British Geological Survey

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Overseas Geology Series

DFID Project No.

Monitoring the Installation of a Series of Water Supply Boreholes: Afram Plains, Ghana

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Front cover illustration: Four women are required to operate a deep-set India MkII hand-pump at the World Vision installed borehole at Nyambakyere

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Executive Summary

The Afram Plains is a remote area bounded on three sides by the Volta Lake. The area experiences water supply difficulties especially during the annual dry season. The hydrogeology of the underlying Voltaian sediments is poorly understood. WaterAid, with its partners, and World Vision have been developing the groundwater resources of the area during the last ten years. Drilling success rates are low, possibly 30-50%, due to the geological complexity of the area. Some understanding of the hydrogeology of the area has been achieved but there is insufficient data for resource assessment.

Geomechanik were contracted to drill up to 17 boreholes during the January – March 2000 period, funded by WaterAid and DfID. A BGS hydrogeologist visited the area to collect information on the hydrogeology of the Afram Plains area and monitor siting, drilling and construction methods used during the installation of some of these boreholes. The information will be used to help inform a DfID project on simple methods for resources assessment. The BGS hydrogeologist accompanied the Geomechanik hydrogeologist during the siting of several boreholes. He also monitored the drilling and construction of six boreholes and logged geological samples from eight boreholes. The interaction of APDO staff with the drilling company during these operations was observed. A representative series of geological exposures of rock types occurring in the area were inspected and these related to topographic features. The location of drilling sites using geological and geomorphologic features was discussed with APDO staff.

The sediments of the Voltaian system are horizontally bedded. The sediments change from sandstone in the west to conglomerate in the east. Shales and mudstones crop out in the south of the area and also underlie the sandstones and conglomerates. These rocks have undergone numerous periods of weathering and low grade metamorphism that has resulted in the sandstone being cemented with iron and manganese oxides. The sandstones are massive and poorly jointed, some layers appear to be cemented with calcium carbonate, as indicated by karst type weathering. The pattern of drainage appears to be fault controlled. Groundwater occurrence is related to poorly developed secondary fracturing within a tight, massive formation. No geological data are available from below 70m depth, the maximum depth of drilling. Conglomerates are exposed along narrow incised valleys where the effects of faulting and jointing appear to be more marked, with increased secondary permeability. The underlying shales are thought to be tight with low permeability, although no survey has been undertaken.

The use of simple test pumping methods, using a bailer or a low capacity 12vDC Whale pump, were demonstrated to APDO staff. The drilling equipment used by Geomechanik is of high quality. Methods of siting, sampling and test pumping need to be improved. Well design needs to be amended to meet the requirements of the CWSC guidelines. A detailed database of all boreholes, dry and wet, drilled in the Afram Plains would help understanding of the groundwater resource.

APDO need to ensure collection of appropriate data and accurate locations for all wet and dry boreholes for storage in their district data-base. All sites need to be accurately located using a GPS and located upon 1:50 000 scale base maps. Pronet, the WaterAid advisory NGO, needs to be more proactive towards WaterAid projects by ensuring that field officers observe and record works on site thereby maintaining their knowledge and database.

The basic contract document between WaterAid and Geomechanik needs to be re-drafted to reflect how water occurs within the Voltaian system with better definition of siting methods to be used, more appropriate depths of drilling, and so that borehole construction conforms to national standards.

There is a need to undertake a detailed study of the geology of the area to gain improved understanding of hydrogeological systems and to assess of how groundwater exists, with determination of hydraulic parameters. It would be helpful to have organisations such as the Geological Survey and universities involved.

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Acronyms and Abbreviations

APDO	Afram Plains Development Organisation
BGS	British Geological Survey
BHC	British High Commission
CSIR	Centre for Scientific and Industrial Research
CWSD	Community Water and Sanitation Division
DANIDA	Danish Aid
DfID	Department for International Development
DRI	Desert Research Institute
GIS	Geographic Information System
GPS	Global Positioning System
KAR	Knowledge and Research
NGO	Non-governmental Organisation
WRI	Water Research Institute

1. INTRODUCTION

Groundwater development problems are experienced within the Afram Plains area of Eastern Ghana. Access to potable water supplies is limited; groundwater development is constrained by geological conditions. During a visit to the Afram Plains in June 99 as part of the DFID KaR project "Groundwater from low permeability rocks in Africa" it was recommended that a hydrogeologist was present for part of the 99/00 drilling programme to help identify the practices of local contractors and increase understanding of the hydrogeology of the area.

WaterAid contracted Geomechanik to site and drill 17 boreholes during the January-March 2000 dry season. WaterAid's local NGO partner, the Afram Plains Development Organisation (APDO), supervised these works. This report details the findings by a British Geological Survey (BGS) hydrogeologist present for part of the drilling. WaterAid and associated NGOs facilitated the visit from 17th January to 7th February 2000. The visit itinerary is in Appendix 1. The terms of reference required:

- Monitor drilling operations
- Demonstrate borehole sample collection, field analysis and location of each borehole using GPS.
- Demonstrate appropriate borehole test pumping techniques.

Furher study in this area forms part of the KAR project "Groundwater from Low Permeability rocks in Sub-Saharan Africa" (2000-2001). This project recognises the need to train counterpart hydrogeologists and drillers in appropriate methods of borehole data collection. Methods comprise integration of remotely sensed data with borehole, geophysical survey and test pumping data adapted to local geology (developed during a 3-year project with WaterAid in Nigeria, Davies and MacDonald, 1999). The outputs from the Ghana study will be groundwater development maps and simple guidelines for developing groundwater resources.

2. THE AFRAM PLAINS AREA - BACKGROUND

The Afram Plains Area is located in the Eastern Region of Ghana, in the Volta River basin between latitudes 6°30' and 7°30'N and longitude 1°00'W and 0°15'E (Figure 1). About 4285 km^2 in extent, this area lies between lake water level at 76m and 300m above sea level. The area is bounded to the north by the Obosum River, to the south and south-west by the Afram River and to the east by the Volta Lake. The main topographic feature is a low ridge, between 200 and 300m high, that trends NE-SW. It is composed of sandstone in the west and conglomerate in the east. In the eastern part of this ridge, valleys are generally narrow and incised to a depth of 60m or more. Valley systems are typically broader and shallower in the western sandstone. South of the ridge soft shales (Figure 2) underlie the flat lakeside plain.

Average annual rainfall of 1200 mm occurs during the April to October wet season. During the November to March dry season the area is affected by dust laden Harmattan winds blowing south from the Sahara. Surface drainage is mainly ephemeral, water from heavy storms drains away by sheet flow, resulting in short lived floods.

The Afram Plains support typical savannah type vegetation, the low lying lakeside plain covered by coarse tussock-grass with few stunted trees and the better drained ridge area supporting dense bush with large trees. The forested areas of the ridge are being cleared for agricultural use, the trees being used for charcoal. Yams and charcoal are important products of the area.

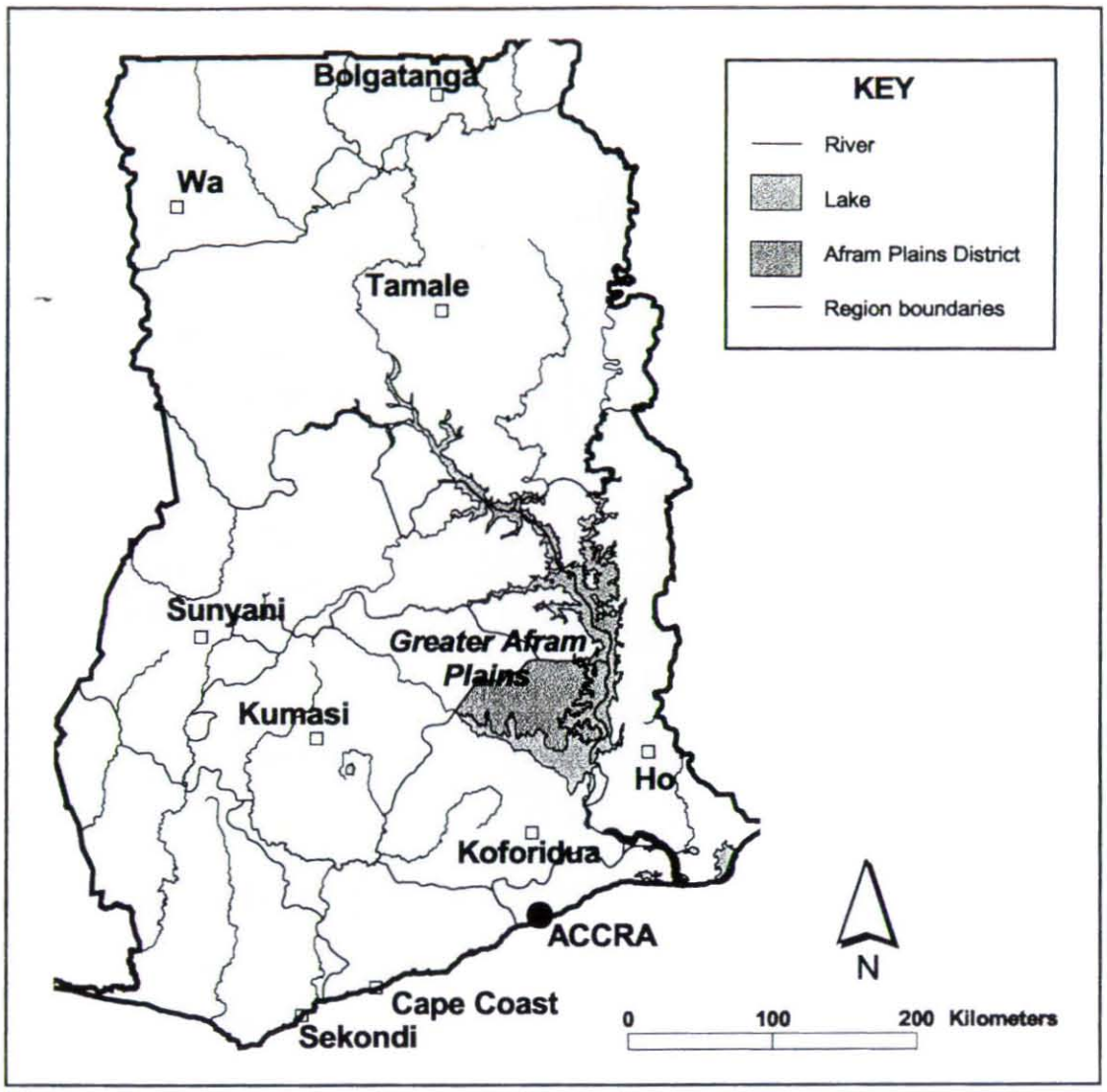

Figure 1 Afram Plains project area location map

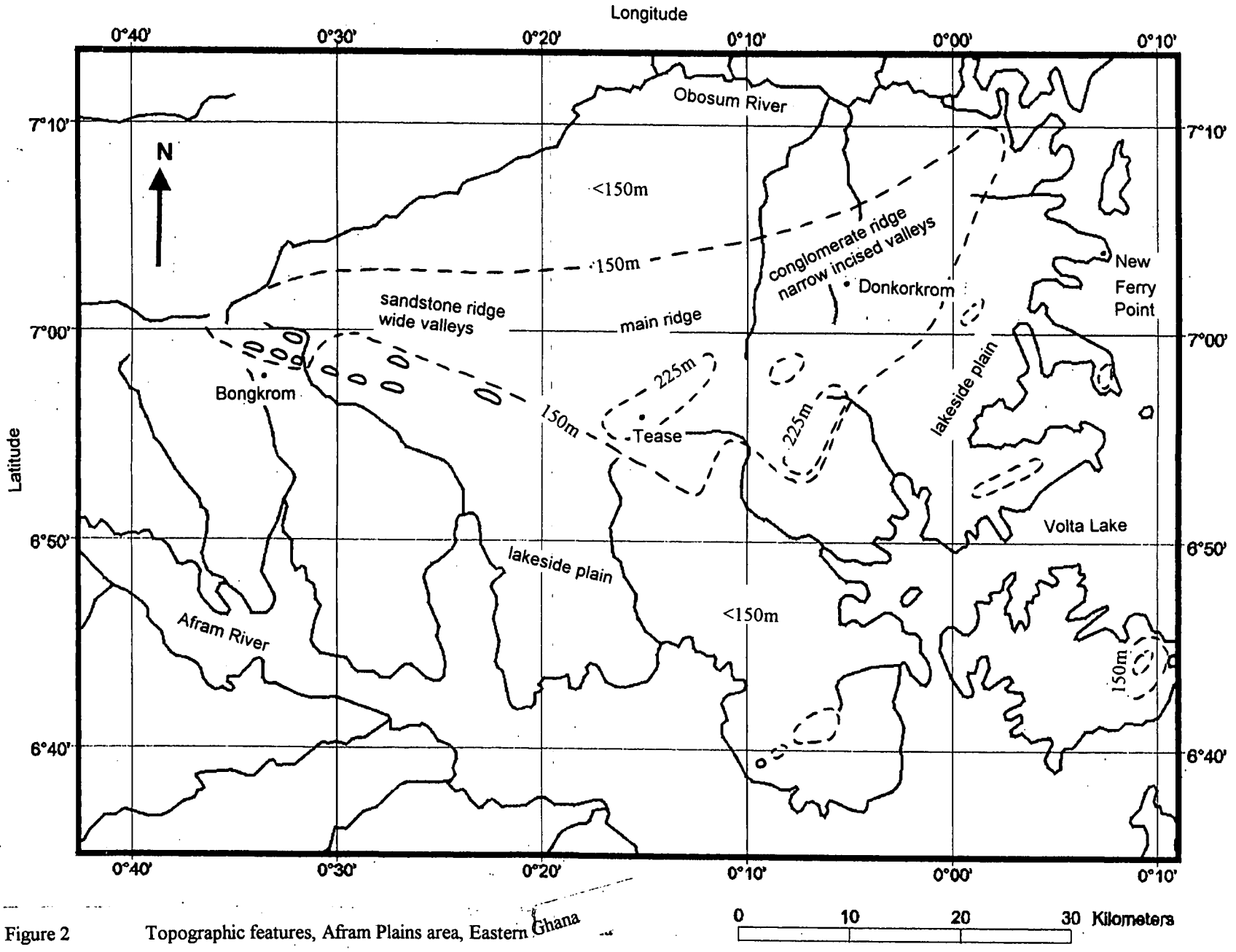

Figure 2 Topographic features, Afram Plains area, Eastern Ghana

Geologically the Afram Plains area is located within the southern part of the Voltaian Basin formed by tectonic movement during the Precambrian to early Palaeozoic Pan-African Orogeny (Grant 1967 and 1969, Shackleton 1976, Ako and Wellman 1985, Black and Liegeois 1993, Castaing et al 1993 and Tidjani 1997). Junner and Hirst (1946), Saunders (1970), Annan-Yorke and Cudjoe (1971), Affaton et al (1980), Kesse (1988) and Anani (1999) describe the Voltaian basin sediments. The Voltaian Formation Obosum Beds of the southern Afram Plains have yet to be studied in detail. Buckley (1986) summarises the geology of the southern Afram Plains. The stratigraphy recognised is listed in Table 1.

Age	Formation	Division		Stratigraphy of the Voltaian Basin according to Junner and Hirst (1946)	Thickness (m)
Lower Palaeozoic	Voltaian	Upper V3	V3b	*Upper Sandstone* Massive, cross-bedded quartz sandstone containing in places beds of shales and mudstones	213.4 m
			V3a	*Thin Bedded Sandstone* Thin bedded flaggy sandstone micaceous ferruginous or feldspathic clay galls and ripple marks common	121.9 m
		Middle V2	V2b	*Obosum Beds* Red, Green, purple, mauve and chocolate arkose, mudstones, conglomerate and some limestones and quartz sandstones cross-bedding common in the sandy and pebbly beds.	152.4 m
			V2a	*Oti Beds* Arkoses, conglomeratic grits, sandstones, mudstones, shales and limestones. Nodular structures common and yellow weathering typical	243.8 m
Infra-Cambrian		Lower V1		*Basal Sandstone* Quartz-sandstone and pebbly grits, grits with ripple marks and galls	61.0 m
Upper Proterozoic	Buem	Buem		Shale, sandstone, arkose and lava	
	Togo	Togo		Quartzite, shale and phyllite	

Table 1 Stratigraphy of the Voltaian Basin from Junner and Hirst (1946)

According to 1970 and 1984 census figures immigration of farmers attracted by fertile soils and improving infrastructure has resulted in a 250% increase in population. APDO assess the current population to be 110,000 (Modoc, 1998). Villages tend to occupy ridge top sites. Medical problems

include malaria, cholera and other water related diseases. The immigrant population has recently introduced guinea worm into the area.

Access is by ferries across the Afram River to the southern village of Ekyiamanfurom and across the Volta Lake from Kpandu.. An all-weather dirt road connects the two ferry points via Tease and Donkorkrom. Access to the north and western areas is via feeder roads and bush tracks into the rural areas, often impassable during the wet season. Telephone communication to the rest of Ghana is via micro-wave link at Donkorkrom.

Access to water supplies in rural areas is difficult especially towards the end of the dry season. Rural water sources include boreholes, shallow wells, seasonal streams and lake water. Gill (1969) produced an outline of the hydrogeology of Ghana, latterly updated by Bannerman and Allison (1991). The Geological Survey Department undertook the first study of the hydrogeology during 1963-65 for the Volta River Authority during the construction of the Volta Dam. During 1984 Prakla Seismos (latterly Geomechanik) drilled 47 water supply boreholes for MISEROR (a West German Catholic NGO) of which 19 were dry (Table 2). Buckley (1986) studied of the hydrogeology of the Tease - Donkorkrom areafor WaterAid, including the use of geophysical surveying methods for borehole siting. The Afram Plains Development Organisation (APDO), formed with WaterAid support in 1986, constructed 15 hand-dug wells during 1986-1992, 6 of which were successful. From 1992 APDO undertook pump and borehole maintenance, hygiene and sanitation education. Between 1990 and 1995 the Conrad Hilton Foundation funded drilling of 152 boreholes in the Afram Plains, 92 of which produced at least 10 l/min (World Vision, 1995). During 1996-1998 WaterAid in association with DfID funded drilling and construction of 68 boreholes of which 23 were dry (Geomechanik, 1996, 1997 and 1998). The Desert Research Institute studied application of remote sensing data to borehole siting in the area (Sander, 1997 and Sander et al, 1997). Acheampong (1996) surveyed groundwater quality of the area. The main groundwater types are CaNa-$ClSO_4$ in the Afram mudstones and CaNaMg-HCO_3 within the sandstones and conglomerates. MacDonald et al (1999) assessed the hydrogeology of the Afram Plains.

Organisation	Period	No. of Bhs	Wet Bhs	Dry Bhs	<11 l/m	<30l/m
Ghana Water and Sewerage Corporation (GWSC) for the Volta River Authority Bannerman 1990	1963-65	10	6			
Prakla Seismos 1984 for MISEREOR (West German Catholic Charity) Buckley 1986, Bannerman 1990	1984	47	28	19	4	11
World Vision (1990-1995)	1990	7	7			
	1990-95	152	92	60		
	2000	70				
WaterAid (1996-1998)	1996	30	25	5		
(see list of boreholes in Appendix 2)	1997	20	10	10	3	4
	1998	18	10	8	2	5
	2000	17				

Table 2 Drilling activities in the Afram Plains area since 1963.

The above studies indicate that limited quantities of groundwater occur in the Obosum sandstones and conglomerates. Moderate borehole success rates were achieved in the Donkorkrom area conglomerates. Within the less permeable massive sandstones in the western ridge area lesser groundwater resources occur. Groundwater occurrence within the Afram Shales has yet to be investigated. Results from the World Vision 1990-1995 programme indicate that

- the average drilling depth was 55m although dry boreholes have been drilled to 77m
- borehole yields of 10-960 l/min were determined. Water was struck at 1-41m with static water levels of 1-20m.
- the aquifers are semi-confined with low primary permeability and some secondary permeability along fracture zones.

Although World Vision and Geomechanik initially used geophysical surveys the hydrogeologists of both organisations now undertake borehole siting using geomorphologic and vegetation features alone. Aerial photography, landsat imagery or 1:50,000 scale topographic maps are not used for site location. Without use of GPS these sites are not accurately located.

Acheampong (1999) determined transmissivities of 1-71.6 m^2/day for sandstone aquifers using data from test pumping of 28 boreholes by Prakla Seismos during 1984. Test pumping data produced by Geomechanik during 1996-98 programmes have still to be assessed. Sandstones are well cemented with iron and manganese oxide and therefore have low intrinsic permeabilities. There is no data describing size or density of fracture zones, nor are there data describing geological processes such as facies of sediment deposition, structure, rates of burial or rates of denudation (Acheampong, 1999).

3. CURRENT METHODS

Siting, drilling and borehole construction by Geomechanik were observed at nine sites, using procedures similar to those of World Vision. Geomechanik regard boreholes yielding more than 7 l/min as successful. Borehole siting and drilling are dry season activities since roads are generally impassable during the wet season.

3.1 Borehole Siting

The Geomechanik hydrogeologist demonstrated location of borehole drilling sites at two villages. At each village the community selected three sites which were then assessed by the hydrogeologist. If these prove dry on drilling the hydrogeologist will locate three more sites. This hydrogeologist uses "local knowledge", geomorphology, drainage and vegetation features to locate sites. Site location tends to be cursory, carried out a day or so before drilling. As mentioned above no use is made of geophysical surveys, aerial photography, topographic maps or, landsat image interpretation.

3.2 Borehole Drilling

Geomechanik uses a mobile drilling unit mounted upon three vehicles (Plates 1 and 2). The German manufactured drilling rig, mounted on a 6x4 truck chassis, has a nominal drilling capacity of 400m at 5.5" (140mm) diameter. An Atlas Copco compressor is mounted upon a 4x4 truck. The third vehicle, a support 6x4 truck, carries water and fuel tanks, casing, screen, temporary steel casing, drilling bits and drilling rods. During drilling, the sub-surface soft weathered material is drilled with a 206mm-diameter drag bit. This formation is cased with temporary 7" (178mm) diameter flush joint steel pipe. Hard rock formations are drilled using a high pressure down the hole hammer with a $6^1/_8$" (155mm) diameter button bit. NB. Settlement of the rig during drilling due to a leaking jack seal probably resulted in the drilling of corkscrewed boreholes at several sites. Dust produced during drilling

Plate 1 Geomechanik drilling rig mounted upon a 6x4 tuck chassis with Atlas Copco compressor mounted on a 4x4 truck chassis at Asanyansu borehole drilling site

Plate 2 Geomechanik 6x4 support vehicle with diesel and water tanks, and racks for casing, screen, drill pipe and drilling tools at Nyambakyere

Plate 3 Dusty conditions when drilling with compressed air at Nsareye "A".

Plate 4 Samples of drill cuttings as taken by the drill crew through black siltstone formation at Akura borehole

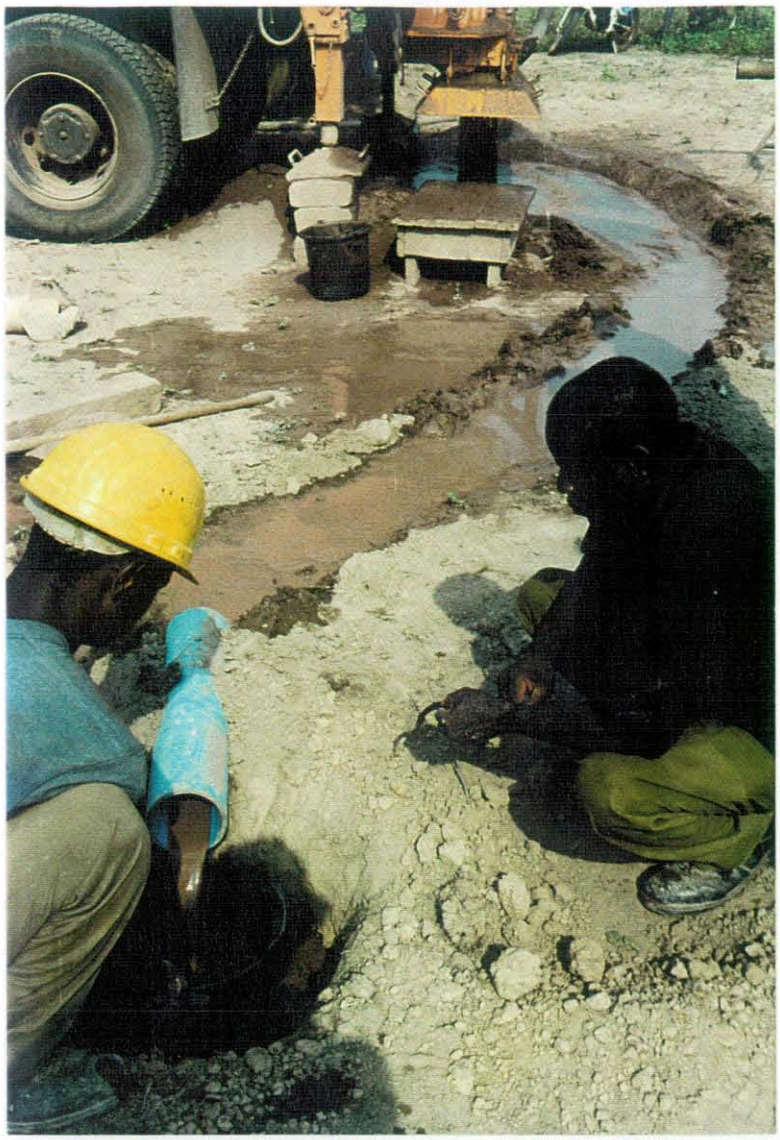

Plate 5
Testing borehole yield during drilling at the end of each three-metre drill rod after water has been struck, at Asanyansu.

Plate 6 Cleaning completed borehole using compressed air at Nyambekyere

adversely affects the compressor and rig power train and drilling staff. Sensible use of water injection would reduce the amount of rock dust produced without hindering recognition of water strike zones (Plate 3).

Lithological samples are obtained at 1m intervals and stored on a cleared area adjacent to the rig (Plate 4). More care is necessary when collecting representative rock chip samples. Details of drilling undertaken and rock formations penetrated are recorded (Appendix 3. Boreholes are normally drilled to 50m, but will be halted by the driller at a shallower depth if yield is sufficient or deepened if dry beyond 50m as advised by the hydrogeologist. The absence of the supervising hydrogeologist for extended periods requires the driller to make decisions regarding the depth of boreholes while lithological samples are not logged in detail. Dry boreholes are backfilled following drilling. As they are not left to stand overnight to allow seepage of water to enter the borehole, abandonment of potentially good low- yielding boreholes may result. The drilling company aims to spend up to two days at each site. Contact with the Accra office is maintained via short wave radio, at set times during the day to report problems and drilling progress.

3.3 Borehole Design, Construction and Test-Pumping

After water has been struck water yield is estimated during drilling at 3m intervals (Plate 5). The minimum acceptable discharge rate is 10 l/min but yields of 7-10 l/min are acceptable within difficult areas such as the Afram Plains. Each borehole is constructed to a standard design using 4" ID flush joint PVC pipe with 1mm slot screen placed against water bearing zones. On withdrawal of the 7" steel temporary casing coarse-grained sand pack is placed in the borehole as a formation stabiliser. Borehole construction details are recorded (Appendix 3). The borehole is then cleaned and developed by surging with compressed air until clear water is produced (Plate 6). Following installation of a cement grout from ground surface to 3m depth the borehole is disinfected using chlorine tablets. Production boreholes are test pumped for three hours using an electrical submersible pump. Water level draw-down measurements are made and the discharge rate is monitored. After three hours the pump is switched off and the rate of water level recovery is monitored for two hours (Appendix 4). These data are sufficient for calculation of formation transmissivity and borehole specific capacity. The borehole is equipped with an Afridev handpump and a water sample obtained for hydrochemical analysis. Water analysis determinations are made for temperature, pH, electrical conductance, dissolved iron, copper, manganese, nitrogen (as nitrate), sulphate, phosphate, zinc, nitrogen (as ammonia), total hardness, calcium hardness, chloride, total coliforms, E. coliforms (Appendix 3. APDO are subcontracted to install the surface concrete pads and pumps.

3.4 Contract

WaterAid and Geomechanik have used the same basic contract document since 1995. Unspent funds are carried over to the next contract for the drilling of additional boreholes. By rolling-over the contract the terms and conditions have not been assessed and amended to incorporate any changes in national specifications introduced by the CWSD. They now advocate the screening of the entire water production zone. This halts the unnecessary placing of lengths of blank pipe within the screened section to protect the pump element when located within the screened section. CWSD now advise the use of 5" internal diameter casings and screens country wide instead of those currently used by Geomechanik. CWSD recommend consultation before new contracts are made to ensure national standards of construction.

4. RESULTS OF ACTIVITIES

Rock types present in the area were examined at a series of geological exposures and representative samples obtained. In the western part of the area two borehole drilling sites were located, the drilling of six borehole observed and chip samples logged from eight boreholes (Table 3). The borehole

locations, determined using a GPS, are shown on Figure 3. Personnel from Geomechanik, APDO and Pronet accompanied the BGS hydrogeologist to the drilling sites. Discussions and observations were made on site. Detailed borehole geological logs are presented in Appendix 4.

Brief descriptions of the main geological elements have been compiled using field observations and detailed borehole logs. Distribution of the main rock types seen at exposure and borehole samples is shown (Figure 3) and in sketch geological section (Figure 4). Only rocks of the Middle Voltaian upper V2 sequence crop out sporadically through a thin mantle of sands, clays and ferricretes within the area.

Bh sites visited				Latitude (N)		Longitude (W)		
No	**Location**	**Status**	**Result**	**Deg**	**Min**	**Deg**	**Min**	**Comments**
1	Bongkrum	Drilled	Wet	6	57.963	0	34.114	Black siltstone with calcite fracture, Q=0.1 l/sec, T=40 m^2/day
2	Isaac	Drilled	Dry	7	3.242	0	35.169	Red/brown medium to fine sandstone, dry
3	Nyamebekyere Adjacent to World Vision Bh	Drilled	Wet	7	4.595	0	36.3	Red/brown medium to fine sandstone, green lined fracture 17 l/min
4	Nsareye	Drilled	Dry	7	1.823	0	34.809	Red/brown medium to fine sandstone, dry
5	Nsareye	Drilled	Dry	7	1.87	0	34.152	Red/brown medium to fine sandstone, dry
6	Akakyi	Drilled	Wet	7	4.106	0	32.867	Red/brown medium to fine sandstone, green lined fracture 400 l/min
7	Asanyansu Adjacent to World vision Bh	Drilled	Wet	7	2.149	0	31.228	Red/brown medium to fine sandstone, orange weathered gravel layer 23 l/min
8	Yaw Bibi Akura	Partly drilled		6	57.503	0	31.886	Black siltstone to fine-grained sandstone,dry, Bh not compleated
9	Apapa	Sited		6	58.563	0	30.399	Not drilled

Table 3 Results of boreholes drilled and logged during the BGS visit

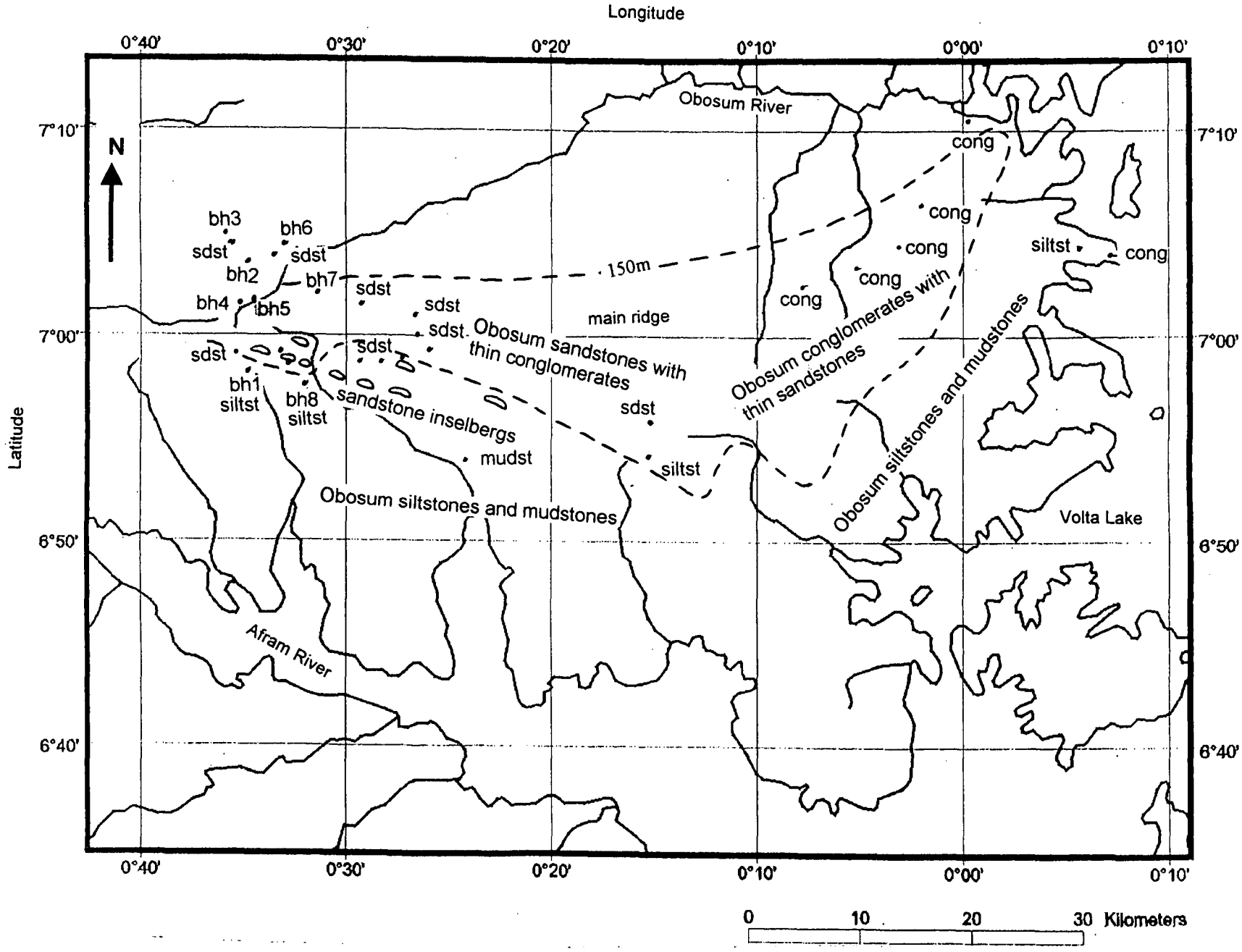

Figure 3 Distribution of the main rock types within the Afram Plains area, Eastern Ghana (Key: sdst-sandstone, cong-conglomerate, siltst-siltstone, mudst-mudstone)

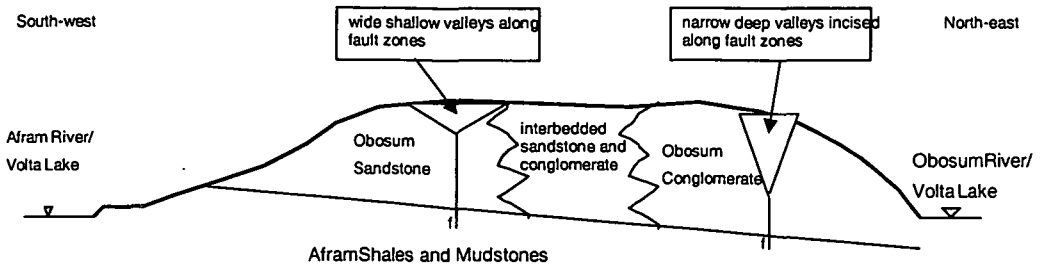

Figure 4 Sketch geological cross section through the Afram Plains area, Eastern Ghana

The Afram Shales - the oldest sediments are reported to be a series of red mudstones that underlie the low lying flat areas adjacent to the lake shores in eastern and southern parts (Plate 7). Little groundwater has been obtained from these soft fine-grained sediments, except from interbedded sandstone layers. Groundwater quality is brackish to saline. The use of geophysical methods to locate groundwater-bearing bodies is difficult within such formations. However little drilling and no investigations have been carried out in the area.

Obosum Sandstones and Conglomerates - this thick sequence of fluvial and/or estuarine sediments underlying much of the area can be divided into lithologically distinct units that grade laterally and vertically into each other.

1.Dark green grey to dark grey siltstones and silty mudstones with interbedded fine grained sandstones were logged in boreholes located in the generally flat lying south-western edge of the area at Bongkrom and Akura (Table 3 bh 1 & 8). These have been fairly well lithified. Small quantities of groundwater were found along thin calcite filled fracture zones discoloured by orange iron oxide (Plate 8). A pumping test was undertaken at a discharge rate of 0.094 l/sec using a Whale pump system. Draw-down of 0.238m was measured after 200 minutes pumping, after which the water level recovered to 12.196m, 165 minutes following cessation of pumping. An average transmissivity of 40 m^2/day was determined (Figures 5 and 6). This is located close to a successful World Vision borehole drilled at Alizimah (N6°57.118' W0°30.672').

2. Cross-bedded dark red brown medium to fine-grained sandstones crop out as isolated inselbergs along the southwestern edge of the area, as at Abotum hill near Bongkrom (Plate 9), and within Tease village in the east (Plate 10). These massive sandstones are well lithified with much manganese and iron oxide cement. Few joints were apparent at outcrop although some calcium carbonate rich beds showed a tendency towards karst weathering. Several boreholes indicated groundwater in small quantities along green-stained fracture zones that underlie wide, shallow valleys indicated by linear zones of taller vegetation (Table 3, bh 2-6).

3. Gravely sandstones are exposed as platforms and low ridges west of Mame Krobe. These fining upward cross-bedded sandstones with interbedded gravely layers give rise to more pronounced valleys and ridges. One of the boreholes showed increased quantities of groundwater from green and orange stained fracture zones and weathered gravel bands (Table 3, bh 7).

Plate 7 Afram Mudstone as excavated from a shallow hand dug well at Takaratwene.

Plate 8 Rock chip samples of black siltstone obtained during drilling of borehole at Akura.

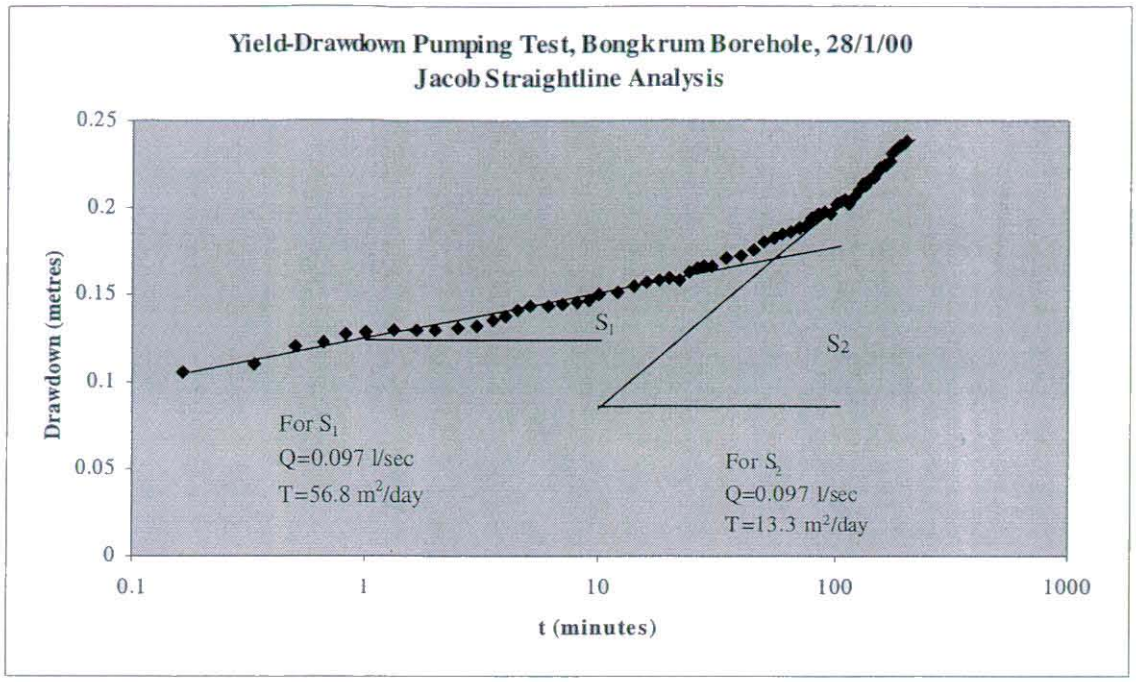

Figure 5 **Jacob Straight Line analysis of yield-drawdown test pumping data from Bongkrom borehole, 28/1/00**

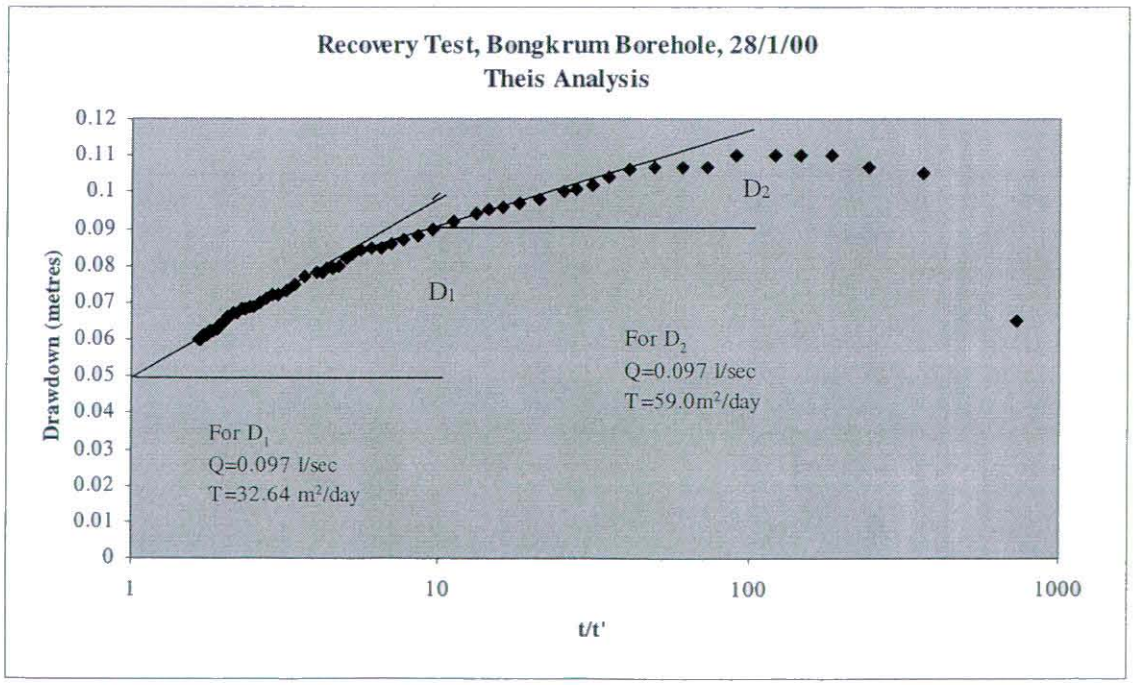

Figure 6 **Theis analysis of recovery test pumping data from Bongkrom borehole, 28/1/00**

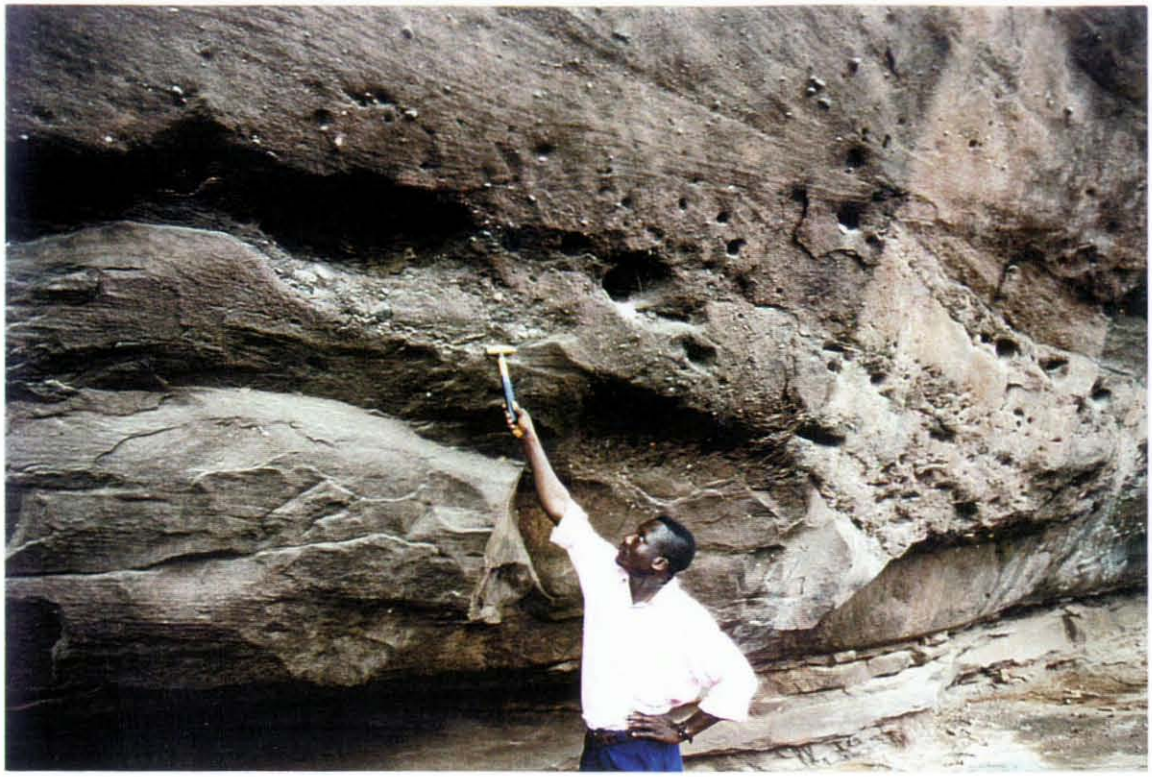

Plate 9 Massive cross-bedded Obosum sandstone, gravelly in places above weathered calcareous sandstone that overlies horizontally bedded quartzitic sandstones, flaggy towards the base, at Abotium Hill.

Plate 10 Cross-bedded sandstone at Tease.

Plate 11 Reddish brown interbedded Obosum sandstones and conglomerates at N7° OO.844' W0° 26.771.

Plate 12 Obosum conglomerate at the new Amankwakurom ferry point. Note well rounded to subrounded matrix supported polymict clasts

4. Coarse-grained conglomerates underlie the higher parts of the ridge within the east where deeply incised valleys occur along fracture zones. Interbedded reddened cross-bedded sandstones and conglomerates are seen to crop out at the Obosum River ferry point (Plate 11) and within Donkorkrom Town. Cleaner, greyer and much coarser conglomerates crop out adjacent to the new ferry point on Volta Lake north east of Donkorkrom (Plate 12).

Superficial deposits - a 1-2m thick tubular ferricrete underlain by a thin yellow white kaolin clay caps much of the sandstone and conglomerate deposits.

4.1 General Observations

Determination of drill penetration rate at one metre intervals can help recognition of hard and soft bands as well as water producing fracture zones. At present penetration rate is recorded per 3m-drill rod length which is insufficient for the recognition of relatively hard and soft layers.

Lithological samples obtained at 1m intervals during drilling were described and placed within a pipe half section forming a pseudo core section designed to show differences in colour and grain size with depth. Such sections can be photographed to produce a record of change and used to indicate the depth and style of weathered zones (Plate 2). Representative core samples should be obtained for the provision of plugs for determining permeabilities, porosities and lithological analysis. Cores from below 60m depth should be obtained to determine if iron and manganese oxide cements are still present with depth and the effects of feldspar grain weathering upon rock permeability, i.e. is there any water seepage from the formation at depth? APDO should keep representative rock chip samples from each borehole drilled with GPS location. A borehole wire-line logging system that includes fluid, natural gamma and resistivity logs would enable recognition of lithology types and fluid inflow zones.

Development of boreholes should be undertaken using an adductor pipe system instead of single air hose, ensuring that water is drawn into the borehole from the formation.

Test pumping exercises need to be better planned. Low cost systems such as bail tests (Plate 13) and the Whale test pump (powered by a Landrover 12 volt battery) (Plate 14) can be used to determine borehole specific capacity and formation transmissivity within low yielding (< 1 l/sec) boreholes. Higher capacity electrical submersible test pump units should be used to test high yielding boreholes (> 2 l/sec). The test pumping data already obtained by Geomechanik need to be analysed. Preferred community borehole operating procedures should be designed using such test results, especially if limited amounts of groundwater are available. At present there is no monitoring of borehole usage or the effects of seasonal climatic change upon borehole yields and water table levels. This should be undertaken by APDO monitoring boreholes, regular visits to user communities, and simple rainfall gauges established at local schools and institutions for regional rainfall patterns to be defined.

Borehole sites and villages should be accurately located using a GPS plotted upon 1:50 000 scale base maps. Borehole locations and geological information need to be incorporated with other relevant data into a regional GIS system organised by APDO. NGO led projects form some of the largest groundwater projects undertaken in Ghana at the present time and therefore potentially form sources of hydrogeological data. Government institutions such as the Geological Survey and CWSD should become involved with such projects so that their databases can be maintained. Baseline maps for field staff use are recommended for all projects within the Afram Plains area to enable villages and other facilities to be located accurately.

Plate 13 APDO staff undertaking a bailer test upon the Akakyi borehole using a 2" diameter x 1 metre long bailing tube.

Plate 14 Undertaking a 3 hour constant rate discharge/drawdown and recovery pumping test using a Whale pump system at Bongkrom. Whale pump produced water at the rate of 0.1 l/sec.

5. INTERACTION WITH STAKE HOLDERS

Details of stakeholder organisations and members of staff met during this study are listed in Appendix 5.

Afram Plains Development Organisation (APDO)

APDO undertake village level pump and borehole maintenance, hygiene and sanitation education, community development and improvement of primary education. They supervised the siting and drilling of 17 boreholes by Geomechanik during January-March 2000. APDO should be consulted during the planning stage of water supply projects in the area as they form the main interface between drilling organisations and local communities. During field visits, the BGS hydrogeologist was accompanied by APDO technical staff.. The use of bailer tests, drawdown – recovery tests using a Whale pump system, site location using a GPS were demonstrated to APDO staff. A GPS and a set of 1:50 000 scale topographic maps were supplied to APDO staff to enable accurate location of boreholes and villages and production of regional base maps (Appendix 6).

At a half-day seminar at Tease the BGS hydrogeologist presented visit findings, making use of rock samples collected and equipment used to provide a practical hands-on session. The procedures used on site and results obtained were discussed within the context of the groundwater resources development project at Oju/Obi in south-eastern Nigeria. The simplified groundwater development potential map for that area was described. The applications of groundwater resource development to other aspects of APDO's operations in the area, such as hygiene, sanitation and primary education, were fully discussed with the Chairman (Mr Modoc) and staff.

WaterAid

WaterAid are the main interface between DfID and local NGOs in the water sector in Ghana. They fully fund the activities of Pronet and the APDO. The WaterAid country representative and staff facilitated the visit of the BGS hydrogeologist to Accra and the Afram Plains. The results of a joint WaterAid/BGS project in Oju/Obi in Nigeria, and visits to WaterAid projects in Zambia and Tanzania were discussed at meetings with WaterAid, Geomechanik, DANIDA, CWSD, BHC/DfID and WaterAid/Pronet staff. The WaterAid representative was present at all meetings. Equipment and maps listed in Appendix 6 were given to WaterAid and APDO.

DfID

During a visit to the DfID office at the BHC this study and the associated KAR project were discussed with the Second Secretary Development (Mr Desmond Wood) and the Projects officer (Mr Owusu Mensah Abunyewa). The results of work undertaken in Nigeria, Tanzania and Zambia were outlined in relation to the water supply problems in the Afram Plains.

World Vision

World Vision plan to drill 70 boreholes within the Afram Plains during the 1999-2000 dry season. World Vision have their own hydrogeologists, based in Kumasi, with an in-house siting and drilling capacity. A visit to Kumasi was not possible. However, the drilling unit was observed and comprises an Atlas Copco Aquadrill Rotamec 50 drilling rig and an Atlas Copco 400 HP XRH 350 compressor, both mounted DAF 1800 trucks.

Pronet

Pronet, an NGO consultancy, are fully funded by WaterAid. The Pronet chairman, Mr R. Bannerman, regarded as the most experienced hydrogeologist in Ghana, has previously worked for Geomechanik. Staff from Pronet accompanied the BGS hydrogeologist to the Afram Plains, providing transport to the area and introduction to members of APDO. The hydrogeology of the Afram Plains area was fully discussed with Mr Bannerman in Accra and with Pronet staff in the field.

DANIDA

DANIDA have been associated with development of the water sector in Ghana for a number of years, through the Water Research Institute and others. Mr Kurt Klitten (Co-ordinator of the DANIDA Water Sector Development Programme) wishes to see a detailed hydrogeological investigation of the Afram plains. He has proposed that DANIDA fund drilling of up to 5 exploration boreholes when BGS undertake detailed studies as part of the ongoing KaR project. He has shown interest in the DfID funded work of BGS in Nigeria as well as BGS's view of the capacity of Geomechanik. Logging equipment loaned to the WRI from a project in India by DANIDA is proposed for use in the Afram Plains. This borehole logging equipment is manufactured by Robertsons Research and maybe capable of digital recording but there is no manual. BGS hold a set of similar equipment for which operation manuals are available.

Geological Survey Department

Geological understanding of the Voltaian sediments of the Afram Plains within the Geological Survey Department is limited to the studies of Junner and Hirst (1946) and Annan-Yorke and Cudjoe (1971) and some unreported work undertaken by Dr E K Barantuoh. The Director wants to participate in survey programmes undertaken. Enthusiastic discussions were had with his staff.

Land Survey Department

A set of 23 1:50 000 topographic maps for the Afram Plains area were purchased as base maps for APDO. These maps are based on 1973-74 aerial photography of the area which is not presently available according to the catalogue (Appendix 7). Also purchased were two 1:125,000 topographic maps of part of the Volta dam region adjacent to the Afram Plains prior to flooding. Also purchased were a set of 1:500,000 road maps for WaterAid for use to locate projects. No 1:250,000 scale topographic maps of the area are available. (Appendix 7).

Geology Department, Legon University, Accra

Although not working directly in the Afram Plains, the University has expertise in the interpretation of satellite data and hydrogeology. They have 15 undergraduate geology students per year and an MSc in hydrogeology. Currently, they are trying to link their students with the Geological Survey to create geological maps. The head of department expressed interest in attaching students to the project to undertake degree level mapping projects.

Water Resources Research Institute

WRI employ 5 hydrogeologists and has knowledge of hydrogeological conditions throughout Ghana. A library of research reports contains little information on the Afram Plains. The new Water Commission set up in Ghana may take over the function of databasing research and project reports. Funds allocated by DANIDA for monitoring of groundwater levels over the past three years are reportedly not spent due to the non-allocation of matching funds by the Government of Ghana.

Community Water Supply and Sanitation Division (CWSD)

The CWSD, developed out of the GWSC, advocate use of a national standard borehole design. They recommend drilling to at least 10m below the initial water struck level. In certain areas an airlifted discharge of 10 l/m is acceptable but CWSD recommend 30l/m minimum. Boreholes should be constructed using 5" (127mm) internal diameter components. CWSD request sight of contracts between NGO's and drilling companies to ensure correct borehole design. A database for the Volta Region is held and they are preparing similar ones for Eastern and Grater Accra regions.

Geomechanik

As Prakla Seismo, Geomechanik have operated within Ghana since before 1984. A range of different capacity drilling rigs is available there. Although most of the work undertaken uses the down the hole hammer drilling system, the resident manager (Mr Gunter Lenz), expressed willingness to undertake coring for the BGS detailed hydrogeological study (January-March 2001). Following the visit of the BGS hydrogeologist to the drilling sites the following comments emerged:- The impact of excessive dust produced during drilling upon vehicles, plant, staff health and the sampling regime is cause for concern as is the failure of the rear left jacking ram and its effect upon borehole verticality. Future boreholes should be completed at an internal diameter of 5" (127mm) in accordance with CWSD advice but until the terms of the present contract can be changed the stocks of 4" casing and screen held would continue to be used. Geomechanik need to create an effective database.

6. DISCUSSION

The Afram Plains area has an increasing water supply problem due to rural population expansion. For their hygiene and sanitation training efforts to be successful, WaterAid needs to provide sustainable water sources. Data collected by World Vision and Geomechanik indicate that aquifers present are of limited extent, primarily occurring along fault zones in sandstone and conglomerate formations. The systematic collection of detailed data from accurately located borehole sites has not been done. No monitoring of seasonal water levels, rainfall patterns nor effects of abstraction have been undertaken.

The drilling equipment used by Geomechanik is good, but there is need to enthuse the drilling and supervisory staff so that quality of borehole sampling, drilling, construction and testing can be improved. The drilling contract document mentioned earlier should be reviewed and renegotiated.

Improving the drill site location procedures would enhance drilling rates. This requires integration of data from geophysical surveys, interpretation of landsat TM images, aerial photography, topographic maps, inspection of geological exposures and conceptual hydrogeological models.

Most of the boreholes drilled to date have reached between 55-70m depth. To understand how groundwater might exist below 70m depth, some 100+m exploration boreholes must be drilled. Data from borehole wireline logging could define the relative importance of seepage flow and fracture flow. Conceptual models of groundwater occurrence in the main rock types should be used to increase borehole success rates and understanding of the groundwater resource. Limited data collected indicate that the low permeability aquifer systems present contain limited groundwater resources. Therefore some measure of expected sustainable yields needs to be obtained at different locations.

Within the Afram Plains the sedimentary rocks present appear to be little disturbed and yet are very old, which suggests repeated cycles of weathering/ diagenesis and burial with low grade metamorphism. Understanding how groundwater occurs includes knowledge of environment or facies of sediment deposition: weathering and diagenetic effects: tectonic framework: soil development: and non-weathered zone lithology. Mineralogy, grain size variations, cement types, feldspar/mica disintegration and clay formation need to be researched.

A base line hydrochemical survey that includes determination of all major, minor and trace elements is needed.

7. CONCLUSIONS

(1) NGOs are expected to produce cost-effective boreholes of minimal dimensions. The borehole design adopted is based upon the smallest acceptable pump. Such tight specifications provide no leeway for difficult geological conditions or poor drilling practices resulting in the drilling of crooked boreholes. Under such conditions, both pump and borehole life may be shortened which may only be remedied by drilling a replacement borehole. Data currently obtained during drilling is just sufficient for borehole design, but not enough to contribute to understanding of the groundwater resource.

(2) NGO water supply projects are often the first drilling programmes to be undertaken within remote rural areas, where the hydrogeology is little understood. Therefore boreholes drilled should be treated as exploration boreholes. The sustainability of the project is dependent upon, among other things, information acquired during the drilling and testing of boreholes. Potentially such data will be of great benefit to subsequent projects. However acquisition of data needed for determination of the potential resource or its long-term sustainability is at times seen as a waste of capital resources.

(3) Where success rates have been low, NGOs often call upon the services of 'expert agencies' for answers to their lack of success. Such "magic bullets" can fail, especially within geological difficult areas. For such areas a more holistic approach is required, in which greater use is made of the local expertise available to maximise the data gathered during such siting and drilling programmes. In addition, time needs to be allocated to producing data that will permit better understanding of the hydrogeological systems involved.

(4) Areas of local expertise include Legon University with landsat image and aerial photograph interpretation: Land Survey Department with digitised 1:50 000 maps: and the Geological Survey staff to map rock exposures and log rock core and chip samples. Also Legon University and WRI hydrogeologists could undertake borehole test pumping. The CWSD could monitor and advise on borehole construction. APDO in co-operation with CWSD could monitor water levels, rainfall and borehole operation. This would result in the collection of good quality data to be fed back into central and regional databases. These data could be used in advising optimum siting methods, drilling depths and potential resource development.

(5) These activities require funding channelled through the lead NGO. Without these activities little knowledge will be gained and the 'success rate' continue to be low. Capacity building is needed at each stage with adequate support such as transport, equipment and staff costs. Additional input may look at wider issues and more scientific aspects of hydrogeology and related topics. These inputs will be available from institutes such as BGS as and when requested.

(6) It is important that the local and international skills-base is maintained. National institutes such as the Geological Survey are in decline due to lack of appropriate work and investment. Meanwhile large NGO based projects are not always seen to be cost effective due to lack of expertise in acquiring the necessary data or understanding for the sustainable long term development of the groundwater resource.

8. RECOMMENDATIONS

(1) Groundwater occurrence within the Afram Plains should be assessed using data from the drilling and testing reports of Geomechanik and World Vision together with groundwater hydrochemistry and landsat imagery studies undertaken by the WRI and DRI. The hydrogeological potential of the three main geological formations will be investigated via deep exploration/test boreholes, geophysical traverses and shallow investigation boreholes all located at sites selected from the results of the assessment. This research will be undertaken as part of the KAR project in association with DANIDA.

(2) The siting, drilling construction and test pumping capabilities of Geomechanik need to be enhanced. This is best done in the field during the drilling of test boreholes for the KaR project and subsequent WaterAid borehole-drilling programme. The adoption of 'best practice' procedures will be achieved 'on site' where good control of exploration work will be achieved through supervision. Representatives of institutions such as Legon University, the Geological Survey and APDO will be encouraged to participate in the studies.

(3) APDO should be encouraged to establish a long-term database necessary for planning of future projects on the Afram Plains. This requires establishment of water level and rainfall monitoring sites. The APDO should be the local repository for all data collected during the KAR project. This report recommends that DfID consider a study of the interaction of NGO-led water projects and country institutions at national and regional level. National institutions should take part in NGO led water supply projects to ensure production of good data from boreholes drilled. Subsequent projects would benefit through improved siting, drilling construction and testing procedures.

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APPENDIX 1 – ITINERARY

January 2000

17 Flight BA2081 from London (Gatwick) to Accra where arrived at 21:00. Met by Mr Gordon Mumbo of WaterAid.

18 To the WaterAid office with Mr Mumbo where introduced to Oduro Donkum, deputy director technical of Pronet. To DANIDA where met with Mr Kurt Klitten and Greg Smith of Gibb. With Gordon Mumbo and Oduro met with Bob Bannerman with whom discussed hydrogeology of the Afram Plains. Visited Mr Gunter Lenz at Geomechanick.

19 Departed from Accra for the Afram Plains. Vehicle problems therefore stayed at Mpraeso overnight.

20 Drove from Mpraeso to the ferry point where crossed the Afram River. Drove to the APDO office at Tease where met Ibrahim. Drove to the drill site. Drove on to Donkorkrom.

21 From Donkorkrom drove to the APDO office in Tease where met with Ibrahim. Pronet driver and vehicle returned to Accra. In APDO vehicle drove to drilling site, noted cross bedded sandstones and conglomerates on the way. Borehole was drilled to a total depth of 52m. Logged samples that had been obtained at one metre intervals. With Carlos and Oduro drove back to Donkorkrom.

22 With the Geomechanik hydrogeologist, Mr Quarm discussed the hydrogeology of the Afram Plains on the way to the drill site. Viewed cleaning of the low yielding borehole with compressed air. To the Nsareye site where recorded drill penetration rate and logged geological samples.

23 Entered borehole data

24 With Mr Quarm to Apapa where located two drilling sites and then to Yaw Bibi Akura where located two more. To Bongkrom where viewed good exposures of Obosum Sandstones and thin conglomerates at Abotuma Hill.

25 To the Nsareye drill sites where logged geological samples. Obtained samples from dry borehole at Issac. At Donkorkrom, Mr Modok the APDO project manager.

26 Oduro returned to Accra. To Nsareye via dry hole at Issac where logged samples. Moved site at Akakyi where drilled to 7m.

27 Entered logging data. Sorted out test pump and checked SEC meter.

28 Shortage of diesel fuel. T the borehole at Bongkrom where demonstrated use of the Whale pump to test borehole. Pumped hole for 200 minutes at 0.097 l/sec and monitored recovery for 3 hours. Obtained chip samples from the Bongkrom borehole. Constructed a bailer test unit.

29 To the Asanyansu drill site. Logged the samples. Borehole constructed and cleaned. Drove to Akakyi showed ADPO staff how to use a bailer to test a borehole. They then used the Whale pump to test the borehole. Logged samples from the Akakyi borehole.

30 Logged samples from Isaac and Bongkrom boreholes. With ADPO staff to the Obosusm River and the new ferry terminal to view the Obosum conglomerate. Noted the occurrence of sandstone and mudstone enroute to the new ferry terminal. Discussions with Mr Modok.

31 With Mr Ibrahim, studied the Geomechanik bill of quantities and the contract for 10 boreholes (expanded to 17 utilising funds left from the last contract). Studied records for the past three contracts. Noted sandstone outcrops at Tease and west of Mame Krobe. To Akura drill site where logged samples to 34m.

February 2000

1 At Tease gave a seminar for APDO staff outlining the results of the Nigeria project and the present visit to the Afram Plains. Good question and answer session. Showed them samples of the rock types present in the area, the Whale test pumping equipment and GPS. Discussions with Mr Modok.

2 Via new ferry point crossed the Volta Lake to Kpando. Drove via the Volta Dam site to Accra where visited Mr Lenz of Geomechanik. To WaterAid office where discussed results of visit with Gordon Mumbo and Oduro.

3 To WaterAid office where gave GPS and dipper to Carlos of APDO. Packed equipment (pH

meter, SEC meter and test pump) in an aluminium box at WaterAid. To BHC where discussed results of visit with Desmond Woode. To the Geological Survey where met with the Director and Deputy Director studying the Voltaian of the Agram Plains. Met with Bob Bannerman to whom described the field visit and results. At the Department of Geology at the University discussed the Voltaian of the Afram Plains with the head of department Mr Atoko and his senior hydrogeologist, Mr Yakubu . At CSIR visited Mr Kartasi of WRI.

4 To the Survey Department to purchased 1:50,000 sheets of the Afram Plains area (base maps for APDO). To the Geological Survey Department to collect maps. To Geomechanik, with Gordon Mumbo, for discussions with Mr Lenz.

5 With Mr Mumbo, met with Mr Edwin Arthur of CWSD. Discussed the activities of the CSWD and results of field visit as well as the Nigeria project. Met with Mr Kurt Klitten of DANIDA at the WaterAid office with Mr Mumbo. Discussed possible future inputs into the Afram Plains area by WaterAid, DfID and DANIDA. DANIDA will be requested to support the drilling of up to 6 deep exploration boreholes.

6 Departed from Accra on flight BA2081 to London Gatwick.

7 Arrived at London Gatwick.

APPENDIX 2 – BOREHOLES DRILLED BY PRAKLA SEISMOS/GEOMECHANIK

Boreholes drilled within the Afram Plains for WaterAid and DfID

Bh No	Village	Wet/dry	Date	Lithology	Yield - l/min
1	Mem Kyemfere	wet	19-20/3/1996	grey fs to ms with sh	10
2	Kpedom	dry	20/03/96	grey fs to ms with sh	
3	Kpedom	dry	21/03/96	grey ms	
4	Kayera	wet	21-22/3/96	brown ms to cs	400
5	Alavanyo	dry	22-23/3/96	brow to grey ms to cs with cong	
6	Alavanyo	wet	23-24/3/96	cong with ms to cs	800
7	Lumnava	wet	24-25/3/96	brown and gret ms to cs and cong	60
8	Kpedzi	wet	25-27/3/96	brown to grey fs to cs	10
9	Agotime	wet	27-28/3/96	brown ms	100
10	Asikasu	wet	28-29/3/96	brown ms to cs	12
11	Yaw Da De	wet	29-30/3/96	brown ms to cs	85
12	Wegbe	wet	01/04/96	khaki to grey ms to cs	400
13	Akyea	wet	02/04/96	grey and brown ms	60
14	Donkorkrom	wet	10-11/4/96	brown ms to cs and cong	100
15	Atakora (Donkorkrom)	wet	11/04/96	brown ms to cs and cong	120
16	Abeka (Donkorkrom)	wet	12/04/96	brown and grey ms to cs	16
17	Abotanso	wet	13/04/96	brown and grey fs to ms	300
18	Abotanso	wet	14/04/96	grey and brown ms to cs	12
19	Kubease-Bodue	wet	15/04/96	brown ms to cs	200
20	Alavanyo	wet	16/04/96	brown ms to cs with cong	85
21	Somsei	wet	17/04/96	brown ms to cs	300
22	Darte Krom	wet	18/04/96	brown ms	15
23	Atta Ayigbe	wet	19/04/96	brown ms	150
24	Addoh Nkwanta	wet	20/04/96	brown ms	20
25	Owiredu	dry	21/04/96	brown ms	
26	Owiredu Akurah	dry	22/04/96	brown ms	
27	Atonso	wet	23/04/96	brown ms	35
28	Atonsu	wet	23-24/4/96	brown ms	20
29	Fodua	wet	24/04/96	brown ms	85
30	Iddrisu Akuraa	wet	25/04/96	brown ms	60
31	Norga 1	wet	10/02/97	brown fs to ms and siltst	20
32	Norga 2	dry	11-13/2/97	brown ms to siltst	
33	Norga 2	wet	13/02/97	brown ms	300
34	Apapasu	dry	14-15/2/97	brown ms	
35	Apapasu	wet	15-18/2/97	brown ms	75
36	Asukese	wet	20/02/97	brown ms	8
37	Tadieso	dry	22-23/2/97	grey ms	
38	Tadieso	dry	06/05/97	grey and brown ms	
39	Kwasi Kune	wet	07/05/97	brown ms	85
40	Kwasi Nfante	dry	8-9/5/97	brown ms	
41	Kwasi Nfante	dry	10/05/97	brown ms	

42	Kwasi Nfante	dry	11-12/5/97	brown ms	
43	Kwasi Nfante	wet	12-15/5/97	brown ms	10
44	Obomin	wet	16-17/5/97	brown ms	200
45	Ahaji Akura	dry	17-18/5/97	brown ms	
46	Alhaji Akura	wet	19-20/5/97	brown ms	200
47	Tuntum Akura	wet	20-23/5/97	brown ms	15
48	Agya Atai	dry	25-26/5/97	grey siltst	
49	Kofi Nyame	wet	26-27/5/97	grey sdst and siltst	7
50	Agya Atai	dry	27-28/5/97	grey sdst and siltst	
51	St Micheal Sch Donkorkrom	wet	30/4-2/5/98	brown ms and quartz cong	15
52	Zabu Zongo Donkorkrom	wet	2-3/5/98	brown ms and quartz cong	200
53	Adiembara	dry	03/05/98	ms	
54	Adiembara	wet	4-5/5/98	brown ms and quartz cong	10
55	Adonteng North	wet	5-6/5/98	brown ms and quartz cong	10
56	Atakora (Donkorkrom)	dry	6-8/5/98	brown ms and quartz cong	
57	Atakora (Donkorkrom)	wet	9-11/5/98	grey ms	120
58	Twerefour Faaso	wet	12-14/5/98	brown ms	120
59	Nyafre	wet	14-15/5/98	brown ms with siltst, sh and cong	25
60	Forifori	wet	16-17/5/98	brown and grey ms and silst	300
61	Kwadwo Gari	dry	18-21/5/98	hard brown ms	
62	Sakabu	dry	22-25/5/98	grey and green grey sh	
63	Sakabu	dry	26-27/5/98	grey and green grey sh with thin sdst	
64	Suntre	dry	27-28/5/98	sh	
65	Kpedome	dry	29/05/98	brown fs to ms some sh	
66	Kpedome	wet	29-30/5/98	brown ms	15
67	Asarekrom	wet	01/06/98	brown ms	35
68	Busanga	dry	2-4/5/98	brown ms	

Boreholes drilled by Prakla Seismos during 1984

Bh No	Village	Wet/dry	Depth (m)	Yield (m3/hr)	Yield (l/sec)
1	Adiembra	dry	125		
2	Adiembra	dry	61		
3	Abomosarefo	dry	31		
4	Abomosarefo	wet	34	1.8	0.5
5	Avatime	wet	34	1.2	0.33
6	Apeabra	wet	40	0.6	0.17
7	Amankwakrom	wet	28	1.8	0.50
8	Amankwakrom	wet	25	9.6	2.67
9	Adiembra	wet	40	1.8	0.50
10	Asikasu	dry	46		
11	Agotime	wet	40	1.8	0.50
12	Kayera	wet	25	9	2.50
13	Bethel	dry	34		
14	Adukrom	wet	40	0.72	0.20
15	Asikasu	dry	40		
16	Asikasu	dry	25		
17	Abotanso	dry	26		
18	Kwaekese	wet	37	9	2.50
19	Koranten	wet	40	0.6	0.17
20	Samsai	wet	52	9	2.50
21	Kyemfre	dry	28	0.9	0.25
22	Kwasikuma	wet	25	12	3.33
23	Bebuso	wet	49		
24	Sawua	wet	49	0.6	0.17
25	Adiembra	dry	47		
26	Bebuso	dry	49		
27	Abotanso	wet	28	1.5	0.42
28	Samanhia	wet	31	1.2	0.33
29	Adiembra	wet	23	9	2.50
30	Donkorkrom	wet	30	0.9	0.25
31	Donkorkrom	wet	21	3.6	1.00
32	Dedeso	dry	46		
33	Tease	dry	31		
34	Dedeso	wet	28	0.9	0.25
35	Dedeso	wet	46	6	1.67
36	Tease	dry	47		
37	Tease	wet	28	3	0.83
38	Amiyaw	wet	30	5.1	1.42
39	Tease	wet	31	0.6	0.17
40	Odumasua	wet	40	2.4	0.67
41	Tease	wet	28	1.8	0.50
42	Mamekrobo	wet	34	7.2	2.00
43	Agya Attan	dry	49		
44	Boakyekrom	dry	37		
45	Agya Attan	dry	35		
46	Mamekrobo	dry	40		
47	Boakyekrom	dry	40		

APPENDIX 3 – BOREHOLE COMPLETION FORMS

PRAKLA SEISMOS
GEOMECHANIK

DRILLING REPORT

Project:

Client:

WELL No: APDO - 11.
* VILLAGE: .....
REGION: EASTERN.
DATE STARTED: 10-04-96.
DATE COMPLETED: 11-04-96.
* DONKOKROM (METHODIST DOWN)

TEMP. CASING AND BIT DIA.	SCALE G.L	GEOLOGICAL FORMATIONS	CIRCULATION LOSS %	MAIN WATER ZONES	TIME / DEPTH m/min	ESTIMATED YIELD Q l/min
8½" ROCK BIT	0	—				
		BROWN SANDY SOIL				
	3	—			0.03	
	4	—				
6⅛" BUTTON BIT	10	HIGHLY WEATHERED SANDSTONE KHAKI, SANDY, SEMISOFT (2)				
	13	—				
		MODERATELY WEATHERED SANDSTONE WITH CONGLOMERATES, CHOC. BROWN, MEDIUM TO COARSE GRAINED, SEMIHARD			0.3	100
	38	TO HARD (3-4)				
		13M 15 L/m				
		20M 30 L/m				
		35M 100 L/m				
	40					
	T.D.					100

WELL DIAGRAMME

- CONCRETE PAD
- 3m CEMENT PLUG
- 02m SAND LAYER
- S.W.L / date:
- PVC PLAIN PIPES 11M
- BACKFILLING 2m
- GRAVEL PACKING 35m.
- GRAVEL PACKING
- 4m SCREEN 35m
- 4m PLAIN PIPE
- 4m SCREEN
- SCREEN SECTION
- 4m PLAIN PIPE
- 4m SCREEN
- 4m PLAIN PIPE
- 4m SCREEN
- PVC BAIL PLUG 2M

CONSUMPTION:

CEMENT ..... 100 ... kg
PVC JOINING GLUE ..... ltr.
PVC SOCKETS ... 11 .....
BENTONITE ..... kg
CMC ..... kg
ROCK BITS 8½" .....
ROCK BITS 6¼" .....
BUTTON BITS 8½" .....
BUTTON BITS 6⅛" .....

MOVED FROM WELL No. ... 13 ...
MOVING TO WELL No. ... 14 ...
TOTAL DISTANCE ... 18 km
WELL DEVELOPMENT ... 2 hrs
WITHDRAW SCREEN/PIPES ... m
BACKFILLING OF AB HOLES ... m

DRILLING RIG No. G.7704
DRILLING CREW No. ... 11 ...
DRILLER Ahmed Hamidu

REMARKS AND STOPPAGE

APPROVED:

PRAKLA-SEISMOS GEOMECHANIK

CERTIFIED:

CLIENT

TEST PUMPING REPORT

Project: Water Well Drilling Programme
Client: Water Aid

Well No: Apdo 11
Hole No. 14
Village: Donkokrom Methodist
Region: Eastern
Date: 19.04.96
Operator: Asenade

Measuring Point Above G.L. 0.50 m
Depth of Pump Inlet: 24 m
Pump Type: SP 5A-12

TEST PUMPING

Date: 19.04.96
S.W.L. 3.88
Start Time: 14:15

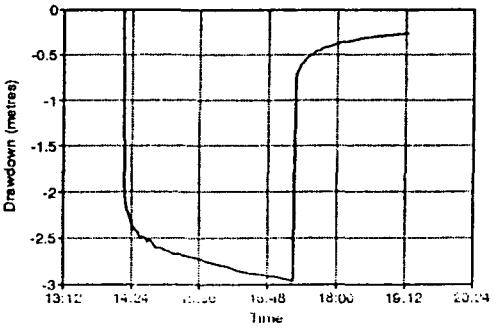
Time	ΔTime	Water Level	Discharge
14:16	1	5.78	120
14:17	1	5.91	120
14:18	1	6.01	120
14:19	1	6.07	120
14:20	1	6.10	120
14:21	1	6.13	120
14:22	1	6.16	120
14:23	1	6.19	120
14:24	1	6.22	120
14:25	1	6.25	120
14:26	1	6.27	120
14:27	1	6.28	120
14:28	1	6.29	120
14:29	1	6.30	120
14:30	1	6.31	120
14:31	1	6.32	120
14:32	1	6.35	120
14:33	1	6.36	120
14:34	1	6.37	120
14:35	1	6.36	120
14:37	2	6.37	120
14:39	2	6.38	120
14:41	2	6.42	120
14:43	2	6.41	120
14:45	2	6.41	120
14:50	5	6.48	120
14:55	5	6.48	120
15:00	5	6.51	120
15:05	5	6.52	120
15:10	5	6.56	120
15:15	5	6.55	120
15:25	10	6.58	120
15:35	10	6.60	120
15:45	10	6.64	120
15:55	10	6.67	120
16:05	10	6.69	120
16:15	10	6.73	120
16:25	10	6.75	120
16:35	10	6.77	120
16:55	20	6.80	120
17:15	20	6.84	120

RECOVERY

Date: 19.04.96
S.W.L. 3.88
Start Time: 17:15

Time	ΔTime	Water Level
17:16	1	4.65
17:17	1	4.60
17:18	1	4.56
17:19	1	4.54
17:20	1	4.52
17:21	1	4.50
17:22	1	4.48
17:23	1	4.47
17:24	1	4.46
17:25	1	4.45
17:27	2	4.43
17:29	2	4.41
17:31	2	4.39
17:33	2	4.38
17:35	2	4.36
17:37	2	4.35
17:39	2	4.34
17:41	2	4.33
17:43	2	4.32
17:45	2	4.31
17:50	5	4.29
17:55	5	4.28
18:00	5	4.26
18:05	5	4.25
18:15	10	4.23
18:25	10	4.21
18:35	10	4.19
18:45	10	4.18
18:55	10	4.17
19:05	10	4.16
19:15	10	4.15

Drawdown / Recovery



Pump Capacity: l/min
at head of: m

CONCRETING REPORT

GEOMECHANIK

Project: WATER WELL DRILL. PROG
Client: WATER AID

WELL No: APDD 11
VILLAGE: *
REGION: EASTERN
DATE: 07/08/96
*DOUKORKROM-METHODIST

CONCRETE PAD		INSTALLATION	
CONSTRUCTION DATE	COMPLETION DATE	SAFETY CAP	NUMBER PLATE
		✓	✓

REMARKS:

CREW No: 1
FOREMAN: Samuel Odum

CONSUMPTION:
CEMENT 300 kg

APPROVED:
PRAKLA-SEISMOS GEOMECHANIK

CERTIFIED:
CLIENT

PUMP INSTALLATION REPORT

GEOMECHANIK

Project:
Client:

WELL No:
VILLAGE:
REGION: DITTO
DATE:

PERMANENT HAND PUMP			INSTALLATION REPORT		
SPECIFICATIONS	CATEGORY A	CATEGORY B	DISCHARGE l / MIN	SAND CONTENT ppm	INSTALLATION DEPTH in m
MANUFACTURER	Meera Cieko		33	—	21
TYPE OF PUMP	Afridev				

REMARK / DETAILS OF ADJUSTMENTS:

S.W.L: 3.01m

CREW No: 2
MECHANIC: K. Asenade

APPROVED:
PRAKLA-SEISMOS GEOMECHANIK

COMMISSIONED:
CLIENT

GHANA

REPORT OF WATER ANALYSIS

WELL Nº APDO-11 VILLAGE DONKORKROM - METHODIST

WELL drilled in Campagne .....

Date and hour of sampling 28/08/96 8:15 Am

ANALYSIS made DONKORKROM 28/08/96 by ADOTEY

SMELL: - TASTE: - COLOUR -

Water taken from the pump			
Temperature		25.8	°C
pH		7.12	-lg[H⁺]
Electrical conductivity		590	µScm⁻¹
Iron	(Fe)	0.01	mg/l
Copper	(Cu)	0.00	mg/l
Manganese	(Mn)	0.0	mg/l
Nitrate Nitrogen	(N)	8.7	mg/l
Sulfate	(SO_4)	0.0	mg/l
Phosphate	(PO_4)	1.5	mg/l
Zinc	(Zn)	0.0	mg/l
Ammonia Nitrogen	(N)	0.05	mg/l
Degree of hardness		209	~~mg~~/l
Calcium hardness	($CaCO_3$)	111	mg/l
Chloride	(Cl^-)	1.0	mg/l

Total Coliform (MPN) < 2.2

E. Coliform (MPN) < 2.2

Remarks:

Results are satisfactory

Att: Jeff Davies

ORIGINAL CONTRACT

GEOMECHANIK Bohrgesellschaft mbH
(Formerly PRAKLA-SEISMOS Geomechanik)

GEOMECHANIK
Bohrgesellschaft

WATER AID
RECEIVED
04 JAN 2000
P. O. BOX 16185
ACCRA

The Country Representative
Water Aid, Ghana
P. O. Box 16185
Airport - Accra.

Attn.: Mr. Sofo Ali Akpajiak.

28th December 1999.

Dear Sir,

QUOTATION FOR DRILLING OF 17 BOREHOLES FOR APDO IN AFRAM PLAINS

Please find attached the above-mentioned Quotation for Drilling of 17 Nos. 100 mm 4" Boreholes in Afram Plains.

We have quoted for an average depth of 50 metres. All scope of work have been quoted for Drilling, Installation, Developing, Pumptesting, Water Quality Analysis, Pad-Installation and Pumps.

Geomechanik will not guarantee quality or quantity of water from the boreholes.

We require an advance payment of 50% of the total cost before commencement of work.

The validity of this Quotation is until 28th February 2000.

We shall start drilling on 7th January 2000. For Pump and Pad Installation we would like to have ADPO as subcontractor.

With Best Regards,

Yours sincerely,

GEOMECHANIK Bohrgesellschaft mbH

Günter LENZ.
(Resident Manager).

file - Drilling

GEOMECHANIK Bohrgesellschaft mbH
MEMMINGER STR. 42
87509 WORINGEN
Tel: +49 8331 9548 50
Fax: +49-8331 9548 51

FAFRAHA-DODOWA ROAD, ACCRA
P.O. Box 1899, Mamprobi, Accra
TELEFON: 76 69 21
TELEFAX: 76 69 22
E-MAIL: GEOMECH@GHANA.COM
REG. NO EXT243

BANKERS
BARCLAYS BANK OF GHANA LTD.
HIGH STREET ACCRA, ACC: 248 54 99
DG BANK BAYERISCHE ZENTRAL-
ACC: 22 45 42 GENO DE FF 701

2/4

GEOMECHANIK Bohrgesellschaft mbH
(Formerly PRAKLA-SEISMOS Geomechanik)

GEOMECHANIK
Bohrgesellschaft

WATER AID, GHANA
WELL DRILLING PROGRAMME
EASTERN REGION, GHANA

BILL OF QUANTITIES

No.	DESCRIPTION OF WORK	UNITS	QTY.	UNIT PRICE DM	TOTAL PRICE DM
1.	MOBILISATION / MOVING				
1.1	Mobilisation / Demobilization	l.s.	1	6,500.00	6,500.00
1.2	Transportation between boreholes, erect and dismantle all drilling plant and equipment	No.	17	620.00	10,540.00
1.3	Transport between boreholes, erect and dismantle all drilling plant and equipment for distances greater than 10 km	km	170	15.00	2,550.00
1.4	Hydrogeological Investigation / Siting	site	17	650.00	11,050.00
2.	BOREHOLE DRILLING & CONSTRUCTION				
2.1	Drilling at a diameter of 200 mm in any material for depths not exceeding 75m below ground level including installation and removal of temporary casing	m	255	85.00	21,675.00
2.2	Drilling at diameter of 150 mm in any material for depths not exceeding 100m below ground level to allow for the free insertion, gravel packing and grouting of permanent PVC lining of 100 mm nominal diameter	m	595	105.00	62,475.00
3.	PVC INSTALLATION 4"				
3.1	Supply and install 100 mm norminal diameter, PVC well casing from 0 m to 75 m	m	595	28.00	16,660.00

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FAFRAHA-DODOWA ROAD, ACCRA
P.O Box 1899, Mamprobi, Accra
TELEFON: 028-21 31 01
TELEFAX: 028-21 31 01
REG. NO EXT 243

BANKERS
BARCLAYS BANK of GHANA Ltd
HIGH STREET ACCRA, ACC: 248 54 99
COMMERZBANK MEMMINGEN
ACC: 730 399 300 BLZ: 731 400 46

3/4

GEOMECHANIK Bohrgesellschaft mbH
(Formerly PRAKLA-SEISMOS Geomechanik)

3.2	Supply and install 100mm norminal diameter, PVC well screen with 2mm slot width from 0 to 75m	m	255	35.00	8,925.00
3.3	Supply and install 100 mm norminal diameter, PVC casing sump with blank end	No.	17	30.00	510.00
3.4	Supply and place gravel pack as specified in annular space as directed by the Engineer (4" PVC)	m	34	12.00	408.00
3.5	Backfilling of borehole	m	200	3.00	600.00
3.6	Backfilling of borehole with grout, as directed by the Engineer	m	51	16.00	816.00
4.	**DEVELOP BOREHOLE (INCLUDING PROVISION, INSTALLATION AND WITHDRAWAL OF ANY EQUIPMENT AND SUPPLY USE OF DISPERSANTS BY:**				
4.1	Surging with compressed air and lifting according to GWSC Well Programme Method	hr.	51	95.00	4,845.00
5.	**BOREHOLE SAMPLING & TESTING**				
5.1	Carry out recovery tests as specified: include for installation, withdrawal of pump and setting up of all ancillary plant and equipment and all measurements and records	hr.	102	115.00	11,730.00
5.2	Carry out recovery tests as specified following step and constant discharge testing include for all measurements and records	hr.	51	90.00	4,590.00
5.3	Disinfect borehole with chlorine tablets	No.	17	22.00	374.00
6.	Construction of concrete well head platform complete with anchor bolts for the handpump and a brass number plate	pc	17	1,050.00	17,850.00

GEOMECHANIK Bohrgesellschaft mbH
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Fax: 49-8331 9548 51

FAFRAHA-DOUDWA ROAD, ACCRA
P.O. Box 1899, Mamprobi, Accra
TELEPON: 028-21 31 01
TELEFAX: 028 21 31 01
REG. NO EXT143

BANKERS
BARCLAYS BANK of GHANA Ltd
HIGH STREET ACCRA, ACC: 248 54 99
COMMERZBANK MEMMINGEN
ACC: 730 399 300 BLZ: 731 400 46

4/4

GEOMECHANIK Bohrgesellschaft mbH
(Formerly PRAKLA-SEISMOS Geomechanik)

GEOMECHANIK Bohrgesellschaft

7.	Field Chemical Analysis / bacteriological test	pc	17	450.00	7,650.00
8.	**HAND PUMP SUPPLY AND INSTALLATION**				
8.1	Afridev Hand Pump	pc	17	2,105.00	35,785.00
8.2.	Handpump Installation	each	17	160.00	2,720.00
				TOTAL:	**228,253.00**

less Advance Payments of 7 boreholes 78,000.00

Actual Due. 150253.00

GEOMECHANIK Bohrgesellschaft mbH
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87789 WORLINGEN
Tel. 449-8331-9548 50
Fax: 449-8331-9548 51

FAFRANJA DODOWA ROAD, ACCRA
P.O. Box 1899, Mamprobi, Accra
TELEFON: 028-21 31 01
TELEFAX: 028 21 31 01
REG. NO EX1243

BANKERS
BARCLAYS BANK of GHANA Ltd
HIGH STREET ACCRA, ACC: 248 54 99
COMMERZBANK MEMMINGEN
ACC:730 399 300 BLZ: 731 400 46

APPENDIX 4 - DETAILED BOREHOLE LOGS

Borehole No.	1
Location	Bongkrom,Afram Plains
Latitude	N 06°57.963'
Longitude	W000°34.114'
Date started	--/01/2000
Date completed	--/01/2000

Depth(m)	Lithology
0- 1	Yellow ochre and grey sandy clay with concretions of sandy red and orange very hard silcretised ferricrete
1- 2	Brown/light grey and orange clay with fragments of concretionary dark red and brown ferricrete
2- 3	Light blue/green, ochre and orange kaolin clay
3- 4	Ochre/green weathered mudstones
4- 5	Ochre green to brown/grey weathered mudstones
5- 6	Soft grey and ochre green weathered mudstones
6- 7	Grey compact mudstones with weathered brown partings
7- 8	Dark green grey splintery hard mudstones with brown partings
8- 9	Hard dark grey mudstones with brown partings
9-10	Hard dark grey mudstones some brown partings
10-11	Hard dark grey mudstone with odd fragment of soft ochre and brown weathered mudstones
11-12	Hard dark grey siltstone to fine grained sandstone with odd thin calcite filled vein
12-13	Dark grey siltstone to fine grained hard sandstone
13-14	Dark grey siltstone to fine grained hard sandstone, with brown weathering along joints
14-15	Dark green/grey hard siltstones
15-16	Dark green/grey hard siltstones
16-17	Dark green/grey hard siltstones
17-18	Hard dark grey to greenish grey siltstones
18-19	Hard dark grey to greenish grey siltstones
19-20	Hard dark grey to greenish grey siltstones
20-21	Hard dark grey to greenish grey siltstones, with odd brown parting
21-22	Hard dark green/grey siltstone; subordinate dark grey and orange very hard streaked fine grained sandstone
22-23	Hard dark greenish grey siltstones
23-24	Hard dark greenish grey siltstones with odd fragment of dark brown/grey mudstone
24-25	Hard dark green/grey siltstone; subordinate dark grey and orange streaked very hard fine grained sandstone
25-26	Very hard dark grey and orange streaked fine grained sandstone to siltstone
26-27	Hard dark green/grey siltstone and very hard streaked dark grey and orange fine grained sandstones
27-28	Very hard streaked dark grey and orange fine grained sandstone to siltstone
28-29	Hard dark green/grey silts; subordinate very hard streaked dark grey and orange fine grained sandstones with odd thin calcite lined vein
29-30	Very hard dark grey siltstone with orange iron oxide lined cracks
30-31	Very hard dark grey siltstones
31-32	Very hard dark grey silty fine grained sandstones
32-33	Very hard dark grey silty fine grained sandstones with odd interbedded thin orange sandstone bands
33-34	Very hard dark grey silty fine grained sandstones

Borehole No.	2
Location	Issac, Afram Plains
Latitude	N 07°03.242'
Longitude	W000°35.169'
Date started	--/01/2000
Date completed	--/01/2000

Depth(m)	Lithology
0- 1	Red orange and light brownish grey sandy clay
1-2	Yellow/grey and light brown/grey sandy clay with rounded yellow to brown silcretised ferricrete nodules
2- 3	Light grey/green sandy clay with red orange partings and yellow orange ferricrete nodules
3- 4	Red/grey to light brown/grey clayey sand with bright orange/ochre partings
4- 5	Fairly soft dark brown ferruginous medium to fine grained sandstone with some pink grains and some black MnO cement
5- 6	Dark black/brown ferruginous medium to fine grained sandstone with some pink grains and much black MnO cement
6- 7	Dark red/brown and black medium to fine grained sandstone, ferruginous with many pink fragmented grains and black MnO cement
7- 8	Dark red/brown and black medium to fine grained sandstone, ferruginous with many pink fragmented grains and black MnO cement
8- 9	Dark red/brown and black medium to fine grained sandstone, ferruginous with many pink fragmented grains and black MnO cement; subordinate very hard fine grained black to black/brown manganiferous sandstone
9-10	Dark red/brown medium to fine grained sandstone, fairly soft with many pink/orange grains and some black MnO cement
10-11	Dark brown/black ferruginous medium to fine grained sandstone with black MnO cement; subordinate light orange and grey medium grained sandstone
11-12	Dark red/brown medium to fine grained sandstone with many pink grains and some black MnO cement, fairly soft with platy fragments
12-13	Dark red/brown ferruginous medium to fine grained sandstone with many pink grains and some black MnO cement; subordinate light orange and grey medium sandstone with no MnO cement
13-14	Dark brown/black ferruginous medium to fine grained sandstone with few pink grains but much black MnO cement
14-15	Dark red/brown fairly soft medium to fine grained sandstone, some pink grains and black MnO cement; subordinate hard orange and grey medium grained sandstone with no MnO cement
15-16	Dark red/brown medium to fine sandstone, pink grains and black MnO cement; subordinate dark red hard sandy siltstone with black mica; grey and orange hard medium sandstone - no MnO; and black/brown fine grained manganiferous sandstone
16-17	Dark red/brown medium to fine grained fairly soft ferruginous sandstone, some pink grains and black MnO cement
17-18	Dark red/brown medium to fine grained ferruginous sandstone with some pink grains and black MnO cement; subordinate orange/brown medium grained sandstone with some black MnO cement
18-19	Dark brown/black medium to fine grained ferruginous sandstone with some pink grains and black MnO cement
19-20	Dark brown medium to fine grained sandstone with pink grains and black MnO cement; subordinate hard orange and grey medium grained sandstone - no MnO cement
20-21	Dark brown medium to fine fairly soft sandstone, some orange grains and black MnO

	cement; subordinate hard brown/black fine manganiferous sandstones; orange and grey hard medium sandstone - no MnO; and grey fine sandstone with mica
21-22	Dark brown medium to fine hard sandstone, some pink/orange grains and black MnO cement; subordinate light grey and orange hard medium sandstone - no MnO cement
22-23	Dark brown medium to fine grained sandstone, some orange/pink grains and black MnO cement; some light blue/grey siltstone and grey and orange medium sandstone
23-24	Dark red/brown ferruginous medium to fine sandstone with orange/pink grains and some black MnO cement
24-25	Dark brown ferruginous medium to fine grained sandstone with pink grains and black MnO cement; subordinate light orange and grey medium sandstone with interbedded light blue/grey mudstone
25-26	Dark brown medium to fine grained sandstone with pink grains and black MnO cement
26-27	Dark red/brown medium to fine grained ferruginous sandstone with many orange/pink grains and some black MnO cement
27-28	Dark brown ferruginous medium to fine grained sandstone with orange/pink grains and black MnO cement
28-29	Dark brown/black medium to fine grained sandstone with some orange/pink grains and much black MnO cement
29-30	Dark brown/black medium to fine grained sandstone with some orange/pink grains and much black MnO cement
30-31	Dark brown/black fine to medium grained sandstone, ferruginous and manganiferous
31-32	Dark orange/brown to brown/black medium to fine grained sandstone with pink/orange grains and black MnO cement; subordinate light orange and grey medium sandstone with no MnO cement
32-33	Dark red/brown fine to medium grained sandstone with much MnO cement, some mica like
33-34	Red/brown to black medium to fine grained sandstone, some orange/pink grains and black MnO cement
34-35	Dark orange/brown medium to fine grained sandstone, some orange grains and black MnO cement
35-36	Dark orange/brown medium to fine grained sandstone with pink/orange grains and black MnO cement; subordinate dark brown/black manganiferous hard fine grained sandstone
36-37	Dark orange/brown medium to fine grained sandstone, some orange grains and black MnO cement
37-38	Dark orange/brown medium to fine grained sandstone with orange/pink grains and black MnO cement; subordinate very hard fine grained brown/black manganiferous sandstone
38-39	Dark brown ferruginous medium to fine grained sandstone with orange grains and black MnO cement
39-40	Dark brown ferruginous medium to fine grained fairly soft sandstone with orange grains and black MnO cement; subordinate orange and light grey medium sandstone with no black MnO cement
40-41	Dark red/brown ferruginous medium to fine grained sandstone with some black MnO cement on bedding planes
41-42	Dark red/brown ferruginous medium to fine grained sandstone with some black MnO cement and mica like deposits on bedding surfaces
42-43	Dark red/brown medium to fine ferruginous sandstone with orange fragmented grains and some black MnO cement on bedding planes; subordinate orange and grey medium sandstone, no MnO
43-44	Dark orange/brown medium to fine grained sandstone with many fragmented orange grains and some black MnO cement

44-45	Dark brown ferruginous medium to fine grained fairly soft sandstone
45-46	Dark orange/brown to dark brown ferruginous medium to fine sandstone, with orange fragmented grains and some black MnO cement along bedding planes
46-47	Dark orange/brown to dark brown ferruginous medium to fine sandstone, with orange fragmented grains and some black MnO cement along bedding planes; subordinate grey and orange medium sandstone - no MnO cement
47-48	Dark red/brown to dark brown ferruginous medium to fine grained sandstone with some fragmented orange grains and black MnO cement the latter especially with fine grained sandstone layers
48-49	Dark orange/brown medium to fine grained sandstone with fragmented orange grains and black MnO cement along bedding planes
49-50	Dark orange/brown ferruginous medium to fine grained sandstone, with fragmented orange grains and black MnO cement, the latter increased in fine grained sandstone layers
50-51	Dark orange/brown to dark brown ferruginous medium to fine grained sandstone with fragmented orange grains and some black MnO cement - hard in parts
51-52	Dark orange/brown ferruginous medium to fine grained sandstone with fragmented orange grains and a little black MnO cement
52-53	Dark orange/brown ferruginous medium to fine grained sandstone with fragmented orange grains and a little black MnO cement
53-54	Dark orange/brown to brown/black medium to fine grained sandstone, some fragmented orange grains and black MnO cement
54-55	Dark orange/brown medium to fine grained sandstone with fragmented orange grains; subordinate black/brown manganiferous fine grained sandstone
55-56	Dark orange/brown medium to fine grained sandstone with fragmented orange grains and some black MnO cement along bedding planes
56-57	Dark orange/brown medium to fine grained sandstone with fragmented orange grains and some black MnO cement along bedding planes
57-58	Dark orange/brown medium to fine grained sandstone with fragmented orange grains and some black MnO cement along bedding planes

Borehole No. 3
Location Nyamebekyere, Afram Plains
Latitude N 07°04.595'
Longitude W000°36.300'
Date started 20/01/2000
Date completed 22/01/2000

Depth(m)	Lithology
0- 1	Light grey very weathered silty fine sand with subordinate light grey clay and orange partings
1- 2	Light grey and pink very weathered sandstone with light grey clay, orange and black Fe and Mn rich partings
2- 3	White to light grey weathered medium to fine grained sandstone, some purple grains with much white kaolin clay, reduced orange Fe oxide weathering
3- 4	White to yellow and light orange very soft kaolin clay
4- 5	Dark red to purple, soft, thinly bedded very weathered silty fine grained sandstone
5- 6	Dark purple fine to medium grained sandstone with pink grains and black cement
6- 7	Dark red fine grained sandstone with weathered white to light green partings
7- 8	Dark red/purple friable fine grained sandstone thinly layered with pink/white intergrain partings
8- 9	Dark purple fine grained sandstone with pink angular weathered grains
9-10	Dark red fine to medium grained sandstone with pink grains, friable platy fragments
10-11	Very hard silicified? black/red fine grained quartzite, some black mica or cryptocrystalline manganese oxide
11-12	Fairly soft dark red and black fine to medium sandstone with pink grains
12-13	Interbedded light red grey hard and dark red and black soft friable medium to fine grained sandstones with some mica
13-14	Dark purple/red friable fine to medium sandstone with some white clay matrix and some mica
14-15	Dark red/black friable medium to fine sandstone weathered with black manganese along betting planes, very micaceous?
15-16	Dark purple/red and black hard micaceous medium to fine grained sandstone, with soft friable bands and black Mn oxide along bedding planes
16-17	Dark purple/red and black fairly hard micaceous medium to fine grained sandstone, with soft friable bands, odd brown/grey layers and black Mn oxide along bedding planes
17-18	Dark purple/red and black hard micaceous medium to fine grained sandstone, with soft friable bands and black Mn oxide along bedding planes
18-19	Dark red/black fairly soft fissile medium to fine weathered sandstone
19-20	Dark red black weathered and friable, fine to medium grained sandstone with odd weathered fracture
20-21	Red/black hard quartzitic medium to fine sandstone with some grey green chlorite deposited along fractures
21-22	Dark red/black hard and soft medium to fine grained sandstones, quartzitic in part
22-23	Dark red/black friable micaceous medium to fine grained sandstone
23-24	Fairly hard dark black/red micaceous medium to fine grained sandstones with some green grey chloritic fragments
24-25	Hard black with red medium to fine grained sandstones
25-26	Hard black to friable dark/red medium to fine grained sandstones
26-27	Dark pink grey quartzite with green chloritic deposits along fractures (WATER STRUCK)
27-28	Hard grey/red medium to fine grained quartzite with green chlorite on fracture surfaces

28-29	Black medium to fine grained sandstone with red grains and orange inclusions
29-30	Pink red and subordinate black medium to fine grained compact sandstones
30-31	Hard pink/red and black well cemented medium to fine sandstone
31-32	Dark red medium to fine grained hard sandstone with much black mica like Mn oxide along bedding planes
32-33	Dark red/black hard medium to fine grained sandstone with black mica like Mn oxide along bedding planes
33-34	Dark red brown and pink medium to fine grained sandstone with black Mn oxide cement
34-35	Dark red brown hard medium to fine grained sandstone with pink and black grains
35-36	Dark brown medium to fine sandstone with pink grains, micaceous in parts with some orange staining
36-37	Dark red/brown fissile medium to fine grained sandstone with pink and black grains and black mica - possibly Mn oxide cement
37-38	Dark red/brown and black medium to fine grained sandstone with pink grains and black mica, some red/orange staining and green grey chlorite
38-39	Dark red/brown medium to fine grained sandstone with pink and black grains, some red/brown fragments and green grey chlorite
39-40	Hard pink/black sandstone, well indurated
40-41	Dark red/brown and black medium to fine sandstones
41-42	Very hard dark brown weathered sandstones with pink and orange grains, friable in parts
42-43	Dark red/brown medium to fine friable sandstones with pink grains and black Mn oxide cement
43-44	Dark red/brown friable medium to fine sandstone with pink and black rounded grains
44-45	Dark red/brown hard medium to fine grained sandstone with pink rounded grains and black Mn oxide cement, softer at 44.5m
45-46	Dark red/brown hard medium to fine sandstone with pink round grains and black Mn oxide cement, softer at 45.25 and 45.5m
46-47	Dark red/brown medium to fine sandstone with pink rounded grains, black Mn oxide cement and mica like Mn oxide along bedding planes, soft at 46.3 and 46.8m
47-48	Red brown medium to fine grained sandstone with rounded pink grains and reduced black Mn oxide cement, softer at 47.35 and 47.6m
48-49	Hard light grey red to dark red/black medium to fine sandstone with black Mn oxide cement
49-50	Light grey red nonweathered and dark red and black weathered medium to fine sandstone. Black Mn oxide cement in weathered
50-51	Dark brown/red and light grey/orange medium to fine sandstone, with black Mn oxide cement in dark brown/red, odd vein of white fault quartz in the lighter rock, softer at 50.5m
51-52	Dark brown medium to fine sandstone with pink grains and black Mn oxide cement. Odd platy fragment of dark brown micaceous siltstone, soft at 51.9m

Borehole No.	4
Location	Nsareye, Afram Plains
Latitude	N 07°01.823'
Longitude	W000°34.809'
Date started	22/01/2000
Date completed	24/01/2000

Depth(m)	Lithology
0- 1	White, light grey and orange yellow to pink clayey top soil
1- 2	Light grey to light brown clayey soil with some black manganiferous partings
2- 3	Red brown and orange sandy clay above friable purple black and pink medium to fine grained sandstone
3- 4	Very hard pink and black medium sandstone with black mica like Mn oxide cement, silicified?, above softer dark red/brown and black medium to fine sandstone with much black Mn oxide
4- 5	Dark red/brown friable medium to fine sandstone with orange/pink grains and black Mn oxide cement
5- 6	Light pink grey medium to fine sandstone with little Mn alternating with dark red medium to fine sandstone with orange pink grains and much black Mn oxide cement
6- 7	Light pink/grey and white granitic sandstone fragments from a conglomerate with dark red/brown medium to fine sandstone with weathered orange pink grains and black MnO cement
7- 8	Light pink/grey and white fine to medium granitic fragments from a conglomerate with dark red/brown medium to fine sandstones with some pink grains and much black MnO cement
8- 9	Light pink/grey and white fine to medium granitic fragments from conglomerate with dark red/brown medium to fine sandstones with some pink grains and much black MnO cement
9-10	Dark red/brown medium to fine sandstone with pink grains and black MnO cement - less than above, no granite frags but odd thin layer of green/blue/grey mudstone or chlorite
10-11	Hard interbedded dark purple/red medium to fine sandstone with black MnO cement and light purple and grey medium granitic sandstone with some white mica.
11-12	Fairly hard red/brown medium sandstone with many pink grains and black MnO cement
12-13	Fairly hard medium to fine grained sandstone mainly dark red/brown with pink grains and black MnO cement but interbedded with lighter reddish orange and pink sandstones with no MnO
13-14	Thinly bedded dark red/brown medium to fine grained sandstone with black MnO cement and some pink grains
14-15	Dark purple/red medium to fine grained sandstone with odd orange rounded grains, much black MnO cement
15-16	Dark red/purple to black medium to fine grained sandstone with pink grains and black MnO cement
16-17	Dark red/pink medium to fine grained sandstone, fairly hard with pink grains and black MnO cement
17-18	Dark red/pink and black medium to fine grained sandstone, fairly hard with pink grains and black MnO cement
18-19	Dark red/brown medium to fine grained sandstone with orange/pink grains and decreased black MnO cement, some platy fragments of red/brown mudstone
19-20	Dark pink/red and black medium to fine grained sandstone with pink and red grains and much black cryptocrystalline and cement MnO. Odd platy fragment of green grey chlorite from a fracture?

20-21	Dark pink/red medium to fine grained sandstone with pink/orange grains and black MnO cement
21-22	Red/black manganiferous medium to fine grained sandstone, fairly hard platy fragments with crystalline MnO
22-23	Dark pink/red fairly hard medium to fine grained sandstone with pink grains and some black MnO cement, with much lighter sandstone with no MnO cement
23-24	Dark pink/red fairly hard medium to fine grained sandstone with pink grains and some black MnO cement; alternating with black and red manganiferous fine grained sandstone with purple grains and much black MnO cement
24-25	Dark red/brown, pink and black medium to fine grained sandstone with pink angular grains and black MnO cement
25-26	Dark red/brown medium to fine grained sandstone with some pin grains and little black MnO cement
26-27	Dark red/brown medium to fine grained sandstone with some pin grains and little black MnO cement
27-28	Hard dark red/black medium sandstone with pink red grains and much black MnO cement and cryptocrystalline form
28-29	Hard dark red/black medium sandstone with pink red grains and much black MnO cement and cryptocrystalline form
29-30	Dark red/brown medium to fine grained sandstone with some pin grains and little black MnO cement
30-31	Dark red/brown medium to fine grained sandstone with some pin grains and black MnO cement; with lighter light brown/pink and grey sandstone bands with greenish grey chlorite
31-32	Dark red/purple medium to fine grained sandstone with pink grains and black MnO cement
32-33	Dark red/purple medium to fine grained sandstone with pink grains and black MnO cement with odd green grey shale like fragment
33-34	Dark red brown medium to fine grained sandstone with pink grains and black MnO cement; subordinate orange and grey medium to fine grained sandstone granitic
34-35	Purple brown and black fairly soft manganiferous medium to fine sandstone, platy fragments
35-36	Dark red/black medium to fine grained sandstone with some pink grains and black MnO cement, fairly hard
36-37	Dark chocolate brown medium to fine grained sandstone with black MnO like mica grains and cement especially along bedding planes
37-38	Dark chocolate brown medium to fine grained sandstone with black MnO like mica grains and cement especially along bedding planes
38-39	Dark red brown medium to fine grained sandstone, platy fragments, some pink grains and black MnO cement
39-40	Dark red brown medium to fine grained sandstone, platy fragments, some pink grains and black MnO cement
40-41	Dark brown and black manganiferous and iron rich medium to fine grained sandstone with some finely crystalline MnO as well as black cement
41-42	Dark brown and black manganiferous and iron rich medium to fine grained sandstone with some finely crystalline MnO as well as black cement; with odd fragment of light grey fine grained sandstone
42-43	Dark brown/black fine grained sandstone with black MnO cement
43-44	Dark red/brown medium to fine grained sandstone with pink grains and black MnO cement
44-45	Dark red/black fine grained manganiferous sandstone with subordinate dark red/brown medium to fine grained sandstone with pink grains and black MnO cement

45-46 Dark red/brown medium to fine grained sandstone with pink grains and black MnO cement

Borehole No.	5
Location	Nsareye, Afram Plains
Latitude	N 07°01.870'
Longitude	W000°34.152'
Date started	24/01/2000
Date completed	26/01/2000

Depth(m)	Lithology
0- 1	Weathered grey white and orange clayey fine grained sand
1- 2	Red brown and black manganiferous and weathered medium to fine grained sandstone with much fine crystalline MnO
2- 3	Red brown very weathered and soft medium to fine grained sandstone with many orange pink grains and black finely crystalline MnO cement
3- 4	Red brown very weathered and soft medium to fine grained sandstone with orange pink grains and black finely crystalline MnO cement
4- 5	Dark brown medium to fine grained weathered sandstone, soft platy fragments with some pink grains and black MnO cement
5- 6	Dark red brown medium to fine grained sandstone, weathered and fairly soft with pink grains and some black MnO cement
6- 7	Dark red brown medium to fine grained sandstone, weathered with many orange pink grains and some black MnO cement
7- 8	Dark red brown medium to fine grained sandstone, weathered with many orange pink grains and some black MnO cement; subordinate hard light orange grey medium to fine grained sandstone with some black MnO cement
8- 9	Dark brown black fine grained sandstone, with few pink grains and much black MnO cement
9-10	Dark red brown medium to fine grained sandstone with many orange pink grains and some black MnO cement
10-11	Dark red brown medium to fine grained sandstone with many orange pink grains and some black MnO cement; subordinate lighter orange grey granitic medium sandstone with no MnO cement
11-12	Dark red/brown medium to fine sandstone with pink grains and black MnO cement
12-13	Dark red/brown medium to fine sandstone with pink grains and black MnO cement, very soft platy fragments
13-14	Dark red brown, pink and black fairly hard medium to fine grained sandstone with many pink grains and some black MnO cement
14-15	Dark red brown, pink and black fairly hard medium to fine grained sandstone with many pink grains and some black MnO cement
15-16	Dark red brown medium to fine grained sandstone with pink grains and black MnO cement; subordinate light grey well cemented sandstone with some orange grains
16-17	Dark red brown medium to fine grained sandstone with pink grains and black MnO cement; subordinate pink red medium sandstone with less MnO cement and some dark red brown fine grained sand with much black MnO cement
17-18	Dark red brown medium to fine grained sandstone with pink grains and black MnO cement
18-19	Dark purple brown fine grained manganiferous sandstone
19-20	Very hard dark red brown medium to fine grained sandstone with many orange pink grains in parts and platy mica like MnO and black cement
20-21	Dark red brown, black and pink fairly hard medium to fine grained sandstone with many orange grains and black MnO cement; subordinate light grey green blue chlorite or mudstone partings
21-22	Dark greyish purple and black hard medium to fine grained sandstone with some pink grains and black MnO as cement and pseudo-mica

22-23	Dark brown purple and black fairly hard platy fragments of medium to fine sandstone with pink grains and black MnO cement
23-24	Dark purple brown and black medium to fine grained fairly soft sandstone with pink grains and black MnO cement
24-25	Dark black brown fairly soft to fairly hard medium to fine grained sandstone with some pink grains and much MnO cement
25-26	Dark red brown medium to fine grained sandstone with pink grains and black MnO cement
26-27	Dark red black medium to fine grained sandstone with pink grains and much black MnO cement; subordinate dark red mudstone fragments
27-28	Dark red brown medium to fine sandstone with pink grains and black MnO cement; subordinate black red manganiferous fine grained sandstone
28-29	Dark red/purple fine to medium sandstone fairly hard to hard with much black MnO cement and pseudo-mica, also pink grains
29-30	Fairly hard black manganiferous fine grained sandstone with subordinate platy soft dark pink-red fine grained sandstone, no black cement
30-31	Fairly hard dark red brown medium to fine grained sandstone with many pink grains and some black MnO cement
31-32	Fairly hard dark red brown medium to fine grained sandstone with many pink grains and some black MnO cement
32-33	Fairly hard dark red brown medium to fine grained sandstone with many pink grains and some black MnO cement
33-34	Fairly hard dark red brown medium to fine grained sandstone with many pink grains and some black MnO cement
34-35	Fairly hard dark red brown medium to fine grained sandstone with many pink grains and some black MnO cement; subordinate light orange and grey medium to fine grained sandstone with some black MnO cement
35-36	Dark purple brown and black ferruginous and manganiferous fine to medium sandstone with few pink grains.
36-37	Dark purple brown ferruginous medium to fine grained sandstone with orange/pink grains and black MnO cement; subordinate light orange and grey sandstone
37-38	Dark reddish brown medium to fine ferruginous sandstone with pink grains and black MnO cement and pseudo-micas
38-39	Dark black brown medium to fine sandstone, ferruginous and very manganiferous, hard with some pink grains
39-40	Fairly hard dark red brown medium grained sand with many ping grains and some black MnO cement, softer and more platy where > MnO cement
40-41	Dark grey medium and fine grained fairly hard sandstone with many pink grains and some black MnO cement; odd fragment of light blue grey chloritic mudstone
41-42	Fairly hard red brown medium to fine grained sandstone with many pink grains with little black MnO cement
42-43	Fairly hard dark purple red medium to fine grained sandstone with pink grains and much black MnO cement especially in fine grained sandstone
43-44	Dark red brown and black medium to fine grained sandstone, fairly soft with some pink grains and black MnO cement
44-45	Dark purple brown ferruginous medium to fine grained sandstone, fairly soft with some pink grains and black MnO cement; odd light blue green grey fragment of siltstone
45-46	Dark purple brown ferruginous medium to fine grained sandstone with some MnO cement
46-47	Dark brown ferruginous fine grained sand with some black MnO cement
47-48	Dark brown and black fairly hard medium to fine grained sandstone with many pink grains and some black MnO cement, silicified? in parts

48-49	Dark red/brown to dark red/black medium to fine grained sandstone with some pink grains and black MnO cement
49-50	Dark brown very hard medium to fine grained sandstone with some pink grains and black MnO cement; odd fragment of grey micaceous fine grained sandstone
50-51	Dark brown/black, dark red/brown and black medium to fine grained sandstones with variable amounts of black MnO cement
51-52	Very hard dark purple/brown and black medium to fine grained sandstone with some light orange and grey sandstone with lightblue grey siltstone.

Borehole No.	6
Location	Akakyi, Afram Plains
Latitude	N 07°04.106'
Longitude	W000°32.867'
Date started	--/01/2000
Date completed	--/01/2000

Depth(m)	Lithology
0- 1	Pinkish white kaolin clay with orange ferricrete nodules with dark brown and black Fe and Mn oxide cores
1- 2	Pink/white to white kaolin clay with odd nodule with black MnO core and orange partings
2- 3	Light yellow white to light ochre kaolin clay with black manganiferous nodules and orange partings
3- 4	Light ochre/white kaolin clay with orange partings above weathered dark brown/orange soft to hard sandstone
4- 5	Hard dark brown to black fine grained manganiferous sandstone
5- 6	Brown/pink to dark brown/pink fairly soft medium to fine grained sandstone with pink/orange grains and some black MnO along bedding planes
6- 7	Dark red/brown ferruginous medium to fine grained sandstone with some pink/orange grains
7- 8	Dark red/brown medium to fine grained sandstone, some MnO cement within finer grained patches
8- 9	Hard red/brown medium to fine grained ferruginous sandstone with pink/orange grains and odd mica fragment
9-10	Red/brown to dark red/brown fairly soft medium to fine grained sandstone, fragmented pink/orange grains, little MnO black cement; subordinate very hard grey medium to fine sandstone with much mica
10-11	Hard dark red/brown fairly hard medium to fine grained sandstone with fragmented orange brown grains; harder and darker where black MnO cement is present
11-12	Dark brown ferruginous medium to fine grained sandstone with fragmented orange grains and some black MnO cement
12-13	Dark red/brown fairly hard medium to fine grained sandstone, harder where black MnO cement is present
13-14	Dark red/brown medium to fine grained sandstone, very soft to hard; subordinate hard black/brown fine grained manganiferous sandstone
14-15	Dark red/brown ferruginous medium to fine grained sandstones, some black MnO cement; subordinate orange and grey medium grained sandstone with grey mica rich partings
15-16	Dark red/brown to orange/grey fairly soft medium to fine grained sandstone with little MnO cement in some layers
16-17	Dark red/brown ferruginous medium to fine grained sandstone, fragmented pink/orange grains, harder where more black MnO cement is present
17-18	Dark brown to purple/brown medium to fine grained sandstone with some fragmented orange grains
18-19	Dark brown to purple/brown medium to fine grained sandstone with some fragmented orange grains
19-20	Dark red/brown medium to fine grained sandstone with fragmented orange grains and some black MnO cement
20-21	Dark red brown fairly hard to hard medium to fine grained sand with fragmented orange grains and some black MnO cement
21-22	Dark red brown fairly hard to hard medium to fine grained sand with fragmented orange grains and some black MnO cement

22-23	Dark purple/brown ferruginous medium to fine sandstone with some black MnO cement
23-24	Dark purple/brown ferruginous medium to fine sandstone with some black MnO cement
24-25	Fairly soft dark orange/brown medium to fine grained sand, ferruginous with fragmented orange grains
25-26	Dark orange/brown medium to fine fairly hard sandstone, with fragmented orange grains and some black MnO cement; odd light blue grey mudstone/chlorite fragment, and dark red mudstone fragment
26-27	Dark brown/orange fairly hard medium to fine sandstone, with fractured orange grains and some black MnO cement
27-28	Dark brown/orange fairly hard medium to fine sandstone, with fractured orange grains and some black MnO cement; with thin layer of grey micaceous sandstone with greenish chloritic stain
28-29	Purple/brown and black hard medium to fine sandstone with some orange grains and black MnO cement; subordinate orange and grey hard medium grained sandstone
29-30	Dark purple/brown medium to fine hard sandstone with orange grains and black MnO cement and mica?
30-31	Dark red/brown medium to fine sandstone, fairly hard with fragmented orange grains; subordinate hard black/brown manganiferous fine grained sandstone
31-32	Dark red/brown medium to fine sandstone, fairly hard with fragmented orange grains; subordinate hard black/brown manganiferous fine grained sandstone
32-33	Dark purple/red cross bedded medium to fine grained sandstone, some black MnO cement
33-34	Dark purple/red medium to fine grained sandstone with some black MnO cement; subordinate dark orange grey medium to fine grained sandstone with little black MnO cement
34-35	Dark red/grey medium to fine grained cross bedded karst weathered? sandstone
35-36	Purple/red compact cross-bedded medium to fine grained sandstone with black MnO on bedding planes
36-37	Purple/brown medium to fine grained sandstone, some black MnO cement and orange grains. Cross-bedded with black mica on bedding planes with orange oxidation spots

Borehole No.	7
Location	Asanyansu, Afram Plains
Latitude	N 07°02.149'
Longitude	W000°31.228'
Date started	28/01/2000
Date completed	29/01/2000

Depth(m)	Lithology
0- 1	Orange brown granular concretionary to tubular siliceous ferricrete with red and black partings
1- 2	Orange brown, red and black tubular very hard siliceous ferricrete; above light greenish grey kaolin clay with brick red partings
2- 3	Light grey kaolin clay with brown/red partings; above brown red weathered siltstone
3- 4	Light brown red weathered mudstone with light greenish grey very weathered kaolinitic bands
4- 5	Very weathered greenish light grey and bright yellow sandy kaolin clay; above fairly soft medium to coarse grained weathered purple red sandstone
5- 6	Purple brown medium to coarse grained sandstone, fairly soft with much weathered pink matrix around rounded grains
6- 7	Purple brown medium to coarse fairly soft sandstone with rounded grains and some fine gravel
7- 8	Dark brown and green rounded quartzitic gravels with some vein quartz
8- 9	Interbedded dark purple brown medium to coarse grained sandstone and rounded to subrounded quartzitic gravels including jasper and vein quartz
9-10	Interbedded dark purple brown medium to coarse grained sandstone with weathered orange grains and rounded to subrounded quartzitic gravels including jasper and vein quartz
10-11	Purple brown and pink medium to coarse sandstone, fairly soft with interbedded fine gravel to very coarse sands with rounded clasts
11-12	Mainly medium to fine grained purple brown sandstone with pink fragments; subordinate rounded fine gravels and very coarse sands, cherty red and brown clasts
12-13	Brown and green rounded fine to coarse cherty gravels; interbedded with fairly soft purple brown medium to fine grained sandstone with pink grains
13-14	Pink/red medium to fine grained sandstones with pink grains and interbedded rounded gravels - pink and green, cherty
14-15	Dark orange/red medium grained sandstone with some pink and green gravel
15-16	Soft orange grey medium grained sandstone with many orange pink grains
16-17	Soft orange grey medium grained sandstone with many orange pink grains
17-18	Very hard orange, pink and grey medium grained sandstone with many pink grains
18-19	Very hard compact purple pink medium grained sandstone with green chlorite along fracture?, pink fine grained matrix
19-20	Fairly soft pink/purple/brown and grey medium grained sandstone with some pink matrix material, odd granitic gravel rounded clast
20-21	Orange brown medium to coarse sandstone with many orange pink fragmented grains, soft; subordinate fairly hard fine grained brown sandstone with some orange grains and little black MnO cement
21-22	Orange brown medium to coarse sandstone with fragmented orange grains
22-23	Fairly hard orange and grey medium to coarse grained sandstone with fragmented orange grains
23-24	Dark orange brown fairly hard medium to coarse sandstone with orange fragmented grains
24-25	Dark orange brown medium to coarse fairly hard sandstone with odd gravel clast; subordinate fairly hard , compact dark grey/black fine grained sandstone with black

	MnO cement
25-26	Dark orange brown fairly soft medium to coarse grained sandstone with odd gravel clast and fragmented grains
26-27	Dark brown/orange ferruginous medium to coarse sandstone, softish with odd gravel clast and fragmented grains
27-28	Dark brown/orange ferruginous medium to coarse sandstone, softish with odd gravel clast and fragmented grains
28-29	Dark brown/orange ferruginous medium to coarse sandstone, softish with odd gravel clast and fragmented grains
29-30	Dark black/brown and orange/pink medium to fine grained sandstone with some black MnO cement in places
30-31	Dark brown/purple medium grained sandstone with NO MnO interbedded with hard black manganiferous fine grained sandstone
31-32	Black/brown fine grained manganiferous sandstone; subordinate orange brown medium sandstone with NO MnO
32-33	Hard orange black medium to coarse grained sandstone, some manganiferous black fine grained sandstone and the odd gravel clast
33-34	Hard dark orange brown medium grained sandstone with pink grains; subordinate hard black manganiferous siltstones with odd gravel clast
34-35	Very weathered quartz gravel with orange coatings (water producing layer)
35-36	Finer gravels to coarse sand, mainly hard quartz rich clasts with orange coatings (water producing layer)
36-37	Orange brown medium grained sandstone with fragmented grains, some quartz gravel
37-38	Hard orange brown medium grained sandstone
38-39	Hard orange brown medium grained sandstone
39-40	Fairly hard medium to coarse grained orange /brown sandstones with green chlorite? on fractures (water producing layer)
40-41	Dark orange/black medium to coarse hard sandstone
41-42	Dark orange/black medium to coarse hard sandstone
42-43	Dark purple/orange/brown medium to coarse hard sandstone with purple MnO cement and fractured grains

Borehole No.	8
Location	Yaw Bibi Akura, Afram Plains
Latitude	N 06°57.503'
Longitude	W000°31.886'
Date started	31/01/2000
Date completed	01/02/2000

Depth(m)	Lithology
0- 1	Light brown/orange and grey silcretised ferricrete nodules with dark brown and black Fe and Mn oxide cores
1- 2	Light ochre brown to light olive grey weathered mudstones with orange partings
2- 3	Ochre brown and darker olive grey weathered mudstones, some black MnO along bedding planes
3- 4	Olive grey weathered but fairly hard mudstones, black MnO along bedding planes
4- 5	Dark greenish grey and olive green to dark grey mudstones, slightly weathered with black MnO stains along bedding planes
5- 6	Dark grey mudstones with orange/brown and black staining along bedding surfaces
6- 7	Dark grey mudstones with orange/brown and black staining along bedding surfaces
7- 8	Dark grey very hard siltstone to very fine sandstone, odd thincalcite vein
8- 9	Dark grey siltstones to very fine sandstones, hard with some mica
9-10	Hard dark grey compact siltstone to very fine grained sandstone
10-11	Dark grey hard siltstone to very fine grained sandstone; subordinate light grey fine grained sandstone with orange brown staining along joint surfaces
11-12	Dark grey to light grey fine grained sandstone with orange/brown weathered surfaces
12-13	Hard dark grey very fine grained sandstone
13-14	Hard dark grey sandy siltstone
14-15	Dark grey muddy siltstone
15-16	Hard dark grey silty very fine grained sandstone
16-17	Dark grey thinly laminated muddy siltstones
17-18	Dark grey very fine to fine grained hard sandstone
18-19	Hard dark grey well laminated sandy siltstone
19-20	Hard dark grey well laminated sandy siltstone
20-21	Hard dark grey very fine grained sandstone
21-22	Hard dark grey very fine grained sandstone, with thin calcite vein
22-23	Hard platy fragments of dark grey muddy siltstone to sandy siltstone with odd fragment of lighter grey very fine sandstone with weathered orange brown surfaces
23-24	Hard dark grey sandy siltstone
24-25	Hard dark grey sandy siltstone with thin calcite and iron pyrite filled vein
25-26	Hard dark grey very fine grained sandstone (very large fragment)
26-27	Hard dark grey silty very fine grained sandstone with iron pyrite inclusion
27-28	Hard dark grey siltstone
28-29	Hard dark grey silty very fine grained sandstones
29-30	Hard dark grey silty very fine grained sandstone with thin brown sandstone? vein
30-31	Hard dark grey silty fine grained sandstone
31-32	Hard dark grey very fine grained sandstone with thin brown sandstone? vein
32-33	Hard dark grey silty very fine grained sandstone, platy fragments
33-34	Hard dark grey sandy silt

Borehole to be continued to 45m on 01/02/00

APPENDIX 5 - LIST OF PERSONS MET

Afram Plains Development Organisation, Donkorkrom and Tease.
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Mr Ibrahim, Deputy Project Manager, APDO
Mr Carlos Kuranteng, Senior Technical Supervisor APDO
Richard Detsa-Akornor, Technical Supervisor, APDO

British High Commission, Osu Link, off Gamel Abdul Nasser Avenue, P.O. Box GP296, Accra, Ghana. Tel (233-21) 221665/7010650, FAX: (233-21) 7010655. Development Section, DfID,
Mr Desmond L Woode, 2nd Secretary (Development), e-mail dl-woode@dfid.gov.uk
Mr Owusu Mensah Abunyewa, Projects Officer, e-mail 0m-abunyewa@dfid.gov.uk

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B Baneoeng-Yakubo, structural geologist/hydrogeologist,

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Charles Edward Oduro, Director, Tel direct: 226490
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Mr Gunter Lenz, Resident Manager
Mr Quarm, Hydrogeologist

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Gregory L Smith, Principal Engineer, e-mail gsmith@gibb.co.uk

Gye Nyame Hotel, Near Multichoice, Ring Road, Asylum Down, Accra. P.O.Box 8820/7721. Tel 223321/223211, FAX: 233-21-226486

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Abdulai Adams, Assistant to Deputy Director, Technical

Royal Danish Embassy, 67, Dr Isert Road, North Ridge, P.O.Box CT 596, Accra. Tel 233-21-221385/226972/301861/301940, FAX: 233-21-228061, e-mail accamb@accamb.um.dk
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APPENDIX 6 - LIST OF EQUIPMENT AND MAPS LEFT WITH WATERAID / APDO

Equipment

1. Warwick equipment aluminium box with padlock and two keys
2. Soil instruments Ltd water level dipper with 50m tape
3. Whale pump 12vDC with 20m of cable, hose and nylon support rope
4. gang electric socket with 3m of cable and three pin plug
5. phOX52 specific conductivity meter with sonde, 5m of cable and carrying case
6. Hanna instruments portable pH meter HI9025CW with temperature probe and BDH Gelplas epoxy sealed combination pH electrode 309-1050-03 with instruction manual, carry case and spare set of batteries
7. 2lb geological hammer
8. Compass clinometer
9. 9v batteries for SEC meter
10. Assorted pens, pencils and tapes
11. Field note book
12. Garmin GPSII plus serial number 40647153
13. Plastic self seal sample bags

Maps

1:50,000 scale topographic maps
0600A1/3
0601A1-4
0601B1-4
0700C1/3
0701A4
0701B3/4
0701C1-4
0701D1-4

APPENDIX 7 - LIST OF MAPS AND AERIAL PHOTOGRAPHS

Maps taken to the UK
1:125,000
North B-31 G-I Ho
North B-30 l-II Afram

Geological maps
Geology map of Ghana with mineral deposits, 1988, scale 1:1,000,000
Geological map of the Voltaian Basin (north of latitude 7°30'), 1964, Ghana Geological Survey, Fig 1
Geological sections, Figures 2,3 and 4
Tentative correlation scheme of the different stratigraphical divisions of the Voltaian Formation figure 5.

Aerial Photographs required

Run	Photos Numbers	Date
G45	73-102	April 1973-November 1974
G45	49-12	
G45	137-170	
G47	116-83	
G57	26-1	
G42	136-110	
G42	11-38	
G39	219-195	
G39	131-155	