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

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Two boys collecting water from a pumping test in Itogo.

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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 is 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 six separate trips, August - September 1996, November - December 1996, February - March 1997, October - December 1997, January - April 1998 and January – February 1999.

EXECUTIVE SUMMARY

The groundwater development potentials of the Agbani Sandstone and dolerite intrusions within the Awgu Shale of northeast Obi were investigated at Itogo and Oluywo. Field investigations were undertaken during January and February 1999. EM34-3 and magnetic surveys were carried out along two 8-km long traverse lines and three resistivity soundings were undertaken at borehole sites. Four boreholes were drilled at 3 sites, with up to 2.5-m of core being taken from each borehole. Chip and core samples were analysed and logged. Three boreholes (BGS48, BGS49 and BGS50) were completed with screen and casing. Test pumping and water quality analysis was carried out at these boreholes and also two that had previously been drilled by BERWASSA. The following conclusions can be made from the test sites:

- No extensive sandstones were encountered at depth. In places, the weathered zone was sandy, and contained good quality groundwater. This weathered sandy zone was easily identified using the EM34-3. Soft mudstone was present beneath the weathered sandy zone, the base of the latter being indicated by a fairly thick compact to broken hard ferricrete layer.

- The weathered zone of the Agbani Sandstone may be considered for hand dug well installation/development, although yields will be low. Completing wells to about 10 m depth (i.e. the base of the weathered sandy zone) would probably provide water for about 30 people. Drilling out horizontally may significantly increase the yield of the well. Targeting wells to where the water table is highest (i.e. in valleys) may also increase the yields from the wells, since there would be a greater saturated thickness of aquifer.

- Water quality from the shallow sandy weathered zone was generally good, although low pH values (4.5) were recorded from several existing hand-dug wells. Groundwater encountered in a thin sandstone layer at depth was brackish.

- The most promising target for groundwater in the area is dolerite – especially where it occurs within valleys.

- The dolerite investigated at Okwutungbe is the thinning eastward extension of the Ito dolerite body. It is composed of hard dark grey/green fine-grained basic rock – it contains some zeolite. Pumping tests indicated transmissivity values of about 1-3 m^2/d for the fractured dolerite; water quality within the dolerite was good.

- The presence of dolerite at shallow depths was easily identified from geophysics: EM34-3 readings reduced and the magnetometer recorded many magnetic anomalies.

- The sustainability of the groundwater resources either from valley dolerite or the shallow sandstone is not known– longer pumping tests and long term monitoring of water levels is required.

The best target for groundwater within the southern Awgu Shales area is dolerite. The alternatives, including rainwater harvesting, piped or tankered water supply, or up-grading existing dry season water sources are likely to be expensive and difficult. Therefore, it is advisable to exert considerable effort in trying to locate dolerite intrusions (where they occur in valleys) somewhere close to the villages. If no dolerite exists, the weathered sandy zone may form a viable alternative for exploitation. Yields from these wells, however, are likely to be low, sufficient for only a few basins per day per household. Yield may be significantly increased by drilling horizontally through the weathered zone. Further work would be required to study the feasibility of low cost, easy methods for horizontal drilling. Another way of maximising the yield of shallow wells in the weathered zone would be to construct them next to rivers, where the water table is high and there is a good source of recharge.

1. BACKGROUND INFORMATION

The groundwater development potentials of the Agbani Sandstone and dolerite intrusions found within the Awgu Shale were investigated at Itogo in northeast Obi. Investigations at Ijegwu, Ugbodum and Adum West had shown the groundwater development potential to be highly variable (Davies and MacDonald 1998, 1999; MacDonald and Davies 1998b). An 8-km traverse from Okwutungbe to Itogo Iyaho was investigated and further geophysics carried out along another eight-kilometre traverse from Ito to Oluywo (see Figure 1). The hydrogeology map (MacDonald and Davies 1998a) indicated that both traverses were underlain by black carbonaceous mudstones of the Awgu Shale formation, Agbani Sandstone horizons and possible dolerite intrusions. Prominent anomalies on the aeromagnetic anomaly map suggest that there may be dolerite intrusions in the area. The satellite image was interpreted to identify lineations indicating fracture zones of potential hydrogeological significance. Figure 2 and 3 show the available map data for the area, satellite lineations and also the location of the geophysics traverses and the test boreholes. Table 1 shows the appropriate maps and aerial photographs for the Itogo and Oluywo.

Both traverses pass through a series of villages. Two boreholes drilled within Itogo by DIFFRI in early 1990 have both been abandoned. The local communities reported that in each case the borehole was abandoned due excessive corrosion of the pump rising main, probably due to the acidic nature of the groundwater (often with pH<5). Community members are unsure of the depth or original yield of the boreholes. Several hand-dug wells have been constructed, by the Catholic Church, along the Itogo traverse line. Little water is abstracted from these wells since yields are very low. In several areas traditional shallow wells contain some water until March, with some of these able to yield 1-2 basins a day until the end of the dry season. However, most people obtain their drinking water from pools along the river Obi, several kilometres away. The traverse lines cross a series of ridges and valleys within an area characterised by well-spaced trees with occasional dense woodland.

Table 1. Available map and satellite image information for the Itogo and Oluywo traverses

Data type	Source
Aerial Photographs	Sheet 270, run 11, 54-57 Sheet 270, run 12, 227-230 Sheet 270, run 13, 15-19 Sheet 270, run 14, 189-191
Topographic maps	1:50,000 Sheet 270SEOturkpo SE
Geology map	Makurdi Area, Map No. 64, Scale 1:250,000
Satellite image	LANDSAT TM 188-055 Acquired 17 January 1986 Bands 4-5-7 (Red, Green, Blue)

2. GEOPHYSICS

Two main geophysical surveys were carried out at Itogo and Oluywo. The first was eight kilometres long and was carried out along the road from Okwutungbe to Itogo Iyaho. EM34-3 and magnetic profiling was undertaken. Additional EM34-3 surveys and resistivity soundings were undertaken around each of the trial borehole sites. The second survey was carried out from Ito to Oluywo. This traverse was also eight kilometres long; both EM34-3 and magnetic profiling was undertaken. According to the available maps (see Figure 2) there should be a possibility of encountering dolerite intrusions within the Awgu Shale in both areas. Table 2 gives a summary of the various traverses and soundings. Data are presented in Appendix 1.

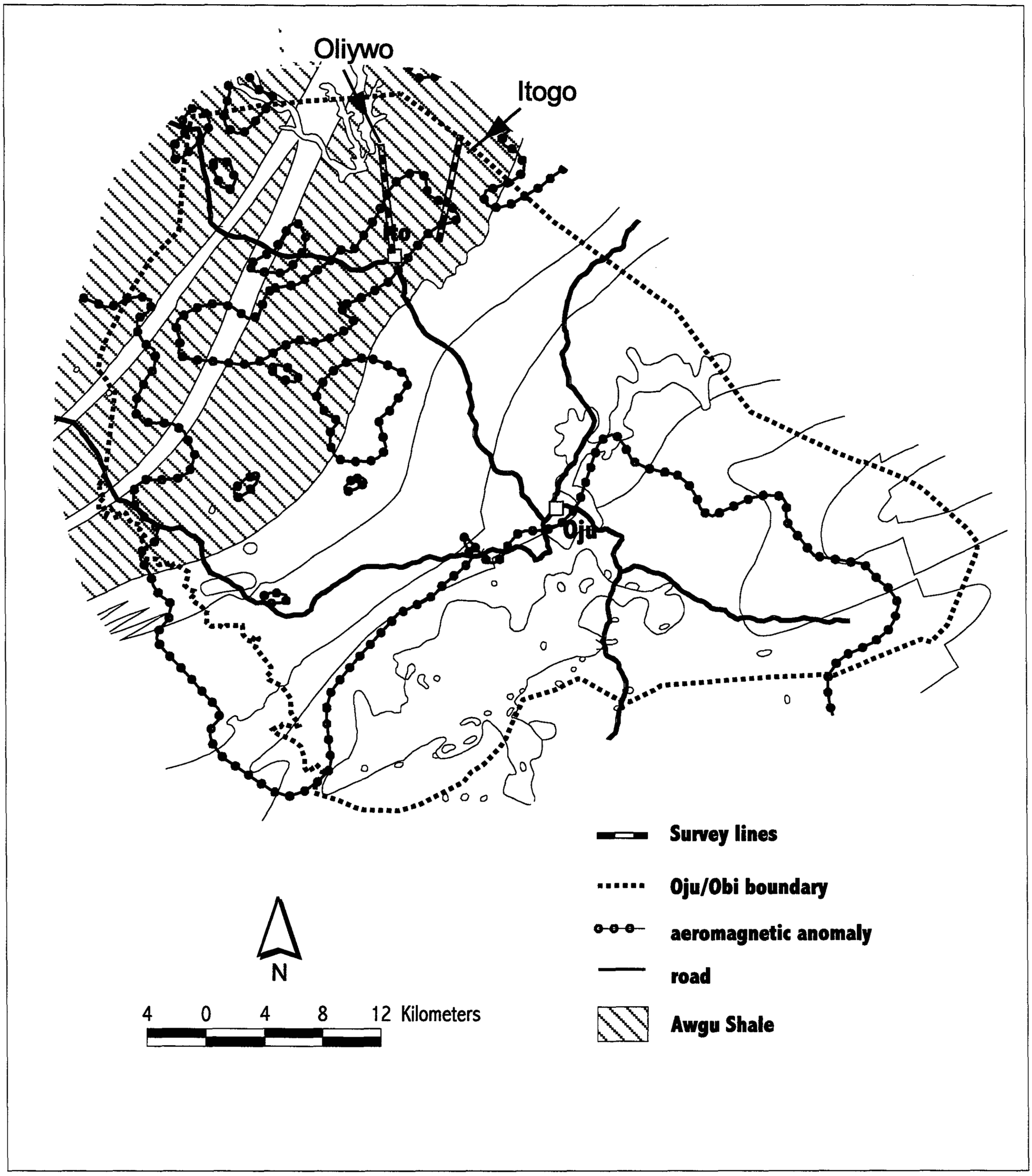


Figure 1. The location of the Itogo and Oluywo surveys and the outcrop of Awgu Shale.

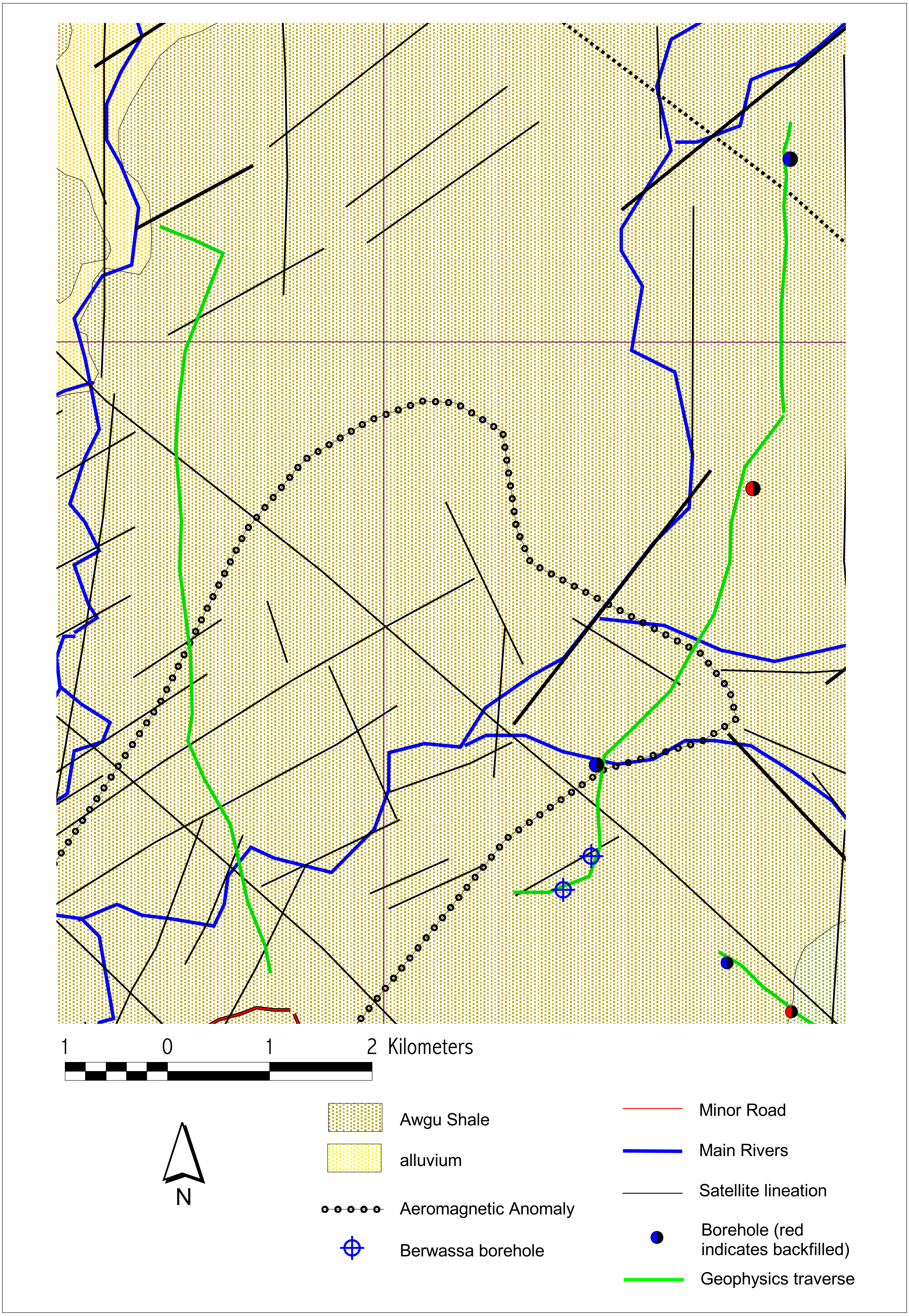


Figure 2. Available map information for Itogo and Oluywo, the locations of boreholes and geophysical surveys are also shown.

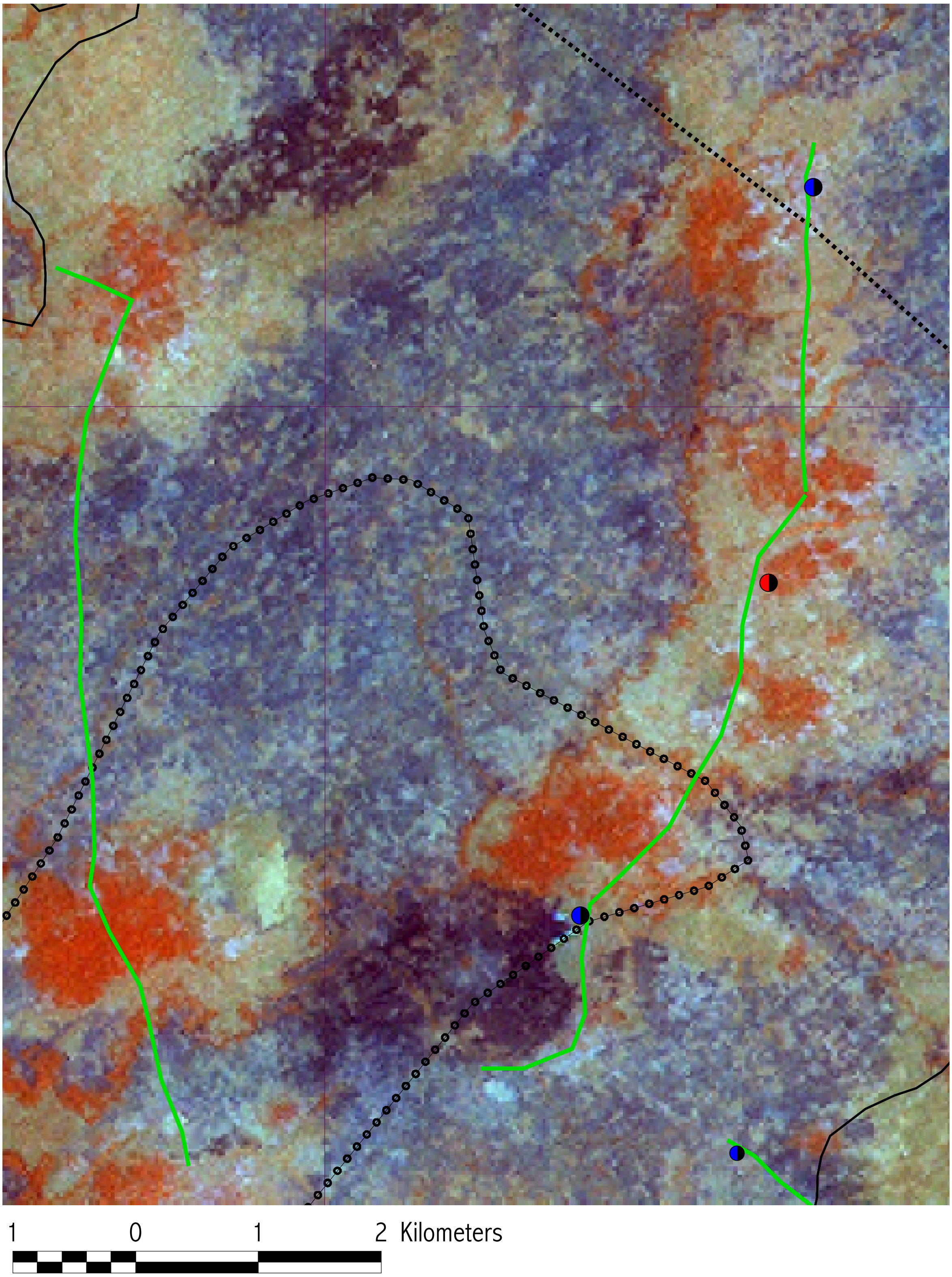


Figure 3. Satellite image for Itogo and Oluywo.

The EM34-3 data indicate that the electrical conductivity of the rocks vary greatly across the traverse. Both traverses are similar to that encountered at Ugbodum (Davies and MacDonald 1999) but different to that encountered in the Awgu Shale to the north (Davies and MacDonald 1998). The data for Itogo are shown in Figure 4 and for Oluywo in Figure 5. A summary of the significant points of the geophysical surveys is given below:

1. Conductivity values are highly variable: vertical coil measurements range from 30 to 120 mmhos/m.
2. Vertical coil readings are generally higher than those taken with the horizontal coil with one notable exception: where vertical coil readings are between 30 and 40 mmohs/m, horizontal coil readings are often slightly higher (e.g. Itogo 4000 m and 8000 m)
3. On the Itogo traverse, vertical coil readings oscillate between peaks of about 100 mmhos/m and troughs of about 40 mmhos/m.
4. Magnetic anomalies are observed along the entire traverse, although many are due to metal found in villages – the most pronounced "natural" anomalies are observed in a low conductivity zone from about 1000-1600 m along IT1.
5. EM34-3 readings taken with a 40 m coil (deeper penetration) generally gave higher conductivity - indicating that conductivity increases with depth; the fact that horizontal coil measurements are lower than vertical measurements indicates that at greater depths, conductivity reduces again.
6. The Oluywo traverse indicates three distinct areas: (1) 0-400 m has very low conductivity and distinct magnetic anomalies; (2) 400-6000 m has high conductivity with occasional "natural" magnetic anomalies; and (3) 6000-8000 m which has low conductivity with some "natural" magnetic anomalies.

Due to the limited time available for this study, only the Itogo traverse was drilled. Three sites were chosen for test drilling:

- BGS 47: 4000 m along IT1 (situated at the start of the village). Here the electrical conductivity at shallow depths was low and there were no "natural" magnetic anomalies.
- BGS 48-49: 8000 m along IT1 (at the edge of the football field). Here conductivity values are low at shallow depths and there are no magnetic anomalies. There are many shallow hand dug wells in the village.
- BGS 50. 1560 m along IT1 (next to short cut). Conductivity is low both at shallow and greater depths. There are also intense short-wave length magnetic anomalies.

BERWASSA had also drilled two boreholes along this traverse. These were located at 240 m and 520 m, where the conductivity is high. These had not been fitted with hand pumps and were tested as part of the study.

Table 2. Main Geophysical Surveys carried out at Itogo and Oluywo (data in Annex 1)

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
IT1	7° 02.059' 8° 21.011'	8 km	20 m	EM34-3 (20 m)	From culvert before Okwutungbe to end of Iyaho
IT2	7° 02.059' 8° 21.011'	8 km	10 m	Magnetic	As IT1
IT3	7° 02.059' 8° 21.011'	1 km	20 m	EM34-3 (40 m)	About 200 m taken at each borehole site on IT1
IT4	7° 4.287' 8° 22.162'		0.5 – 64 m	Offset Wenner	BGS47
IT5	7° 5.972' 8° 22.168'		0.5 – 64 m	Offset Wenner	BGS48 and BGS49
IT6	7° 2.743' 8° 21.116'		0.5 – 64 m	Offset Wenner	BGS50
OI1	7° 1.728' 8° 19.364'	8 km	20 m	EM34-3 (20 m)	
OI2	7° 1.728' 8° 19.364'	8 km	10 m	Magnetic	

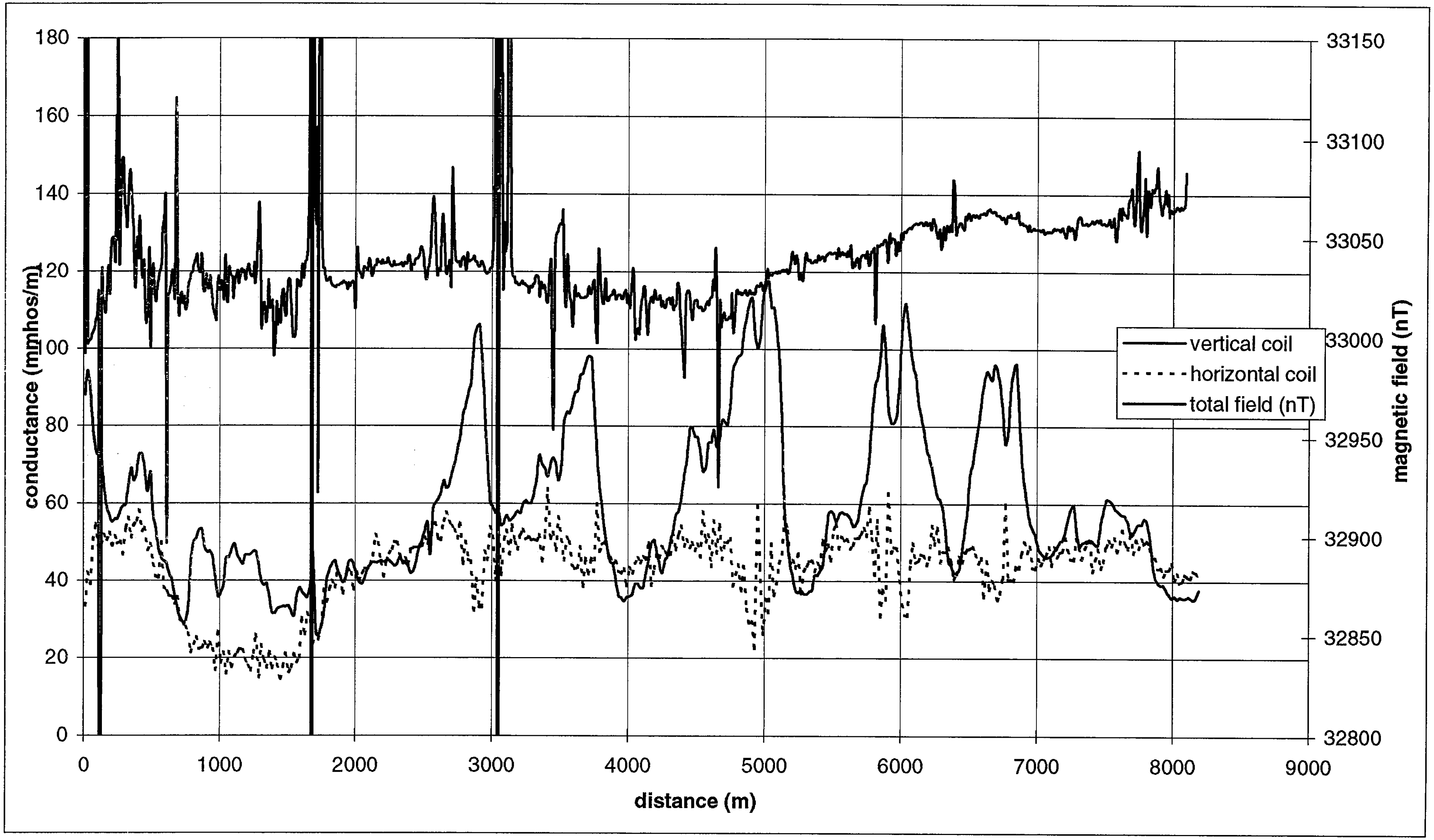


Figure 4. EM34-3 (with 20 m coil separation) and magnetic field data for Itogo.

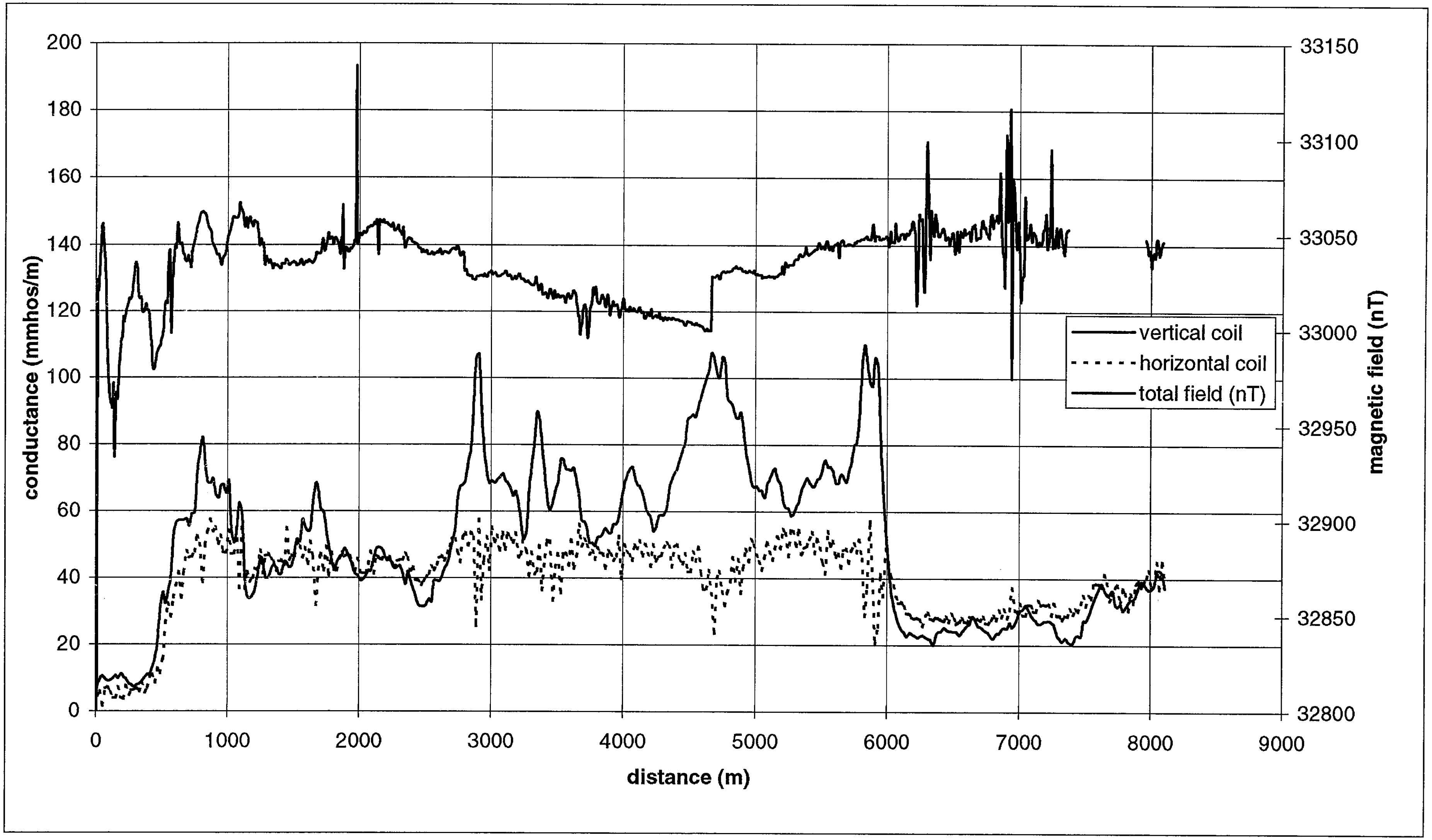


Figure 5. EM34-3 (with 20 m coil separation) and magnetic field data for Oluywo.

3. DRILLING

Four boreholes were drilled along the Itogo traverse. The boreholes were drilled with a drag bit through the soft weathered horizon and hammer through the unweathered bedrock. Core samples were taken from each borehole. Summary information on the boreholes is given in Table 3. More details on construction etc. are given 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	Water strike	Comments
BGS47	7° 04.287' 8° 22.162'	8/2/99	31.7 m	165 mm	29.8 – 31.7 m	Little at 10.5 and 18 m	Back-filled due to collapse.
BGS48	7° 5.972' 8° 22.168'	9/2/99	31.9	165 mm	29.3 – 31.9	7, 8 18.8, 20.5	
BGS49	7° 5.972" 8° 22.168'	9/2/99	10.5	165 mm	8.5 – 10.5	6.5, 7	
BGS50	6° 59.345 8° 15.409'	10/2/99	31.75	165 mm	17.5-19.5 29.5-31.75	4.7, 10.7, 14.5	
BER1	7° 2.12' 8° 21.053'		30 m	Completed with 4"			Very hard splintery shales
BER2	7° 2.204' 8° 21.115'		30 m	Completed with 4"			Soft carbonaceous shales

Rock chip samples for every 0.5-m from boreholes BGS47, BGS48, BGS49 and BGS50 were logged, photographed and analysed along with the core samples. Full details of the logs from each of these boreholes are given in Annex 3 and summarised below. Figure 6 shows a schematic of the borehole logs. At BGS47, BGS48 and BGS49 about 6-m of clayey fine-grained weathered sand occurs underlain by a prominent ferricrete layer at about 10-m below ground surface in each case. These sands could represent a weathered capping of Agbani Sandstone that crops out in the Obi River channel to the west. The ferricrete appears to have accumulated within the most permeable part of the sand sequence above the junction with the underlying impermeable black carbonaceous mudstones. At BGS50 the eastern extremity of the Ito dolerite intrusion is met. Below the dolerite a fining downward sequence of light grey silty sandstone above light grey siltstone that passes downward though grey mudstones into black carbonaceous mudstones is met. This is similar to a sequence met at BGS42 and BGS45 on the Ugbodum traverse. These light grey silty sandstones may form part of the Agbani Sandstone unit within the black carbonaceous mudstones of the Awgu Shales Formation.

Two additional boreholes were drilled by BERWASSA at the village of Okwutungbe during the summer of 1998. These boreholes were about 30-m deep and were both completed with screen and casing. A rough estimate of the lithology could be made from examining from the spoil heap beside each borehole. These have been included in Table 3.

Summary lithological log: BGS47

0.0 – 1.5	Soil/ferricrete horizon
1.5 – 4.0	Clayey very weathered horizon
4.0 – 6.5	Sandy clay
6.5 – 8.0	Clayey fine-grained sand
8.0 – 9.0	Sandy clay
9.0 – 10.0	Clayey fine-grained sand
10.0 – 10.5	Hard red ferricrete band

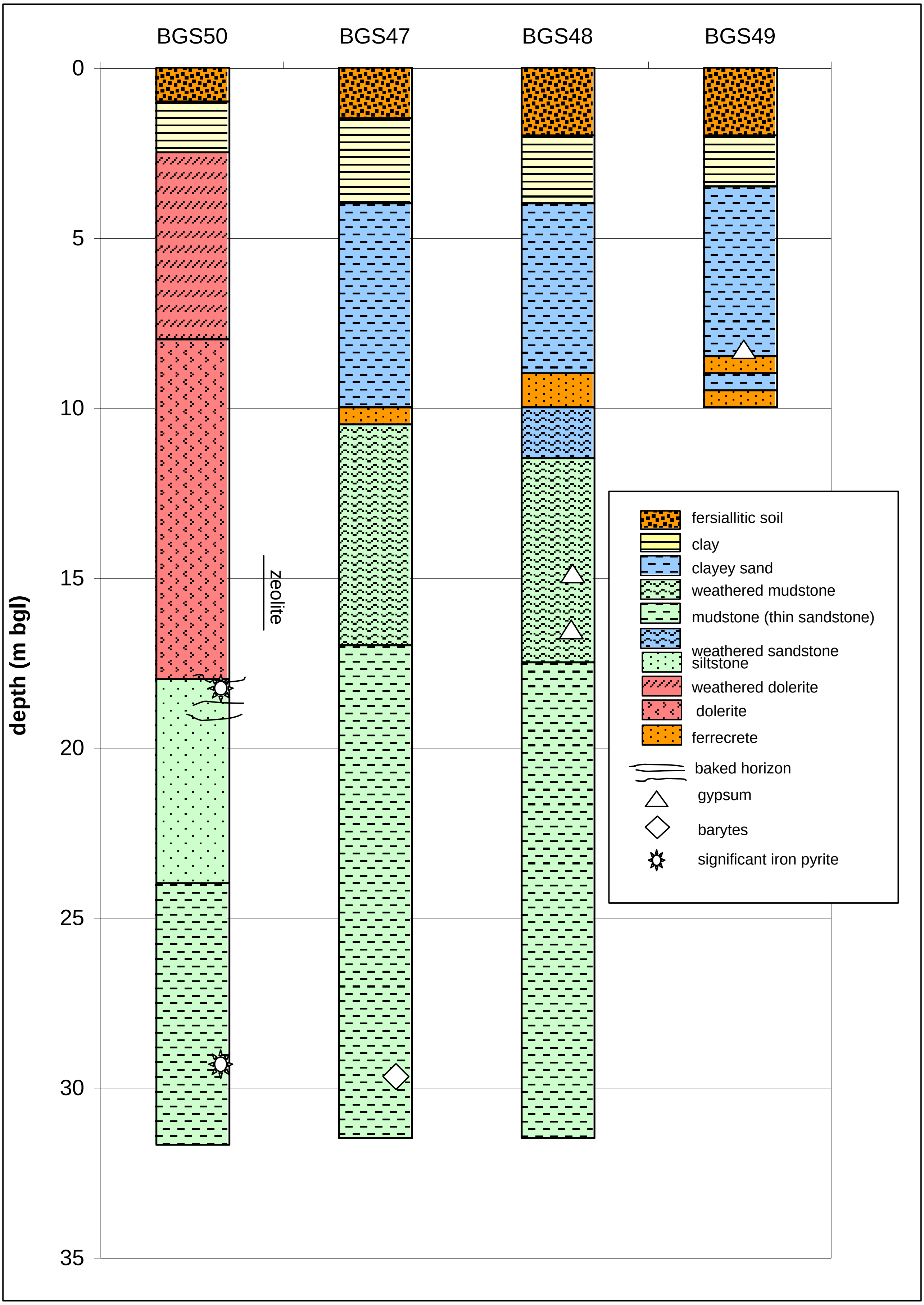


Figure 6. Simplified borehole logs for Itogo. (Horizontal axis not to scale).

10.5 – 15.0	Very weathered mudstones
15.0 – 17.0	Weathered mudstones
17.0 – 31.37	Black carbonaceous mudstones
31.37 – 31.41	Muddy chloritic fine- to medium-grained sandstone
31.41 – 31.69	Black carbonaceous mudstones

Summary lithological log: BGS48

0.0 – 2.0	Soil/ferricrete horizon
2.0 – 4.0	Clayey very weathered horizon
4.0 – 5.0	Silty fine grained sand
5.0 – 5.5	Clays
5.5 – 9.0	Clayey fine grained sand
9.0 – 10.0	Nodular to gravely ferricrete
10.0 – 11.0	Silty mudstones
11.0 – 11.5	Clayey fine-grained sandstone
11.5 – 15.0	Weathered mudstones
15.0 – 17.5	Grey mudstone some gypsum
17.5 – 19.0	Black carbonaceous mudstones some gypsum
19.0 – 20.5	Grey mudstones
20.5 – 23.0	Dark grey to black carbonaceous mudstones
23.0 – 26.5	Dark grey mudstones
26.5 – 29.0	Dark grey to black carbonaceous mudstones
29.0 – 29.92	Black sandy carbonaceous mudstones
29.92 – 30.20	Dark grey to black muddy fine-grained sandstones
30.20 – 31.90	Dark grey to black muddy fine-grained sandstones with carbonaceous mudstones

Summary lithological log: BGS49

0.0 – 2.0	Soil/ferricrete horizon
2.0 – 3.5	Clayey very weathered horizon
3.5 – 5.5	Weathered sandy clays
5.5 – 6.5	Weathered clayey sand
6.5 – 8.5	Clayey fine- to medium-grained sand
8.50 – 8.70	Hard broken nodular ferricrete
8.70 – 8.72	Clayey fine sand
8.72 – 9.05	Hard tubular ferricrete
9.05 – 9.30	Sandy clay to clayey sand
9.30 – 9.36	Hard nodular ferricrete
9.36 – 9.71	Clayey sands and clays
9.71 – 10.31	Clays with anhydrite nodules and hard ironstones
10.31 – 10.50	Mudstones with nodules of anhydrite and ironstones

Summary lithological log: BGS50

0.0 – 1.0	Soil/ferricrete horizon
1.0 – 2.5	Very weathered doleritic fine-grained sand and clay
2.5 – 8.0	Weathered dolerite
8.0 – 14.5	Medium-grained dolerite
14.5 – 17.0	Medium- to coarse-grained dolerite with white zeolite
17.0 – 17.66	Dolerite baked purple grey fine-grained sandstone contact zone
17.66 – 18.20	Fine-grained fractured dolerite

18.20 – 20.5	Light grey silty fine-grained sandstone
20.5 – 24.0	Light grey shaley siltstones
24.0 – 26.5	Shaley grey mudstones
26.5 – 29.5	Shaley black carbonaceous mudstone
29.5 – 31.50	Dark grey pyritic carbonaceous mudstone, sandy in parts
31.50 – 31.75	Black carbonaceous mudstones

4. TEST PUMPING

A variety of pumping tests was carried out on the exploratory boreholes; the BERWASSA boreholes were also tested. Table 4 gives a summary of the test pumping; data and analyses are given in Annex 4. The bailer tests were analysed using the Theis Recovery method (Kruseman and de Ridder 1990) and Barker's large diameter well method (Barker 1989). The longer pumping tests were analysed using standard drawdown and recovery methods (Kruseman and de Ridder 1990).

The best aquifer properties were measured in BGS50. Like BGS46 at Ugbodum (Davies and MacDonald 1999), this borehole was drilled in a valley that was underlain by dolerite. This borehole could sustain a handpump, although the long-term sustainability of the water supplies is not known. Longer term testing should be carried out in the area and water levels in the vicinity monitored. The boreholes drilled into the sandstones had poor yields. Transmissivity values of 0.1 m^2/d were measured. Therefore, hand dug wells constructed at these sites would be unlikely to serve 250 people. Family wells, however, serving about 30 people may be the best way to develop this resource.

The two Berwassa boreholes were also tested. BER1 showed moderate aquifer properties, although there was a distinct increase in the drawdown rate after 9.5 m. This can be attributed to the dewatering of an important fracture. Therefore, continual use of this borehole may cause pump failure. BER2 had extremely poor aquifer properties and would never sustain a handpump.

A water sample was taken from each of the boreholes for hydrochemical analysis. This was taken either during the pumping test or later using the Whale pump or bailers. Field measurements undertaken proved conductivities from BGS48 to be high (see Table 5). Like BGS41, most water form this borehole came from thin sandstone layers at depth (this borehole was drilled using foam, so there was also a possibility of contamination). Samples from the other boreholes had low conductivity. Groundwater from the shallow sources had lower conductivity than deeper sources.

Table 4. Summary of pumping tests carried out at Itogo. (Annex 4 contains data and analysis).

Borehole and Test	Date	Casing height above ground	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m^2/d)
BGS48						
Whale	10/2/99	0.15 m	6.415 m	90 mins	0.13 l/s	Jacob 0.14 Theis rec 0.11
BGS49						
Bailer test	10/2/99	0.65 m	6.722 m	2:30 mins	0.21 l/s	Barker: 0.04
BGS50						
Whale	11/2/99	0.35 rn	3.53 m	335 mins	0.12 l/s	Jacob 1.7 Theis rec 3.6
BER1						
Whale	5/2/99	0.56 m	5.556 m	300	0.11 l/s	Jacob (early) 1.2 Jacob (late) 0.23 Theis rec 0.1
BER2						
Bailer test	11/2/99		5.66 m	14:46	0.24 l/s	Barker: 0.002 Unreliable analysis

Table 5. Chemistry samples taken from Itogo.

Sample No	Source	date	Conductivity (μS/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	$CaCO_3$ (mg/l)	Comments
Oju/406	Ber 1	5/2/99	279	139	6.41	30.2	56	Smell of hydrogen sulphide [7° 2.123 8° 21.053]
Oju/409	River obi	9/2/99	202	100	6.08	27.2	28	Taken from river obi near Itogo [7° 3.375 8° 21.216]
Oju/410	River obi	9/2/99	124.1	62.2	5.9	29.4	25	Taken from further upstream
Oju/411	BGS48	10/2/99	4990	2520	6.65	29.1	178	Foam used in drilling – sample taken after 1.5 hours pumping
Oju/412	Shallow well	10/2/99	98.4	49.5	4.46	26.8	1	From shallow well next to BGS49
Oju/413	Shallow well	10/2/99	54.8	27	4.58	29.5	0	From shallow well 1 km from BGS47 [7° 4.287 8° 22.162]
Oju/414	BGS50	11/2/99	558	278	6.93	29.3	144	Taken after 4 hours pumping

5. SUMMARY AND CONCLUSIONS

The groundwater potential of the Awgu Shales, Agbani Sandstone and dolerite intrusions was investigated in northeast Obi. Various geophysical traverses were carried out at both Itogo and Oluywo, and a series of boreholes drilled and tested. The following work was undertaken in northeast Obi:

- 16 km of EM34-3 surveys at 20 m intercoil spacing; 40 m intercoil spacing was undertaken around the borehole sites
- 16 km magnetic profiling
- 3 resistivity VES
- 4 boreholes were drilled and approximately 2.5-m of core taken from each borehole
- chip and core samples from each borehole were logged, photographed and analysed, as well as being explained to the local community leaders and WASU representatives
- three boreholes, BGS48, BGS49 and BGS50 were screened and cased
- short pumping tests were carried out on BGS48, BGS49 and BGS50 and also two other boreholes drilled by BERWASSA.
- water samples were taken from each borehole for hydrochemical analysis.

The geophysical surveys could be interpreted in light of the drilling:

1. Conductivity values were highly variable (vertical coil measurements vary from 10 to 140 mmhos/m). This reflects variations in the geology.

2. Low conductivity measurements (< 40 mmhos/m for the vertical coil) indicated the presence of sand within the weathered zone (similar to the Ugbodum traverse (Davies and MacDonald 1999). The sandy weathered zone was underlain by high conductivity mudstone (indicated by the 40 m EM34-3 measurements and resistivity soundings.

3. Marked reductions in conductivity (approximately 40 mmhos/m) and the presence of magnetic anomalies indicated the presence of shallow dolerite. Here the conductivity at depth was also low: illustrated by the lower horizontal coil readings and the consistently low 40 m EM34-3 measurements

4. The dolerite had high conductivity soil – clearly observed on the resistivity soundings. This is probably due to the high smectite content of the soil

5. No drilling was carried out in high conductivity areas. However, from the drilling carried out along the north Obi traverse (Davies and MacDonald 1998) and Ugbodum (Davies and MacDonald 1999), these will correspond to soft mudstone. Spoil from the Catholic hand dug wells and the Berwassa boreholes substantiate this.

6. Resistivity soundings corroborated the EM34-3 surveys. High resistivity measurements correspond to the shallow (0-10 m) sandy weathered zone. The low resistivity mudstone underlying the weathered zone is easily detected.

Several conclusions can be made from geology and test pumping:

- No extensive sandstone was encountered at depth. In places, the weathered zone was sandy, and contained good quality groundwater. These sands may have formed by the weathering and erosion of the interbedded mudstones and sandstones that form the Agbani Sandstones. In time, the clays may be washed away, leaving only the sands.

- Groundwater found within a thin sandstone layer at depth was of poor quality.

- The dolerite at Okwutungbe is the extension of the Ito dolerite body within black carbonaceous mudstones. Where encountered within a valley, the dolerite contained zeolite and was fractured. Sufficient groundwater was found to support a hand pump.

- One of the BERWASSA boreholes encountered hard shales which were fractured and contained some groundwater. Although no dolerite was encountered in the spoil heap, it is probably that these mudstones had been baked by a nearby intrusion. Any magnetic anomalies around the borehole would have been masked by the tin roofs within the village.

The most promising target for groundwater in the area is dolerite – especially where it occurs within valleys. Extensive geophysical surveys around village locations may identify the presence of dolerite. The weathered zone of the Agbani Sandstone may also be considered for hand dug wells, although yields will be low. Completing wells to about 10 m depth (i.e. through the weathered sandy zone to the base of the underlying ferricrete zone) would probably provide water for about 30 people. Drilling out horizontally may significantly increase the yield of the well. Targeting wells to where the water table is highest may also increase the yields from the wells, since there would be a greater saturated thickness of aquifer. For example, BGS30, drilled along the north Obi traverse, encountered similar geology, but next to a river; yields here were significantly higher than those encountered at BGS48-49. Therefore it may be advisable to locate dry season sandstone wells close to rivers or within depressions.

No drilling was carried out along the geophysical traverse from Ito to Oluywo. However, several observations may be made. The extensive dolerite intrusion at Ito was easily identified by very low EM34-3 measurements and intense magnetic anomalies. The last 2-km of the traverse, determined low conductivity indicative of Agbani Sandstone. Spoil heaps from various wells indicate interlayered sandstone and mudstone. Some hand-dug wells within this area have been successful (although others, noticeably the NIGEP wells have failed). Like the Itogo traverse, it is probably advisable to put dry season sources, in sandstone areas close to rivers. Some magnetic anomalies were also noted on the traverse, therefore it is possible that dolerite intrusions transect the area – more surveying would be advisable to try and identify dolerite before developing sources within the sandstone.

References

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

Davies J and MacDonald A M 1998. The hydrogeology of the Oju/Obi area, Eastern Nigeria: north Obi traverse data report. British Geological Survey, Technical Report WC/98/52R.

Davies J and MacDonald A M 1999. The hydrogeology of the Oju/Obi area, Eastern Nigeria: Ugbodum area data report. British Geological Survey, Technical Report WC/99/3R.

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 1998a. Groundwater development maps of Oju and Obi local government areas, eastern Nigeria. British Geological Survey, Technical Report WC/98/53.

MacDonald A M and Davies J 1998b. The hydrogeology of the Oju/Obi area, Eastern Nigeria: Adum West area data report. British Geological Survey, Technical Report WC/98/66R.

Annex 1: Geophysics data

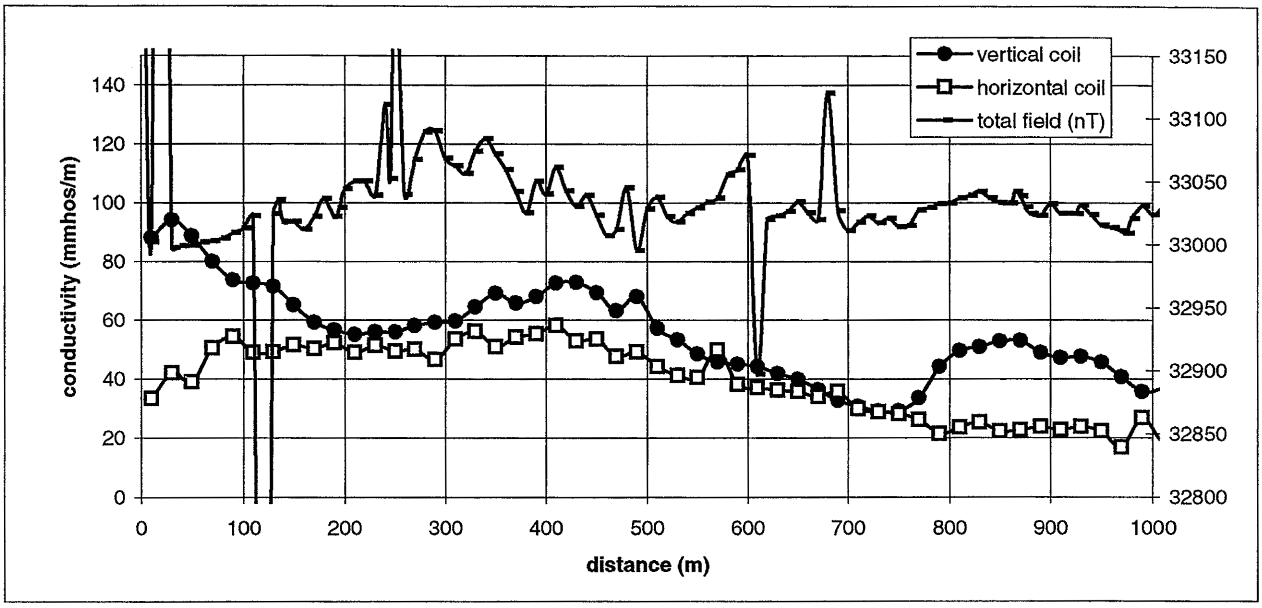
Itogo

IT 1

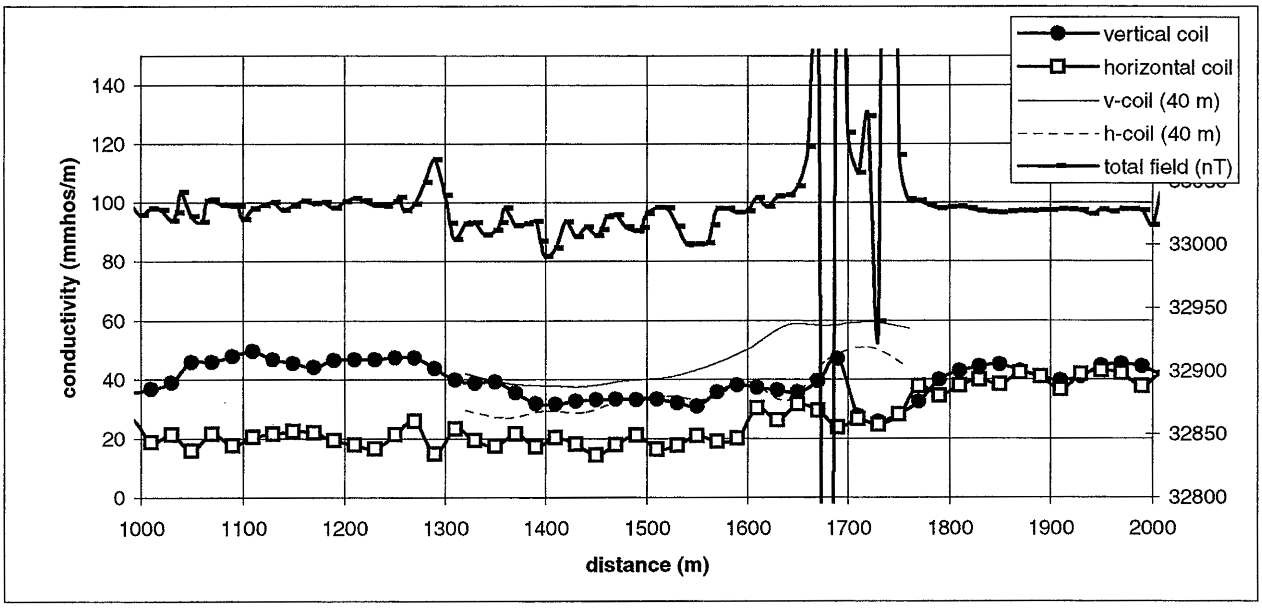
GPS start:	7 degs 02.059; 8 degs 21.011'	
GPS finish	7 degs 06.025; 8 degs 22.168'	
Date and time:	25/1/99 - 26-1/99	
Survey:	IT 1	from culvert before D92Okwutungbe to latrine at the end of Iyahc
	IT2	as IT1 using magnetic
	IT 3	EM34-3 with 40 m separation - adjacent to test boreholes

D (m)	comment	D (m)	comment	D (m)	comment
0 m	culvert	3800	end church	7660	mango tree right
90	village sign	3880	path R and palm tree	7700	small x-raods
120	deeper life church	3940	Big Mango right	7840	pit latrine right
180	mango left	3980	footpath left	7900	2 palm trees left
240	borehole left	4000	start village	7940	AGC sign left
320	coke sign	4180	culvert	8020	4 big mango trees
420	beginning Och junction	4260	end of C&S church	8075	latrine left
520	borehole left	4360	Y to clinic	8140	latrine right
540	signboard	4480	uncompleted church L	8170	end wire fence
620	cashew tree	4520	guava tree R		
730	St Catherines hdw	4560	2 palm trees R		
1110	Otu Obarike signboard	4620	start market		
1180	methodist church	4700	end market		
1300	malina & path left	4770	path right		
1540	weathered dolerite??	4790	existing borehole		
1570	main short cut to Sect	4840	church left		
1680	beginning 1st bridge	4980	culvert		
1740	end 2nd bridge	5080	footpath left		
2000	signboard	5120	palm trees left		
2120	large tree	5220	malina and mango L		
2165	footpath left	5320	junction L & R		
2220	bamboo tree R	5380	welcome sign		
2280	footpath x-ing	5520	school comp stats		
2365	mango tree left	5630	catholic sign		
2420	FSP clinic signboard	5640	catholic HDW		
2480	Itogi Ipini signboard	5920	wooden bridge		
2560	much zinc in village	6120	Y junction right		
2580	malina tree left	6240	banana left		
2640	Y junction right	6320	small hotel		
2720	path left	6380	coconut tree right		
2740	small culvert R	6440	broken ant hill		
2820	end village	6520	end cassava farm		
2915	Y junction	6580	path right		
3040	start bridge	6700	path right to zinc roof		
3125	small culvert	6860	on wooden bridge		
3160	road right	6950	path left		
3320	borehole sight left	7000	mango trees left		
3340	methodist signboard	7120	leefless tree		
3340	much zinc	7170	path right		
3440	road right	7230	small x roads		
3540	culvert by the right	7260	path left		
3600	primary School sign	7355	road right to school		
3685	1st malina in School	7420	St Judes HDW		
3740	catholic HDW	7480	mango tree left		

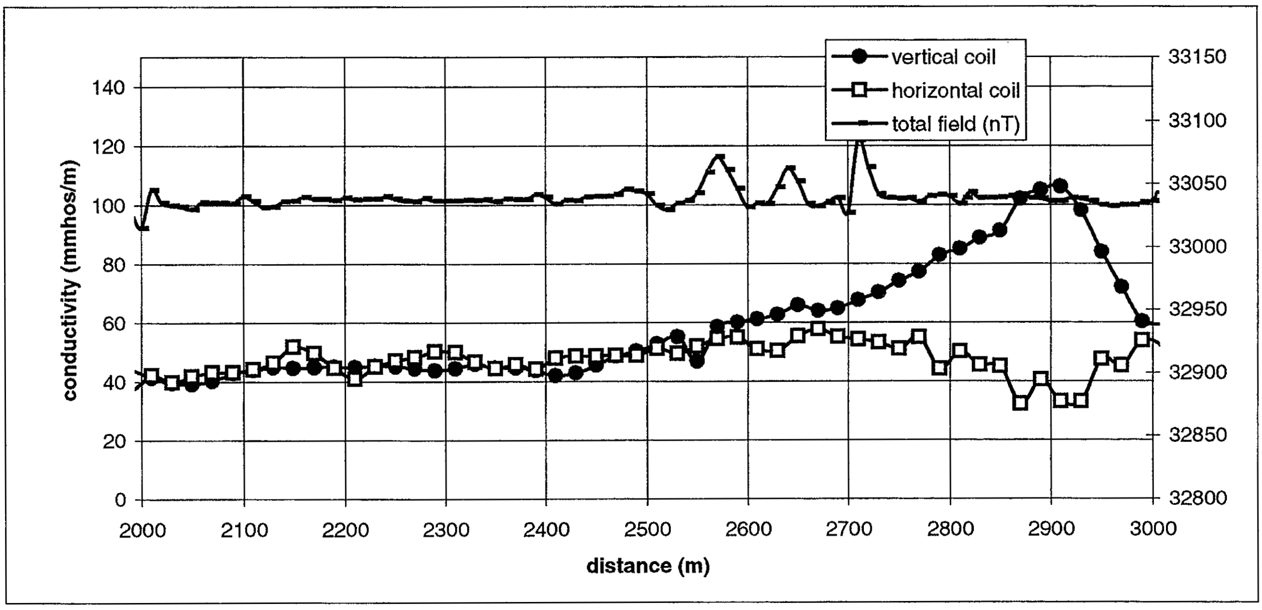
distance	strike
0	68
220	62
440	340
640	0
1740	26
2060	38
2340	64
2660	30
3440	8
3720	11
3900	5
4460	4
4740	20
4800	16
5040	28
5700	14
4800	0
6160	344
6400	352
7620	40



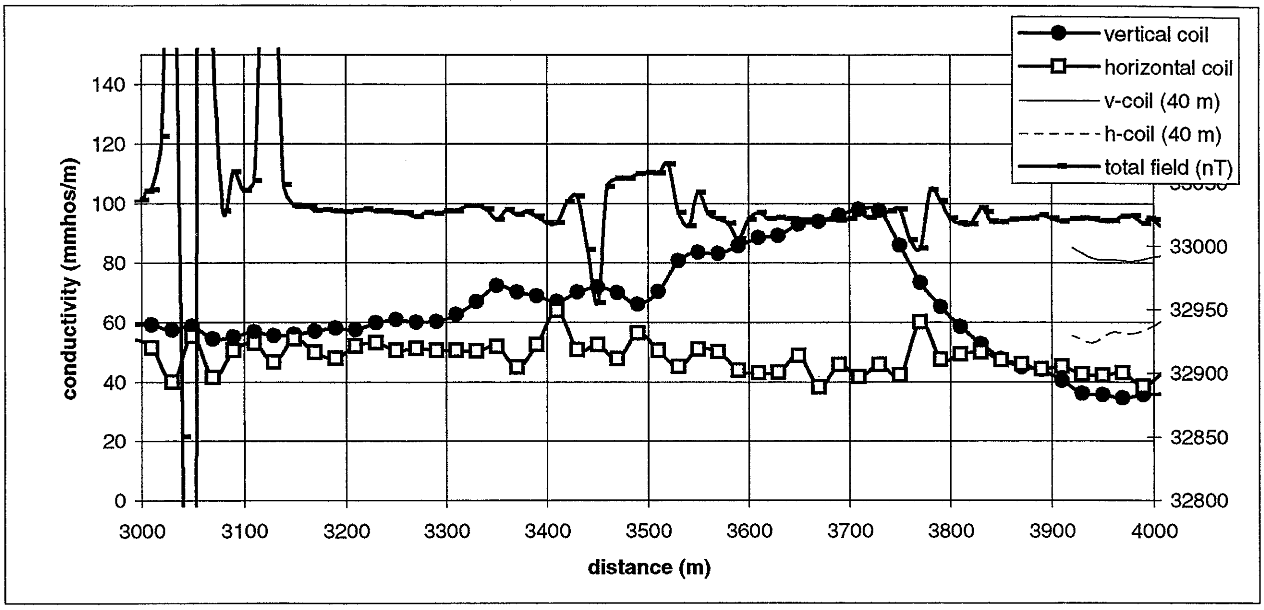
vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
distance (m)



vertical coil
horizontal coil
v-coil (40 m)
h-coil (40 m)
total field (nT)
conductivity (mmhos/m)
distance (m)



vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
distance (m)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horizontal coil
v-coil (40 m)
h-coil (40 m)
total field (nT)
conductivity (mmhos/m)
distance (m)
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40
60
80
100
120
140
32800
32850
32900
32950
33000
3000
3100
3200
3300
3400
3500
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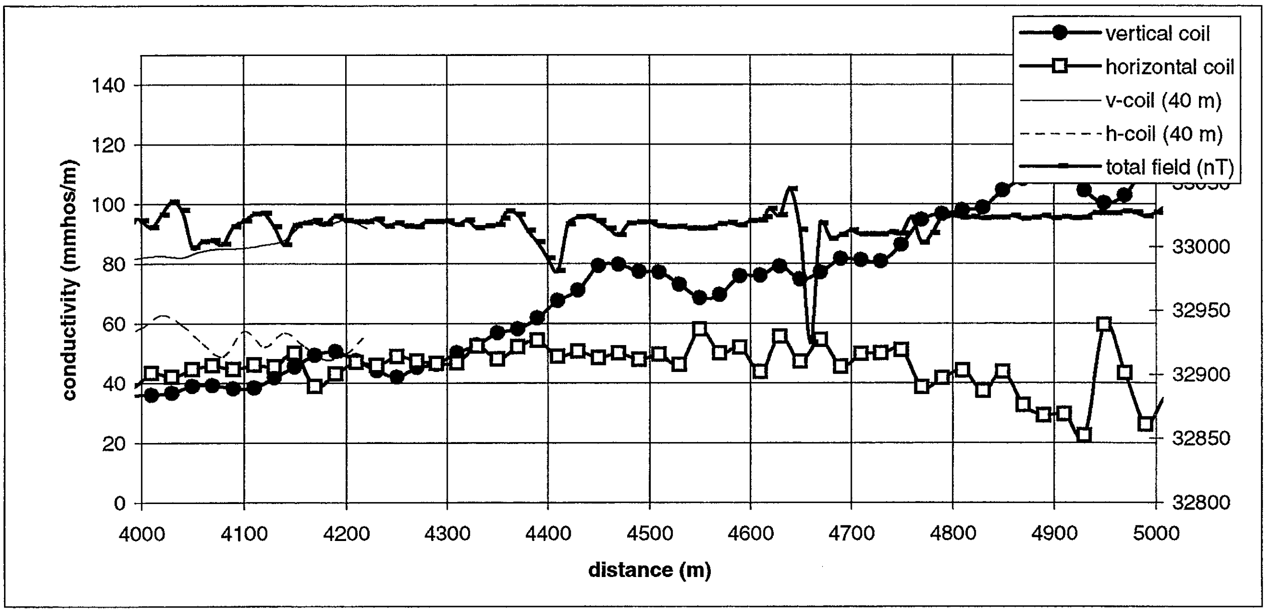
3700
3800
3900
4000


vertical coil
horizontal coil
v-coil (40 m)
h-coil (40 m)
total field (nT)
conductivity (mmhos/m)
distance (m)
0
20
40
60
80
100
120
140
32800
32850
32900
32950
33000
4000
4100
4200
4300
4400
4500
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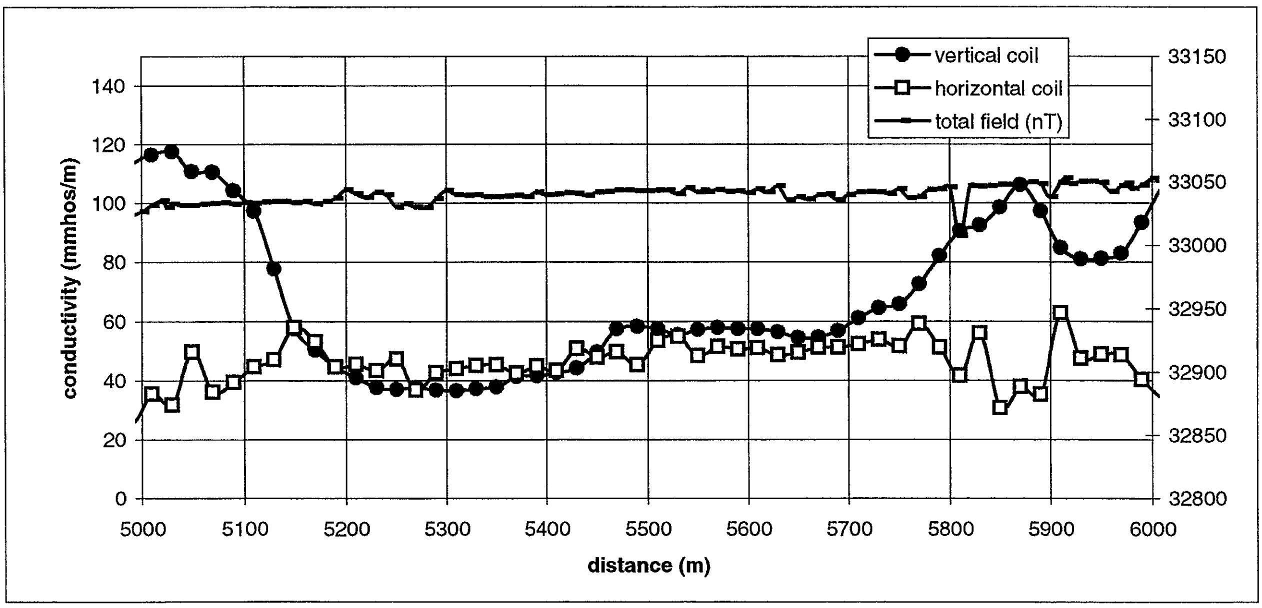
4700
4800
4900
5000


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
distance (m)
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20
40
60
80
100
120
140
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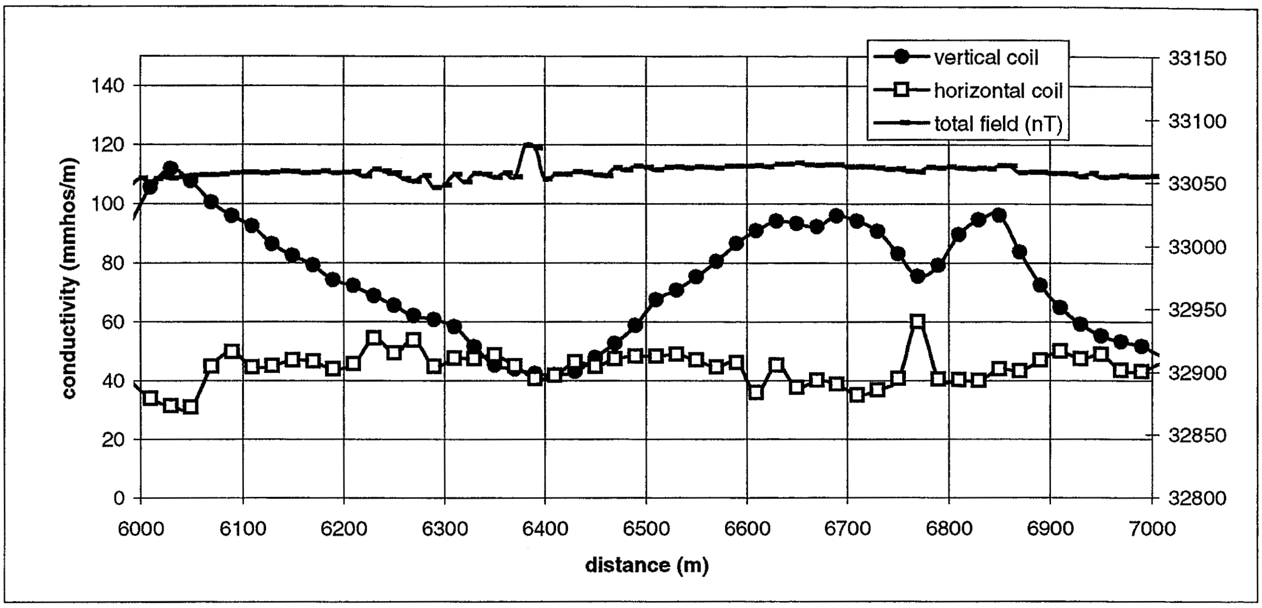
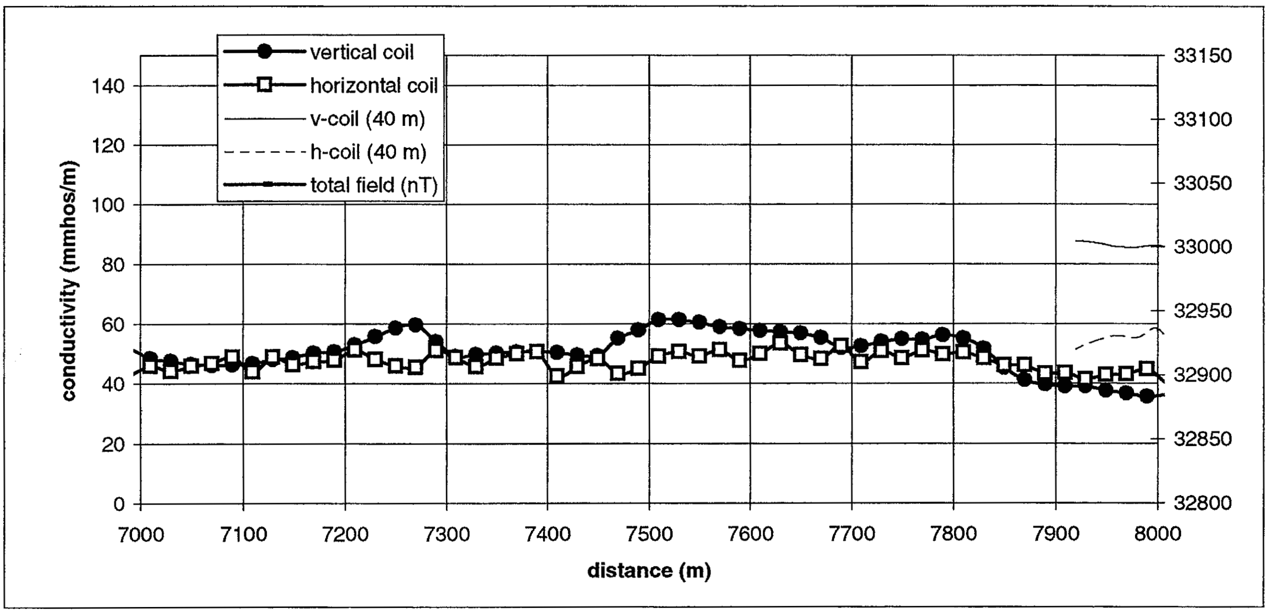
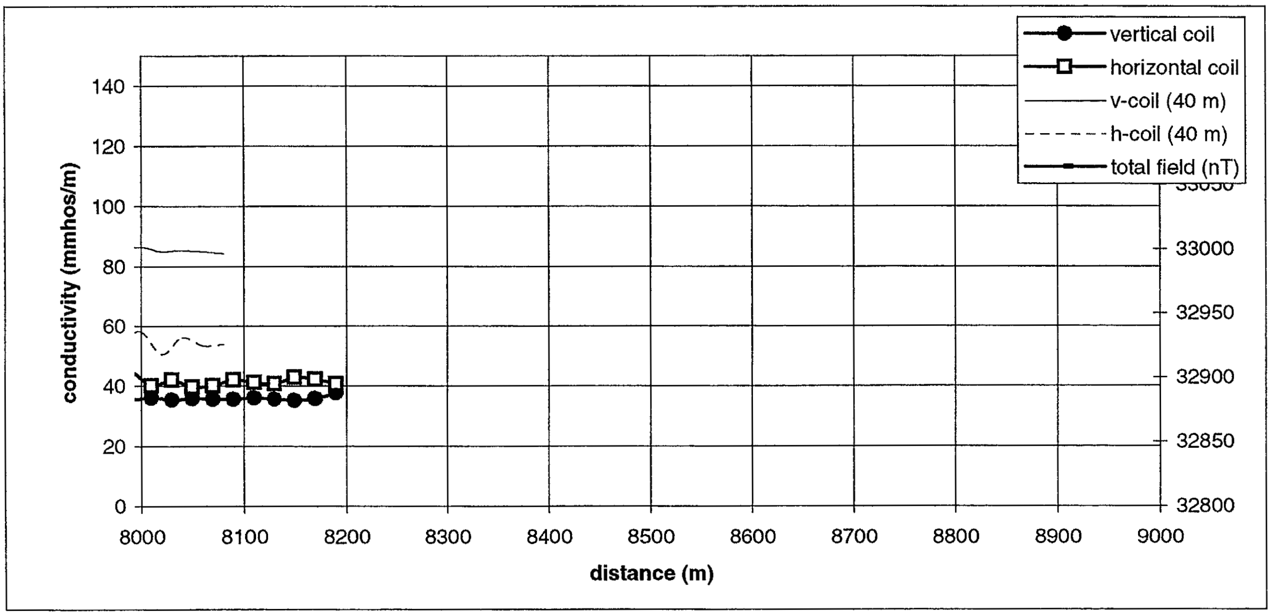
5700
5800
5900
6000


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33150
33100
33050
33000
32950
32900
32850
32800
6000
6100
6200
6300
6400
6500
6600
6700
6800
6900
7000
distance (m)

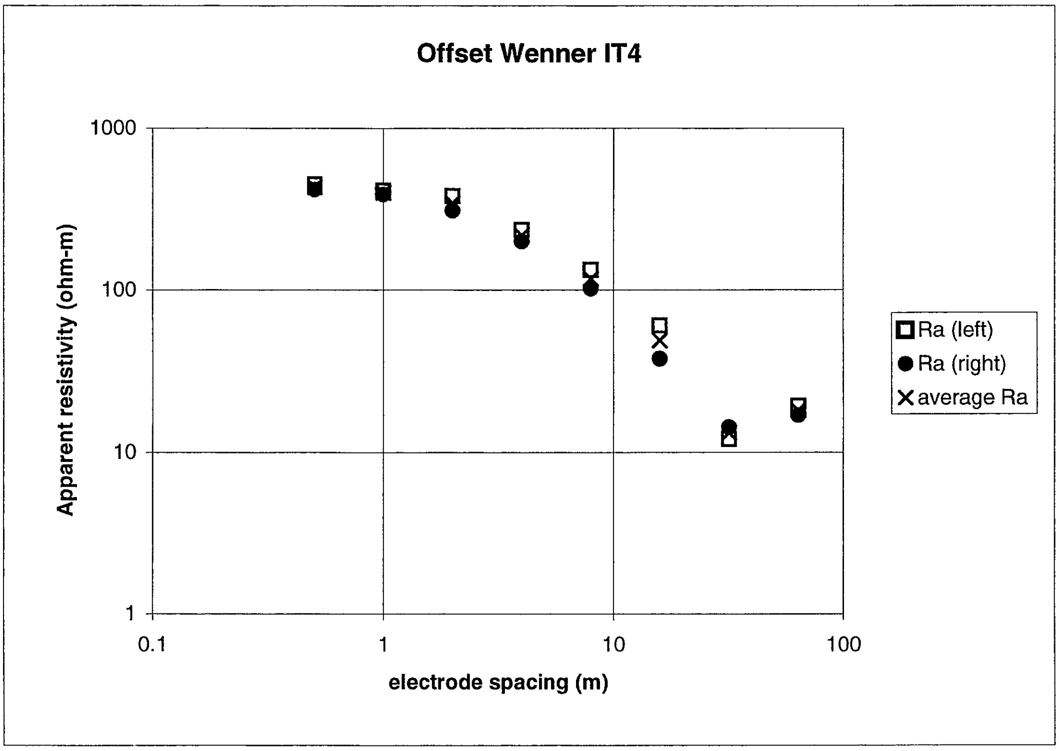

vertical coil
horizontal coil
v-coil (40 m)
h-coil (40 m)
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33150
33100
33050
33000
32950
32900
32850
32800
7000
7100
7200
7300
7400
7500
7600
7700
7800
7900
8000
distance (m)


vertical coil
horizontal coil
v-coil (40 m)
h-coil (40 m)
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33000
32950
32900
32850
32800
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
9000
distance (m)

Itogo 4

Resistivity 1: Offset Wenner
BGS47
7 degs 4.287' 8 degs 22.162
10/02/99

spacing	left	right	Ra (left)	Ra (right)	average Ra
0.5	142.8	132.7	448.392	416.678	432.535
1	65.4	62	410.712	389.36	400.036
2	30.2	24.6	379.312	308.976	344.144
4	9.35	7.95	234.872	199.704	217.288
8	2.64	2.03	132.6336	101.9872	117.3104
16	0.6	0.375	60.288	37.68	48.984
32	0.06	0.071	12.0576	14.26816	13.16288
64	0.048	0.042	19.29216	16.88064	18.0864



DATA SET: ITOGO4

CLIENT: WaterAid
LOCATION: Obi, Nigeria
COUNTY: Itogo
PROJECT: Water and Sanitation
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: Feb 1999
SOUNDING: 1
AZIMUTH: 11.5 Deg N-NE
EQUIPMENT: BGS128

Offset Wenner Configuration

FITTING ERROR: 1.783 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	427.7	1.88	-1.88	0.00440	805.2
2	134.9	8.06	-9.94	0.0597	1088.0
3	5.11	23.28	-33.22	4.54	119.1
4	225.1				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	417.819	427.724	438.371
	2	124.866	134.946	143.301
	3	3.469	5.119	6.090
	4	127.533	225.136	832.067
THICK	1	1.754	1.883	2.025
	2	7.766	8.063	8.602
	3	15.761	23.284	28.082
DEPTH	1	1.754	1.883	2.025
	2	9.595	9.945	10.544
	3	26.305	33.229	37.812

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	432.0	424.8	1.66
2	1.00	400.0	408.9	-2.24

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
3	2.00	344.0	342.0	0.578
4	4.00	217.0	215.9	0.502
5	8.00	117.0	119.6	-2.26
6	16.00	49.00	47.94	2.14
7	32.00	13.20	13.50	-2.28
8	64.00	18.10	17.85	1.32

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

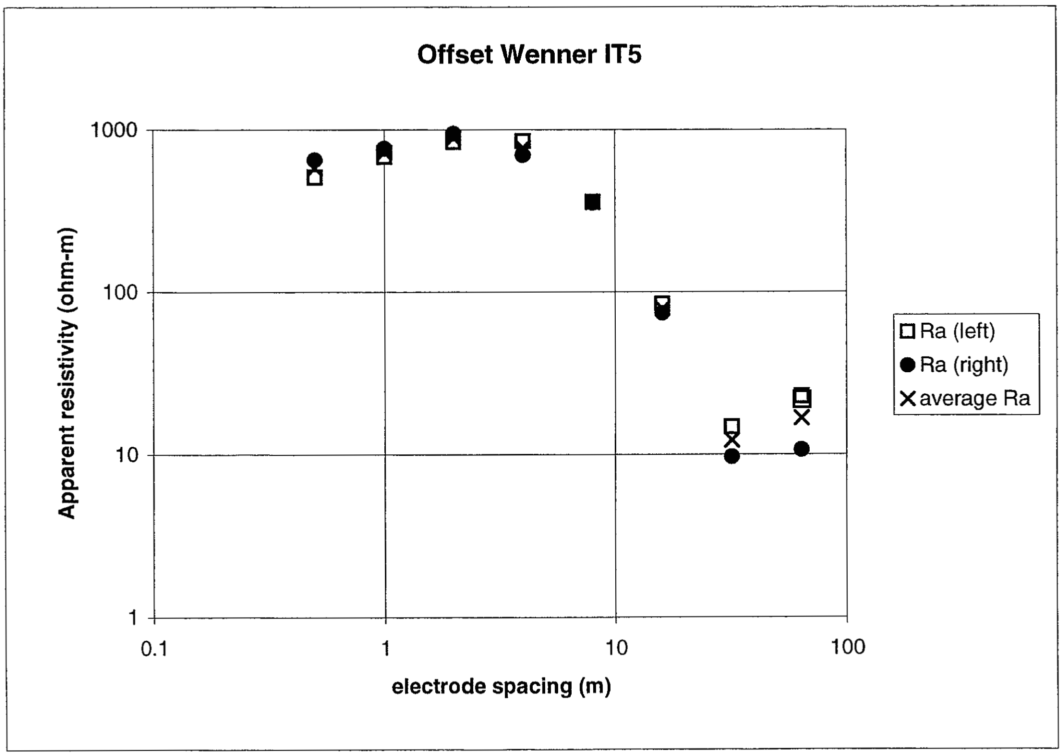
	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.99						
P 2	-0.01	0.88					
P 3	0.00	-0.06	0.55				
P 4	0.00	0.02	0.02	0.01			
T 1	0.02	0.10	0.04	-0.01	0.88		
T 2	0.00	0.05	0.07	-0.01	-0.03	0.96	
T 3	0.00	-0.05	-0.45	-0.05	0.03	0.06	0.51

Itogo 5

Resistivity 2: Offset Wenner
BGS48

10/02/99

spacing	left	right	Ra (left)	Ra (right)	average Ra
0.5	161.6	207	507.424	649.98	578.702
1	108.4	121.9	680.752	765.532	723.142
2	66.6	75	836.496	942	889.248
4	33.8	27.7	849.056	695.824	772.44
8	7.13	7.02	358.2112	352.6848	355.448
16	0.838	0.739	84.20224	74.25472	79.22848
32	0.0732	0.048	14.71027	9.64608	12.17818
64	0.0565	0.0265	22.70848	10.65088	16.67968



DATA SET: ITOGO5

CLIENT: WaterAid
LOCATION: BGS48
COUNTY: Itogo
PROJECT: Water and Sanitation
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: Feb 1999
SOUNDING: 1
AZIMUTH: 11.5 Deg N-NE
EQUIPMENT: BGS128

Offset Wenner Configuration

FITTING ERROR: 1.225 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	499.0	0.545	-0.545	0.00109	272.0
2	1315.5	2.20	-2.75	0.00168	2900.6
3	253.7	6.06	-8.81	0.0239	1539.1
4	4.36	18.86	-27.68	4.32	82.38
5	78.99				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	477.049	499.061	535.445
	2	1243.405	1315.587	1484.518
	3	215.039	253.786	293.471
	4	2.789	4.366	5.447
	5	60.733	78.990	144.674
THICK	1	0.489	0.545	0.669
	2	1.888	2.205	2.412
	3	5.807	6.065	6.482
	4	12.311	18.869	24.116
DEPTH	1	0.489	0.545	0.669
	2	2.480	2.750	2.948
	3	8.445	8.815	9.260
	4	21.537	27.683	32.823

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	579.0	574.8	0.715
2	1.00	723.0	734.9	-1.65
3	2.00	889.0	883.5	0.609
4	4.00	772.0	759.6	1.59
5	8.00	355.0	361.8	-1.91
6	16.00	79.20	78.44	0.951
7	32.00	12.20	12.30	-0.897
8	64.00	16.70	16.59	0.612

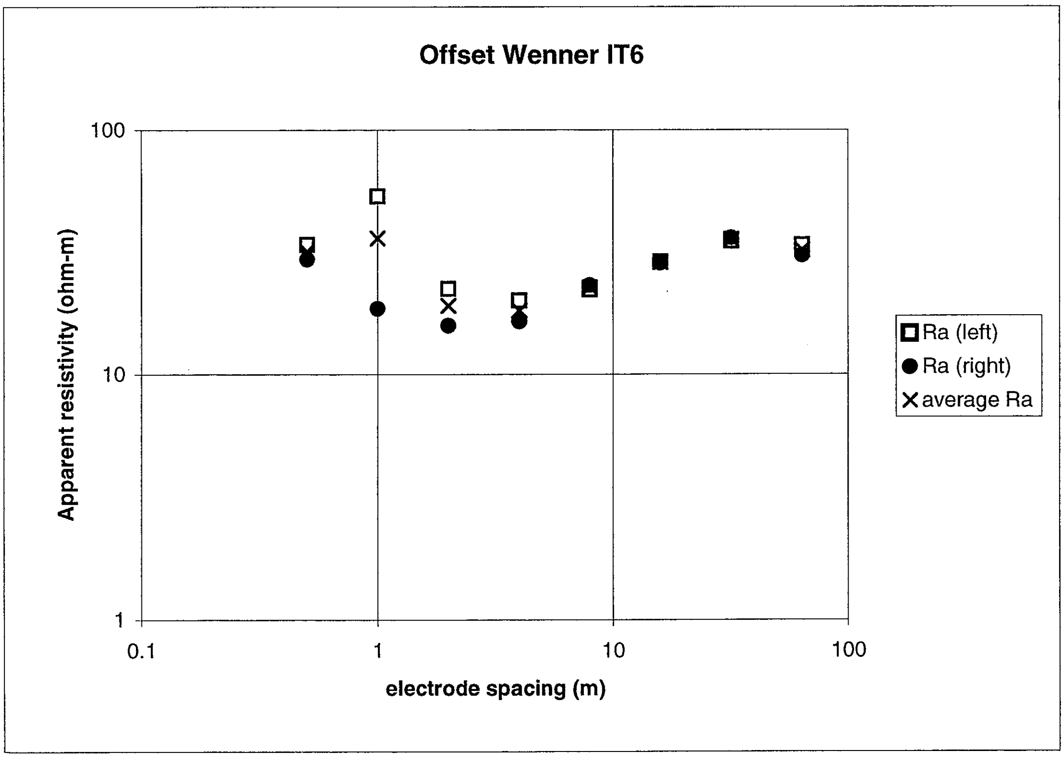
PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	P 5	T 1	T 2	T 3	T 4
P 1	0.90								
P 2	-0.01	0.81							
P 3	0.02	-0.05	0.44						
P 4	0.00	0.01	-0.07	0.51					
P 5	0.00	-0.01	0.07	0.07	0.05				
T 1	-0.17	-0.18	0.04	0.01	-0.01	0.50			
T 2	0.02	0.24	0.28	-0.01	0.00	0.23	0.57		
T 3	0.00	-0.04	0.13	0.07	-0.06	-0.04	0.02	0.92	
T 4	0.00	0.01	-0.03	-0.47	-0.11	0.00	0.00	0.04	0.48

Itogo 6

Resistivity 3: Offset Wenner
BGS50
7 degs 2.743; 8 degs 21.116
11/02/99

spacing	left	right	Ra (left)	Ra (right)	average Ra
0.5	10.8	9.42	33.912	29.5788	31.7454
1	8.52	2.96	53.5056	18.5888	36.0472
2	1.78	1.26	22.3568	15.8256	19.0912
4	0.796	0.654	19.99552	16.42848	18.212
8	0.441	0.461	22.15584	23.16064	22.65824
16	0.287	0.284	28.83776	28.53632	28.68704
32	0.1743	0.18	35.02733	36.1728	35.60006
64	0.084	0.0762	33.76128	30.6263	32.19379



DATA SET: ITOGO6

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COUNTY: Itogo
PROJECT: Water and Sanitation
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SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: Feb 1999
SOUNDING: 1
AZIMUTH: 11.5 Deg N-NE
EQUIPMENT: BGS128

Offset Wenner Configuration

FITTING ERROR: 1.547 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	35.15	0.569	-0.569	0.0162	20.03
2	16.47	5.56	-6.13	0.337	91.73
3	45.24	40.57	-46.71	0.896	1835.9
4	15.79				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	33.288	35.150	37.317
	2	15.492	16.480	17.364
	3	41.302	45.249	50.816
	4	10.727	15.793	21.782
THICK	1	0.468	0.570	0.681
	2	4.608	5.567	6.494
	3	26.470	40.576	56.775
DEPTH	1	0.468	0.570	0.681
	2	5.229	6.137	7.025
	3	33.283	46.712	62.432

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	31.70	31.70	-0.0296
2	1.00	36.00	24.89	30.85

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
3	2.00	19.10	19.09	0.0513
4	4.00	18.20	18.34	-0.808
5	8.00	22.70	22.20	2.20
6	16.00	28.70	29.52	-2.87
7	32.00	35.60	35.01	1.63
8	64.00	32.20	32.31	-0.367

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.97						
P 2	-0.01	0.97					
P 3	0.00	-0.01	0.90				
P 4	0.00	0.01	0.06	0.24			
T 1	0.06	0.05	0.02	-0.02	0.81		
T 2	-0.02	-0.06	-0.11	0.08	0.11	0.76	
T 3	0.00	0.01	0.15	0.32	-0.02	0.15	0.44

oluywo

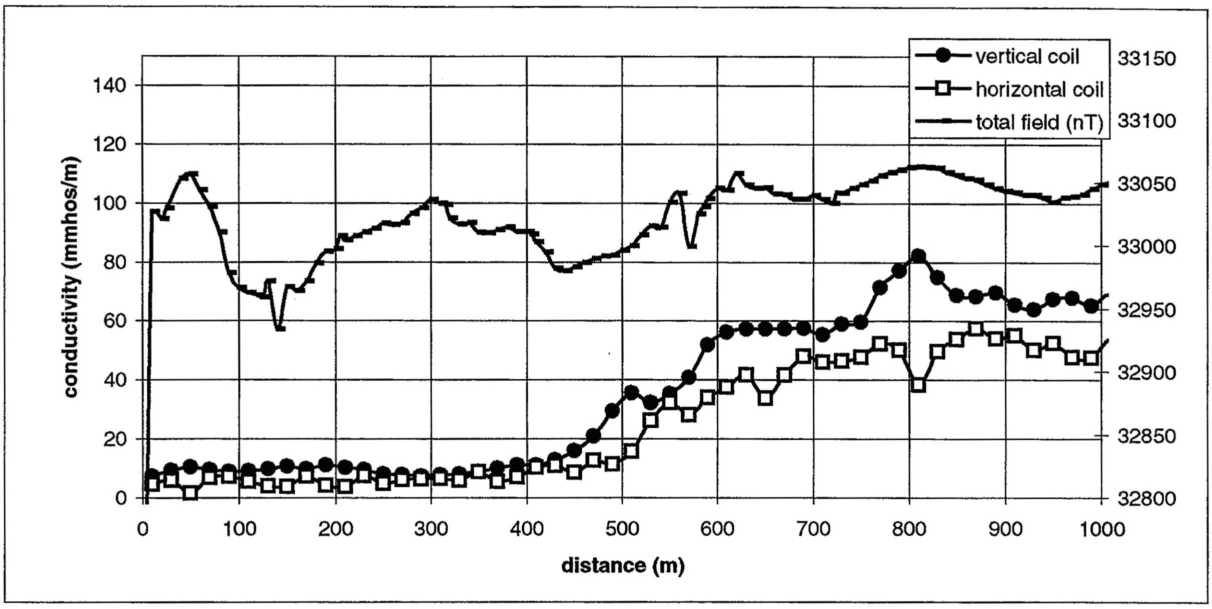
OL1

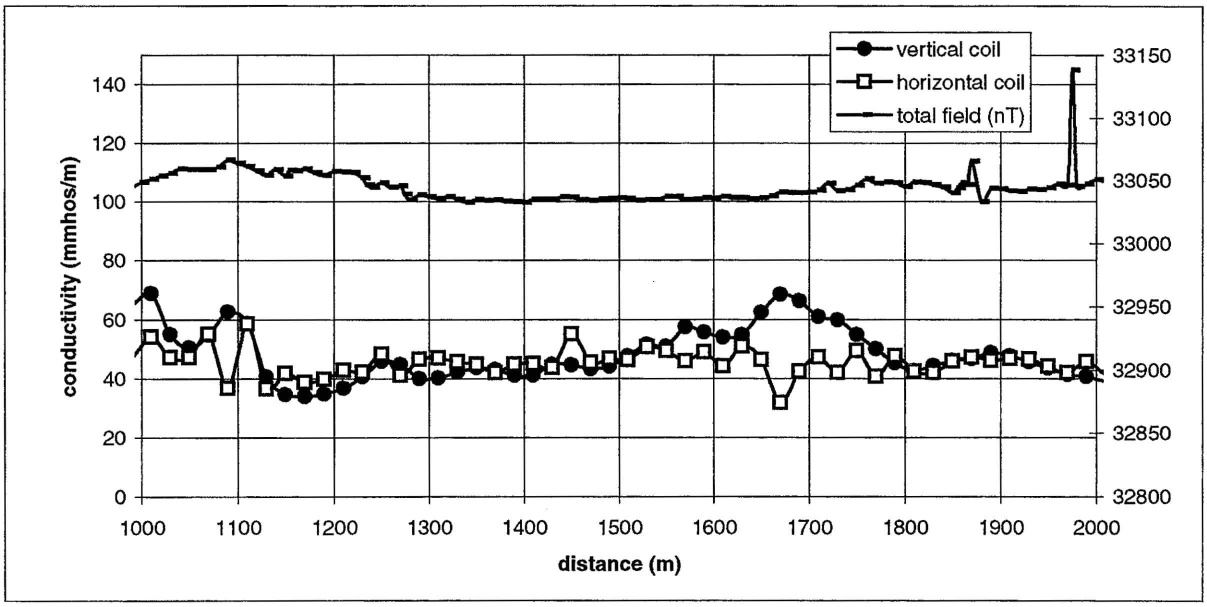
GPS start: 7 degs 01.728' 8 degs 19.364
GPS finish
Date and time: 27/1/99 - 28/1/99
Survey: Ol 1 from culvert at school on the outskirts of Ito, along road to Oluywo. EM34-3 20 m cable

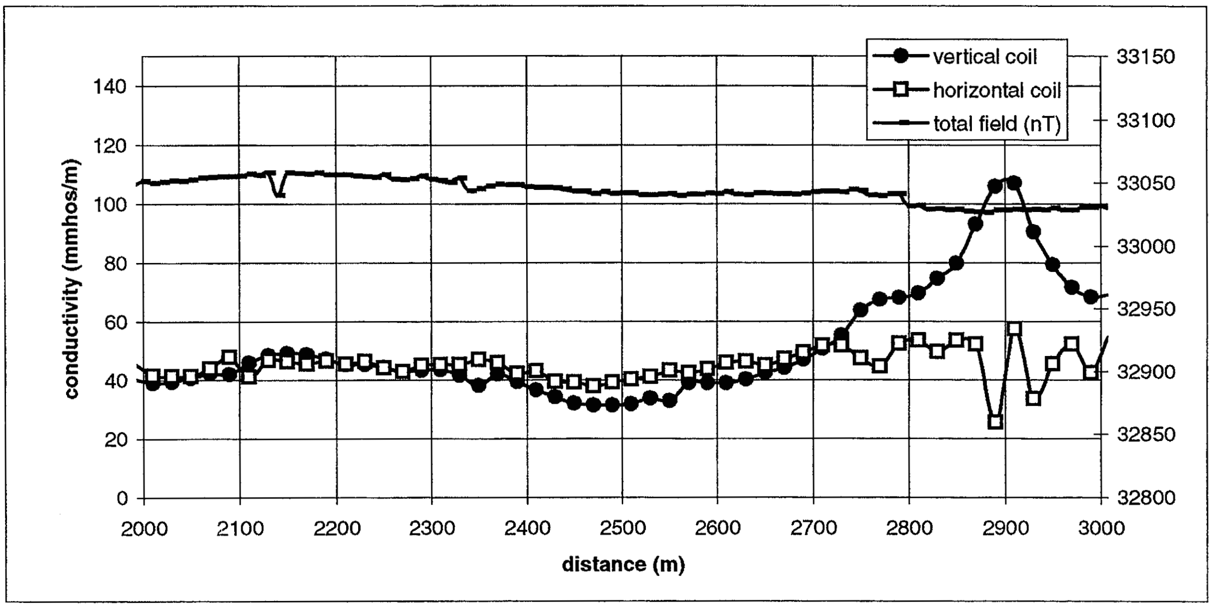
D (m)	comment	D (m)	comment
0	culvert	3880	path left
20	ferrecrete exposed	3960	small anthill left
125	road to school	3980	tall green tree right
160	malina tree by 2nd road	4100	2 small green trees
240	3rd road to school	4200	locus bean tree R
300	1st mango tree	4280	half dead mango
360	edge school comp	4330	opp huge tree
500	road R with malina av	4440	farm path right
560	zinc right	4460	large yellow tree R
600	malina by bricks	4660	large tree right
660	path r to mud huts	4810	path right big tree
800	ruts in road (down)	4840	dry tree right
880	locusbean tree	4890	small farm track right
970	2 palm trees	5060	fig tree
1060	tree at top valley	5160	dry tree left
1100	start bridge	5220	locus tree left
1160	path (erosion) right	5300	dry tree r mango l
1260	small path right	5420	Agba tree left
1320	sign post left	5540	small path left
1400	palm tree 50 m right	5585	path right
1440	sandy road	5660	large Agba
1550	big tree left	5890	bridge
1640	big tree left	5980	mumurini tree
1720	sign post	6030	path right
1820	palm tree left	6085	path right
1870	raod to Anyoye	6120	main path left
2020	mango tree left	6170	1st malina in playgrnd
2130	AoG signboard	6200	sign board right
2200	large mango right		start village
2340	road junction		much zinc to end
2460	road x-ing	6350	palm tree right
2600	small road to right	6400	C&S signboard
2680	large palm right	6470	methodist church
2740	methodist church left	6540	metal signboard right
2800	road x-ing	6620	catholic well
2910	stream bed	6760	main road
3060	st mary's church	6950	path rigth
3220	small road right	7000	mango left
3380	end bridge	7080	large mango in market
3520	dry tree	7360	thatched bathroom R
3580	tall skinny tree R	7400	palm tree right
3700	large locus right	7485	mango tree
3730	small anthill r	7680	road left
3760	2 large trees right	7740	bamboo left

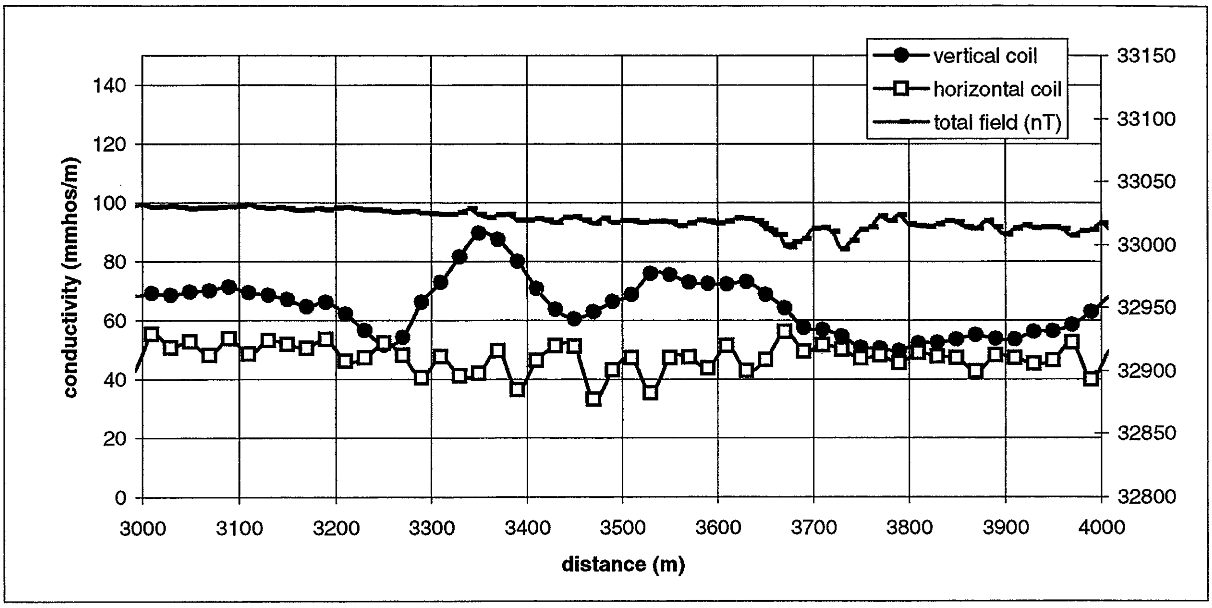
D (m)	comment
7860	wooden bridge left
7960	dry tree right
8100	bamboo in stream

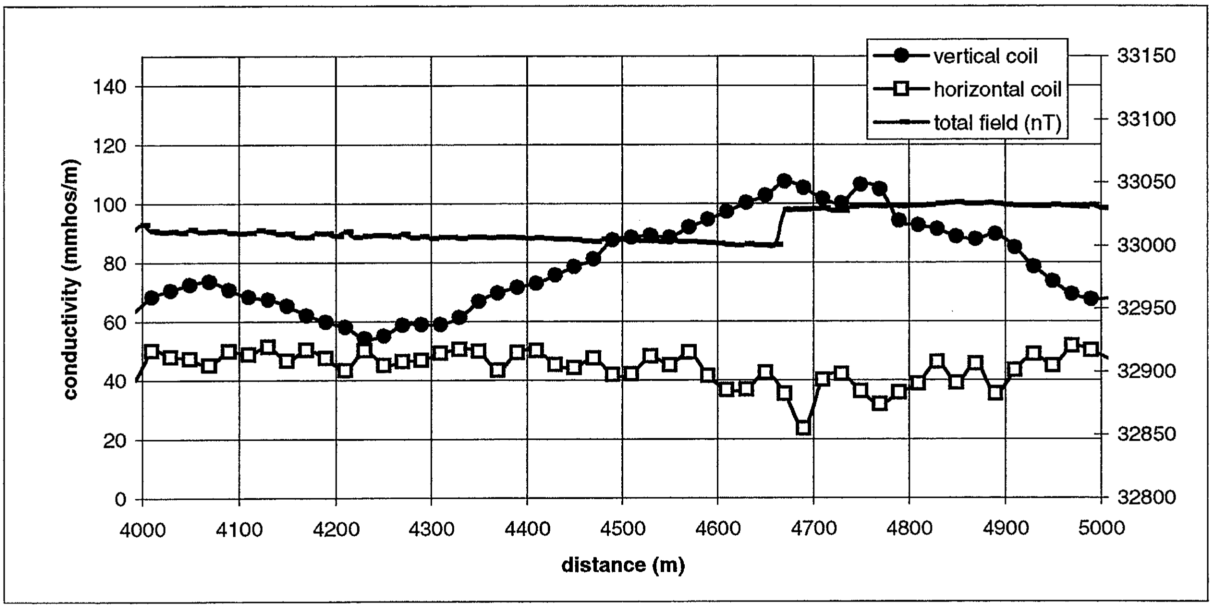
distance (m)	strike
0	344
720	349
1160	340
1280	320
1760	322
3260	20
2940	357
4360	358
4680	356
5060	5
6640	42
6800	14
6980	2
7480	22
8980	335
8100	359

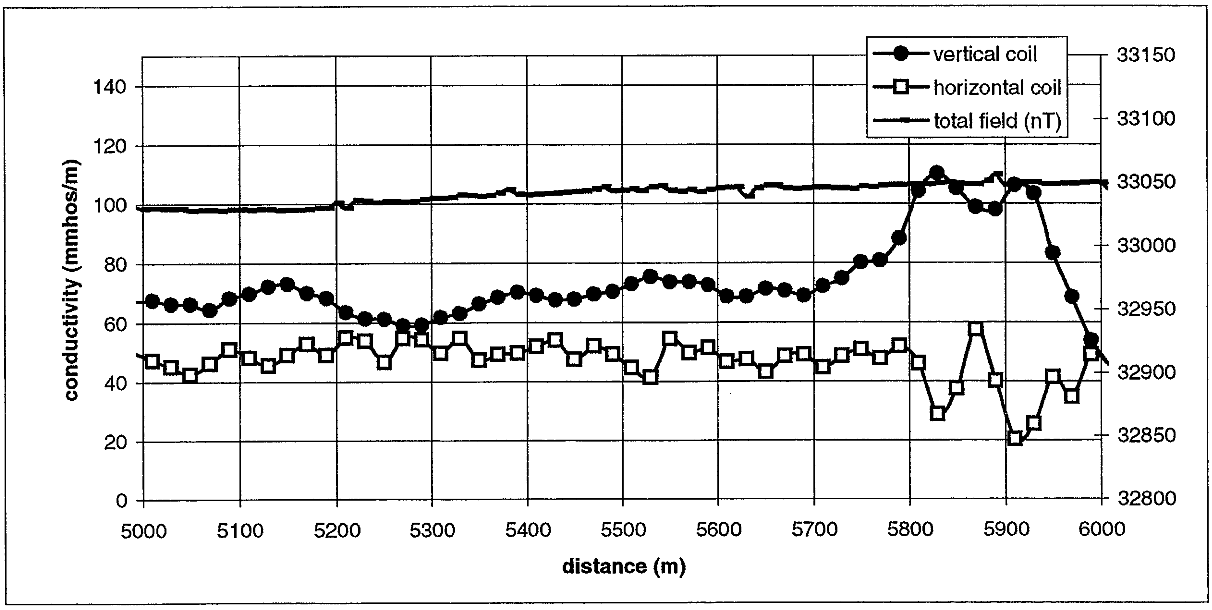

vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
33150
33100
33050
33000
32950
32900
32850
32800
0
100
200
300
400
500
600
700
800
900
1000
distance (m)

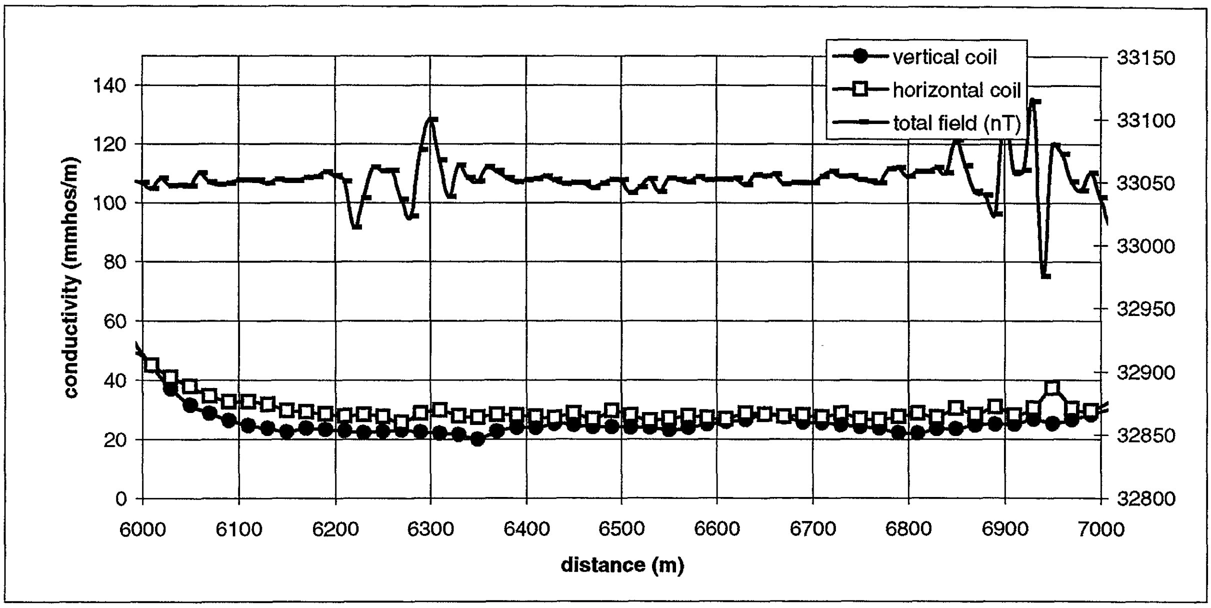

vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
33150
33100
33050
33000
32950
32900
32850
32800
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
distance (m)

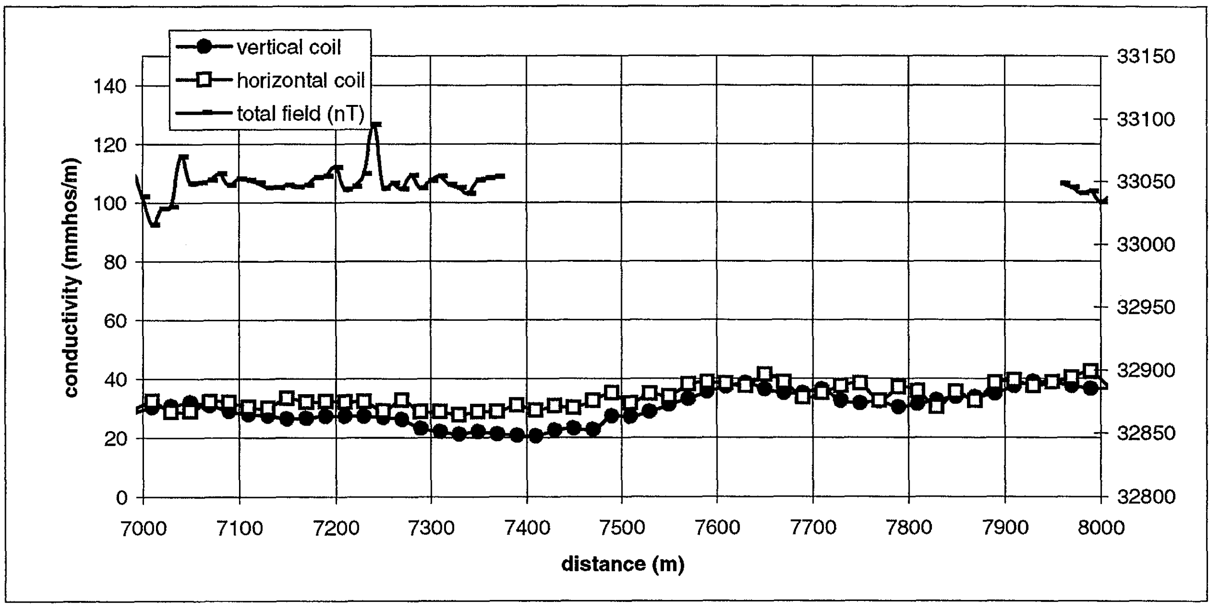

vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
33150
33100
33050
33000
32950
32900
32850
32800
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
distance (m)

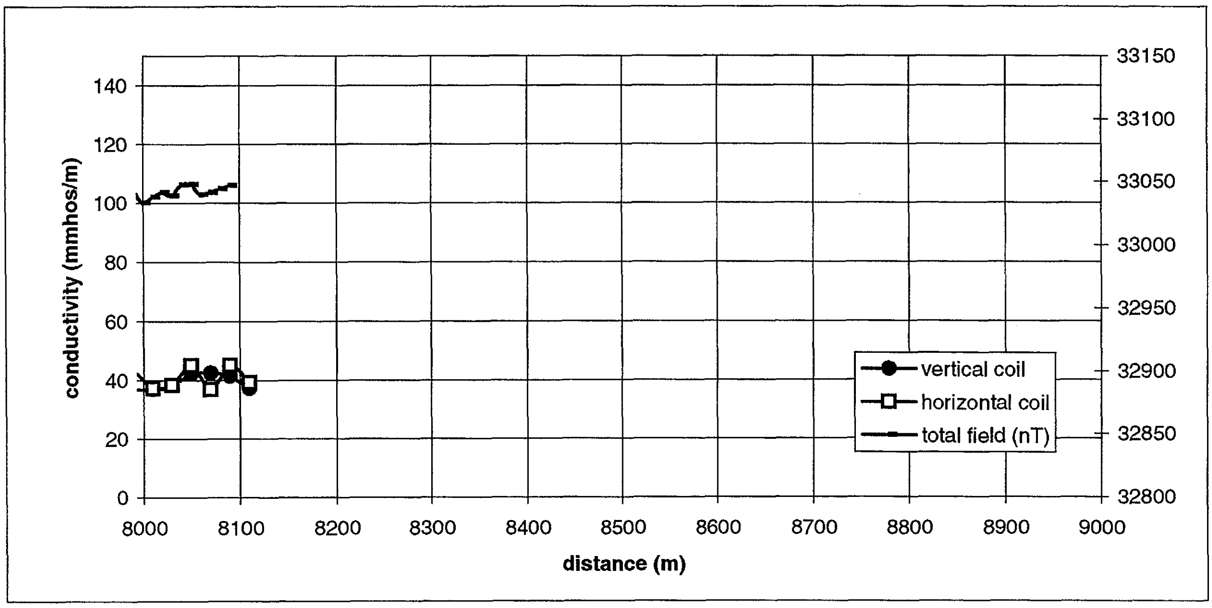

vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
32800
32850
32900
32950
33000
33050
33100
33150
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
distance (m)


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
32800
32850
32900
32950
33000
33050
33100
33150
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
distance (m)


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
0
20
40
60
80
100
120
140
32800
32850
32900
32950
33000
33050
33100
33150
5000
5100
5200
5300
5400
5500
5600
5700
5800
5900
6000
distance (m)


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33150
33100
33050
33000
32950
32900
32850
32800
6000
6100
6200
6300
6400
6500
6600
6700
6800
6900
7000
distance (m)

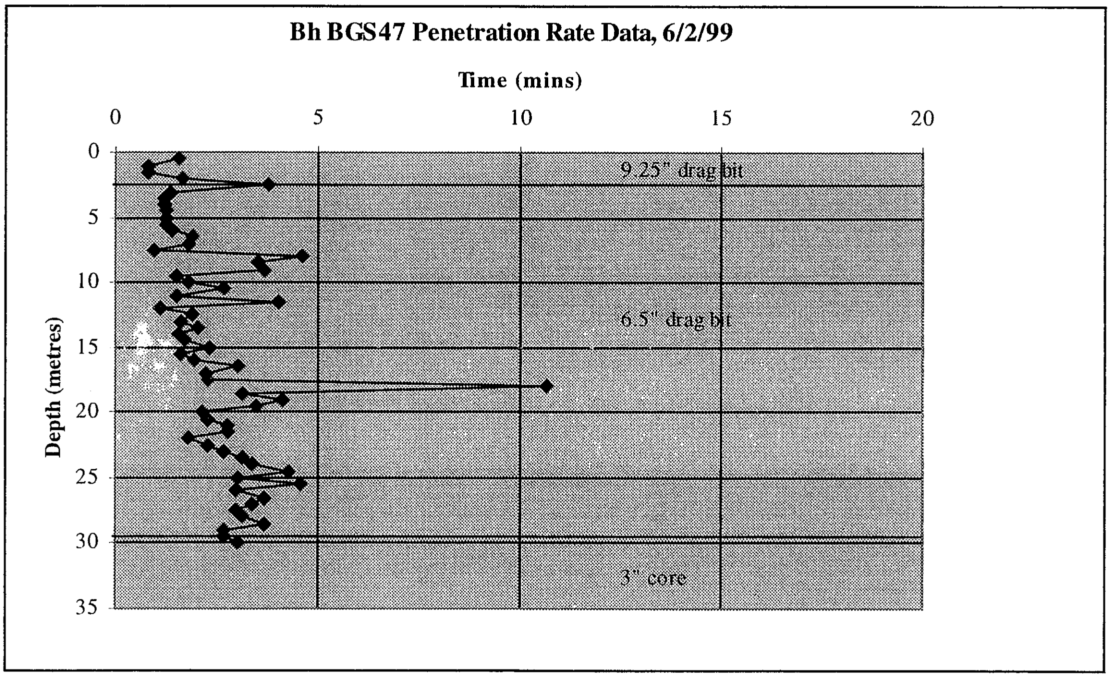

vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33150
33100
33050
33000
32950
32900
32850
32800
7000
7100
7200
7300
7400
7500
7600
7700
7800
7900
8000
distance (m)


vertical coil
horizontal coil
total field (nT)
conductivity (mmhos/m)
140
120
100
80
60
40
20
0
33150
33100
33050
33000
32950
32900
32850
32800
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
9000
distance (m)

Annex 2: Drilling and borehole construction data

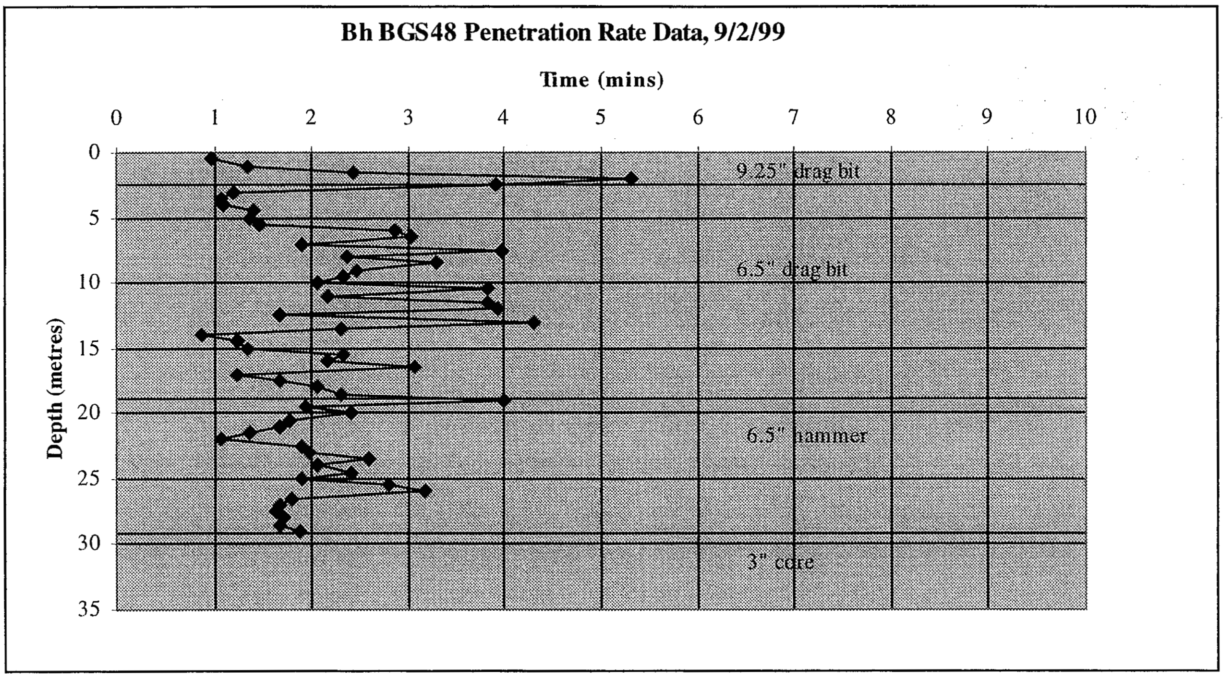
Borehole Drilling/Construction Details: Borehole BGS47

Borehole Drilling/Construction Details	
Date drilling started	6/2/99
Date drilling completed	8/2/99
6/2/99 – Drilled with 9.25” drag bit	0.0 - 2.5m
6/2/99 - Drilled with 6.5” drag bit	2.5-29.8m
6/2/99 – Cored at 3”	29.8 - 31.69m
Depths water struck	
Depth of borehole on completion	31.69mbgs
Borehole diameter	$6^1/_2$”
Casing erected in hole	none



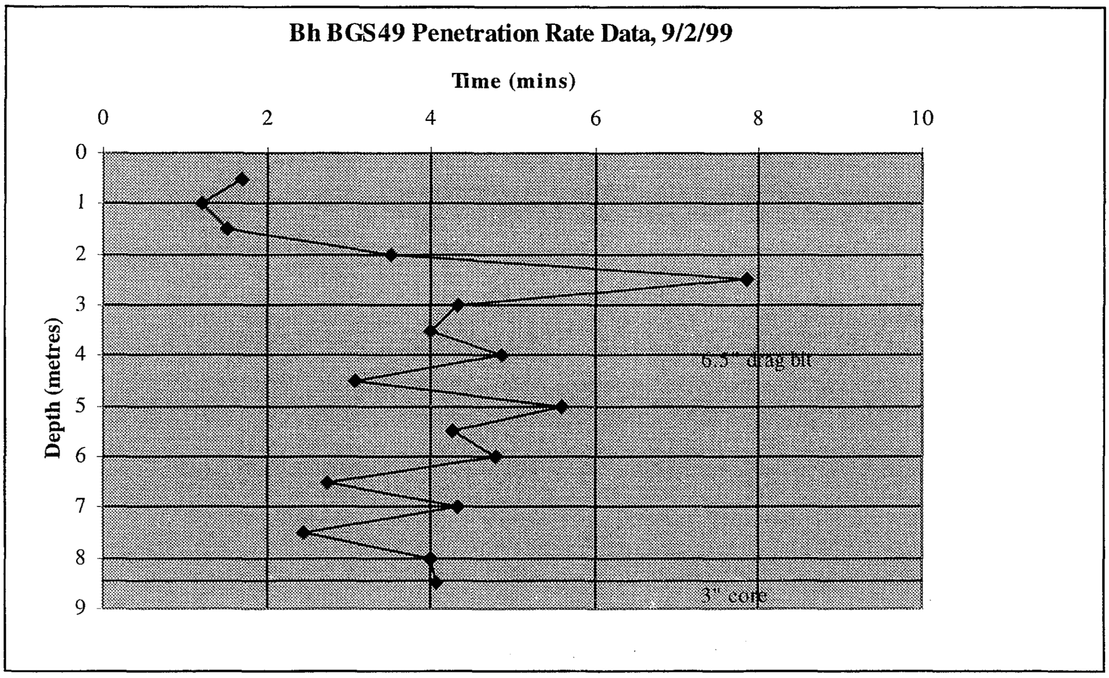
Borehole Drilling/Construction Details: Borehole BGS48

Borehole Drilling/Construction Details	
Date drilling started	8/2/99
Date drilling completed	9/2/99
8/2/99 – Drilled with 9.25" drag bit	0.0-2.5m
8/2/99 - Drilled with 6.5" drag bit	2.5 - 18.5m
8/2/99 - Drilled with 6.5" hammer	18.5 - 29.3m
8/2/99 – Cored at 3"	29.3 - 31.90m
Depths water struck	7.0, 8.0, 18.8, 20.5
Depth of borehole on completion	31.90mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	3x5.8mx125mm casing
	1x2.9mx125mm screen
	1x2.9mx125mm casing
	1x5.8mx125mm casing
	1x1.0mx125mm casing



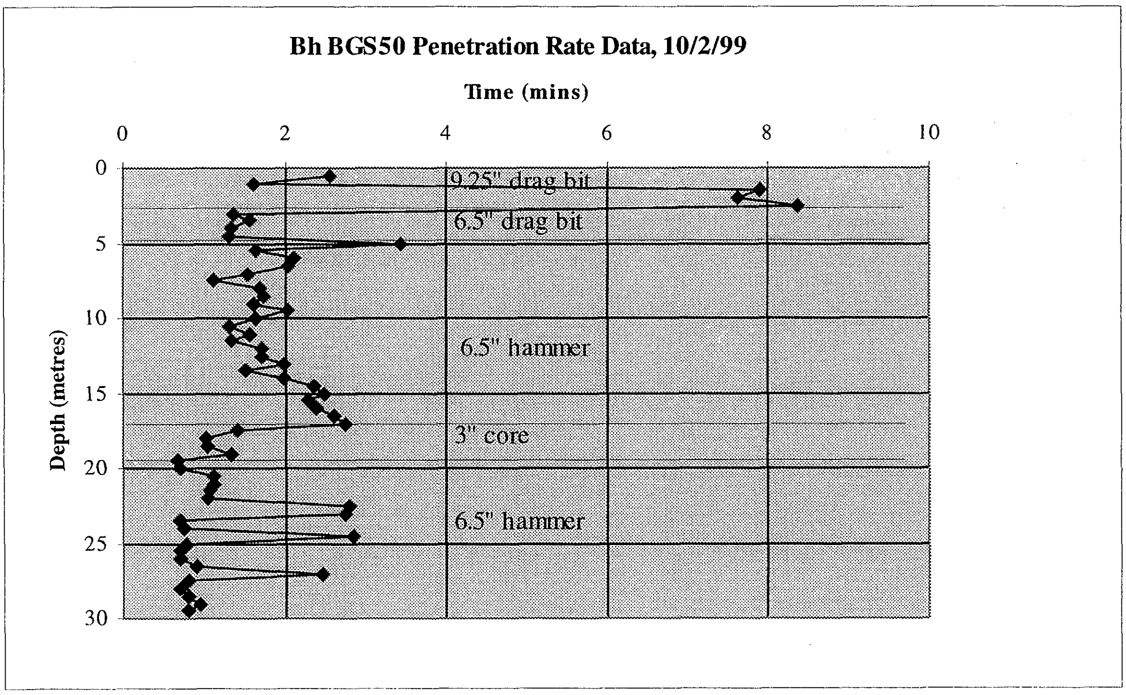
Borehole Drilling/Construction Details: Borehole BGS49

Borehole Drilling/Construction Details	
Date drilling started	9/2/99
Date drilling completed	9/2/99
9/2/99 – Drilled with 6.5" drag bit	0.0 - 8.5m
9/2/99 – Cored at 3"	8.5 - 10.5m
Depths water struck	6.5, 7.0,
Depth of borehole on completion	10.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x5.8mx125mm casing 2x2.9mx125mm screen



Borehole Drilling/Construction Details: Borehole BGS50

Borehole Drilling/Construction Details	
Date drilling started	10/2/99
Date drilling completed	10/2/99
10/2/99 – Drilled with 9.25" drag bit	0.0 - 2.5m
10/2/99 - Drilled with 6.5" drag bit	2.5 - 4.7m
10/2/99 - Drilled with 6.5" hammer	4.7 - 17.5m
10/2/99 – Cored at 3"	17.5 - 19.5m
10/2/99 - Drilled with 6.5" hammer	17.5 - 29.5m
10/2/99 – Cored at 3"	29.5 - 31.75m
Depths water struck	4.7, 10.7, 14.5,
Depth of borehole on completion	31.75mbgs
Borehole diameter	6 1/2"
Casing erected in hole	1x5.8mx125mm casing 6x2.9mx125mm screen 2x5.8mx125mm casing



Annex 3: Lithological logs

Lithological Log: BGS47

Soil/ferricrete horizon	
0.0 - 0.5	Pale brown 10YR6/3 top soil upon brownish yellow 10YR6/8 and red 10R5/8 lateritic nodules
0.5 - 1.0	Black manganiferous nodules with red 10R4/8 and brownish yellow 10YR6/8 rims
1.0 - 1.5	Black manganiferous nodules with red 10R4/8 and brownish yellow 10YR6/8 rims
Clayey very weathered horizon	
1.5 - 2.0	Yellowish red 5YR4/6 clay with light grey and brownish yellow 10YR6/8 patches
2.0 - 2.5	Mottled brownish yellow 10YR6/8, light grey and red 10R4/8 clays
2.5 - 3.0	Mottled nodules of reddish brown 2.5YR5/4 and yellow 10YR7/8
3.0 - 3.5	White clay with odd weak red 10R4/3 nodule with red 2.5YR5/8 and reddish yellow 7.5YR6/8 mottling
3.5 - 4.0	Mottled white, red 10R5/8 and yellowish red 5YR5/8 clays
Sandy clay	
4.0 - 4.5	Mottled white, yellow 10YR7/8 and weak red 10R5/4 silty clay
4.5 - 5.0	White sandy clay with yellow 10YR7/8 and weak red 10R5/8 mottles
5.0 - 5.5	Light bluish grey 8/5PB clay with yellow 10YR7/8 and weak red 10R5/8 partings
5.5 - 6.0	White sandy clay with yellow 10YR7/8 mottles
6.0 - 6.5	Mottled light grey clay, yellow 10YR7/8 and yellowish red 5YR4/6 sandy clays
Clayey fine-grained sand	
6.5 - 7.0	Light grey clayey fine-grained sand with yellow mottles
7.0 - 7.5	Light grey clayey fine-grained sand with yellow 10YR7/8 and yellowish red 5YR4/6 mottles
7.5 - 8.0	Light grey clayey fine-grained sand with yellow 10YR7/8 and yellowish red 5YR4/6 mottles
Sandy clay	
8.0 - 8.5	Light grey 7/N sandy clay with reddish yellow 7.5YR6/8 and red 10R4/8 partings - becoming more of a clayey fine- to medium-grained weathered sandstone
8.5 - 9.0	Light grey to grey sandy clay with brownish yellow 10YR5/8 partings
Clayey fine-grained sand	
9.0 - 9.5	Light grey white and brownish yellow 10YR6/6 clayey fine-grained sand
9.5 - 10.0	Hard brown ferricrete, strong brown 7.5YR5/8 fine-grained weathered sandstone and soft light grey clayey fine-grained sandstone
Hard red ferricrete band	
10.0 - 10.5	Light grey weathered fine-grained sandstone with thin dusky red 10R3/4 and dark reddish grey 10R3/1 hard ferricrete band (water?)
Very weathered mudstones	
10.5 - 11.0	Bluish grey 6/5PB weathered clayey mudstones soft with orange brown partings
11.0 - 11.5	Bluish grey 5/5PB weathered clayey mudstones soft with orange brown partings
11.5 - 12.0	Grey 2.5Y5/1 weathered shaley mudstone with pale yellow 5Y8/4 sulphurous partings
12.0 - 12.5	Dark grey to grey weathered shaley mudstones with yellow 10YR7/8 partings
12.5 - 13.0	Dark grey to grey weathered shaley mudstones with yellow 10YR7/8 partings
13.0 - 13.5	Dark grey to black soft weathered shaley mudstones, some yellow and pale yellow patches
13.5 - 14.0	Weathered black carbonaceous mudstones with grey 10YR5/1 and pale yellow 2.5Y8/4 partings
14.0 - 14.5	Grey 2.5Y6/1 weathered clayey mudstone with yellowish brown 10YR5/6 partings
14.5 - 15.0	Grey and grey brown 10YR5/2 weathered very shaley mudstone with brownish yellow10YR6/6 partings
Weathered mudstones	
15.0 - 15.5	Dark grey to black weathered shaley mudstones with brownish yellow 10YR6/8 partings
15.5 - 16.0	Black to greyish brown 10YR5/2 weathered shaley mudstones with yellow 10YR7/8 partings
16.0 - 16.5	Soft black to dark grey shaley carbonaceous mudstones with weathered inter-bands of

	brownish yellow 10YR6/8 and reddish brown partings
16.5 - 17.0	Black carbonaceous shaley mudstones with reddish brown 2.5YR4/4 layer at the base of the weathered zone, also some brown 10YR5/3 partings
Black carbonaceous mudstones	
17.0 - 17.5	Black carbonaceous shaley mudstone
17.5 - 18.0	Hard band within black carbonaceous mudstone, some water
18.0 - 18.5	Black carbonaceous mudstone
18.5 - 19.0	Black carbonaceous mudstone
19.0 - 19.5	Black carbonaceous mudstone
19.5 - 20.0	Black carbonaceous mudstone
20.0 - 20.5	Black carbonaceous mudstone
20.5 - 21.0	Soft black carbonaceous mudstone
21.0 - 21.5	Soft dark grey to black fairly carbonaceous blocky mudstone
21.5 - 22.0	Soft dark grey shaley mudstones
22.0 - 22.5	Soft dark grey to black fairly carbonaceous blocky mudstones
22.5 - 23.0	Soft dark grey to black shaley mudstones
23.0 - 23.5	Soft shaley black carbonaceous mudstone
23.5 - 24.0	Soft shaley black carbonaceous mudstone
24.0 - 24.5	Soft shaley black carbonaceous mudstone
24.5 - 25.0	Soft shaley black carbonaceous mudstone
25.0 - 25.5	Soft shaley black carbonaceous mudstone
25.5 - 26.0	Soft dark grey shaley mudstone
26.0 - 26.5	Yellowish brown 10YR5/8 hard calcrete band within dark grey shaley mudstones
26.5 - 27.0	Soft dark grey/black shaley carbonaceous mudstones
27.0 - 27.5	Soft dark grey/black shaley carbonaceous mudstones
27.5 - 28.0	Soft dark grey/black shaley carbonaceous mudstones
28.0 - 28.5	Soft dark grey shaley mudstones
28.5 - 29.0	Soft dark grey shaley mudstones
29.0 - 29.5	Soft black carbonaceous mudstones
29.5 - 30.0	Soft black carbonaceous mudstones
30.00 - 30.58	Well bedded homogeneous compact black carbonaceous mudstones with white thin barytes deposits on bedding planes
30.58 - 30.77	Compact well bedded black carbonaceous mudstone with some iron pyrite - no baryte
30.77 - 31.00	Black compact carbonaceous mudstones
31.00 - 31.12	Black compact carbonaceous mudstones with barytes along bedding planes
31.12 - 31.13	Thin grey rubbly muddy limestone, some iron pyrite and fossil fragments
31.13 - 31.37	Black compact carbonaceous mudstones with baryte on bedding planes, some iron pyrite, nodular irregular sandstone at 31.27m
Muddy chloritic fine- to medium-grained sandstone	
31.37 - 31.41	Greenish light grey chloritic fine- to medium-grained muddy sandstone, slumped bedding, much disseminated and nodular iron pyrite
Black carbonaceous mudstones	
31.41 - 31.46	Compact well bedded carbonaceous mudstone
31.46 - 31.65	Compact black carbonaceous mudstone with barytes on bedding planes and nodular iron pyrite especially within tubules
31.65 - 31.69	Black carbonaceous sandy mudstones with nodular iron pyrite, some fragments of lingula and microfossils - odd gravel sized fragment

Lithological Log: BGS48

Soil/ferricrete horizon	
0.0 - 0.5	Yellowish red 5YR5/6 clayey fine-grained sand below brown 7.5YR5/3 fine-grained soil
0.5 - 1.0	Yellowish red 5YR5/8 clayey fine-grained sand
1.0 - 1.5	Some black manganese oxide nodules within yellowish red 5YR5/8 clayey fine -grained sand
1.5 - 2.0	Larger black manganese oxide nodules with strong brown 7.5YR5/8 and red 10R5/6 rims
Clayey very weathered horizon	
2.0 - 2.5	Mottled light grey 2.5Y7/2, yellow 10YR7/6 and yellowish red 5YR6/8 clays. Some black manganese oxide nodules with red and brown rims
2.5 - 3.0	Mottled 8/10Y light greenish grey, brownish yellow 10YR6/8 and weak red 10R4/4 clays
3.0 - 3.5	Mottled red 10R4/8, brown 7.5YR4/4 and reddish yellow 7.5YR6/8 ferricrete nodules with light grey clay
3.5 - 4.0	Light grey silty clay
Silty fine-grained sand	
4.0 - 4.5	Mottled light bluish grey, red and orange yellow clayey silt to fine-grained sand
4.5 - 5.0	Light greenish grey 8/10Y clayey silt to fine-grained sand, some strong brown 7.5YR5/8 partings
Clays	
5.0 - 5.5	Mottled light greenish grey 8/5GY, red 7.5R4/6, strong brown 7.5YR5/8 and yellow 10YR7/8 clays
Clayey fine-grained sand	
5.5 - 6.0	Mottled light greenish grey 8/10Y, red 10R4/8 and brownish yellow 10YR6/8 clayey sands
6.0 - 6.5	Mottled light greenish grey 8/10Y, red 10R4/8 and brownish yellow 10YR6/8 clayey sands
6.5 - 7.0	Damp variegated light grey, red, yellow and strong brown clayey fine-grained sands
7.0 - 7.5	Mainly light grey clayey fine-grained sands
7.5 - 8.0	Very damp mottled light greenish grey, red, strong brown and yellow clayey fine -grained sand
8.0 - 8.5	Hard brown and yellow ferricrete/limonite band with light bluish grey 8/10B clayey fine-grained sand with yellowish red 5YR5/8 and brownish yellow 10YR6/8 layers
8.5 - 9.0	Mainly white clayey fine-grained sand with yellow and strong brownish yellow mottles
Nodular to gravely ferricrete	
9.0 - 9.5	Nodular and cemented yellow 10YR7/8 limonite and red 10R4/8 ferricrete with some black manganese oxide and hard brown iron oxide partings. Also a thin hard dark brown quartzitic layer
9.5 - 10.0	Brown and yellow gravely ferricrete, coarse-grained sand and gravel
Silty mudstones	
10.0 - 10.5	Light grey weathered clayey siltstone some brown partings
10.5 - 11.0	Grey weathered silty mudstones
Clayey fine-grained sandstone	
11.0 - 11.5	Mottled light bluish grey 8/5PB, red 2.5YR5/8, yellowish red 5YR5/8 to yellowish brown 10YR5/8 weathered clayey fine-grained sandstone
Weathered mudstones	
11.5 - 12.0	Light grey weathered mudstones
12.0 - 12.5	Dark grey to grey weathered mudstone with brown partings
12.5 - 13.0	Dark grey weathered shaley mudstones with brown partings
13.0 - 13.5	Dark grey weathered shaley mudstones with red and brown partings
13.5 - 14.0	Grey to dark grey weathered mudstones with red 7.5R4/8 and strong brown 7.5YR5/8 partings
14.0 - 14.5	Grey weathered blocky shale with pale yellow 5Y8/4 partings

14.5 - 15.0	Dusky red 5R3/4 band within reddened dark grey mudstones
Grey mudstone some gypsum	
15.0 - 15.5	Soft grey weathered shaley mudstones
15.5 - 16.0	Soft grey weathered shaley mudstones with prominent yellowish brown 10YR5/8 layer
16.0 - 16.5	Grey to dark grey soft weathered shaley mudstones, some white gypsum
16.5 - 17.0	Dark grey to black weathered carbonaceous mudstones
17.0 - 17.5	Soft grey to black carbonaceous shaley mudstones with brownish yellow 7.5YR5/6 partings, some gypsum or barytes
Black carbonaceous mudstones some gypsum	
17.5 - 18.0	Black carbonaceous mudstone with brownish yellow partings and some gypsum
18.0 - 18.5	Black carbonaceous mudstone
18.5 - 19.0	Grey black carbonaceous shaley mudstone with odd hard siltstone band, some water from hard band
Grey mudstones	
19.0 - 19.5	Dark grey weathered mudstone
19.5 - 20.0	Dark grey weathered mudstone
20.0 - 20.5	Dark grey carbonaceous mudstone
Dark grey to black carbonaceous mudstones	
20.5 - 21.0	Dark grey black carbonaceous mudstone
21.0 - 21.5	Black carbonaceous mudstone, very soft
21.5 - 22.0	Black carbonaceous mudstone, very soft
22.0 - 22.5	Dark grey to black carbonaceous mudstone, very soft
22.5 - 23.0	Black very carbonaceous mudstone very soft
Dark grey mudstones	
23.0 - 23.5	Dark grey very soft mudstones
23.5 - 24.0	Dark grey very soft mudstones
24.0 - 24.5	Dark grey very soft mudstones
24.5 - 25.0	Dark grey soft mudstones
25.0 - 25.5	Soft dark grey mudstone
25.5 - 26.0	Soft grey to dark grey mudstone
26.0 - 26.5	Dark grey soft mudstone
Dark grey to black carbonaceous mudstones	
26.5 - 27.0	Dark grey to black carbonaceous soft mudstone
27.0 - 27.5	Dark grey to black carbonaceous soft mudstone
27.5 - 28.0	Dark grey to black carbonaceous soft mudstone
28.0 - 28.5	Dark grey to black carbonaceous soft mudstone with silty horizons
28.5 - 29.0	Dark grey very soft mudstones
Black sandy carbonaceous mudstones	
29.30 - 29.40	Black compact carbonaceous mudstones, some light grey sandy lumps
29.40 - 29.57	Compact black carbonaceous mudstones becoming sandier below 29.50m
29.57 - 29.70	Dark grey to black sandy carbonaceous blocky mudstones, grey fine-grained sandstone layer below 29.67m
29.70 - 29.82	No core
29.82 - 29.92	Black compact carbonaceous mudstones with thin fine-grained sandstone stringers
Dark grey to black muddy fine-grained sandstones	
29.92 - 29.98	Black to grey muddy fine-grained sandstone
29.98 - 30.20	Compact black carbonaceous mudstone, some grey fine-grained sandstone stringers
Dark grey to black muddy fine-grained sandstones with carbonaceous mudstones	
30.20 - 30.23	Black to grey muddy fine-grained sandstone
30.23 - 30.42	Very sandy black carbonaceous compact mudstone with much thin grey fine-grained sandstone bands
30.42 - 30.52	Compact sandy black carbonaceous mudstones with numerous light grey sandstone stringers
30.52 - 30.60	Grey and dark green chloritic fine grained muddy sandstone, several bright green sandy masses
30.60 - 31.90	Dark grey to black shaley splintery mudstones

Lithological Log: BGS49

Soil/ferricrete horizon	
0.0 - 0.5	Yellowish red 5YR5/8 sandy soil
0.5 - 1.0	Yellowish red 5YR5/6-8 sandy soil
1.0 - 1.5	Black centred nodules of manganese oxide and dark red haematite nodules, some white clay
1.5 - 2.0	Red, black and brown laterite nodules surrounded by white and pale yellow clays
Clayey very weathered horizon	
2.0 - 2.5	Mottled red, yellow, brown and white clays
2.5 - 3.0	White, dark red and pink clays
3.0 - 3.5	Mottled red, yellow and white silty clays
Weathered sandy clays	
3.5 - 4.0	Mottled red, light grey and orange-yellow sandy clay
4.0 - 4.5	Mottled dark red, light grey and yellowish brown sandy clays
4.5 - 5.0	Mottled red, light grey and yellowish brown very sandy clay
5.0 - 5.5	Mottled red, light grey and yellowish brown very sandy clay
Weathered clayey sand	
5.5 - 6.0	Gravely layer - mottled light grey, yellow and red clayey fine-grained sand with hard dark red haematite layer
6.0 - 6.5	damp - light bluish grey clayey sand with dark red oxide nodules and yellow mottles
Clayey fine- to medium-grained sand	
6.5 - 7.0	Very damp - light grey to white clayey fine- to medium-grained sand
7.0 - 7.5	Light grey clayey fine- to medium-grained sands with reddish yellow and yellowish brown mottles
7.5 - 8.0	Light grey clayey fine- to medium-grained sands with reddish yellow and yellowish brown mottles
8.0 - 8.5	Light grey clayey fine- to medium-grained sands with reddish yellow and yellowish brown mottles
Hard broken nodular ferricrete	
8.50 - 8.59	Hard nodular ferricrete composed of rounded pisoliths up to 5mm diameter of yellow, orange, red and brown iron oxy-silicates with dark purple sandy siliceous cement
8.59 - 8.64	Broken hard nodular ferricrete composed of rounded pisoliths up to 5mm diameter of yellow, orange, red and brown iron oxy-silicates with dark purple sandy siliceous cement
8.64 - 8.67	Hard, mainly yellow brown nodular ferricrete
8.67 - 8.70	Broken hard, mainly yellow brown nodular ferricrete
Clayey fine sand	
8.70 - 8.72	Light grey clayey fine sand
Ferricrete	
8.72 - 9.05	Gravely yellow brown ferricrete, compact and hard with tubular horizons and black manganese oxide cemented layers
Sandy clay to clayey sand	
9.05 - 9.20	Light grey and brown yellow interbedded sandy clay and clayey fine to medium grained sands. Sandy layers commonly brown with red partings
9.20 - 9.25	Light grey sandy clay
9.25 - 9.30	Yellow brown clayey sand
Ferricrete	
9.30 - 9.36	Hard yellow brown nodular ferricrete
Clayey sands and clays	
9.36 - 9.50	Light grey and yellow brown clayey sands, the brown sand horizons are more permeable
9.50 - 9.64	Variegated red, dark grey, light grey, yellow and yellow brown clays
9.64 - 9.71	Mottled grey and yellow brown fine to medium clayey sand
Clays with anhydrite nodules and hard ironstones	
9.71 - 10.03	Mottled light grey and brownish yellow 10YR6/8 to yellowish brown 10YR5/6 clays
10.03 - 10.24	Light grey to grey clays with yellowish brown and pale brown layers with small

	nodules of white anhydrite
10.24 - 10.31	Thin bands of dusky red 7.5R3/4 nodular iron oxide up to 5mm thick within lower part of the light bluish grey and yellow brown clays
Mudstones with nodules of anhydrite and iron stones	
10.31 - 10.40	Weathered yellow brown and light grey silty mudstones, very soft
10.40 - 10.43	Dusky red layer of tabular nodules of hard iron oxide
10.43 - 10.50	Very weathered light brown to yellowish brown mudstones, some anhydrite gypsum

Lithological Log: BGS50

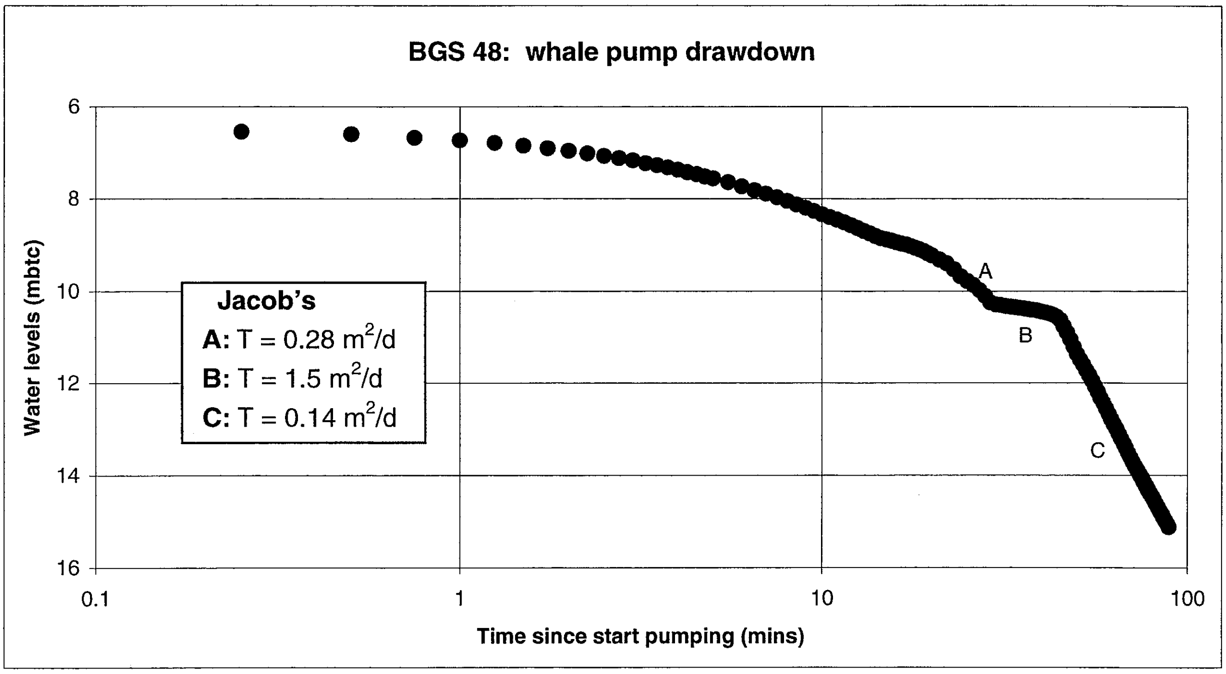
Soil/ferricrete horizon	
0.0 - 0.5	Very dark grey 2.5Y3/1 top soil above brown 10YR4/3 sandy soil
0.5 - 1.0	Light olive brown 2.5Y5/4 clayey fine-grained sand of weathered dolerite
Very weathered doleritic fine-grained sand and clay	
1.0 - 1.5	Dark yellowish brown 10YR4/6 clayey sand with layers of grey 5Y5/1 clay between core stones
1.5 - 2.0	Dark yellowish brown 10YR4/4 weathered dolerite fine-grained sand with some grey 5Y5/1 clay between corestones
2.0 - 2.5	Dark yellowish brown 10YR3/6 weathered dolerite fine-grained sand, with increased black fragments, with some grey 5Y5/1 clay between corestones
Weathered dolerite	
2.5 - 3.0	Dark yellowish brown 10YR3/4 weathered dolerite
3.0 - 3.5	Dark yellowish brown 10YR4/6 weathered dolerite with many black fragments
3.5 - 4.0	Dark yellowish brown 10YR4/6 weathered dolerite with increased black fragments
4.0 - 4.5	Dark brown black weathered dolerite
4.5 - 5.0	Dark brown black weathered dolerite, hard after 4.70m. First water struck at 4.70
5.0 - 5.5	Hard light green and soft brown layers
5.5 - 6.0	Weathered brown and hard black fragments of dolerite
6.0 - 6.5	Black and green medium grained hard dolerite
6.5 - 7.0	Soft dark green/brown weathered dolerite
7.0 - 7.5	Soft dark green/brown weathered dolerite
7.5 - 8.0	Brownish dark green very weathered dolerite
Medium grained dolerite	
8.0 - 8.5	Black and green medium-grained dolerite
8.5 - 9.0	Black and green medium-grained dolerite
9.0 - 9.5	Black and green medium-grained dolerite
9.5 - 10.0	Black and green medium-grained dolerite
10.0 - 10.5	Black and green medium-grained dolerite
10.5 - 11.0	Black and green medium-grained dolerite, water struck
11.0 - 11.5	Black and green medium-grained dolerite
11.5 - 12.0	Black and green medium-grained dolerite, some fracturing
12.0 - 12.5	Black and green medium-grained dolerite
12.5 - 13.0	Black and green medium-grained dolerite
13.0 - 13.5	Hard black and green medium-grained dolerite
13.5 - 14.0	Black and light green medium-grained dolerite, some dark brown patches and veined fractures
14.0 - 14.5	Hard black and green medium-grained dolerite, water struck
Medium to coarse-grained dolerite with white zeolite	
14.5 - 15.0	Black and green medium- to coarse-grained dolerite with occasional zeolite vein
15.0 - 15.5	Black and dark green medium- to coarse-grained hard dolerite with occasional zeolite vein
15.5 - 16.0	Black and green medium to coarse-grained dolerite
16.0 - 16.5	Black and dark green medium-grained hard dolerite with occasional zeolite vein
16.5 - 17.0	Black compact fine-grained hard dolerite with some thin bands of white zeolite
Dolerite baked purple grey fine-grained sandstone contact zone	
17.0 - 17.5	Contact zone between dolerite and hard purple grey baked sandstones, some white zeolite and iron pyrite along fracture zones - more water
17.50 - 17.66	Dark purple grey hard baked silty fine-grained sandstone, fractured, fractures infilled with iron pyrite
Fine-grained fractured dolerite	
17.66 - 18.20	Dark grey purple fine-grained dolerite, a series of parallel intrusions. Dolerite is broken to 17.90 with much chlorite and iron pyrite formation on fracture surfaces. Below 17.90 dolerite layers are more compact separated by thin layers of hard dark purple silty sandstones, much fracturing with iron pyrite deposition along the fractures

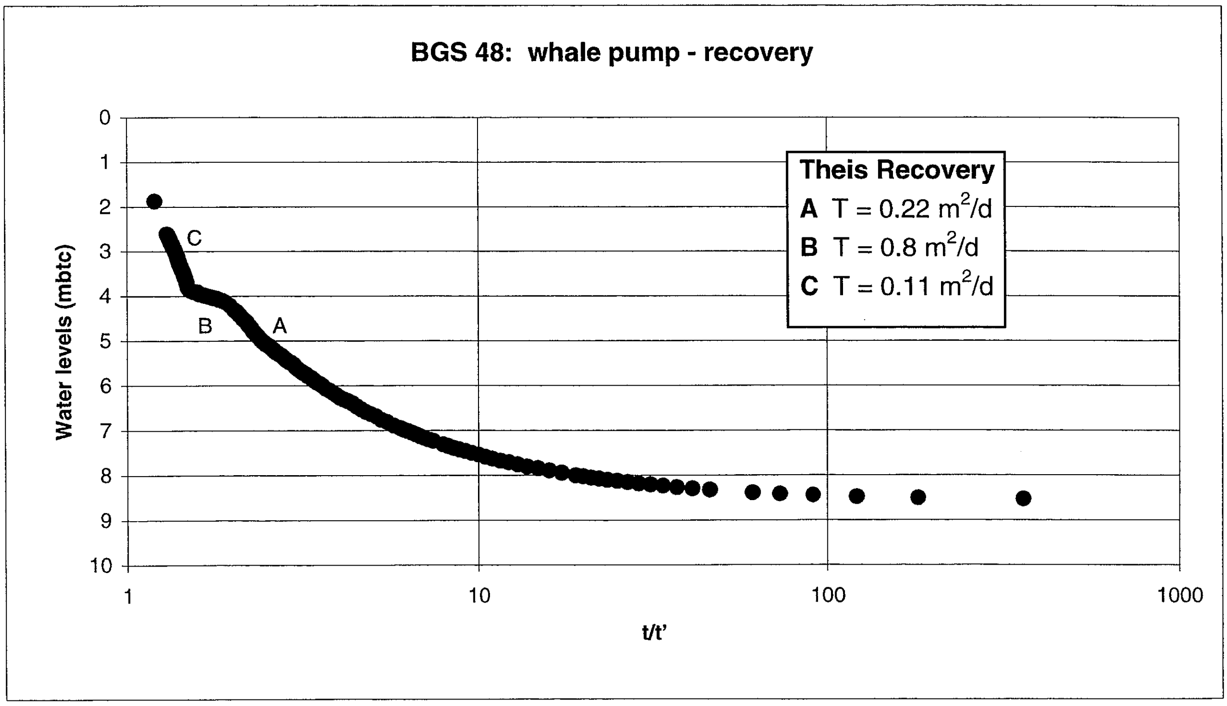
Light grey silty fine-grained sandstone	
18.20 - 18.66	Grey to light grey hard baked siltstones and silty fine-grained sandstones. Iron pyrite deposited along occasional sub-vertical fractures
18.66 - 18.71	Thin light grey to dark greenish grey fining upward ash? bands capped with thin layer of iron pyrite
18.71 - 18.85	Light grey very silty fine-grained sandstone mildly baked?, iron pyrite line sub-vertical fractures
18.85 - 19.38	Light grey fine-grained sandstone? sand grains set within a very fine silty to clayey matrix. Some sub-vertical iron pyrite lined fractures. Occasional coarser bands at 18.93 and between 19.36-19.38, the latter being a fining upwards band
19.38 - 19.85	Homogeneous light grey sandy? very fine-grained clayey siltstone, parallel bedding with sand grains set in fine grained matrix
19.85 - 20.0	Light grey silty fine-grained sandstone
20.0 - 20.5	Light grey silty fine-grained sandstone
Light grey shaley siltstones	
20.5 - 21.0	Light grey to grey evenly bedded spotted grey siltstone
21.0 - 21.5	Light grey shaley siltstone with grey spots
21.5 - 22.0	Grey shaley siltstone with grey spots
22.0 - 22.5	Soft light grey shaley siltstone with grey spots
22.5 - 23.0	Soft light grey siltstone evenly bedded with grey spots on bedding planes, some iron pyrite
23.0 - 23.5	Soft light grey siltstone with grey spots
23.5 - 24.0	Soft light grey siltstone with grey spots
Shaley grey mudstones	
24.0 - 24.5	Soft shaley grey mudstones
24.5 - 25.0	Soft shaley grey mudstones
25.0 - 25.5	Dark grey mudstones
25.5 - 26.0	Grey to dark grey shaley mudstones
26.0 - 26.5	Dark grey soft shaley carbonaceous mudstone
Shaley black carbonaceous mudstone	
26.5 - 27.0	Splintery to shaley fairly hard black carbonaceous mudstones
27.0 - 27.5	Fairly hard shaley black carbonaceous mudstone
27.5 - 28.0	Shaley black carbonaceous mudstone
28.0 - 28.5	Shaley black carbonaceous mudstone
28.5 - 29.0	Shaley black carbonaceous mudstone
29.0 - 29.5	Dark grey soft carbonaceous mudstone
Dark grey pyritic carbonaceous mudstone, sandy in parts	
29.50 - 29.88	Dark grey pyritic shaley to splintery hard, brittle mudstones with much iron pyrite on uneven bedding planes
29.88 - 30.06	Dark grey to black carbonaceous mudstones, fairly hard with uneven bedding, some iron pyrite along bedding planes
30.06 - 30.07	Dark grey muddy fine-grained sandstone band
30.07 - 30.45	Black carbonaceous soft mudstones, some iron pyrite filled veins in soft bands
30.45	Thin light grey fine-grained sandstone band
30.45 - 30.83	Dark grey parallel bedded shaley mudstones, some iron pyrite
30.83 - 31.50	Fairly hard parallel bedded dark grey shaley mudstone, much iron pyrite along sub-vertical fractures
Black carbonaceous mudstones	
31.50 - 31.63	Unevenly bedded black carbonaceous mudstone
31.63 - 31.66	Black ashy fine-grained black carbonaceous mudstone - baked horizon? adjacent to possible hard band
31.66 - 31.75	Black carbonaceous mudstones, sandy in parts with uneven bedding

Annex 4: Pump test data

BGS 48: whale pump test

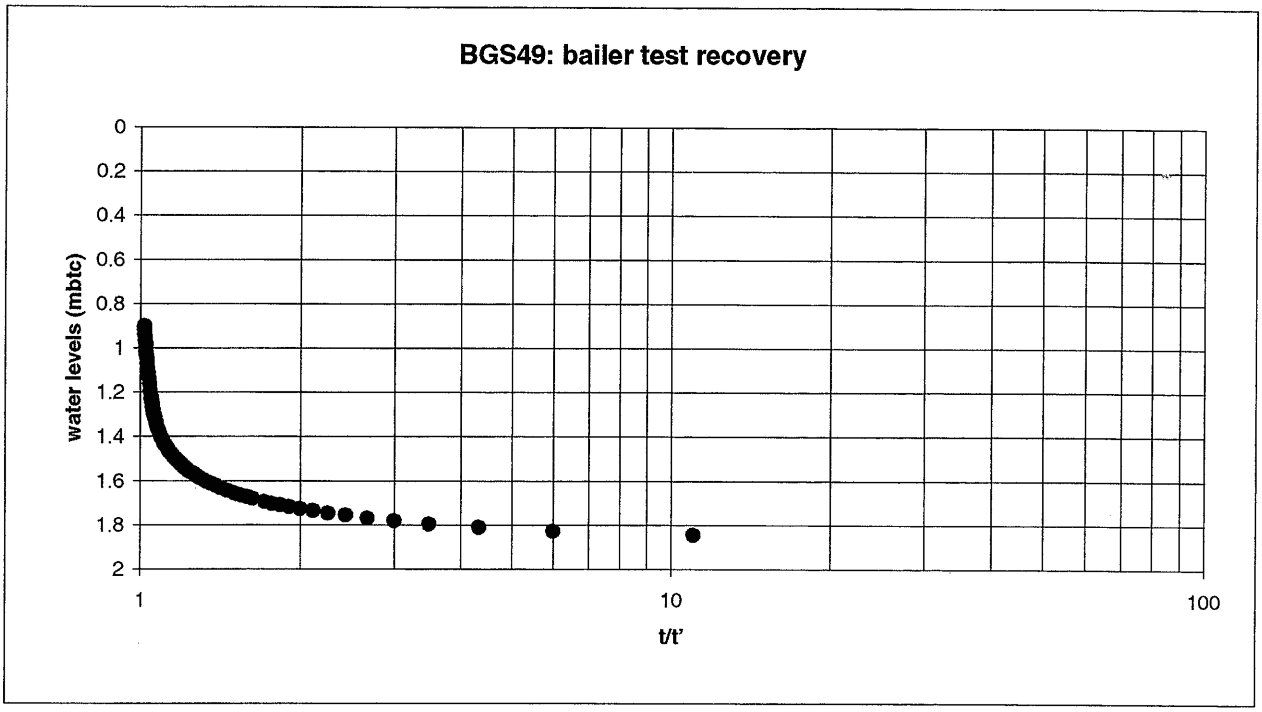
GPS: 7 degs 5.972 8 degs 22.168
date 10/02/98
casing 0.15 m
rwl: 6.415 m btc
whale pump 60 m deep
length of test; 90 minutes
pumping rate = 0.15l/s - 0.11 ls
average rate = 0.13 l/s = 11.2 m3/d

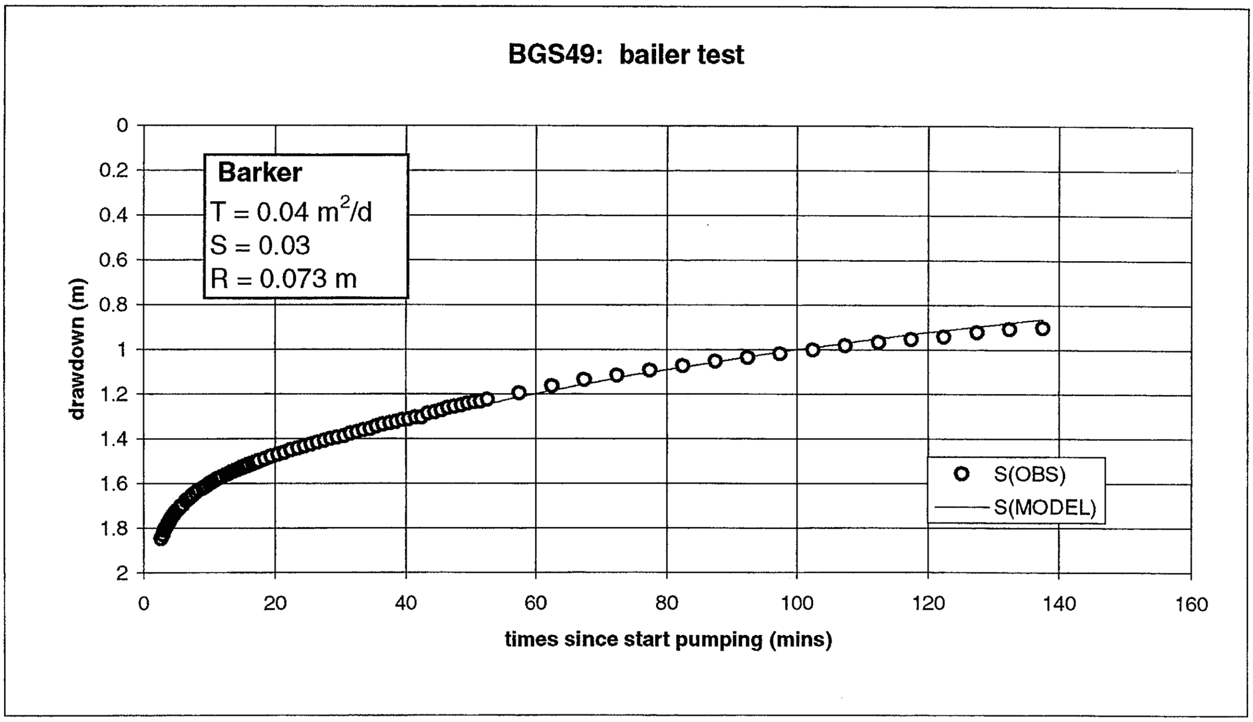




BGS49: bailer test

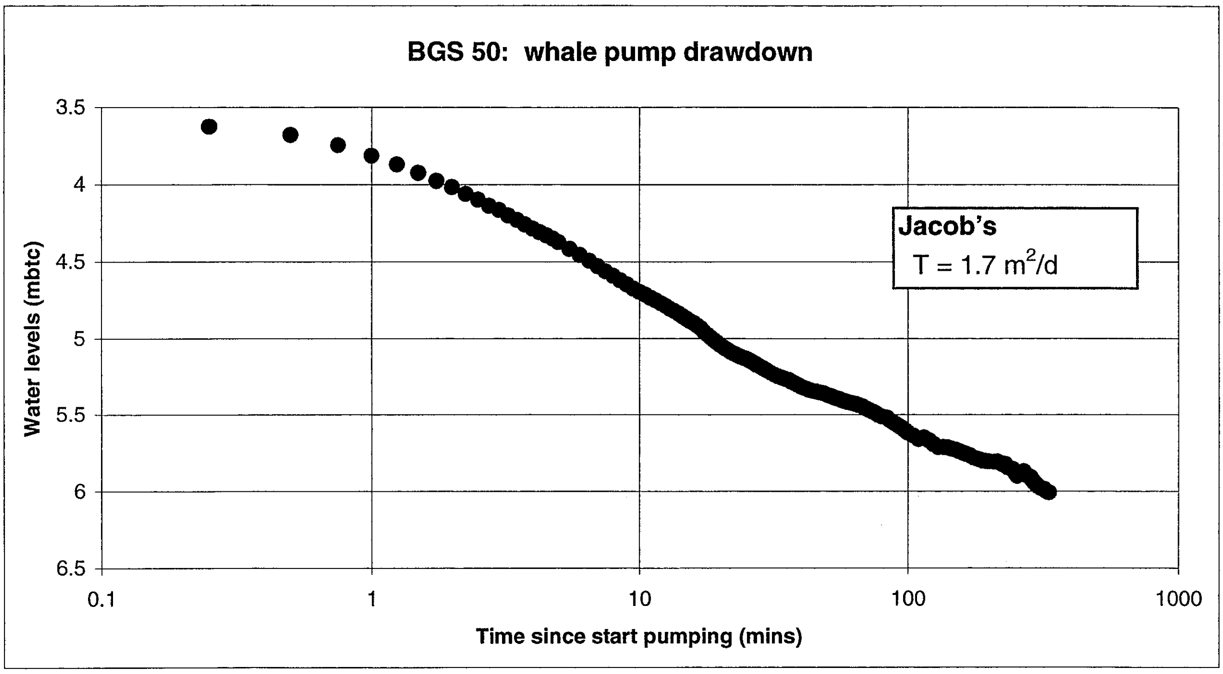
GPS: 7 degs 5.972 8 degs 22.168
date 10/02/99
casing 0.65 m
rwl: 6.722 m
7 bails in 2.5 mins
pumping rate = 0.21 l/s - 17.8 m3/d

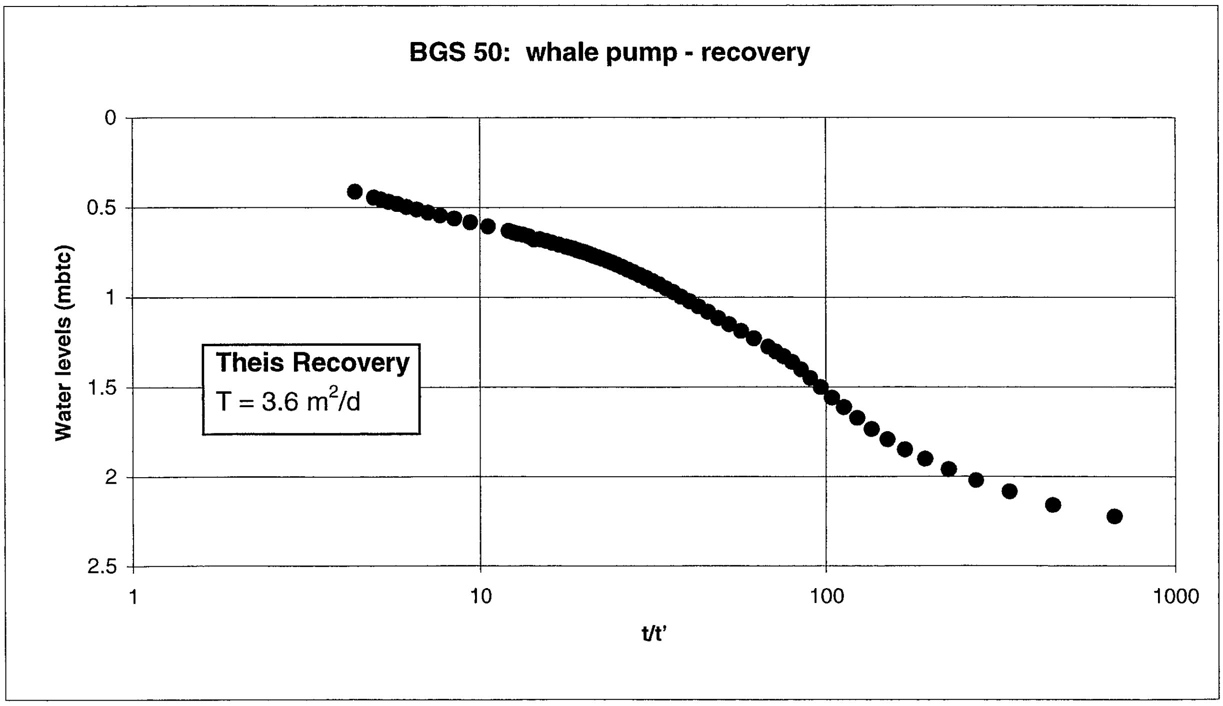




BGS 50: whale pump test

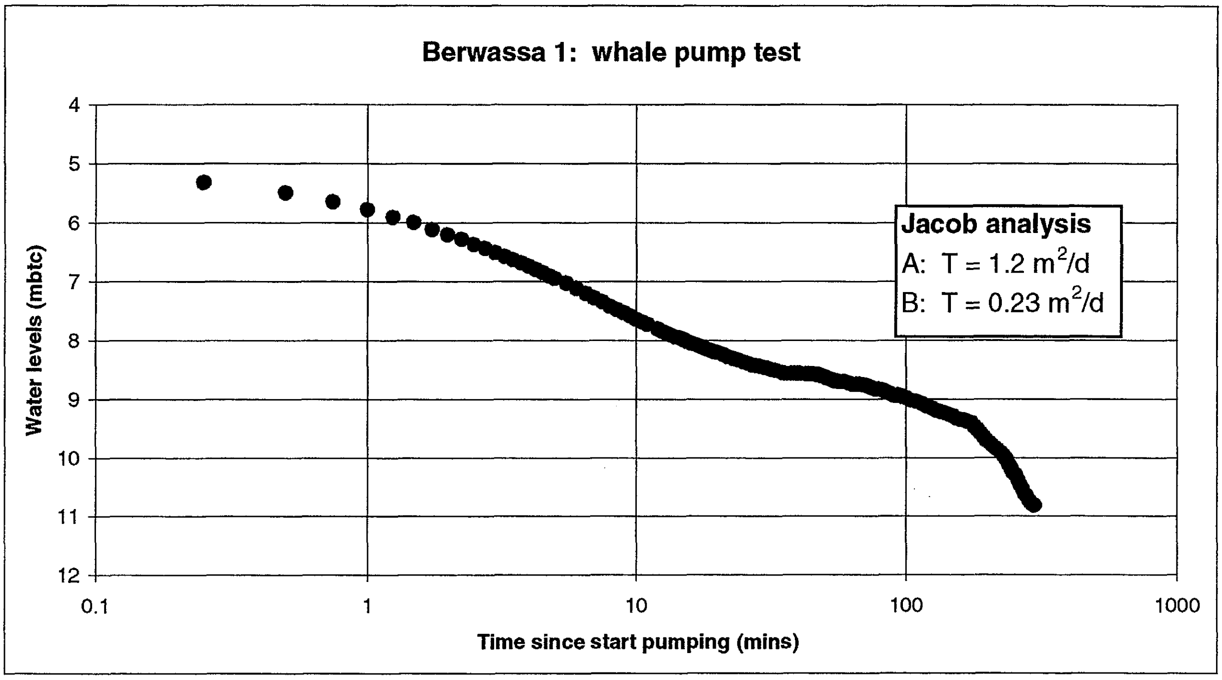
GPS: 7 degs 02.743; 8 degs 21.116
date 11/02/99
casing
rwl: 3.53 m btc
whale pump
length of test; 335 minutes
pumping rate = 0.12l/s = 10.4 m3/d

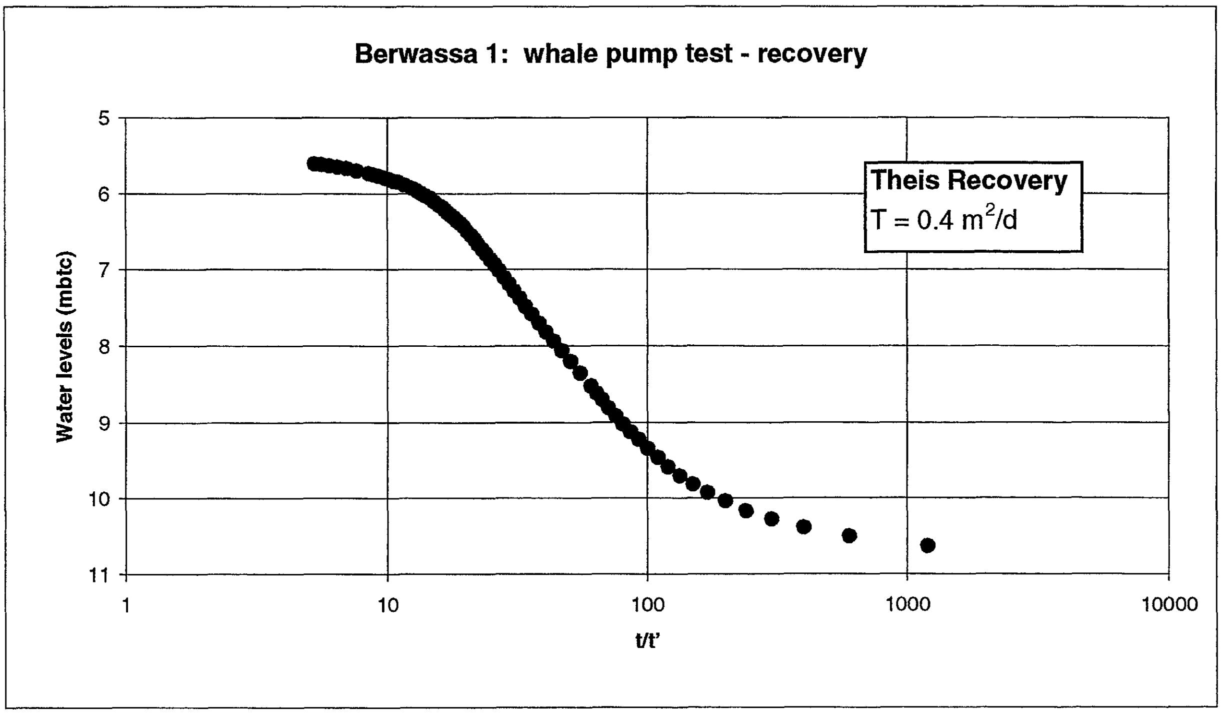




Berwassa 1: whale pump test

GPS: 7 degs 2.12' 8 degs 21.053'
date 05/02/99
casing 0.56 m
rwl: 5.056 m
pump at 12.5 m
length of test; 300 minutes
pumping with one whale pump: 0.125 - 0.1 l/s
average over test = 0.11 l/s = 9.5 m3/d





berwassa 2: bailer test

GPS: 7 degs 2.204' 8 degs 21.115
date 11/02/99
casing
rwl: 5.66 mbtc
43 bails in 14:46 mins
pumping rate = 0.24 l/s - 21 m3/d