 - 9.5	Fairly weathered hard medium grained sandstone with kaolin clay
9.5 - 11.0	Soft medium grained sandstone, fairly weathered
11.0 - 12.5	Soft fine to medium grained sandstones with kaolin cement and shaley partings
12.5 - 14.5	Carbonaceous siltstones with interbedded thin very hard medium grained quartzite
14.5 - 18.0	Fissile silty fine grained sandstone with thin hard quartzite bands
18.0 - 19.5	Fine to coarse grained sandstone interbedded with shaley silty mudstones
19.5 - 20.5	Friable fine to medium sandstone with compact limestone
20.5 - 26.5	Hard fine to coarse grained quartzose sandstone bands with shaley micaceous mudstone partings
26.5 - 28.5	Shaley silty mudstones with thin friable to hard medium to coarse grained sandstone bands
28.5 - 29.5	Friable fine to medium grained sandstones with thin shaley silty mudstones
29.5 - 31.0	Carbonaceous shaley mudstones
31.0 - 32.0	Fine to coarse grained friable quartzose sandstones with interbedded shaley mudstones
32.0 - 36.5	Friable and soft fine to coarse grained quartzose sandstone with black micaceous partings
36.5 - 37.5	Carbonaceous shaley mudstones
37.5 - 42.5	Hard to friable medium grained quartzose sandstones with shaley mudstone partings
42.5 - 43.5	Carbonaceous shaley mudstones
43.5 - 45.5	Friable to hard medium grained quartzose sandstones with shaley mudstones
45.5 - 47.5	Carbonaceous shaley mudstones and siltstones
47.5 - 48.5	Fine grained sandstones and siltstones
48.5 - 51.0	Carbonaceous shaley mudstones and siltstones interbedded with thin hard fine to medium grained sandstone bands
51.0 - 54.5	Friable medium to fine grained sandstones with shaley partings
54.5 - 56.5	Carbonaceous silty mudstones
56.5 - 58.0	Shaley siltstones with interbedded thin fine to medium grained sandstones
58.0 - 59.0	Carbonaceous silty mudstones with interbedded fine to medium grained sandstones
59.0 - 63.0	Friable and soft medium grained sandstones shaley partings, some weathering
63.0 - 66.5	Soft friable fine to medium grained sandstones with carbonaceous partings and kaolin cement
66.5 - 67.0	Hard quartzitic medium grained sandstone with shaley mudstone partings
67.0 - 70.0	Soft friable fine to medium grained sandstone with thin hard bands and shaley mudstone partings
70.0 - 72.5	Soft friable fine to medium sandstone with kaolin cement
72.5 - 74.0	Hard fine to medium grained sandstones
74.0 - 75.5	Soft friable fine to medium grained sandstones
75.5 - 76.5	Soft friable medium grained sandstones with shaley mudstone partings
76.5 - 78.0	Hard fine to medium grained quartzitic sandstone with shaley mudstone partings
78.0 - 79.0	Fractured medium grained quartzitic sandstone and carbonaceous mudstones, much quartz and calcite veining
79.0 - 81.5	Fairly hard medium grained quartzitic sandstone with interbedded carbonaceous shaley mudstones, some calcite veining
81.5 - 84.0	Hard fine to medium grained quartzitic muddy sandstone
84.0 - 84.85	Sandy bioturbated calcareous mudstones
84.85 - 84.90	Hard compact limestone
84.90 - 87.50	Compact and hard carbonaceous silty mudstones with thin bands of hard fine grained sandstones



## Summary lithological log: BGS 13A

3.10 - 4.90	Medium to coarse grained feldspathic and micaceous sandstone
4.90 - 5.90	Hard medium grained quartzite
5.90 - 6.40	Friable medium to coarse grained sandstone
6.40 - 8.30	Hard compact fine to medium grained quartzite

## 4. PUMPING TESTS

Only boreholes BGS13 and 13a were fitted with screen and casing. A variety of short tests were carried out on these two boreholes using bailers and Whale pump systems. No long test could be carried out since the yields were low. In addition, gas flowing from BGS13 caused cavitation within the Whale pumps causing their failure after only a few minutes of pumping. A summary of the pumping tests carried out at Odaleko Adiko is given in Table 4. Test pumping data and analyses are presented in Annex 4. The tests were analysed using methods described by Barker (1989) and Kruseman and de Ridder (1990).

The results of test pumping conducted upon boreholes BGS13 and BGS13a indicate that the Makurdi Sandstone at Odaleko Adiko has poor aquifer properties. Neither borehole had sufficient yield to sustain a hand pump; and any hand dug well constructed there would have but a low yield. The deep borehole shows a complex reaction to pumping – recovery speeds up at two depths (about 8 m and 4 m). The shallow borehole gives a classic response to pumping – but has a very low transmissivity (0.07 m<sup>2</sup>/d). Any hand dug well would need to penetrate at least 15 m into the sandstone to gain sufficient seepage area to contain some water in the late dry season. If fractures were present in the sandstone, then the well yield could be significantly greater.

**Table 4. Summary of pumping tests carried out at Odaleko Adiko. (Annex 4 contains data and analyses).**

Borehole and Test	Date	Casing (magl)	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m <sup>2</sup> /d)
BGS 13						
Bailer test	21/3/98	0.2 m	Overflowing slightly	9:40 mins	0.32 l/s	Barker: 0.15 m <sup>2</sup> /d Theis Rec: analysis unreliable
Whale test 1	16/3/98	0.2 m	Overflowing slightly	10 mins	0.14 l/s	Barker: 0.14 m <sup>2</sup> /d Theis Rec: analysis unreliable
BGS 13a						
Bailer test	23/2/98	0.2 m	3.85 m	2:30 mins	0.17 l/s	Barker: 0.074 m <sup>2</sup> /d Theis Rec: analysis unreliable

Water samples for hydrochemical analysis were obtained from boreholes BGS13 and BGS13a. Brackish water with gas flows under artesian pressure from BGS13 at about one litre per minute, therefore there was no need to use a pump to take a sample. BGS13a could not be pumped for more than three minutes before running dry, therefore a water sample had to be taken without extensive pumping. There is also a strong possibility that the shallow groundwater had been contaminated by the artesian flow from BGS13. Hydrochemical parameters measured at the well head are shown in Table 5. Detailed hydrochemical analyses are presented in Annex 5. The groundwater from BGS13a is saline and not fit for human consumption. There are also significant quantities of gas being released from the groundwater; the type of gas is not known.

**Table 5. Chemistry samples taken from Odaleko Adiko.**

ID No	Sample No	date	Conductivity ( $\square$ S/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	HCO <sub>3</sub> titr (50ml 1.6M)	Comments
BGS13	250	2/4/98	6470	3250	7.44	30	1312	artesian - gassy - sample fizzed violently with acid
BGS13a	222	21/3/98	513	259	8.13	30	115	Low yielding so not pumped. – possible contamination from BGS13

## 5. SUMMARY AND CONCLUSIONS

The groundwater potential of the Makurdi Sandstone and Upper Eze-Aku Shale was investigated at Odaleko Adiko. Various geophysical surveys were undertaken and a series of boreholes drilled and tested. The following work was undertaken:

- 3 km of EM34-3 surveys
- 0.6 km magnetic profiling
- 3 resistivity VES
- 2 deep boreholes drilled and two shallow observation boreholes cored
- chip and core samples from each borehole were logged and analysed
- two borehole, BGS13 and BGS13a were screened and cased
- short bailer tests were carried out on BGS13 and BGS13a
- water samples for hydrochemical analysis were taken from boreholes BGS13 and BGS13a.

The geophysical surveys highlighted the following:

1. The EM34-3 can be used to differentiate mudstone from sandstone. The mudstone had electrical conductivity of greater than 30 mmhos/m (using 20 or 40 m intercoil spacing); sandstone had conductivity of less than 15 mmhos/m.
2. On the mudstone, variation in conductivity with inter-coil spacing and coil orientation implies that a shallow 5-15 m clay layer governs the high conductivity. Within the sandstone, both vertical and horizontal coil readings were similar since there was no shallow high conductivity layer.
3. Resistivity sounding results correlated with the EM34-3 surveys. Within the mudstone, resistive fersiallitic soil overlies approximately 10 m of very low resistivity clay, followed by moderate resistivity (30-50 ohm-m) bedrock. In the sandstone, the unsaturated zone has high resistivity while the saturated sandstone at 2-3 m depth has moderate resistivity (90 ohm-m). Note that it is the shallow weathered zone that gives the largest contrast between the two lithologies, not the unweathered bedrock.

Analysis of the rock and chip samples and test pumping indicated the following:

- The Eze-Aku shale comprises mudstones interbedded with siltstones and some micaceous fine sandstones. There are also some shelly to muddy limestone layers which contained some water, but not enough to be hydrogeologically significant. Limestone layers in the Upper Eze-Aku at Ochingini were harder and more fractured and contained much water (MacDonald and Davies 1998).
- The top 10-15 m of the Eze-Aku Shale is highly weathered. A sandy soil overlies a few metres of laterite followed by a smectite to illite-smectite rich clay.

- The Makurdi Sandstone comprises fine to coarse grained well cemented feldspathic sandstone. Mudstones, siltstones and limestones are interbedded within the sandstone.
- The top few metres of the sandstone have been weathered. Feldspar crystals and much of the cement have been removed increasing the inter-granular porosity and permeability. From about 5-10 m a very hard silcrete layer has developed, however, the sandstone becomes softer beneath this layer.
- The inter-granular permeability of the sandstone is low. Analysis of pumping tests produced transmissivity values of between 0.07 and 0.14 m<sup>2</sup>/d. Groundwater seeps very slowly into the borehole. A hand dug well, which has a much larger surface area would have a higher chance of success – wells must be dug beneath the silcrete layer to about 15 m depth. No fractures were found in the sandstone – their presence would significantly increase the yield.
- Groundwater was found in a fractured limestone layer at about 80 m depth in BGS13. The groundwater was of poor quality and not suitable for drinking. The main targets for groundwater are therefore slow seepage from the shallow sandstone layers.

The groundwater potential of the Makurdi Sandstone at Odaleko Adiko is moderate to low. The sandstone is highly cemented and has few fractures. Deep hand dug wells would be the best technology to access the available groundwater. If the sandstone is at all fractured, the yield would be much increased. Large diameter deep wells would give the highest seepage area from inter-granular flow, and also increase the probability of intersecting a fracture.

The groundwater potential of the Upper Eze-Aku Shales at Odaleko Adiko is low. Some water was found within the muddy limestone layers, but not enough for a well or borehole. Where the limestones are more competent and fractured, the groundwater potential would be higher.

## REFERENCES

- Barker J A, 1989. Programs to simulate and analyse pumping tests in large diameter wells. British geological Survey technical report WD/89/24.
- Kruseman G P and de Ridder N A, 1990. Analysis and evaluation of pumping test data. IRLI publication 47, The Netherlands.
- MacDonald A M and Davies J. 1998. The hydrogeology of the Oju/Obi area, Eastern Nigeria: Ochingini traverse – data report. British Geological Survey Technical WC/98/51R

## **Annex 1: Geophysical data**

# Odaleko Adiko

**GPS start:** Malina Tree 6 degs 59.195 8 degs 22.312

**GPS finish**

**Date and time:** 18/11/97 12:00 - 15:00

**Survey:** (OA 1) From Malina tree at junction in the village to river. EM34-3 20 m separation  
 (OA 2) From Malina tree back down to the mango tree. EM34-3 20 m separation  
 (OA 3) From mango tree back into the village. EM34-3 20 m separation

**General comments:** They have no well in the village due to problems of collapsing sand  
 Collapse well ended in ferrosol - iron and kaolinite mottles  
 Take water from a pond/spring in a shallow depression to north-east  
 Pond beside a stream - both dry by January  
 Wet season source is from dugouts in a far village. They might have to wait for up to 3-4 days to fetch water in March.  
 Dune bedded, well consolidated Makurdi sandstone exposed in river.

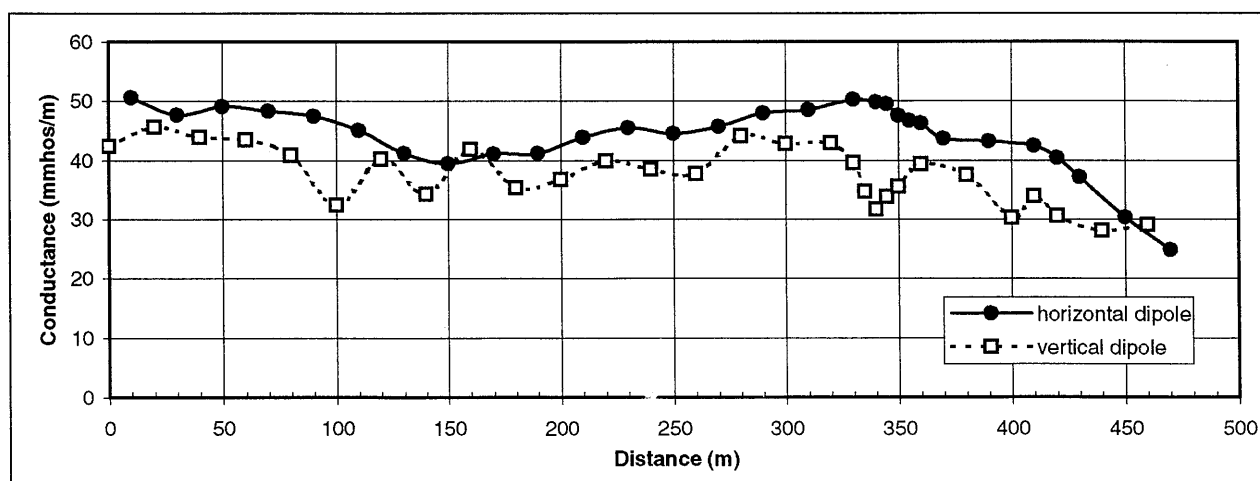
## OA 1 (20 m separation)

**Strike:**

position (m)	strike (deg)
0	41
60	61
180	45
280	42
380	35

**Comments:**

position (m)	comments
0	Malina Tree
100	small path right
140	end village
180	
340	small depression - rice field
410	down
480	Bridge



## OA 2 (20 m separation)

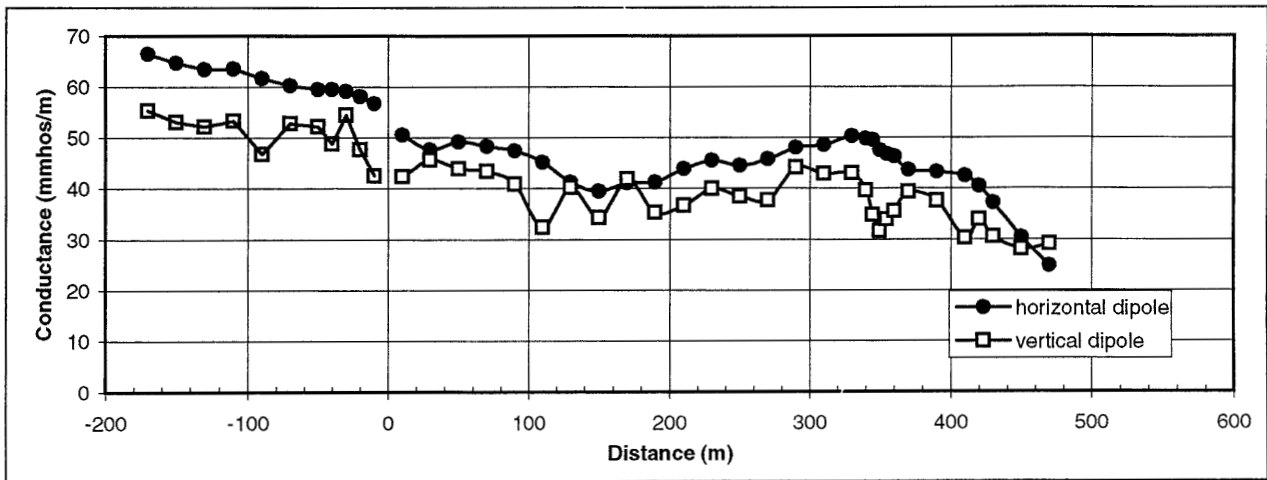
Strike:

position (as OA1)	strike (deg)
0 (0)	221
40 (-40)	216
120 (-120)	214

Comments:

position (as OA1)	comments
0 (0)	Malina Tree
160 (-160)	Mango tree - boundary

## OA 1 and 2 (20 m separation)



OA 3 data missing

# Odaleko Adiko

OA 4/5/6/7

GPS start: Malina Tree 6 degs 59.195 8 degs 22.312  
 GPS finish  
 Date and time: 19/11/97 09:00 - 15:00  
 Survey: (OA 4) Redoing some of OA 1 EM34-3 20 m separation  
 (OA 5) From mango to river. EM34-3 40 m separation  
 (OA 6) From mango tree bto river. Magnetic.  
 (OA 7) From mango to river. EM34 40m separation.

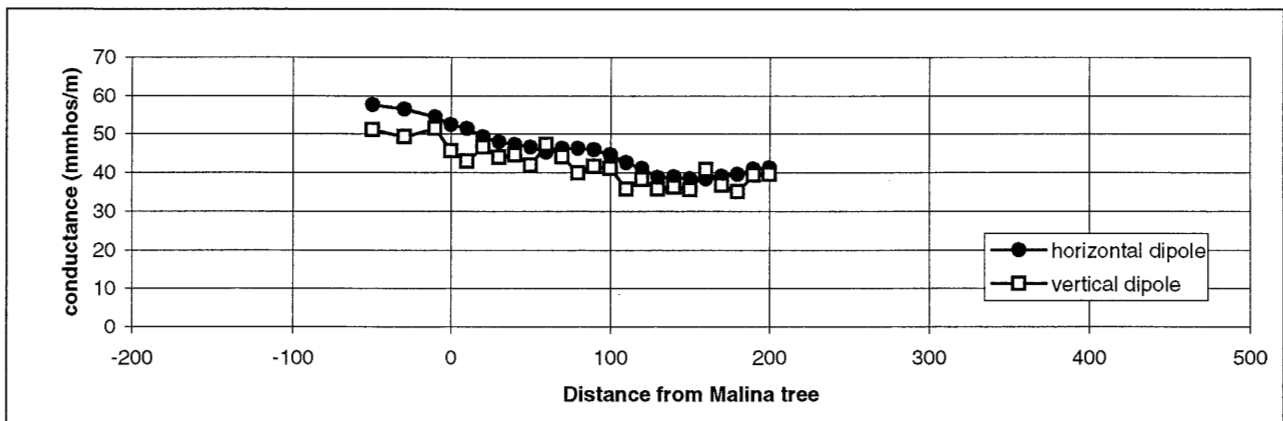
**Strike:**

position (m)	strike (deg)
-160	34
0	41
60	61
180	45
280	42
380	35

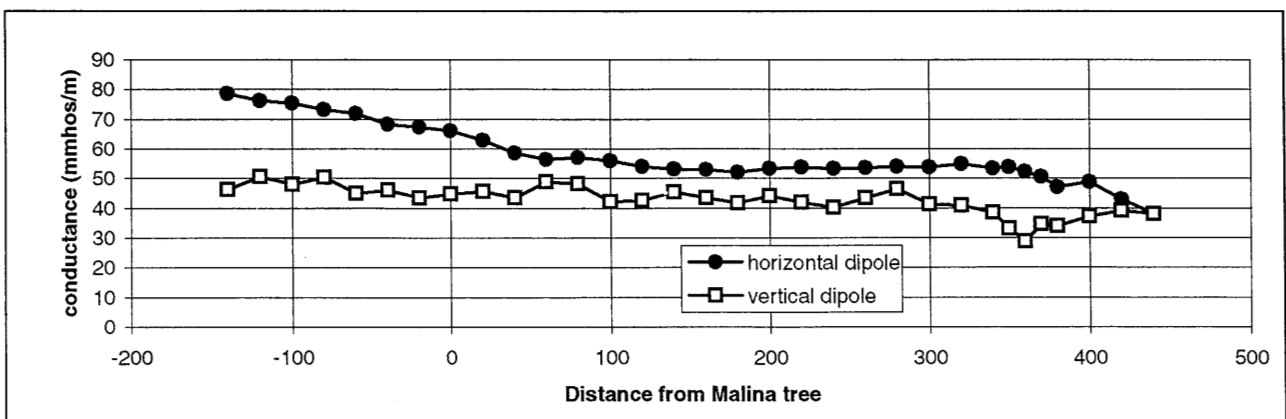
**Comments:**

position (m)	comments
-160	mango tree
0	Malina Tree
100	small path right
140	end village
180	path
340	small depression - rice field
410	down
480	Bridge

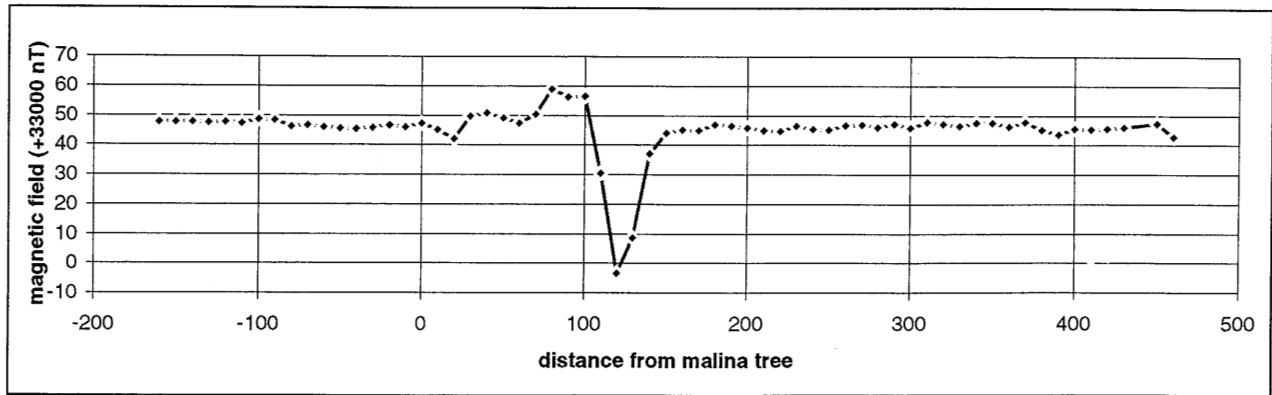
## OA 4 (EM 20m sep)



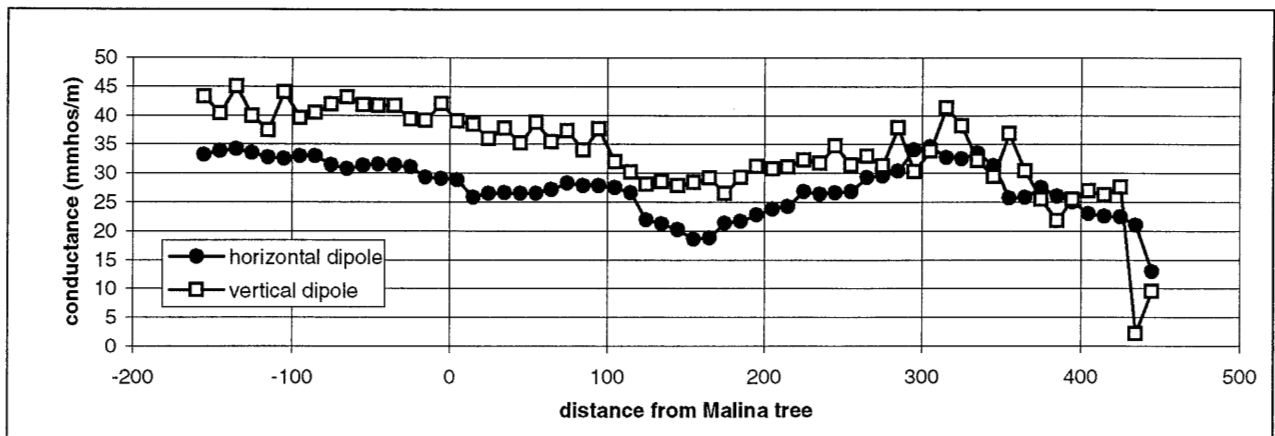
## OA 5 (EM 40m sep)



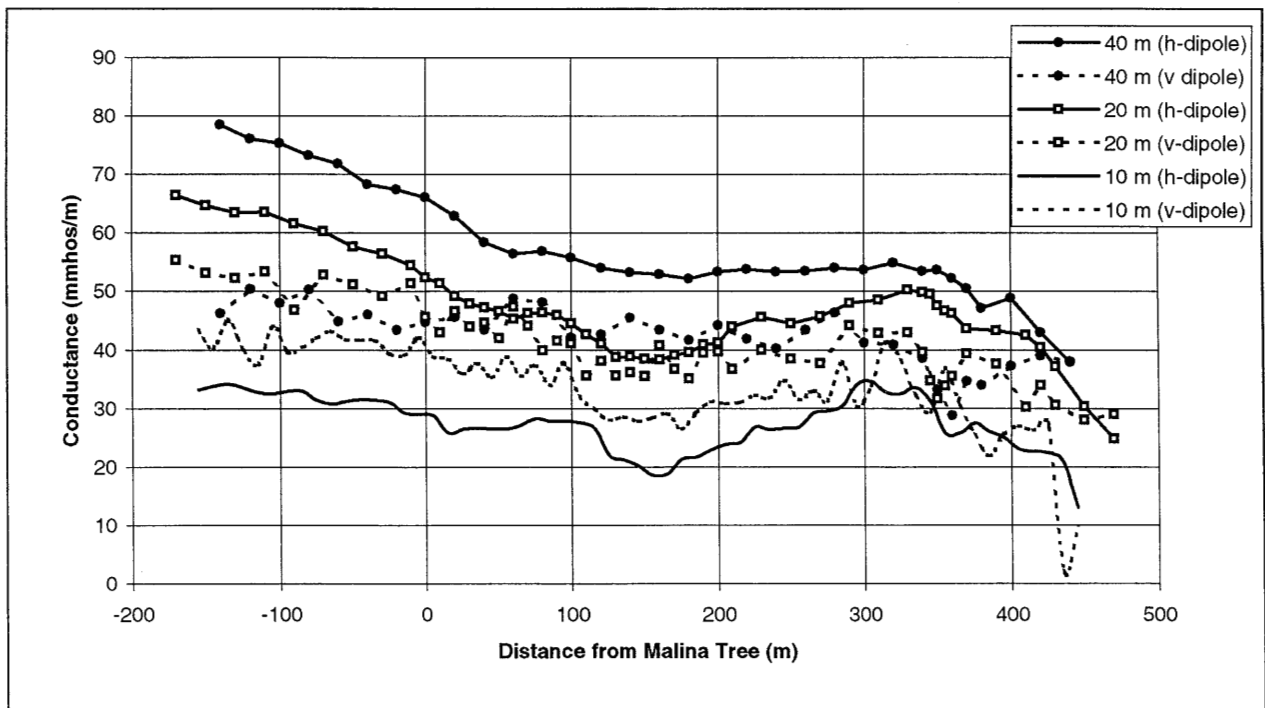
## OA 6 (magnetic)



## OA 7 (EM34 10m sep)



## OA 1,2,5,7





# Odaleko Adiko

OA 8/9/10/11/12

GPS start: Malina Tree 6 degs 59.195 8 degs 22.312

GPS finish

Date and time: 13/01/98 09:00 - 15:00

- Survey:
- OA 8 From Malina tree right angles to 1-7 up hill. EM34 20m separation
  - OA 9 From Top of line 8 (mango tree) across fields to palm tree. EM34 20m
  - OA 10 From Hill (crossing end of Line 8) back to palm tree main road. EM34 20m
  - OA 11 On path linking OA8 and OA10. EM34 20m
  - OA 12 From aborted borehole towards end of village near end of OA 11. EM34 20m

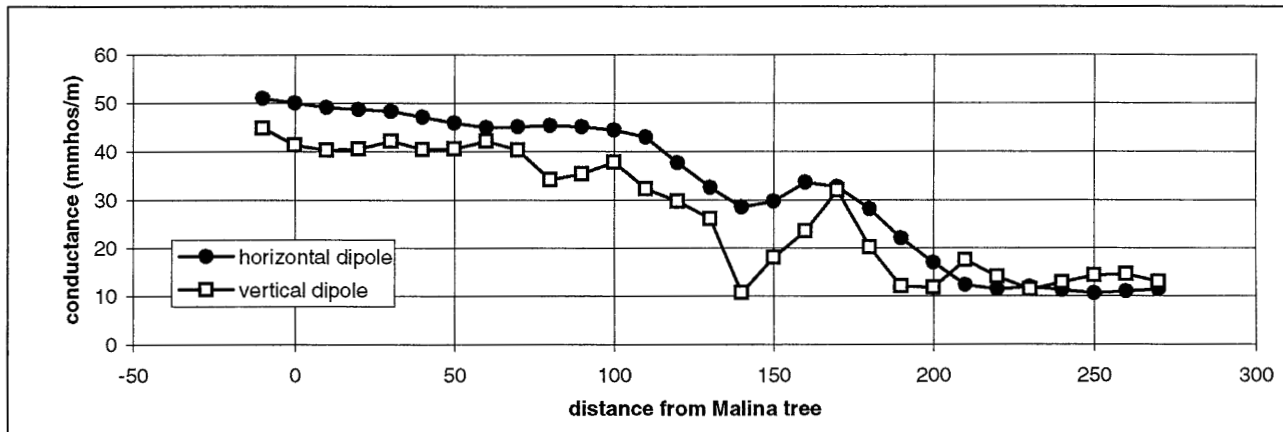
## OA 8:

Strike:

position (m)	strike (deg)
-20	141
60	134
130	149
200	168
230	165

Comments:

position (m)	comments
-20	Receiver trailing
0	Malina Tree
30	steel roof 5m right
90	palm tree in compound
150	Steel roof
170	line 11 crossing
210	beginning yam farm
260	on path opp Mango tree beginning Line 9



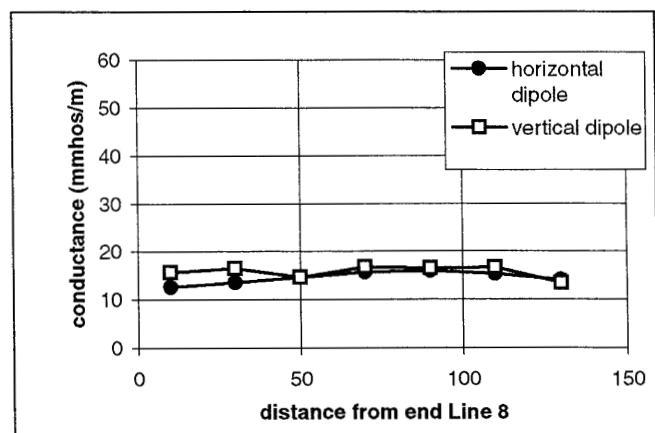
## OA 9:

Strike:

position (m)	strike (deg)
0	75
120	75

Comments:

position (m)	comments
0	from path at end line 8 straight through fields to Palm tree
130	cross small path line of OA 10



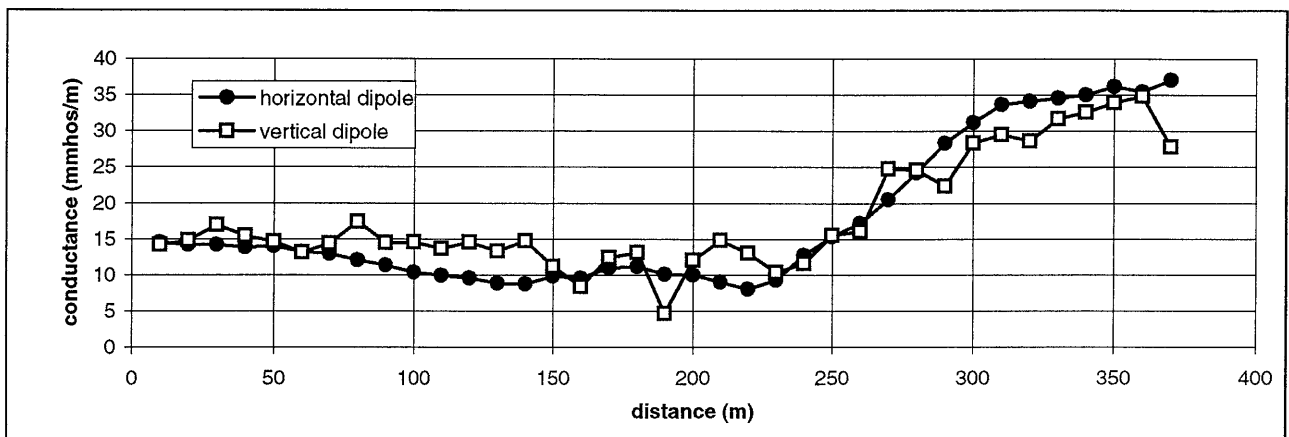
# OA 10:

## Strike:

position (m)	strike (deg)
0	345
100	345
140	345
300	345

## Comments:

position (m)	comments
0	Receiver trailing. Top of Beneseed farm next to "tree stick". Route mainly bush.
40	cross end OA 9
60	crossing small path
130	large mango tree
140	Large path
230	small path
270	large path
300	small path - cassava farm
380	Main Road next to large palm. About 65 m from bh towards river.



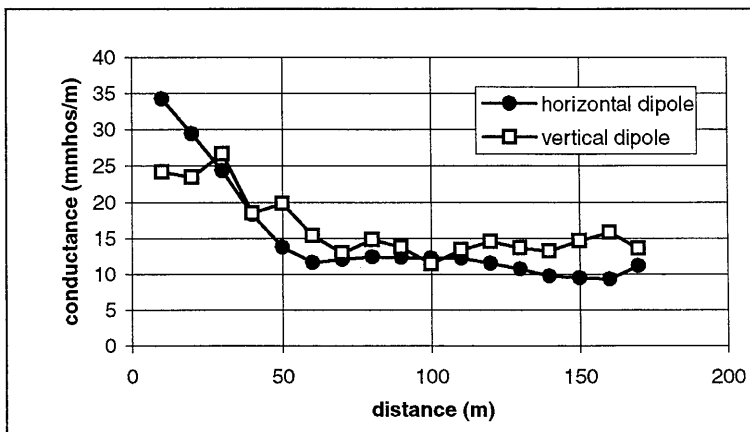
# OA 11:

## Strike:

position (m)	strike (deg)
0	74
30	67
150	67

## Comments:

position (m)	comments
0	Receiver trailing. Start at compound with R on 170 m up OA 8.
150	Mango tree. Crosses OA 10 (140 m)



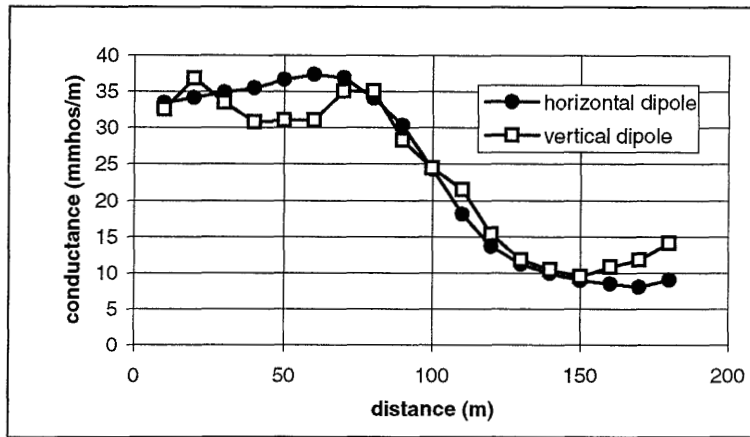
# OA 12:

## Strike:

position (m)	strike (deg)
0	114
60	120
120	127

## Comments:

position (m)	comments
0	Receiver trailing. Start on borehole with R on 170 m up OA 8.
80	Cross small path
110	OA 10 crossing
140	small path
190	First hut in the last compound.

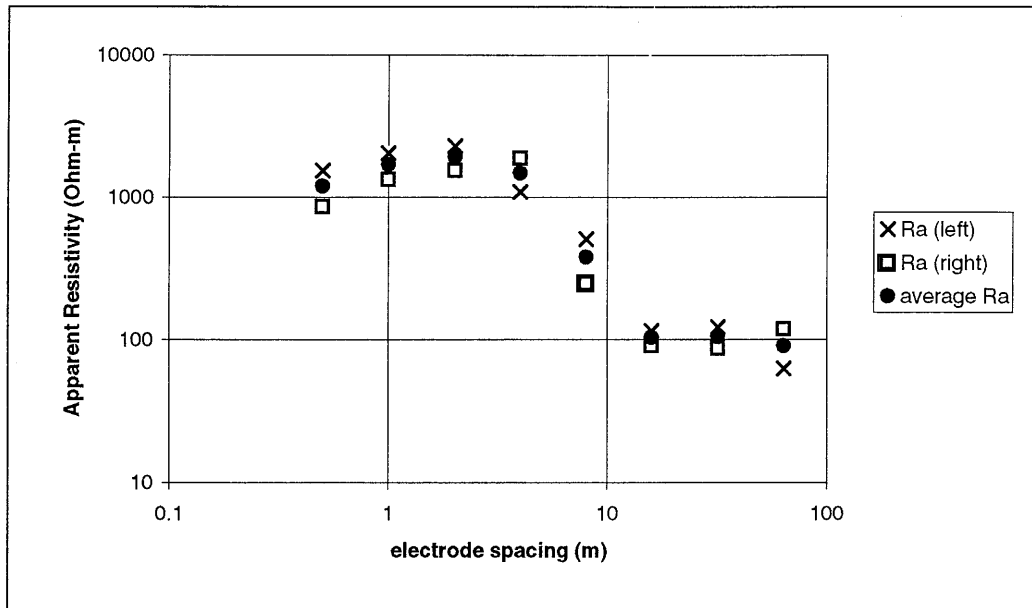


# Odaleko Adiko

# OA 13

Resistivity Survey 3                      6 degs 59.180; 8 degs 22.399  
Located on mango tree; 140 m along OA 10; 150 m along OA 11  
Offset Wenner                              Right to end of village  
Strike 68 degs  
14/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	487	272	1529.18	854.08	1191.63
1	325	212	2041	1331.36	1686.18
2	181	121.7	2273.36	1528.552	1900.956
4	43.4	74	1090.208	1858.88	1474.544
8	10.14	4.95	509.4336	248.688	379.0608
16	1.145	0.9	115.0496	90.432	102.7408
32	0.607	0.43	121.9827	86.4128	104.1978
64	0.155	0.293	62.2976	117.7626	90.03008



DATA SET: OA 13

CLIENT: WaterAid  
 LOCATION: Odaliko Adiko  
 COUNTY: Oju, Nigeria  
 PROJECT: Borehole  
 ELEVATION: 0.00  
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: 14 Jan 98  
 SOUNDING: 3  
 AZIMUTH: 68 degs  
 EQUIPMENT: BGS128

Offset Wenner Configuration

FITTING ERROR: 5.015 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m <sup>2</sup> )
			0.0		
1	907.8	0.481	-0.481	5.299E-04	436.6
2	4657.5	1.31	-1.79	2.822E-04	6122.2
3	93.78				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO			
1	759.525	907.804	1096.420
2	3164.538	4657.508	7800.199
3	89.006	93.790	99.041
THICK			
1	0.338	0.481	0.699
2	0.765	1.314	1.984
DEPTH			
1	0.338	0.481	0.699
2	1.424	1.796	2.350

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
1	0.500	1191.0	1182.1	0.738
2	1.00	1686.0	1680.7	0.313
3	2.00	1901.0	2007.5	-5.60
4	4.00	1474.0	1382.7	6.19
5	8.00	379.0	384.3	-1.42
6	16.00	103.0	107.7	-4.64

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
7	32.00	104.0	95.22	8.44
8	64.00	90.00	94.10	-4.56

PARAMETER RESOLUTION MATRIX:

"F" INDICATES FIXED PARAMETER

P 1	0.98				
P 2	-0.05	0.77			
P 3	0.00	0.00	1.00		
T 1	-0.04	-0.14	0.00	0.90	
T 2	0.05	0.24	0.00	0.15	0.75
	P 1	P 2	P 3	T 1	T 2

# Odaleko Adiko

# OA14

Resistivity Survey 4

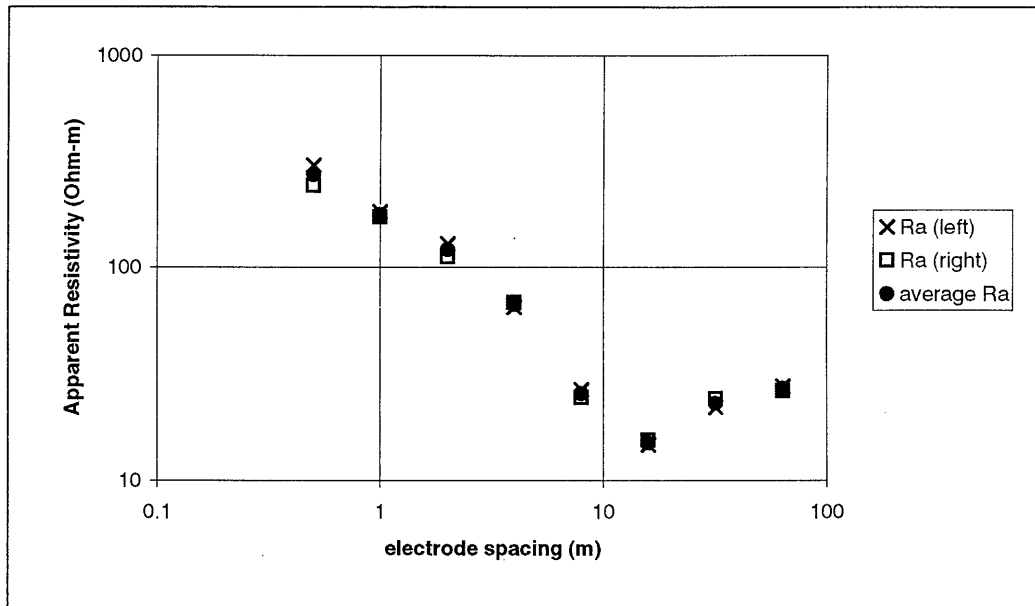
45 m from malina tree towards village

Offset Wenner Left to Malina tree

Strike 135 degs

14/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	96.3	77.4	302.382	243.036	272.709
1	29	27.5	182.12	172.7	177.41
2	10.25	8.91	128.74	111.9096	120.3248
4	2.59	2.71	65.0608	68.0752	66.568
8	0.528	0.486	26.52672	24.41664	25.47168
16	0.146	0.153	14.67008	15.37344	15.02176
32	0.1095	0.1196	22.00512	24.03482	23.01997
64	0.0686	0.065	27.57171	26.1248	26.84826



DATA SET: OA 14

CLIENT: WaterAid  
 LOCATION: Odaliko Adiko  
 COUNTY: Oju, Nigeria  
 PROJECT: Borehole  
 ELEVATION: 0.00  
 SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: 14 Jan 98  
 SOUNDING: 4  
 AZIMUTH: 135 degs  
 EQUIPMENT: BGS128

Offset Wenner Configuration

FITTING ERROR: 3.835 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m <sup>2</sup> )
			0.0		
1	327.8	0.491	-0.491	0.00150	161.1
2	111.8	3.00	-3.49	0.0268	335.8
3	7.63	7.27	-10.76	0.952	55.52
4	34.31				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO	1 276.992	327.873	426.240
	2 92.343	111.812	130.063
	3 4.055	7.636	11.800
	4 29.318	34.314	41.983
THICK	1 0.349	0.492	0.680
	2 2.631	3.004	3.362
	3 3.597	7.271	12.967
DEPTH	1 0.349	0.492	0.680
	2 3.075	3.495	3.930
	3 7.338	10.767	16.273

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
1	0.500	272.8	270.6	0.816
2	1.00	177.5	181.1	-2.08

No.	SPACING (m)	RHO-A (ohm-m)		DIFFERENCE (percent)
		DATA	SYNTHETIC	
3	2.00	120.3	115.7	3.84
4	4.00	66.60	69.52	-4.39
5	8.00	25.48	24.86	2.44
6	16.00	15.02	15.69	-4.47
7	32.00	23.01	21.58	6.20
8	64.00	26.85	27.63	-2.91

PARAMETER RESOLUTION MATRIX:

"F" INDICATES FIXED PARAMETER

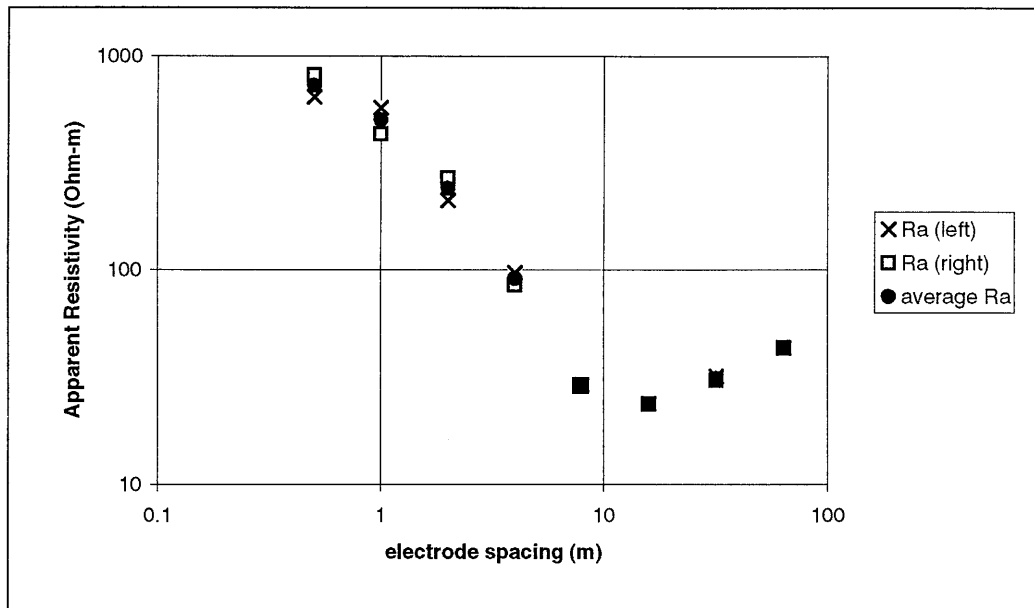
P 1	0.93						
P 2	-0.03	0.94					
P 3	-0.01	-0.03	0.58				
P 4	0.00	0.01	0.00	0.92			
T 1	0.09	0.08	0.03	-0.01	0.81		
T 2	0.00	0.03	0.07	-0.01	-0.02	0.97	
T 3	-0.01	-0.02	-0.44	-0.08	0.02	0.06	0.41
	P 1	P 2	P 3	P 4	T 1	T 2	T 3

# Odaleko Adiko

# OA15

Resistivity Survey 5                      6 degs 59.214; 8 degs 22.361  
On abandoned borehole site (again)  
Offset Wenner                              Right to river  
Strike 135 degs  
14/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	205	258	643.7	810.12	726.91
1	91.1	68.7	572.108	431.436	501.772
2	16.67	21.3	209.3752	267.528	238.4516
4	3.85	3.38	96.712	84.9056	90.8088
8	0.577	0.575	28.98848	28.888	28.93824
16	0.236	0.234	23.71328	23.51232	23.6128
32	0.1578	0.1518	31.71149	30.50573	31.10861
64	0.1072	0.1068	43.08582	42.92506	43.00544





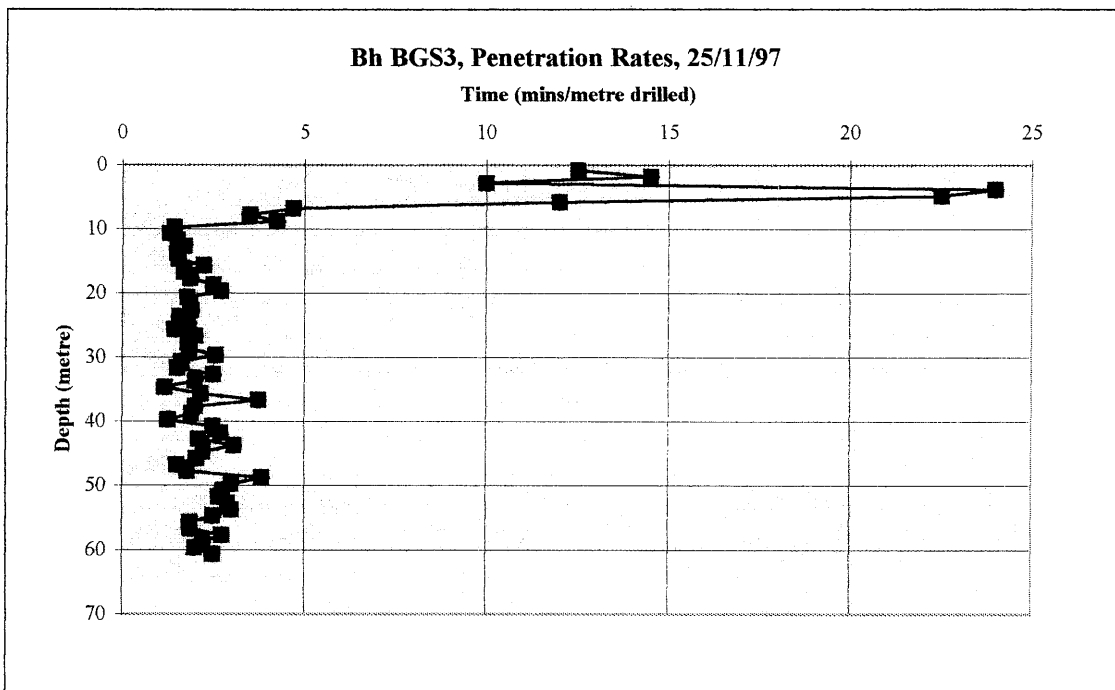


## **Annex 2: Drilling and borehole construction data**

### Borehole BGS3

#### Borehole Drilling/Construction Details

Date drilling started	25/11/97
Date drilling completed	26/11/97
25/11/97 - Drilled with 8.5" tricone	0.0 - 8.7m
25/11/97 - Drilled with 6.5" tricone	8.7 - 27.7m
26/11/97 - Drilled with 6.5" tricone	27.7 - 60.7m
Depths water struck	8.7, 18.7, 41.7, 42.7, 46.7, 48.7
Depth of borehole on completion	60.7m bgs
Borehole diameter	6 <sup>1</sup> / <sub>2</sub> "
Casing erected in hole	none
Rest water level below ground surface	4.41m



**Borehole BGS3A**

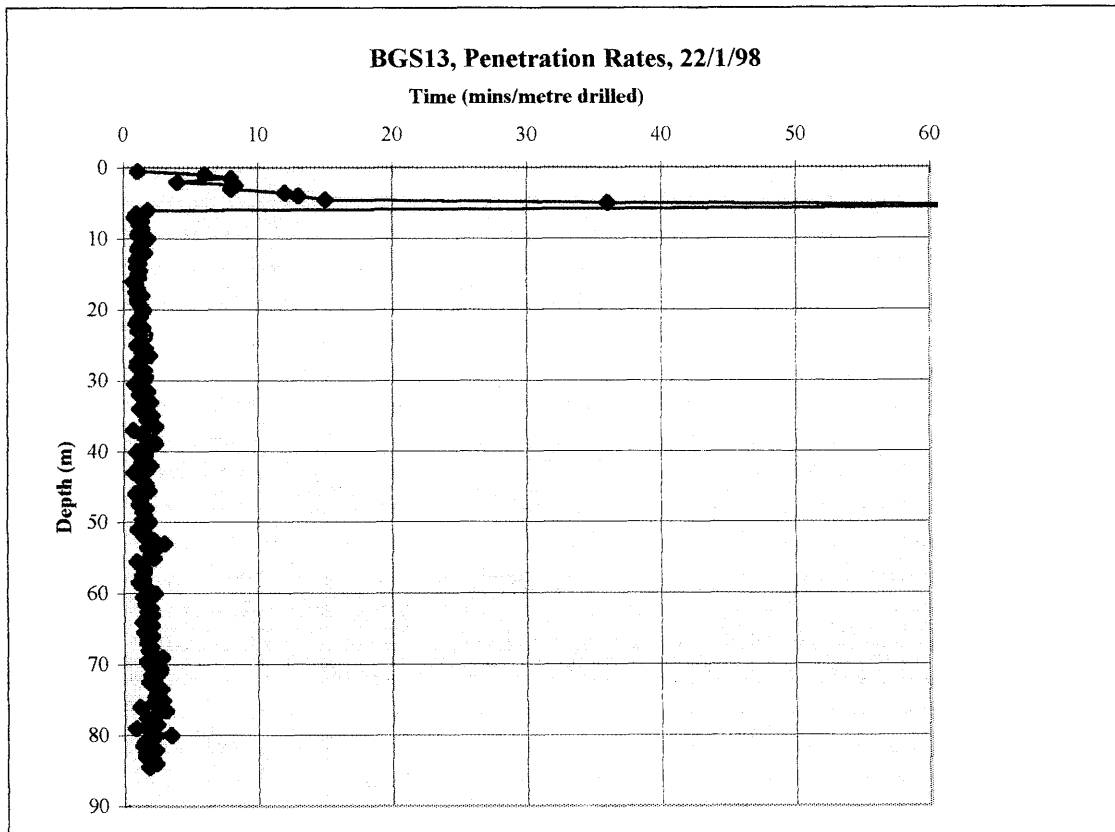
## Borehole Drilling/Construction Details

Date drilling started	27/11/97
Date drilling completed	29/11/97
27/11/97 - Cored at 3"	0.0 - 7.85m
28/11/97 - cored at 3"	7.85 - 16.0m
Depth of borehole on completion	16mbgs
Borehole diameter	4"
Casing erected in hole	none

### Borehole BGS13

#### Borehole Drilling/Construction Details

Date drilling started	22/1/98
Date drilling completed	24/1/98
22/1/98 - Drilled with 8.5" tricone	0.0 - 6.5m
22/1/98 - Drilled with 6.5" tricone	6.5 - 51.5m
23/1/98 - Drilled with 6.5" tricone	51.5 - 84.5m
23/1/98 - Cored at 3"	84.5 - 87.5m
Depth water struck	45.5 (damp), 67.5 (damp), 71.0 (damp), 73.5 (damp), 77.5 (flowing), 78.5 (increased flow), 82.0 (more water)
Depth of borehole on completion	87.5mbgs
Borehole diameter	6 1/2"
Casing erected in hole	5x2.9mx125mm casing 1x5.8mx125mm casing 1x2.9mx125mm casing 7x2.9mx125mm screen 8x5.8mx125mm screen
Original top of casing above ground level	1.08m
Total length of casing/screen	88.58m
Amount of casing removed	0.50m
Rest water level below casing top	artesian



## **Borehole BGS13A**

### **Borehole Drilling/Construction Details**

Date drilling started	26/1/98
Date drilling completed	27/1/98
23/1/98 - Drilled with 6.5" tricone	51.5 - 84.5m
26/1/98 - Cored at 3"	0.0 - 5.8m
27/1/98 - Cored at 3"	5.8 - 8.3m
Depth of borehole on completion	8.3mbgs
Borehole diameter	6 <sup>1</sup> / <sub>2</sub> "
Casing erected in hole	1x5.8mx125mm casing
Original top of casing above ground level	0.20m
Total length of casing/screen	5.8m
Amount of casing removed	0.00m
Rest water level below casing top	3.52m

## **Annex 3: Lithological logs**

## Lithological Log: BGS3

---

### Soil/ferrecrete zone

- 0.0 - 0.7 Light brown to orange brown clayey top soil  
0.7 - 1.7 Orange red/pink 10R5/8 clayey fine grained ferrisol  
1.7 - 2.7 Pink red 7.5R4/6 fine grained ferrisol with yellow partings  
2.7 - 3.7 Orange brown 7.5R5/8 fine ferrisol with hard orange haematitic nodules
- 

### Clayey very weathered zone

- 3.7 - 4.7 Bright yellow 10YR7/8 smectitic? damp silty clay  
4.7 - 5.7 Bright yellow 10YR6/8 clay above orange brown to olive brown silty clay with light blue grey mottles
- 

### Weathered micaceous siltstones

- 5.7 - 6.7 Olive brown 2.5Y4/4 and orange brown very weathered micaceous siltstone  
6.7 - 7.7 Orange brown to olive brown 2.5Y6/4 very weathered micaceous siltstone  
7.7 - 8.7 Mottled light grey and olive brown 2.5Y5/4 weathered very micaceous siltstone  
8.7 - 9.7 Hard, light orange and light grey micaceous siltstone
- 

### Non-weathered massive silty shales and shaley mudstones

- 9.7 - 10.7 Hard grey micaceous siltstones above dark grey soft shaley mudstones  
10.7 - 11.7 Alternations of hard light grey micaceous sandy siltstones and dark grey soft shales  
11.7 - 12.7 Dark grey shales with thin silty partings  
12.7 - 13.7 Dark grey shales with thin silty partings  
13.7 - 14.7 Dark grey carbonaceous non-calcareous shaley mudstones
- 

### Fairly weathered shaley mudstones

- 14.7 - 15.7 Light grey to dark grey carbonaceous non-calcareous shaley mudstones with light brown partings  
15.7 - 16.7 Grey shaley non-calcareous mudstones with light brown clayey partings  
16.7 - 17.7 Grey shaley non-calcareous mudstones with light brown clayey partings  
17.7 - 18.7 Dark grey carbonaceous non-calcareous sometimes micaceous shaley mudstones
- 

### Limestone

- 18.7 - 19.7 Light grey muddy limestone
- 

### Non-weathered zone

- 19.7 - 20.7 Dark grey carbonaceous soft non-calcareous shaley mudstones  
20.7 - 21.7 Dark grey carbonaceous soft non-calcareous shaley mudstones  
21.7 - 22.7 Dark grey carbonaceous soft non-calcareous shaley mudstones  
22.7 - 23.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones  
23.7 - 24.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with thin muddy limestones
- 

### Muddy limestones

- 24.7 - 25.7 Grey muddy limestones and dark grey black soft carbonaceous non-calcareous shaley mudstones
- 

### Massive shaley mudstones with calcite veining

- 25.7 - 26.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with subordinate grey muddy limestones and **calcite** veins  
26.7 - 27.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with subordinate grey muddy limestones
- 

### Muddy limestones

- 27.7 - 28.7 Light grey muddy limestones  
28.8 - 29.7 Light grey muddy limestones and dark grey black soft carbonaceous non-calcareous shaley mudstones
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### Massive shaley mudstones with calcite veining

- 29.7 - 30.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones  
30.7 - 31.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with **calcite** veins  
31.7 - 32.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones, some **calcite** veining  
32.7 - 33.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with odd **calcite** vein



- 33.7 - 34.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones  
34.7 - 35.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones some vein  
**calcite**
- 

**Calcite veined zone - water producing zone**

- 35.7 - 36.7 Dark grey black soft carbonaceous non-calcareous shaley mudstones with  
interbedded thin light grey muddy limestones and **calcite** bands  
36.7 - 37.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone with muddy  
limestones and **calcite** bands
- 

**Massive shaley mudstones**

- 37.7 - 38.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone  
38.7 - 39.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone  
39.7 - 40.7 Dark grey black micaceous soft carbonaceous non-calcareous shaley mudstone,  
interbedded with grey uneven calcareous mudstones  
40.7 - 41.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone
- 

**Muddy limestones with calcite veining**

- 41.7 - 42.7 Grey to light grey calcareous mudstone to muddy limestone with **calcite** veining  
42.7 - 43.7 Grey calcareous mudstones and muddy limestones some **calcite** bands  
43.7 - 44.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone interbedded with  
harder light grey and white muddy limestones and calcareous mudstones with  
**calcite** veins
- 

**Massive shaley mudstones**

- 44.7 - 45.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone  
45.7 - 46.7 Dark grey black soft carbonaceous non-calcareous shaley mudstone
- 

**Muddy limestones with calcite veining**

- 46.7 - 47.7 Blocky grey black mudstone with calcareous mudstones and muddy limestones  
47.7 - 48.7 Light grey to dark grey muddy limestones, uneven fracture with **calcite** bands  
48.7 - 49.7 Dark grey fine grained shaley limestone, uneven to sub-concoidal fracture, **calcite**  
veining  
49.7 - 50.7 Light grey and dark grey muddy limestones with **calcite** veining
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**Calcareous mudstones with calcite veining**

- 50.7 - 51.7 Dark grey and white shaley mudstones, micaceous with **calcite** partings, calcareous  
shale to limestone.  
51.7 - 52.7 Grey shaley to uneven calcareous mudstones with white **calcite** veins  
52.7 - 53.7 Grey shaley to uneven calcareous mudstones, some **calcite** veins
- 

**Calcite veined zone - water producing zone**

- 53.7 - 54.7 Dark grey black carbonaceous shaley mudstones, some vein **calcite**  
54.7 - 55.7 Hard dark grey black carbonaceous non-calcareous shaley mudstones to siltstones,  
some **calcite** veining  
55.7 - 56.7 Dark grey black carbonaceous soft shaley mudstones  
56.7 - 57.7 Soft grey black shaley mudstones, with **calcite** veins  
57.7 - 58.7 Soft dark grey black soft shaley mudstones, with harder light grey calcareous bands  
58.7 - 59.7 Grey shaley to uneven non-calcareous mudstones with calcite veins
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**Massive shaley mudstone**

- 59.7 - 60.7 Soft grey black shaley mudstones
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## Summary lithological log: BGS3A

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### Soil/ferrecrete zone

- 0.00 - 2.53 No core  
2.53 - 3.40 Pink red and white mottled nodular ferrecrete, nodular concretions within a groundmass of red ferrecrete and white kaolin clay.
- 

### Clayey very weathered zone

- 3.40 - 4.00 Orange yellow and light blue grey mottled clay  
4.00 - 4.40 Light blue grey and orange mottled sandy clay with mica  
4.40 - 5.00 Orange and light blue grey clayey sand
- 

### Weathered micaceous, clayey siltstones with some fine grained sandstones

- 5.00 - 5.15 Olive brown weathered micaceous silty fine sandstone  
5.15 - 5.45 Orange brown and orange yellow with little light grey blue sandy clay  
5.45 - 6.00 Light golden brown weathered soft micaceous silty fine grained sandstone  
6.00 - 6.75 Light brown and light grey fairly hard fairly weathered micaceous silty fine grained sandstone  
6.75 - 7.00 Light brown and light grey fairly hard weathered micaceous silty fine grained sandstone with orange partings  
7.00 - 7.30 Light brown and light grey weathered micaceous silty fine grained sandstone with orange partings  
7.30 - 7.85 Olive brown very weathered and broken silty fine grained micaceous sandstone, fairly clayey and wet  
7.80 - 7.90 Light olive brown fissile micaceous siltstone
- 

### Limestone

- 7.90 - 8.05 Grey hard dense shelly limestone
- 

### Fairly weathered micaceous shaley siltstones

- 8.05 - 8.15 Light olive brown to grey very weathered clayey micaceous siltstone  
8.15 - 8.55 Light grey and light olive brown unevenly fissile micaceous shaley siltstone  
8.55 - 9.25 Light blue grey and light olive brown micaceous unevenly fissile shaley siltstones with orange brown partings  
9.25 - 9.35 Light blue grey and light olive brown micaceous unevenly fissile shaley siltstones with orange brown partings, very weathered and clayey
- 

### Massive micaceous fine grained sandstones

- 9.35 - 9.75 Thicker bedded more massive olive green/brown silty micaceous fine sandstones
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### Massive silty and shaley mudstones

- 9.75 - 10.20 Dark grey black carbonaceous shales with brown partings, broken to weathered - possible zone of water movement  
10.20 - 11.65 Dark grey black carbonaceous silty micaceous mudstones, massive at first breaks into thin laminae on drying, with discontinuous thin light grey layers.  
11.65 - 12.55 Grey non-calcareous micaceous silty mudstones with fresh water bivalves
- 

### Limestone

- 12.55 - 12.65 Grey dense limestone
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### Massive siltstones and shaley mudstones

- 12.65 - 12.85 Dark grey and white banded thinly bedded very muddy siltstone with white calcareous partings  
12.85 - 13.50 Grey and light grey well laminated, non-calcareous fairly micaceous siltstone  
13.50 - 13.75 Dark grey thinly laminated shaley non-calcareous mudstones  
13.75 - 13.80 Light grey calcareous shaley mudstones  
13.80 - 14.50 Dark grey black finely laminated non-calcareous shaley mudstones  
14.50 - 14.70 Black very fine grained carbonaceous mudstone
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### Muddy limestone

- 14.70 - 15.15 Grey white muddy limestone with shell fragments
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### Shaley siltstones and mudstones

- 15.15 - 15.56 Black carbonaceous non-calcareous micaceous shaley siltstone  
15.56 - 15.70 Black carbonaceous non-calcareous fairly micaceous shaley siltstone with fine sandstone bands

15.70 - 16.00 Soft black carbonaceous non-calcareous micaceous shaley thinly laminated mudstones with freshwater bivalve casts

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## Summary lithological log: BGS13

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### Soil/ferrecrete horizon

0.0 - 0.5	Brown 7.5YR4/4 fine grained sandy soil with black carbonaceous fragments
0.5 - 1.0	Yellowish red 5YR5/6 fine quartzitic sand with few red brown ferrecrete nodules up to 4-8mm, subrounded
1.0 - 1.5	Dark yellow red 5YR5/6 fine to medium sand with many weak red 10R4/3 nodules of ferrecrete - haematitic up to 4mm diameter
1.5 - 2.0	Yellow red 5YR5/6 medium to fine sand with some weak red 10R4/3 nodules of ferrecrete
2.0 - 2.5	Yellow red 5YR5/6 fine to coarse sand with haematitic nodules and slabs of dark purple, red and black manganiferous ferrecrete up to 25mm across, layering 5-10mm thick
2.5 - 3.0	Yellow red 5YR5/8 medium to coarse sand some white mica and fragments and nodules of dark red to black ferrecrete 2-5mm diameter
3.0 - 3.5	Yellow red 5YR5/8 medium subrounded quartzitic sand with nodules and fragments of dark red ferrecrete up to 15mm diameter

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### Clayey very weathered fine to medium sandstone

3.5 - 4.0	Reddish yellow 5YR6/8 medium grained rounded to subrounded quartz sand, some white kaolin clay
4.0 - 4.5	Reddish yellow 7.5YR7/6 medium to coarse quartzitic sand, numerous fragments of white kaolin clay and orange iron oxide
4.5 - 5.0	Reddish yellow 7.5YR6/6 fine to medium quartzitic sand, some mica, much blue white kaolin clay
5.0 - 5.5	Reddish yellow 7.5YR7/6 fine to coarse sandstone, much white kaolin clay, some coarse nodules of dark red ferrecrete

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### Weathered friable fine to medium sandstone with kaolin cement

5.5 - 6.0	Opaque white and light orange, subrounded fine to medium grained sandstone with white kaolin clay cement
6.0 - 6.5	White fine to medium grained soft, friable sandstone with kaolin clay cement
6.5 - 7.0	White fine to medium grained soft, friable sandstone with kaolin clay cement with brown limonitic specks, some interbedded thin grey mudstones (mud drapes)
7.0 - 7.5	White to orange white medium grained arkosic sandstone, white kaolin clay cement with orange to black limonitic specks and thin light grey mudstones, some white mica and some calcite cement?
7.5 - 8.0	White to grey white weathered soft arkosic micaceous fine grained sandstone, increased white kaolin clay and white mica partings, some specks of orange limonite, some calcite?

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### Fairly weathered hard medium grained sandstone with kaolin clay

8.0 - 8.5	Harder grey white medium grained arkosic sandstone, much kaolin clay, some calcite in harder calcite bands?, some orange limonitic specks.
8.5 - 9.0	Compact grey white fairly soft medium arkosic sandstone, much kaolin clay, some calcite?, thin layers of grey mudstones with orange limonitic specks
9.0 - 9.5	Compact soft to hard grey white medium sandstone with white kaolin and/or calcite cement (reacts with conc. HNO <sub>3</sub> ), some brown limonitic specks and light grey shaley mudstones

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### Soft medium grained sandstone, fairly weathered

9.5 - 10.0	Grey white to orange white feldspathic? medium grained sandstone, translucent to opaque white to grey white grains, some white kaolin or calcite cement, weathered orange in patches, some white mica, much kaolin clay and some grey mudstones
10.0 - 10.5	Off white soft poorly cemented medium grained feldspathic? quartzose sandstone, white kaolin cement, some calcite, some dark grey tin mudstone partings
10.5 - 11.0	Soft white medium grained feldspathic sandstone, medium translucent to white opaque grains of quartz and feldspar with orange brown weathered partings, much white mica

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### Soft fine to medium grained sandstones with kaolin cement and shaley partings

11.0 - 11.5	Soft white fine to medium grained feldspathic sandstone with white kaolin cement,
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	some large grains of white chalky kaolin, white mica, some black carbonaceous partings with mica
11.5 - 12.0	Light grey white soft medium feldspathic sandstone, hard black carbonaceous partings, much white kaolin, some grey thin shaley mudstone partings
12.0 - 12.5	Light grey kaolinitic medium grained sandstone, some disseminated pyrite, some thin black carbonaceous partings

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**Carbonaceous siltstones with interbedded thin very hard medium grained quartzite**

12.5 - 13.0	Grey silty fine sandstones, very uneven earthy texture with interbedded very hard quartzitic sandstone bands, some bivalve? imprints in fine silty sandstones
13.0 - 13.5	Grey siltstone, soft with earthy texture, some disseminated pyrite. Bands of light grey white very hard quartzite
13.5 - 14.0	Dark grey carbonaceous siltstones, earthy uneven texture, bivalve or rain drop imprints. Interbedded soft thin bands of saccharoidal medium grained quartz sandstone with black carbonaceous partings and very hard light grey/white quartzites
14.0 - 14.5	Interbedded dark grey siltstone, thin white fine grained quartz sandstones and hard light grey quartzite bands

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**Fissile silty fine grained sandstone with thin hard quartzite bands**

14.5 - 15.0	Grey siltstone with uneven earthy texture with thin bands of soft white medium grained quartzose sandstone
15.0 - 15.5	Dark grey silty fine grained sandstone
15.5 - 16.0	Dark grey silty fine sandstone with thin beds of white medium grained quartzose sandstones
16.0 - 16.5	Dark grey silty fine grained sandstone interbedded with thin layers of white medium grained quartzose sandstone with thin carbonaceous partings and hard thin quartzite bands
16.5 - 17.0	Grey white fine grained fissile sandstone with harder quartzite bands
17.0 - 17.5	Dark grey soft carbonaceous siltstones, with interbedded thin off-white quartzitic sandstone bands
17.5 - 18.0	Off white to light grey quartzite, compact dark grey siltstones and grey to light grey shaley mudstones

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**Fine to coarse grained sandstone interbedded with shaley silty mudstones**

18.0 - 18.5	Light grey to grey shaley siltstones to mudstones, some thin coarse grained sandstone bands
18.5 - 19.0	Grey white thinly bedded fine to medium sandstone with grey mudstone partings interbedded with dark grey siltstones and light to dark grey mudstones, bivalve impressions?
19.0 - 19.5	White medium to coarse grained feldspathic sandstones with thin dark grey mudstone partings

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**Friable fine to medium sandstone with compact limestone**

19.5 - 20.0	White friable fine to medium grained sandstones and grey compact limestone (reacts with conc. HNO <sub>3</sub> )
20.0 - 20.5	White fine to medium grained sandstones, thinly bedded with dark grey mudstone partings, some grey limestone

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**Hard fine to coarse grained quartzose sandstone bands with shaley micaceous mudstone partings**

20.5 - 21.0	White fine to medium grained quartzose sandstones with thin black mudstone partings
21.0 - 21.5	Hard off white to light grey, medium grained quartzites with thin black carbonaceous partings, some soft white fine grained thinly bedded sandstone
21.5 - 22.0	Off white to light grey hard quartzitic fine grained sandstone with dark grey thin mudstone partings
22.0 - 22.5	White medium to fine grained quartzitic sandstone with black carbonaceous thin partings
22.5 - 23.0	White medium to fine grained quartzitic sandstone with black/dark grey thin mudstone partings
23.0 - 23.5	Light grey to white quartzitic medium to coarse sandstone with thin black shaley partings, some dark grey shaley mudstones
23.5 - 24.0	Light grey to white quartzitic medium to fine sandstone, fairly hard, with black

	shaley and micaceous thin partings, some dark grey shaley siltstones
24.0 - 24.5	Light grey white hard quartzitic medium to fine and medium to coarse grained sandstones with thin black very micaceous shaley partings
24.5 - 25.0	Light grey white hard medium to fine grained quartzitic sandstone with thin black shaley partings
25.0 - 25.5	Light grey white hard medium grained quartzitic sandstone with thin black very micaceous shaley partings
25.5 - 26.0	Light grey white hard medium and medium to coarse grained quartzitic sandstone with thin black micaceous carbonaceous partings, some black grey shaley mudstones
26.0 - 26.5	Light grey white hard medium to coarse grained quartzitic sandstones with frequent thin black micaceous carbonaceous silty mudstone partings.

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**Shaley silty mudstones with thin friable to hard medium to coarse grained sandstone bands**

26.5 - 27.0	Dark grey compact shaley muddy siltstones with interbedded light brown grey/white hard coarse grained quartzitic fairly micaceous sandstones
27.0 - 27.5	Dark grey compact shaley muddy siltstones with reduced grey white hard medium grained sandstones, some orange iron oxide discolouration
27.5 - 28.0	Grey shaley siltstones with thin friable medium to coarse quartzose sandstone partings
28.0 - 28.5	Grey shaley silty mudstones with interbedded thin friable medium grained quartzose sandstone bands

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**Friable fine to medium grained sandstones with thin shaley silty mudstones**

28.5 - 29.0	Light grey white with orange partings, thinly bedded fine to medium hard quartzitic sandstones with thin dark grey silty mudstone partings
29.0 - 29.5	Thinly bedded light grey to white friable fine to medium fairly micaceous quartzose sandstones with thinly bedded grey muddy siltstone bands

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**Carbonaceous shaley mudstones**

29.5 - 30.0	Dark grey shaley mudstones
30.0 - 30.5	Dark grey compact to shaley carbonaceous mudstones
30.5 - 31.0	Dark grey compact to shaley carbonaceous mudstones with thin orange stained friable medium grained sandstones

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**Fine to coarse grained friable quartzose sandstones with interbedded shaley mudstones**

31.0 - 31.5	White grey soft friable fine to medium grained quartzose sandstones with some grey shaley partings
31.5 - 32.0	Dark grey carbonaceous shaley mudstones and white grey friable coarse grained thinly bedded quartzose sandstones

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**Friable and soft fine to coarse grained quartzose sandstone with black micaceous partings**

32.0 - 32.5	Light grey white medium to fine grained soft friable quartzose sandstone
32.5 - 33.0	Light grey to white friable medium to coarse quartzose sandstone with hard bands with thin black carbonaceous partings
33.0 - 33.5	Light grey white friable fine to coarse grained quartzose sandstone with thin grey muddy fairly micaceous partings
33.5 - 34.0	Light grey white friable to hard fine to coarse grained quartzose sandstone with thinly bedded grey muddy partings
34.0 - 34.5	Light grey white friable soft fine to coarse grained quartzose sandstone, some mica, some thin grey muddy partings
34.5 - 35.0	Light grey white friable soft fine to coarse grained quartzose sandstone, some white fragments of kaolin or feldspar, with some black micaceous partings, some orange specks
35.0 - 35.5	Light grey white friable soft fine to coarse grained quartzose sandstone, some white fragments of feldspar/kaolin, some black micaceous partings, some orange specks
35.5 - 36.0	Light grey white friable soft fine to coarse grained quartzose sandstone, some white fragments of feldspar/kaolin, some black micaceous partings, some orange specks
36.0 - 36.5	Light grey white friable soft fine to coarse grained quartzose sandstone, some white fragments of feldspar/kaolin, some black micaceous partings, some orange specks with dark grey shaley mudstones

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**Carbonaceous shaley mudstones**

36.5 - 37.0	Dark grey shaley carbonaceous mudstones
37.0 - 37.5	Dark grey shaley carbonaceous silty mudstones with thin sandstone bands

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**Hard to friable medium grained quartzose sandstones with shaley mudstone partings**

37.5 - 38.0	Light grey and orange hard medium grained quartzitic sandstone with grey muddy partings
38.0 - 38.5	Light grey to white friable to hard quartzitic sandstones with interbedded shaley dark grey muddy siltstones
38.5 - 39.0	Light grey white thinly bedded friable quartzitic sandstones with thin micaceous grey partings
39.0 - 39.5	Light grey hard well bedded quartzitic sandstones, some orange discoloration with black and dark grey micaceous partings
39.5 - 40.0	Light grey white thinly bedded friable medium grained quartzose sandstone with interbedded grey thinly bedded mudstones and shales
40.0 - 40.5	Light grey friable to hard thinly bedded medium grained quartzitic sandstones with thin grey black micaceous muddy partings
40.5 - 41.0	Light grey hard to friable fine to medium grained shaley quartzitic sandstones with interbedded grey shaley mudstones
41.0 - 41.5	Light grey fine to medium grained hard to friable thinly bedded quartzitic sandstones interbedded with grey shaley carbonaceous mudstones
41.5 - 42.0	Light grey white arkosic friable fine to coarse grained quartzose sandstones with white fragments of feldspar/kaolin, some thinly bedded grey shaley mudstones
42.0 - 42.5	Light grey to white friable fine to coarse grained quartzose sandstone, some white kaolin cement and orange specks, some grey thin shaley partings

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**Carbonaceous shaley mudstones**

42.5 - 43.0	Grey thinly bedded shales
43.0 - 43.5	Interbedded dark grey carbonaceous shaley mudstones and thin fine to coarse grained light grey white quartzitic sandstones with white kaolin cement

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**Friable to hard medium grained quartzose sandstones with shaley mudstones**

43.5 - 44.0	Light grey white hard to friable fine to coarse grained thinly bedded sandstones with black to dark grey thinly bedded shaley partings
44.0 - 44.5	Light grey white thinly bedded quartzose sandstones with grey thinly bedded shaley mudstones
44.5 - 45.0	Interbedded thin light grey white friable to hard medium quartzitic sandstones and dark grey shaley carbonaceous mudstones
45.0 - 45.5	Light grey white friable to hard fine to coarse quartzitic sandstones, with white kaolin cement and thin dark grey shaley partings

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**Carbonaceous shaley mudstones and siltstones**

45.5 - 46.0	Dark grey carbonaceous shaley mudstones
46.0 - 46.5	Dark grey carbonaceous shaley mudstones to grey shaley siltstones with thin very fine sandstones
46.5 - 47.0	Grey shaley siltstones
47.0 - 47.5	Dark grey shaley carbonaceous mudstones with some thin sandstone bands

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**Fine grained sandstones and siltstones**

47.5 - 48.0	Grey fine bedded siltstones with thin fine grained sandstones bands
48.0 - 48.5	Light orange grey fine grained quartzitic sandstones interbedded with grey siltstones and light grey to dark grey micaceous and carbonaceous shaley mudstones

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**Carbonaceous shaley mudstones and siltstones interbedded with thin hard fine to medium grained sandstone bands**

48.5 - 49.0	Dark grey carbonaceous shaley mudstones interbedded with light grey white friable fine to coarse quartzitic sandstone bands and grey siltstones, some harder sandstone bands
49.0 - 49.5	Dark grey carbonaceous shaley mudstones to siltstones with some mica interbedded with hard light grey and orange fine to medium quartzitic sandstone layers with black to dark grey partings
49.5 - 50.0	Dark grey carbonaceous shaley mudstones to grey shaley siltstones with thin friable medium grained light grey white sandstone bands
50.0 - 50.5	Dark grey carbonaceous shaley mudstones to grey shaley siltstones with some hard sandstone bands
50.5 - 51.0	Grey shaley mudstones to siltstones

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**Friable medium to fine grained sandstones with shaley partings**

51.0 - 51.5	Light grey white feldspathic friable medium grained quartzose sandstones, with white kaolin cement, interbedded with grey shaley siltstones and mudstones
51.5 - 52.0	Light grey white hard fine to medium quartzitic sandstones, with thin black muddy micaceous partings
52.0 - 52.5	Light grey white friable medium grained sandstone, quartzitic with feldspar
52.5 - 53.0	Light grey white quartzitic medium to fine grained hard sandstone with black partings
53.0 - 53.5	Light grey white friable medium grained quartzitic sandstone with thin black shaley partings
53.5 - 54.0	Light grey white friable medium grained quartzitic sandstone with thin black shaley micaceous partings
54.0 - 54.5	Friable white fine grained quartzitic sandstone with kaolin clay cement, interbedded with grey siltstone with thin shale layers

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**Carbonaceous silty mudstones**

54.5 - 55.0	Dark grey carbonaceous mudstones with thin bands of whitish medium grained friable sandstone
55.0 - 55.5	Dark grey carbonaceous mudstone with grey silty mudstones, some friable white sandstone bands
55.5 - 56.0	Dark grey carbonaceous shaley mudstone
56.0 - 56.5	Grey shaley siltstones and shaley mudstones, some dark grey carbonaceous mudstones

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**Shaley siltstones with interbedded thin fine to medium grained sandstones**

56.5 - 57.0	Grey fine grained with sandstone interbedded with grey silty mudstone
57.0 - 57.5	Grey shaley siltstones with some dark grey carbonaceous mudstones with thinly bedded grey fine to medium grained quartzitic sandstones with orange patches
57.5 - 58.0	Light grey siltstone with some thin bands of friable light brown fine to medium grained sandstone with black partings and some grey quartzite

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**Carbonaceous silty mudstones with interbedded fine to medium grained sandstones**

58.0 - 58.5	Black carbonaceous silty mudstone to grey siltstone and occasional friable to well cemented fine to medium quartzitic sandstone
58.5 - 59.0	Dark grey silty mudstone with interbedded friable light grey/white medium grained sandstones with intermittent light grey and orange very hard quartzites

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**Friable and soft medium grained sandstones shaley partings, some weathering**

59.0 - 59.5	Light grey and orange to light brown hard fine to medium grained quartzite with grey silty partings
59.5 - 60.0	Light grey medium to fine grained friable sandstones with black micaceous partings with some orange patches
60.0 - 60.5	Light grey medium to fine grained friable sandstones with black micaceous partings with some orange patches
60.5 - 61.0	Light grey medium grained well cemented friable sandstone with orange patches and grey shaley partings
61.0 - 61.5	Friable light grey white medium grained quartzitic sandstone with dark shaley partings, some grey shaley mudstones/siltstones and hard light grey quartzite
61.5 - 62.0	Friable light grey white medium grained quartzitic sandstone with kaolinitic cement
62.0 - 62.5	Friable light grey white medium sandstone with black to dark grey shaley partings
62.5 - 63.0	Friable soft fine to coarse light grey white sandstone with kaolin cement

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**Soft friable fine to medium grained sandstones with carbonaceous partings and kaolin cement**

63.0 - 63.5	Soft friable fine to medium grained sandstone, dark grey muddy partings, kaolin cement
63.5 - 64.0	Soft friable light grey fine to medium grained sandstone some kaolin cement
64.0 - 64.5	Very soft friable fine to medium grained light grey to white sandstone, some mica and kaolin cement
64.5 - 65.0	Very soft friable light grey to white fine to medium grained sandstone with thin black carbonaceous layers/streaks
65.0 - 65.5	Soft friable light grey to white fine to medium grained sandstone with some thin interbedded grey shaley mudstones
65.5 - 66.0	Soft friable light grey to white fine to medium grained sandstone with increased thin



interbedded dark grey shaley mudstone layers  
66.0 - 66.5 Soft friable light grey to white fine to coarse grained sandstone with white kaolin clay, some thin black partings

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**Hard quartzitic medium grained sandstone with shaley mudstone partings**

66.5 - 67.0 Light grey fairly hard quartzitic medium grained sandstone with grey shaley partings, much grey shaley mudstone

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**Soft friable fine to medium grained sandstone with thin hard bands and shaley mudstone partings**

67.0 - 67.5 Soft friable light grey to white fine to medium grained quartzitic sandstone with some white kaolin cement, few dark grey shaley partings, some hard white fine grained calcareous thin layers  
67.5 - 68.0 Very soft friable light grey to white fine to medium grained sandstone with white kaolin cement, quartzitic sands with thin grey shaley mudstones  
68.0 - 68.5 Very soft friable light grey to white fine to medium grained sandstone with kaolin cement  
68.5 - 69.0 Soft friable light grey fine to coarse grained quartzitic sandstone with some hard white bands, some grey clay partings, some black organic carbon streaks  
69.0 - 69.5 Soft friable light grey to white fine to medium grained quartzitic sandstone with white kaolin cement, some thin grey shale bands  
69.5 - 70.0 Soft light grey to white fine to medium grained quartzitic sandstone with black carbonaceous and grey mudstone partings

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**Soft friable fine to medium sandstone with kaolin cement**

70.0 - 70.5 Soft light grey and white fine to coarse sandstone with white fragments and kaolin cement  
70.5 - 71.0 Soft friable light grey to white fine to medium grained sandstone with white fragments, kaolin cement, thin hard layers and thin dark grey interbeds  
71.0 - 71.5 Soft friable light grey to white fine to medium grained quartzitic sandstone with white kaolin cement and black organic carbon streaks  
71.5 - 72.0 Very soft friable light grey to white fine to medium grained quartzitic sandstone with white kaolin cement and a few black carbonaceous streaks  
72.0 - 72.5 Soft friable light grey to white fine to medium grained sandstone with some black carbonaceous streaks

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**Hard fine to medium grained sandstones**

72.5 - 73.0 Soft to hard light grey to white fine to medium grained sandstone with some black carbonaceous streaks  
73.0 - 73.5 Fairly hard friable light grey and fairly soft light grey to white fine to medium grained sandstones  
73.5 - 74.0 Light grey fairly hard quartzitic sandstones and white soft fine grained sandstones

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**Soft friable fine to medium grained sandstones**

74.0 - 74.5 Soft friable light grey to white fine to medium grained sandstone  
74.5 - 75.0 Soft friable light grey to white fine to medium grained sandstone  
75.0 - 75.5 Soft friable light grey to white medium to fine grained sandstone with thin black organic carbon partings

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**Soft friable medium grained sandstones with shaley mudstone partings**

75.5 - 76.0 Grey to white muddy friable soft medium sandstone with grey thin shaley partings  
76.0 - 76.5 Grey to white muddy friable soft medium sandstone with thick band of dark grey shaley carbonaceous mudstones some thin black carbonaceous partings

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**Hard fine to medium grained quartzitic sandstone with shaley mudstone partings**

76.5 - 77.0 Fairly hard light fawn grey fine to medium sandstone with black organic partings, some grey shaley mudstone partings  
77.0 - 77.5 Hard light grey quartzitic sandstone to quartzite with black carbonaceous partings with some white vein **quartz**  
77.5 - 78.0 Fairly hard dark grey to light grey medium grained quartzitic sandstone, some white **calcite** veining, some grey carbonaceous shaley partings

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**Fractured medium grained quartzitic sandstone and carbonaceous mudstones, much quartz and calcite veining**

78.0 - 78.5 Dirty grey to light grey medium grained quartzose sandstone faulted against compact dark grey carbonaceous mudstones, much broken ochre and white vein **quartz**  
78.5 - 79.0 Light grey saccoroidal quartzose medium grained sandstones faulted against dark

grey carbonaceous mudstones with iron sulphide, some **calcite** veining, some light green mudstone partings

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**Fairly hard medium grained quartzitic sandstone with interbedded carbonaceous shaley mudstones, some calcite veining**

- 79.0 - 79.5 Light fawn grey hard quartzitic sandstones with black carbonaceous partings, some thin black mudstone layers, some white **calcite** veining
- 79.5 - 80.0 Light grey saccaroidal fairly hard fine to medium grained sandstones, much calcite cement, some white **calcite** veining and black carbonaceous partings
- 80.0 - 80.5 Light grey saccaroidal fine to medium grained quartzitic sandstones, some black hard mudstone partings with white **quartz** veining
- 80.5 - 81.0 Soft black carbonaceous earthy textured shaley mudstones but hard where fractured, some light grey saccaroidal medium grained fairly hard quartzitic sandstone, white veining along faulting may be **barytes** rather than **calcite**
- 81.0 - 81.5 Light grey and fawn grey fairly hard medium grained quartzitic sandstones with black carbonaceous partings, some fractured fragments with little vein **calcite**

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**Hard fine to medium grained quartzitic muddy sandstone**

- 81.5 - 82.0 Dark grey fine to medium grained hard quartzitic very muddy sandstone
- 82.0 - 82.5 Dark grey muddy and light grey fine to medium grained hard quartzitic sandstones
- 82.5 - 83.0 Dark grey muddy and light grey fine to medium grained hard quartzitic sandstones
- 83.0 - 83.5 Dark grey muddy and light grey fine to medium grained hard quartzitic sandstones with black carbonaceous mudstones, hard where fractured
- 83.5 - 84.0 Light grey quartzitic fine to medium sandstones and dark grey muddy fine grained sandstones

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**Sandy bioturbated calcareous mudstones**

- 84.0 - 84.5 Black carbonaceous mudstones interbedded with light grey quartzitic sandstones
- 84.50 - 84.85 Bioturbated calcareous mudstone, mudstone varies from black through dark grey to light grey with increasing depth as quantity of calcareous material increases, some subvertical **calcite** filled veining

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**Harh compact limestone**

- 84.85 - 84.90 Hard compact grey limestone

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**Compact and hard carbonaceous silty mudstones with thin bands of hard fine grained sandstones**

- 84.90 - 85.10 Black carbonaceous micaceous silty mudstones, splintery with uneven fracture
- 85.10 - 85.45 Black carbonaceous hard sandy micaceous siltstones with calcitic bivalve shells? and iron **pyrite** nodules, high angle of cleavage noted
- 85.45 - 85.70 Black carbonaceous fractured and cleaved hard splintery mudstones
- 85.70 - 85.80 Fairly hard black carbonaceous and micaceous sandy siltstone
- 85.80 - 86.00 Black very carbonaceous abd soft splintery micaceous mudstone
- 86.00 - 87.20 Hard micaceous cleaved thinly laminated carbonaceous sandy siltstone some calcareous shell fragments??
- 87.20 - 87.50 Soft carbonaceous splintery black mudstones
-

## Summary lithological log: BGS 13A

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### Medium to coarse grained arkosic and micaceous sandstone

- 3.10 - 3.45 Yellow and red brown weathered and white unweathered medium to coarse grained sandstone, softish, some mica
- 3.45 - 3.70 Medium grained compact white to reddish white friable fairly micaceous sandstone, red oxide lined fracture at 3.65-3.68, Black biotite, organic carbon and black manganese oxide on some bedding planes
- 3.70 - 4.90 Grey white compact cross bedded medium grained arkosic sandstone, black organic carbon and manganese oxide along bedding planes, black speckled and small black fragments. Water bearing fractures weathered yellow at 3.97-4.07 and 4.30, sandstone is fairly friable
- 

### Hard medium grained quartzite

- 4.90 - 5.80 Hard more dense medium grained quartzitic sandstone
- 5.80 - 5.90 Light grey hard very dense quartzite
- 

### Friable medium to coarse grained sandstone

- 5.90 - 6.40 Medium to coarse grained, cross bedded sandstone hard to friable, some mica, brownish white, some black organic carbon and manganese oxide along bedding planes
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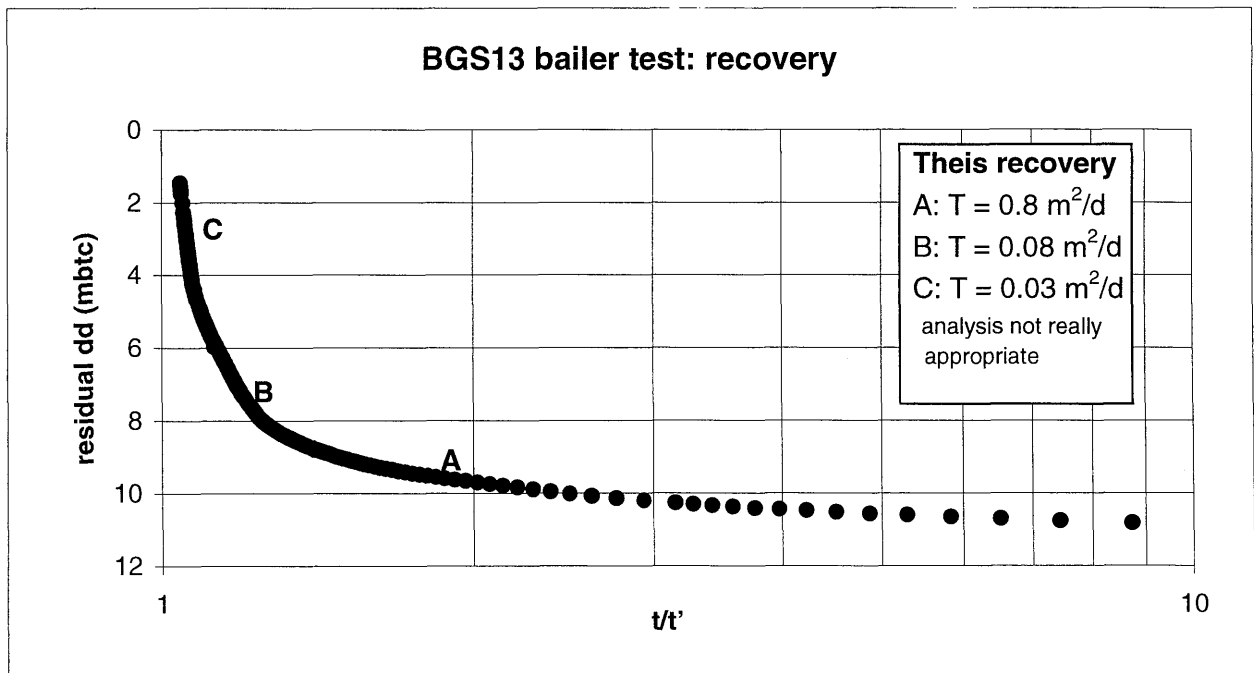
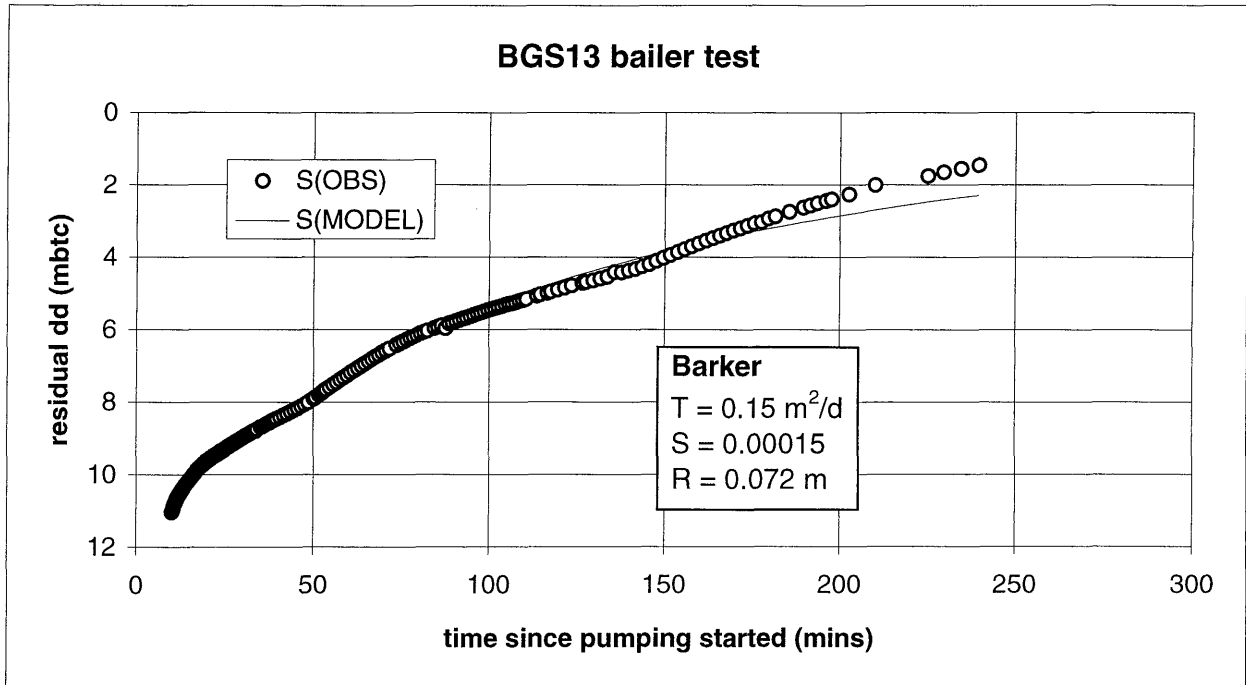
### Hard compact fine to medium grained quartzite

- 6.40 - 78.30 Light grey and orange brown hard compact fine to medium grained quartzite
-

## **Annex 4: Pump test data**

# BGS 13: bailer test

date: 21/3/98  
rwl overflowing  
height casing = 0.2 m agl  
no bails 41  
time 9:40 mins  
prate = 0.32 l/s



# BGS13: whale test

date: 16/3/98

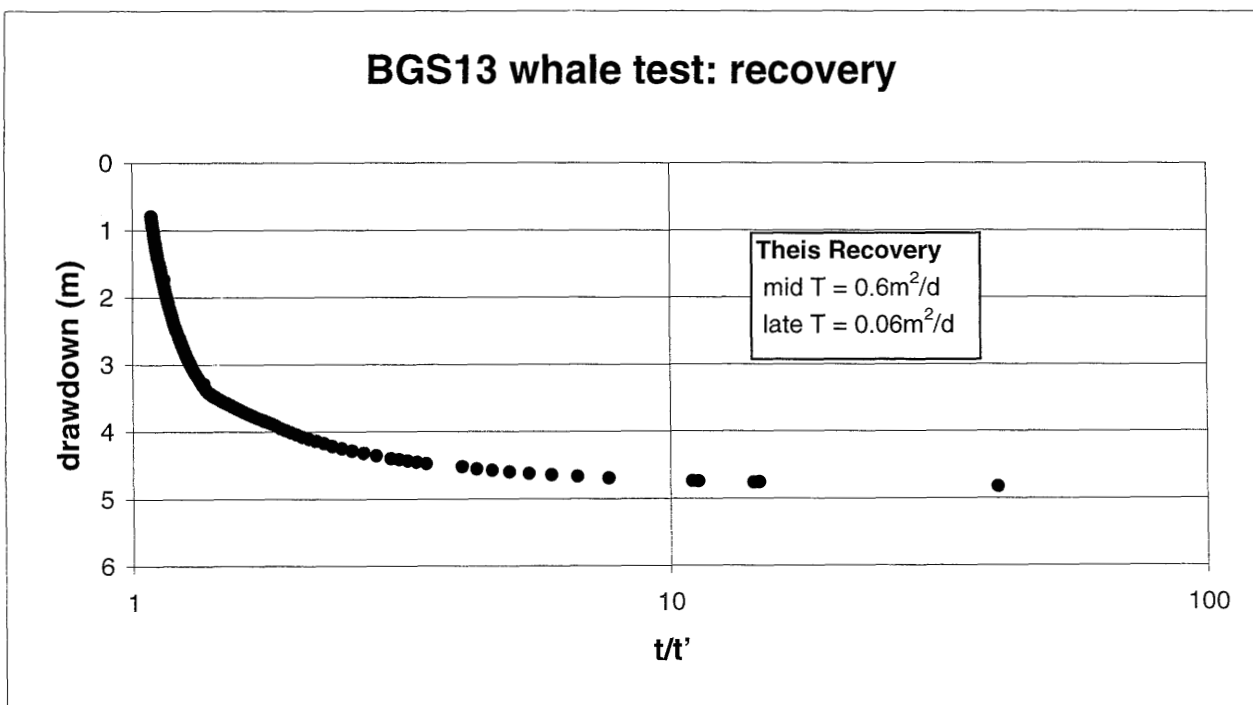
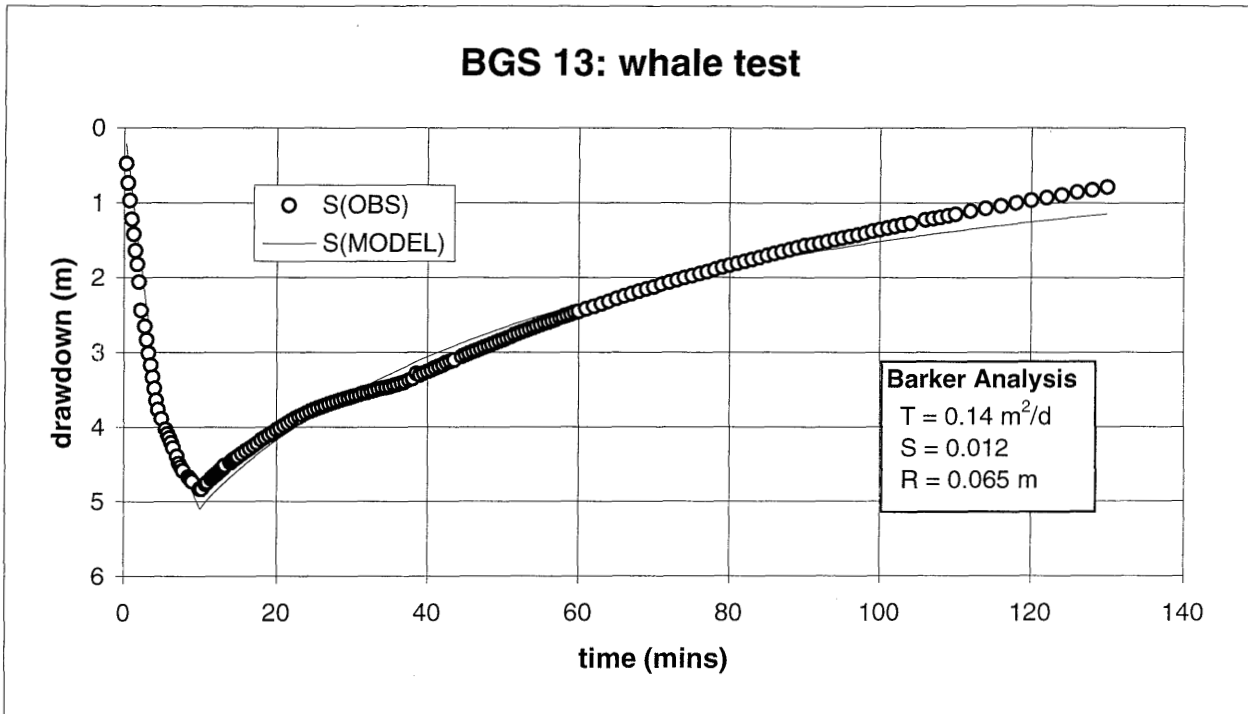
One whale pump

0.188 l/s 0-5 mins

0.088 l/s 5-10 mins

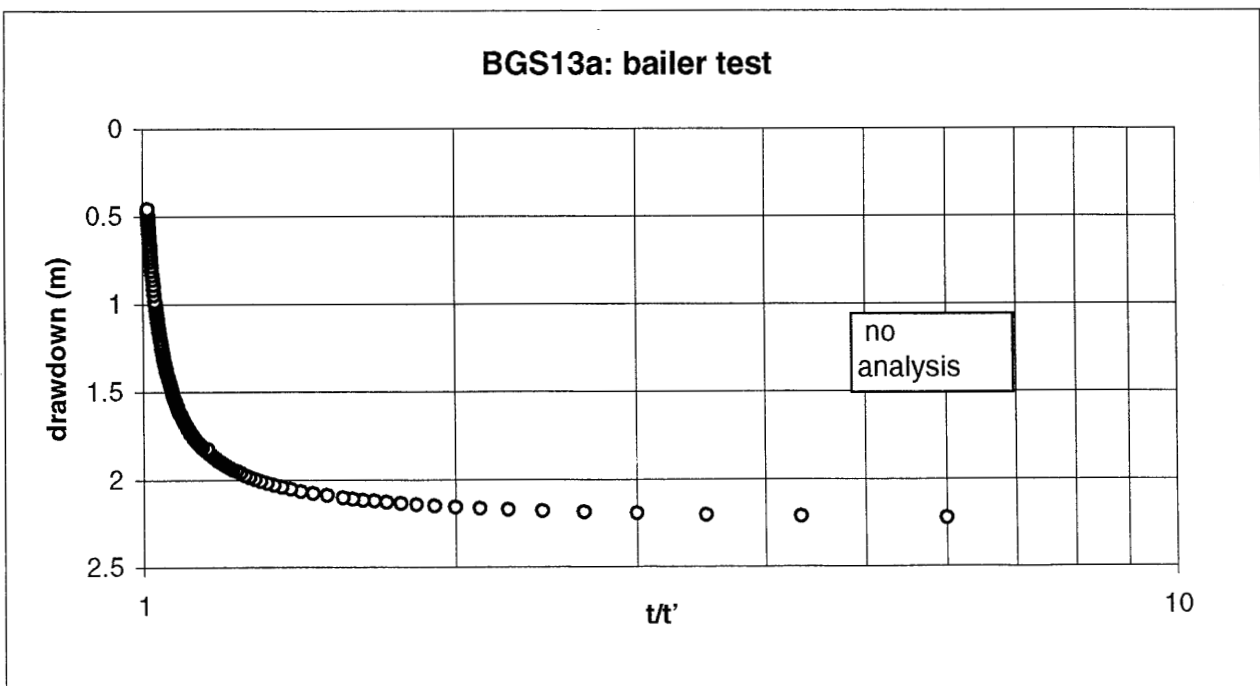
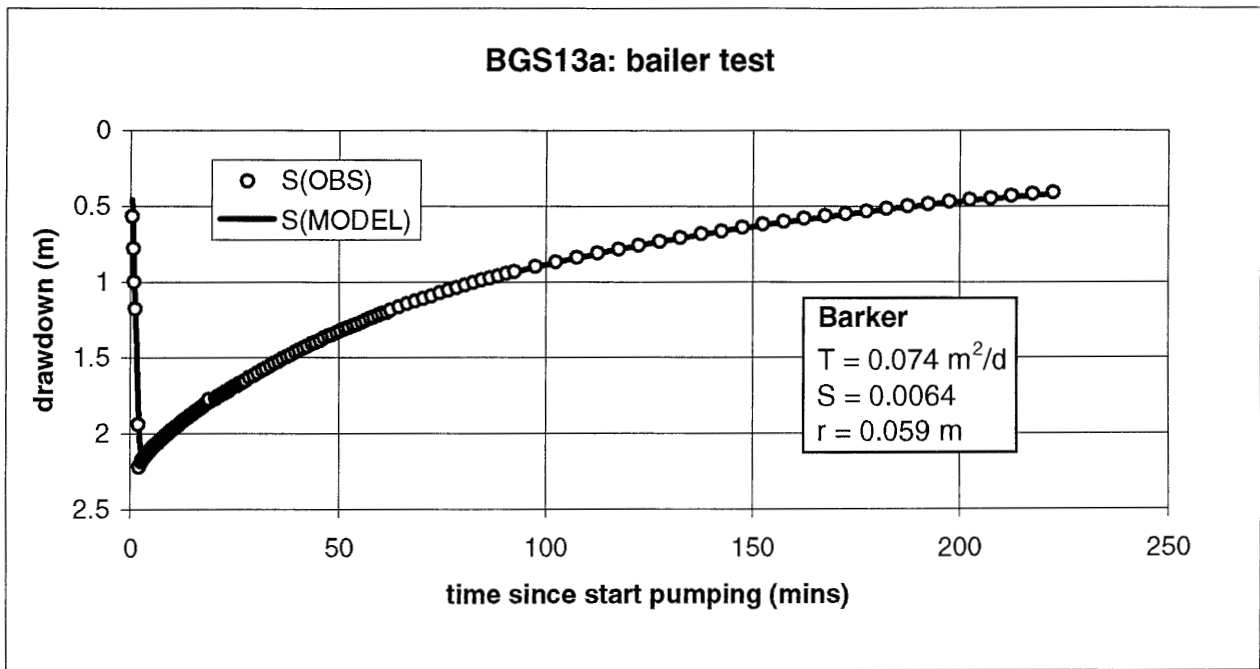
rwl overflowing slightly

height of casing = 0.2 m



# BGS13a: whale pump test

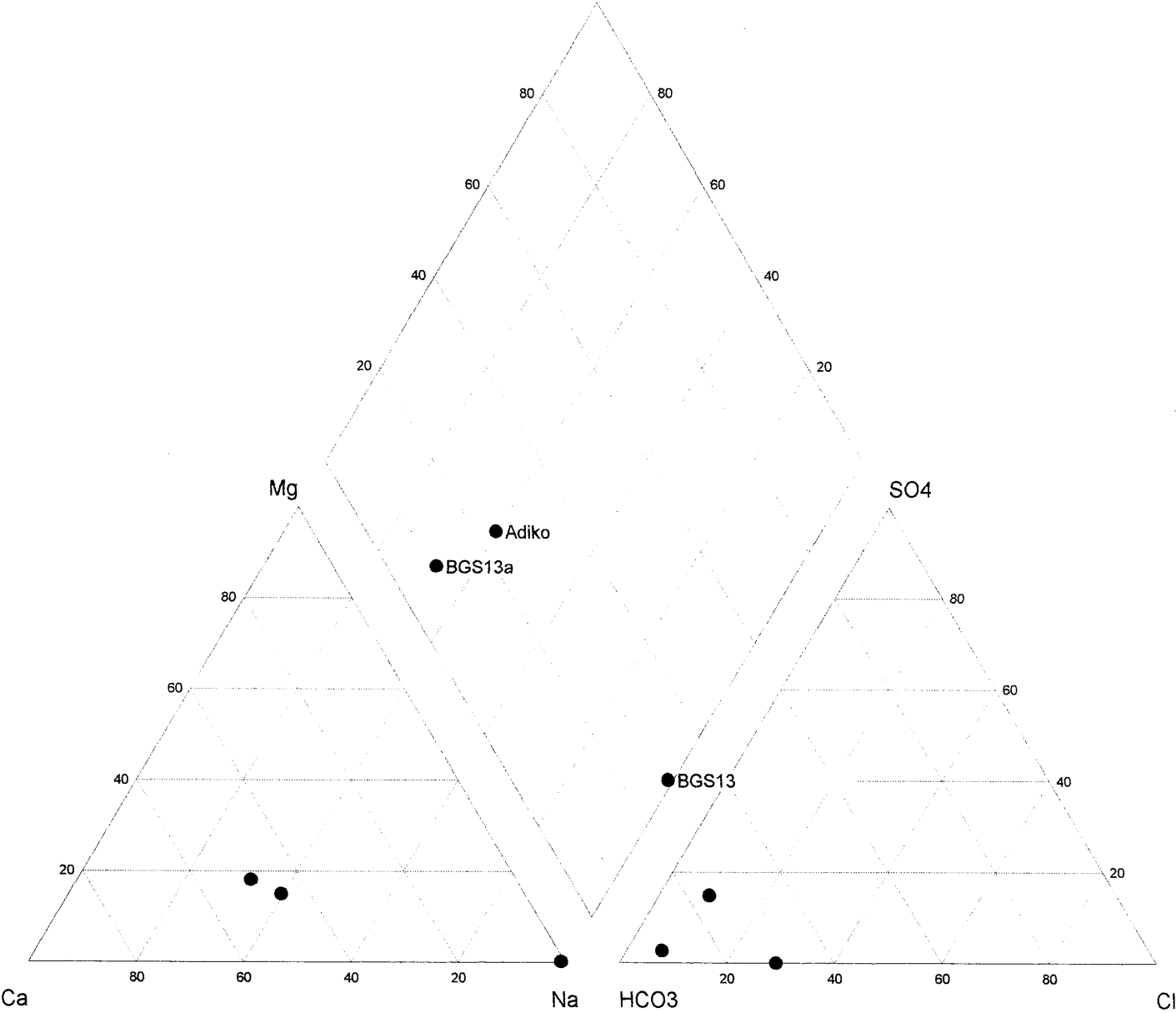
date: 23/02/1998  
using 1 whale pump  
rwf: 3.85m  
casing = 0.2 m  
length of pumping = 2:30 mins  
pumping rate = 0.17 l/s



## **Annex 5: Water quality data**



# Groundwater Chemistry - Odaleko



# Odaleko Adiko

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
8.367	6.977	33	Adiko	6.01	29.4	20	11	2	0.6	2	0.4	1.7	0.8
8.373317	6.986333	222	BGS13A	8.13	30.3	513	280	40.8	2.5	54.5	12.1	6.5	
8.373317	6.986333	250	BGS13	7.44	30	6470	3200	1730	10.1	10.6	2.3	1.1	

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
33		3.5	0.014	0.017			0.8	0.057	0.0034	0.03	0.009
222		23.9	0.271	0.098	0.011	-0.03	0.14	0.341	0.0064		
250		5.5	0.095	1.69	0.284	0.31	0.34	0.045	0.14		