British Geological Survey

DFID

TECHNICAL REPORT WC/00/16
Overseas Geology Series

DFID Project No. R7353

Project report on visit to Ethiopia to rapidly assess groundwater development issues in the Hintalo Wajerat Woreda (March 2000)

J Davies and P D Merrin

British Geological Survey, Wallingford

Natural Environment Research Council

International Division
British Geological Survey
Keyworth
Nottingham
United Kingdom NG12 5GG

British Geological Survey

TECHNICAL REPORT WC/00/16
Overseas Geology Series

DFID Project No: R7353

Project report on visit to Ethiopia to rapidly assess groundwater development issues in the Hintalo Wajerat Woreda (March 2000)

J Davies and P D Merrin

This document is an output from a project funded by the Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID.

DFID classification:
Subsector: Water and Sanitation
Theme: WI – Improve integrated water resources development and management, including systems for flood and drought control
Project Title: Groundwater from low permeability rocks in Sub-Saharan Africa
Project reference: R7353

Bibliographic reference:
Davies J and Merrin P D, 2000. Project Report on Visit to Ethiopia to Rapidly Assess Groundwater Development Issues in the Hintalo Wajerat Woreda (March 2000).
BGS Technical Report WC/00/16C

Keywords:

Front cover illustration: Women collecting water in clay pots (einera) from a basalt/sandstone contact spring, Senale, Hintalo Wajerat Woreda, South Tigray

Keyworth, Nottingham, British Geological Survey, 2000

Contents

List of Figures

List of Tables

List of Plates

List of Abbreviations

BGS	British Geological Survey
BPED	Bureau of Planning & Economic Development
DFID	Department for International Development
EBr	Ethiopian Birr
EOC/DICAC	Ethiopian Orthodox Church/Development and Inter-Church Aid Commission
GIS	Geographical Information System
GPS	Ground Positioning System
GSE	Geological Survey of Ethiopia
KAR	Knowledge and Research
NGO	Non Governmental Organisation
WMERB	Water Mines and Energy Resource Bureau, Makelle

Technical glossary

Aquifer - A rock formation that contains sufficient groundwater to be useful for water supply.

Basalt - Fine-grained, dark, igneous rock. Groundwater flow is primarily through fractured zones.

Borehole - A cylindrical hole, usually greater than 20 m deep and 100 mm in diameter constructed by a drilling rig to allow groundwater to be abstracted from an aquifer. Note: American use of the term 'well' to mean both boreholes and shallow wells.

Geophysics - Techniques for measurement of the physical properties of rocks without drilling boreholes. In certain circumstances results from geophysics surveys can be used to infer the presence of groundwater.

Mesa - Flat-topped, steep-sided plateau

Porosity - The ratio of void space in rock to the total rock volume - expressed as a percentage. Rocks with high porosity can store greater volumes of groundwater.

Permeability - Rate of groundwater flow through a cross section of aquifer. Permeability is higher when there are interconnected fractures.

Pumping test - A test that is conducted to determine aquifer or borehole characteristics.

Sandstone - A rock that is made from cemented sand grains – usually has a high potential for groundwater.

Shallow well - A large diameter (usually greater than 1 m) hole, dug to less than 20 m depth to access groundwater.

Siltstones and mudstones - Fine-grained rocks made of mud and or very fine-grained particles. Usually have a low potential for groundwater.

Success rate (borehole drilling) - Imprecise term, normally taken as the number of successful boreholes divided by the total number of boreholes drilled – expressed as a percentage. Different organisations have different measures for denoting a successful borehole.

Travertine - A variety of pale coloured calcareous tufa, some varieties of which are porous. Characteristic of hot springs in volcanic regions.

Weathered zone - A layer of rock beneath the soil zone that has been altered by physical breakdown or chemical decomposition.

Yield - The volume of water discharged from a well or borehole, measured in m^3d^{-1} or ls^{-1}.

1. INTRODUCTION

During March 2000, WaterAid invited a team from the British Geological Survey (BGS) to travel to Ethiopia to assess groundwater development problems faced in the Hintalo-Wajerat Woreda, located in the Southern Zone of Tigray Region, northern Ethiopia (Figures 1 and 2). Within the Woreda area, WaterAid and their partners realise that access to potable surface water sources is limited while groundwater development is constrained by difficult geological conditions. This report details the key findings of the visit, and provides a record of information gathered and people met.

This assessment forms part of a two-year project aimed at developing groundwater development tools to increase the success of water supply projects in geologically difficult areas of sub-Saharan Africa. The project is funded by the Department for International Development (DFID) under the Knowledge and Research (KAR) programme. Groundwater development problems facing four WaterAid programmes in Ghana, Ethiopia, Tanzania and Zambia are being examined. Techniques developed during the project will be used to produce groundwater development maps for two areas where the siting of sustainable groundwater supplies has proven difficult. A brief introduction to the project is provided in Annex A.

Two BGS staff, Jeffrey Davies (Hydrogeologist) and Philip Merrin (Hydrogeologist), visited Ethiopia between 6-15th March 2000. WaterAid facilitated the visit; an itinerary for the visit is given in Annex B. The terms of reference were as follows:

(i) to assess the problems that WaterAid and their partners face in developing groundwater in the Hintalo-Wajerat Woreda;

(ii) to ascertain the current expertise, tools and equipment WaterAid and partners have to site boreholes and wells;

(iii) to collect and evaluate data and information relevant to groundwater resource development within the Hintalo-Wajerat Woreda, Tigray State, northern Ethiopia;

(iv) to recommend follow-up work.

The first two aims were addressed by visiting the area and discussing the occurrence of groundwater there with members of the EOC, government institutions, Makelle University and contract drillers; the third aim was addressed by visiting various institutes in Makelle and Addis Ababa (Annex C).

2. SUMMARY

Water supply is a major problem within the Hintalo-Wajerat Woreda area. Surface water occurrence in the area is usually limited to the main June – August wet season (the Meher rains) and the small rains of March – April (the Belg rains). The seasonal rains can be unreliable; prolonged periods of drought may occur. Most rivers in the area are ephemeral. Locating sustainable groundwater resources to supply a growing population is therefore vital. However, development is constrained by uncertainty of geological controls on groundwater availability. In the area, groundwater occurs within Mesozoic sediments and Tertiary basalt flows and dolerite intrusions. The hydrogeological development potential of each of these units is not fully understood. These groundwater resources need to be developed using properly constructed boreholes, protected springs and hand-dug wells.

Borehole, hand dug well and protected spring sites should be located using information derived from geological and topographic maps, geophysical surveys and aerial photographs. The main aim is to minimise the distance travelled to collect water. Therefore, surveys should be designed to locate

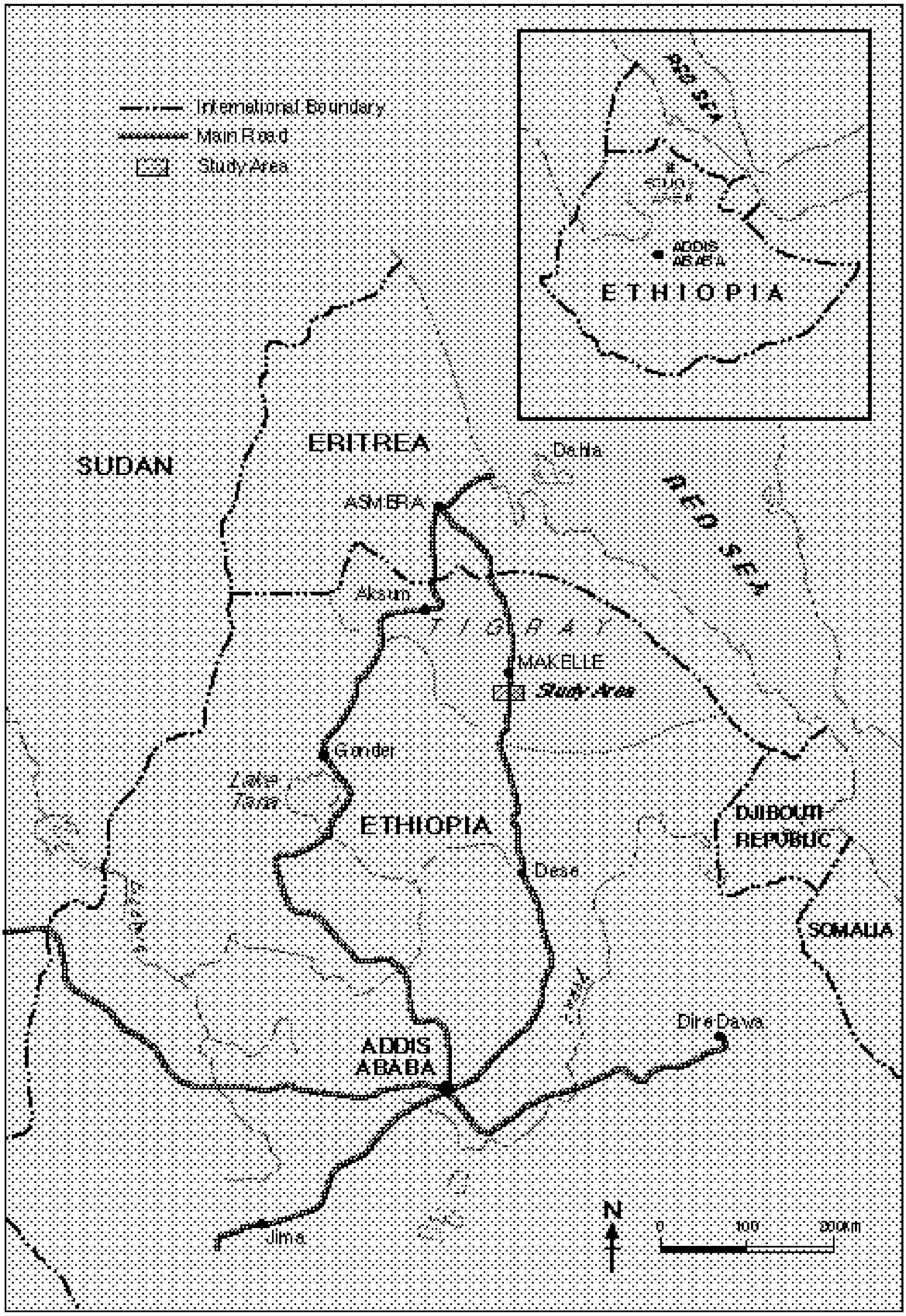

Figure 1 Map of Ethiopia showing location of the study area within Tigray

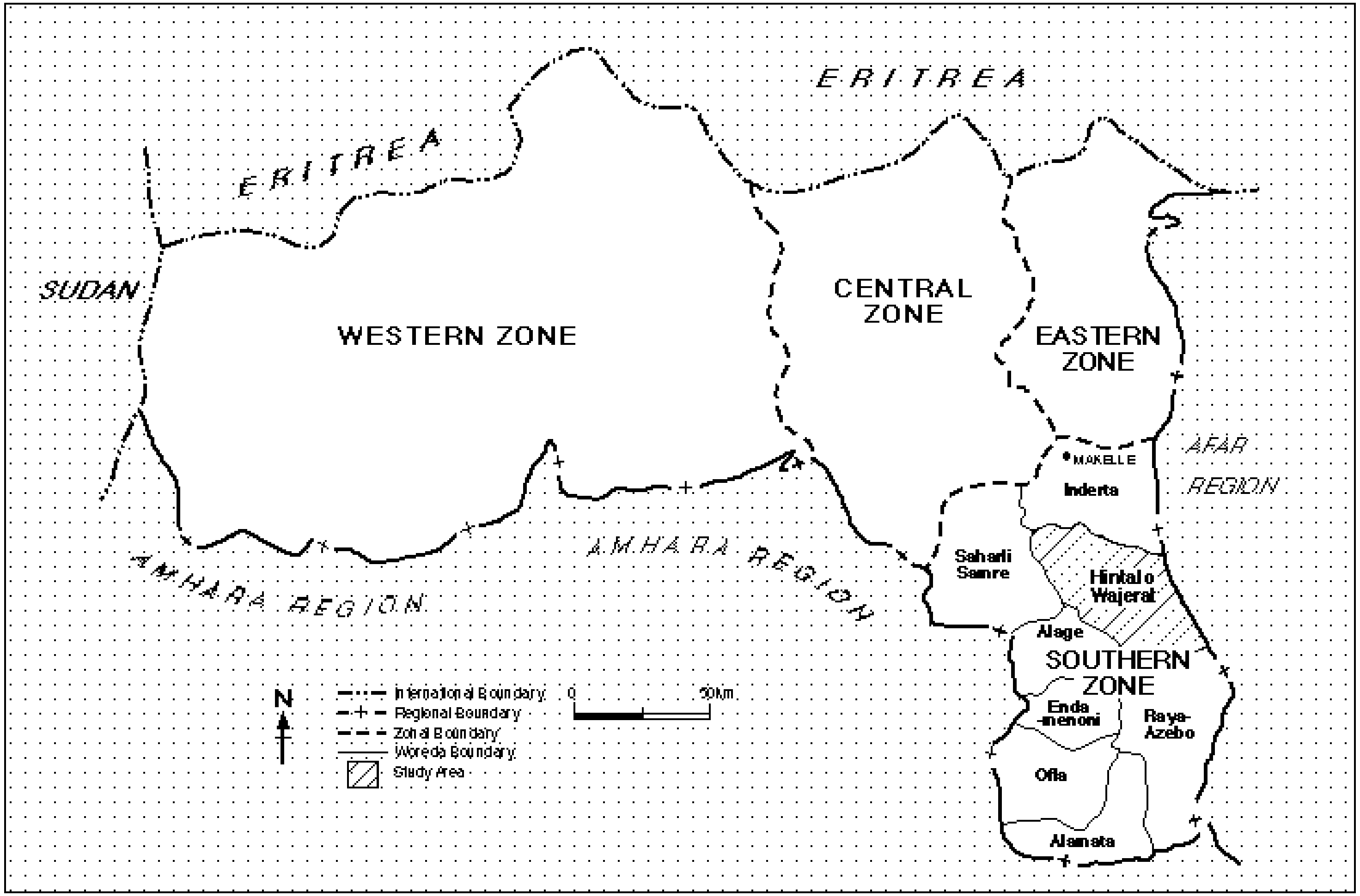

Figure 2 **Map of Tigray Region showing location of Hintalo-Wajerat Woreda**

groundwater abstraction sites close to villages. The region has been geologically surveyed and a number of maps and reports have been published (Annex D).

The Geological Survey of Ethiopia (formerly the Ethiopian Institute of Geological Surveys), a part of the Ministry of Mines and Energy, includes a Hydrogeology, Engineering Geology and Geothermal Department located in Addis Ababa. This department is the main source of hydrogeological expertise and data within Ethiopia. At regional level, the Water Mines and Energy Resource Bureau in Makelle hold reports and results from regional surveys and projects pertinent to the Hintalo-Wajerat Woreda area.

Borehole drilling success rates are often the only criteria used to evaluate and compare drilling programmes, but these need to be treated with caution. The benefits of drilling in more difficult areas needs to be considered; a drilling programme with a lower relative success rate in areas where water is particularly scarce may realise greater benefits than a more successful programme in already well-supplied areas. These benefits will only be realised if adequate data are collected and used to expand the knowledge base.

WaterAid and its partner organisations have not yet undertaken a groundwater development programme in the Hintalo-Wajerat Woreda area. An assessment of the water supply of the area conducted by EOC/DICAC provides the basis for proposals submitted to WaterAid. Other NGO's are believed to have operated in the Tigray Region but not currently in the Hintalo-Wajerat Woreda area.

The KAR project resources dictate that only two countries can be selected for more detailed follow-up work. The Hintalo-Wajerat Woreda area, which is one of the poorest in Ethiopia, would make a good case study, not least because of the interest and support offered by the local organisations and government departments and the quality of existing geological and hydrogeological data. Use of a Makelle based borehole-drilling organisation would avoid mobilisation costs of equipment from Addis Ababa. However, a major constraint to the project would be the remoteness and accessibility of some parts of the area, which has poorly maintained mountain tracks to some of the communities. WaterAid, their NGO partners and government organisations showed much interest in the groundwater assessment methods outlined. All wanted to participate in the KAR project. There was particular interest shown in the groundwater development map of the Oju/Obi area in Nigeria (Davies and MacDonald, 1999).

3. BACKGROUND INFORMATION ON ETHIOPIA AND THE HINTALO-WAJERAT WOREDA REGION

Ethiopia has made significant socio-economic improvements since the end of the civil war. However, the Southern Zone of Tigray Region in north Ethiopia is one of the poorest regions in the country and contains a largely subsistence farming population. At the present time, further development is constrained by the continuing border tension between Ethiopia and Eritrea. Much of the background information presented here has been obtained from a project proposal entitled "Hintalo-Wajerat Water Supply, Sanitation and Hygiene Education Project proposal" prepared by the Ethiopian Orthodox Church for submission to WaterAid. This project aims to improve the water supply status of 55,000 people and 22,000 livestock within one of the poorest areas of Ethiopia.

The Hintalo-Wajerat Woreda lies between latitudes 12º 55'N and 13º 20'N and longitudes 39º 20'E and 39º 55'E. The elevation of the area ranges from 1400 to 2850 mAOD. The relatively flat northern area around Adi Gudom forms part of the Makelle Plateau. The Adi Shoha Highlands to the south and west and Desa Escarpment to the east are characterised by rugged mountains and deeply incised valleys (Figure 3).

Average temperature in the area is about 18°C. However, in the highlands, the temperature drops to 5°C during November to January. The climate is warm and dry for most of the year apart from the two rainy seasons. The dry season lasts from September to April, with the main rains (Meher rains) during June – August and the small rains (Belg rains) during March - April. Rainfall patterns can be erratic; prolonged periods of drought do occur, as experienced at the present time (Table 1). In the north-west of the region average annual rainfall is up to 850 mm, decreasing to 300-400 mm in the east.

Month	**Monthly Mean**		**Monthly Minimum**		**Monthly Maximum**	
	Makelle	Wukro	Makelle	Wukro	Makelle	Wukro
January	3.6	1.0	0.0	0.0	11.7	4.9
February	3.5	4.2	0.0	0.0	7.7	11.3
March	35.6	43.7	0.4	0.0	63.9	115.4
April	48.8	48.2	1.0	6.5	125	79.6
May	42.4	46.1	0.1	0.0	92.2	73.5
June	38.3	33.9	6.2	0.0	69.0	88.8
July	186.6	173.1	109.2	141	268.2	185.3
August	203.3	190.2	100.5	5.3	237.7	379.1
September	26.9	38.6	1.3	0.0	70.1	113.1
October	18.0	2.2	0.0	0.0	82.9	6.5
November	17.2	5.2	0.0	0.0	54.2	20.9
December	5.5	0.3	0.0	0.0	21.7	1.0

Table 1 Monthly mean, minimum and maximum rainfalls at Makelle and Wukro (mm) for 1992-1997, from EOC (1999)

The Hintalo-Wajerat Woreda area is located astride a major north-south trending surface water divide, with the Danakil Depression to the east and the Tekeze River basin to the west. This drainage system is relatively young with deeply incised valleys. Topographically, the area can be divided into three zones (Figure 3). The Desa Escarpment east of the water divide is typified by rugged topography, with incised fault controlled valleys, which include the highest parts of the area. The Makelle Plateau and Adi Shoha Highlands are located to the west of the water divide. The Makelle Plateau of the central and north-western parts of the area, is characterised by gently undulating topography. The rugged Adi Shoha Highlands rise steeply from the southern edge of the plateau to more than 2750 mAOD.

The Hintalo-Wajerat Woreda area is underlain by two main rock sequences (Table 2 and Figure 4):

- Jurassic to Cretaceous age sedimentary rocks comprising sandstones, limestones and shales;
- Tertiary age volcanic basalts and dolerites.

	Formation (thickness metres)	Lithology	Physiographic character
Tertiary	Trap Volcanics (200 m)	Black olivine basalt	Extensive mesas
	Makelle Dolerite (60 m)	Black andersine dolerite	Cliffs in Agula Shale/Antalo Limestone
Cretaceous	Amba Aradam Formation (60-200 m)	White sandstones and conglomerates	A cliff at the base of mesas formed by Trap Volcanics
	Agula Shale (60-250 m)	Grey, green, red and black shale with gypsum	Wide terraced slopes
Jurassic	Antalo Limestone (690-740 m)	Limestone	Cliffs and gradual terraced slopes
	Adigrat Sandstone (300-650 m)	Sandstone	Steep cliffs

Table 2 Stratigraphic succession found within the Hintalo-Wajerat Woreda area

The Jurassic to Cretaceous age sediments comprise basal Adigrat Sandstones, overlain by the Antalo Group of Antalo Limestone and Agula Shale. Sandstones of the Cretaceous Amba Aradam Formation overlying Agula Shale are exposed as high cliffs in the Hintalo and Hiwane areas. These sediments were deposited during a marine transgressive/regressive cycle (Mohr, 1971). The Antalo Limestone is the result of a marine transgressive phase during the Upper Jurassic. Subsequent regression resulted in a semi-arid lagoonal environment and deposition of the Agula Shale. Finally, following an erosional phase, fluvial-lacustrine sandstones and conglomerates of the Amba Aradam Formation were deposited (Chernet and Eshete, 1982).

Precambrian basement, not exposed within the Woreda area, is overlain by Adigrat Sandstone Formation composed of fine to coarse-grained, cross-bedded, well-cemented sandstone that crops out in the east of the area. This sandstone formation contains lenses of conglomerate and siltstone and is typically laterised to a depth of about 20 metres (Tefera et al, 1996). The uppermost part contains thin beds of limestone near the transition to the Antalo Group, indicative of the commencement of the marine transgression.

The Antalo Group is composed of the Antalo Limestone Formation that rests conformably on Adigrat Sandstone and the younger Agula Shale Formation that underlies much of the Makelle Outlier. The limestone is extensively exposed in the mountainous areas to the east of Mai Kaieh and in the Adi Shoah Highlands to the south, as seen at Mai Nebri and Muja. The limestone also crops out on the Makelle Plateau south of Kwah and around Adi Gudom where it has been developed as a source of local building material. The limestones are yellow to white, generally well-bedded and finely crystalline (Plate 1). The basal limestones are sandy and there is an increase in marl content eastwards and upwards in the sequence (Chernet and Eshete 1982). The Antalo Limestone is about 700 m thick in the eastern part of the Makelle Outlier and is fossiliferous in part. South and west of Mai Nebri the upper limestones become shaley and sandy with occasional lenticular oyster shell banks. Within the gorge down stream of Mai Nebri these limestones have been intruded by thick horizontally bedded columnar Makelle dolerites (Plate 6).

The grey, green, red and black Agula Shales that underlie extensive flat lying broad valley areas of the Makelle Plateau are 60-250 m thick (Plate 2). These shales are hard and well jointed to soft and

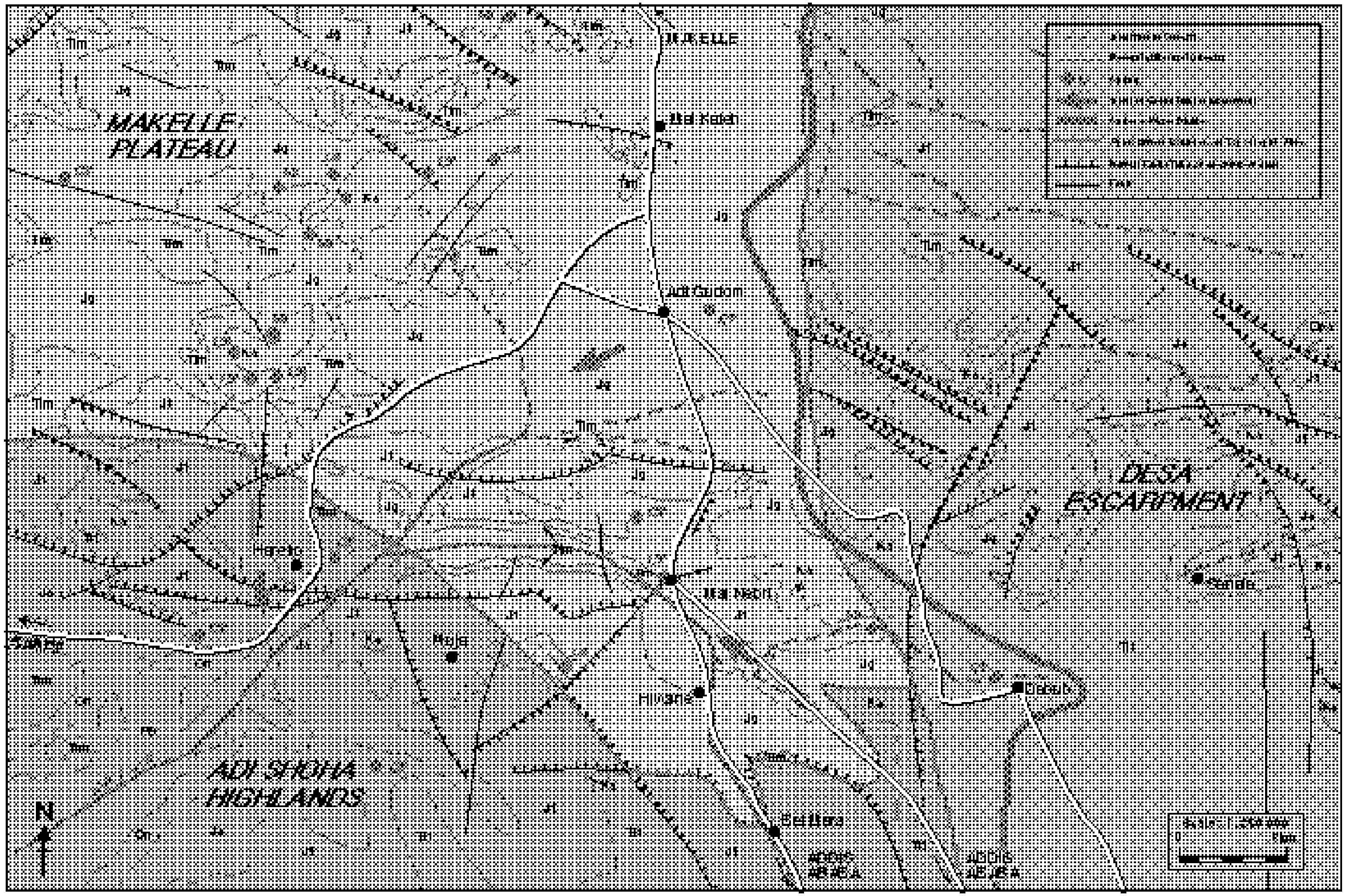

Figure 3 Summary of hydrogeology map of the Hintalo-Wajerat Woreda with major topographic area

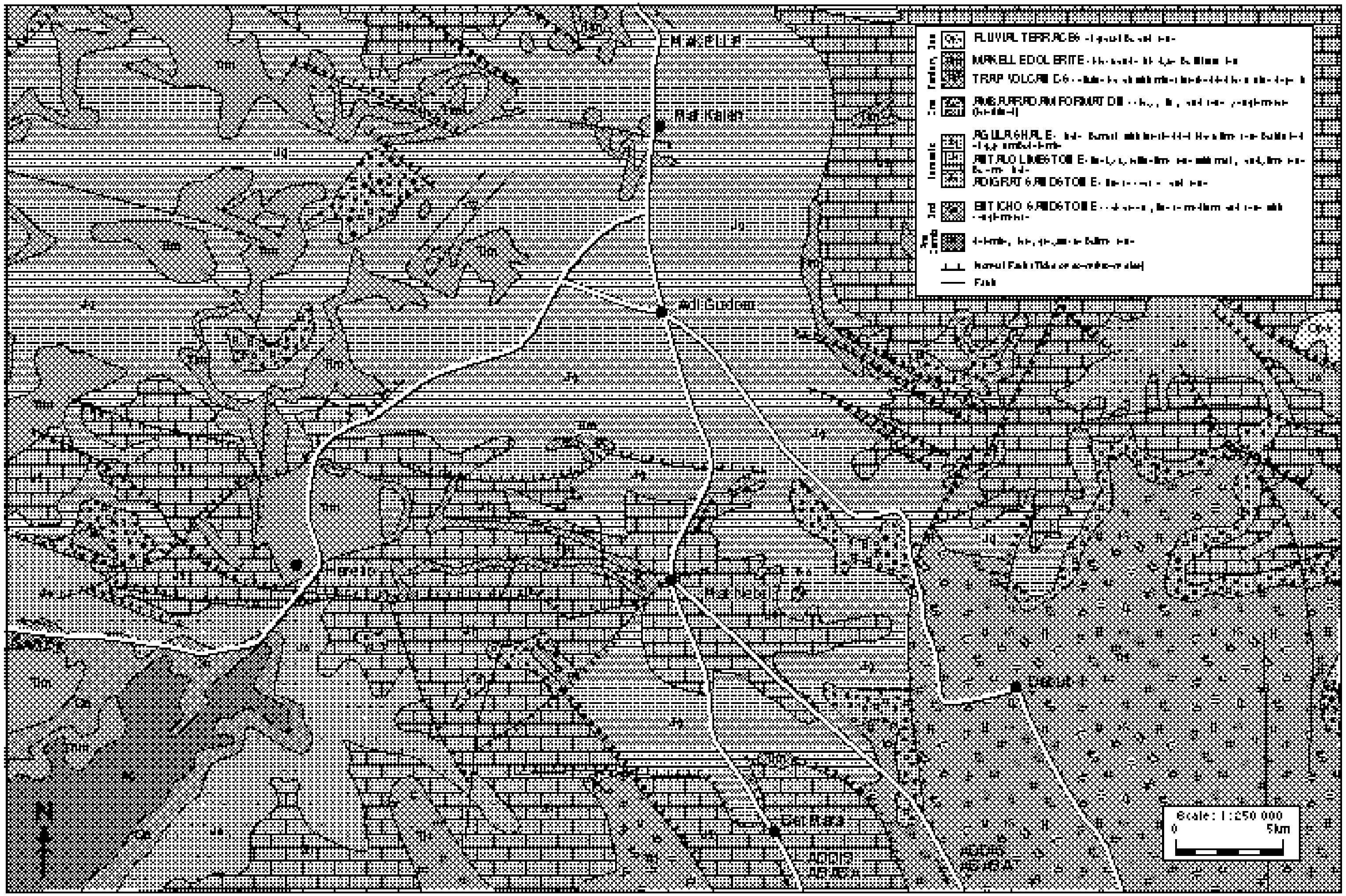

Figure 4 Summary geology map of the Hintalo-Wajerat Woreda

splintery (Chernet and Eshete 1982). Thin interbeds of gypsum, limestone, dolomite and marl are common toward the top of the shale sequence, with fractures and dolerite intrusions.

The Amba Aradam Formation, formerly known as the Upper Sandstone, lies unconformably upon both the Antalo Limestone and Agula Shale. The formation is composed of fine-grained sandstone to conglomerates (Plate 3) that have been laterised. The formation crops out as high cliffs often capped by Trap Series volcanics (Plate 4) (Chernet and Eshete 1982). Rafted segments of this sandstone occur within the overlying Trap volcanic sequence (Plate 5).

The Tertiary volcanics can be divided into two types: the intrusive dolerites and the extrusive basalts although the two phases are thought to be co-magmatic. The Makelle Dolerites are represented by fine grained, crystalline sills and dykes, most commonly as intrusions (sills) within the Antalo Limestone west of Mai Nebri (Plate 6), and in the Agula Shale to the west of Adi Gudom. These sills form steep sided cliff features and rounded hilltops. The basaltic Trap volcanics occur in rugged mountainous areas south and south-east Mai Nebri where they crop out as layered olivine flood basalts with scouriacious tops commonly with palaeosol surfaces (Plate 7). These basalt flows often exhibit columnar jointing (Plate 8) and are interbedded with occasional lacustrine limestone and silt deposits.

These geological formations have undergone subsequent folding and faulting. Within the Makelle Plateau folding of the sedimentary formations was gentle with NW/SE axes related to fault belts. The regional dip of these strata is less than five degrees to the north-east. Faulting mainly occurred after deposition of the Agula Shale but before deposition of the Amba Aradam Formation.

Recent alluvial deposits occur as fan deltas composed of black peaty cotton soils underlain by coarse grained conglomeratic alluvium especially where streams issue from the mountains into the valleys (Plate 9). Small plains underlain by such soils have developed within the broader valleys and flat areas upon shales, such as in areas upstream of Mai Nebri and south of Adi Gudom. Such flat to gently sloping areas have been intensively developed for irrigation. Presumably the soils were developed under a dense vegetative cover that protected them from erosion. Since removal of this cover the soils have been subject to erosion with incision of deep gullies (Plate 10). Narrow, linear terraces have been developed for irrigation along the perennial river valleys in the south of the area. Soil profiles are generally shallow throughout the area; erosion having reduced the thickness of superficial deposits. The farming communities classify the soils as reguid, maekelay and rekik types (deep, medium and shallow) which is based on the ability of soils to store water and the fertility of the land. Of the proportion of arable land available in the area 31% of the soil types are deep, 34% medium and 35% shallow. Underlying geological formations and topography influence soil type. Much terracing has been carried out in the area by local communities, employed under food for work programmes, with the aim of reducing soil erosion by retarding the surface water flow during storms.

Ethiopia is divided into regions, of which Tigray is the most northern and contains the project area. Each region is divided into zones. The project area is located in the Southern Zone. Each zone has a number of woredas (administrative regions). The project area is the Hintalo-Wajerat Woreda that is divided into 19 tabias (or kebeles) similar to parishes (Figure 5). These are then further divided into villages, called kushets. The distributions of community and livestock populations within these tabia areas during 1992 are listed in Table 3. The average population density within the Woreda is approximately 125 persons per km^2.

Plate 1 **Antalo Limestone at Muja**

Plate 2 **Agula Shale west of Adi Gudom, with horizontal and dipping gypsum bands developed along bedding plains and joints respectively**

Plate 3
Mixed supported conglomerate within the Ambra Aradam Sandstone South east of Hiwane

Plate 4 **Cliffs of laterised Amba Aradam Sandstone south east of Hiwane within the Adi Shoha Highlands**

Plate 5 **Rafted white Amba Aradam Sandstone within black Trap Volcanics Basalts**

Plate 6 **Prominent columnar jointed Makelle Dolerite sill within Antalo Limestone cropping out along valley side west of Mai Nebri**

Plate 7 **Successive Trap Volcanic Basalt flows with scouriacous surfaces cropping out near Debub**

Plate 8 **Columnar jointing within thicker Trap Volcanic Basalt flow between Adi Gudom and Debub**

No.	Tabia	Male	Female	Total	No. of Kushets	Area (Ha)	Livestock
1	Hagre Selam	4321	4355	8676	4	8112	7285
2	Senale	4089	4111	8200	4	3380	4306
3	Hareko	4019	4130	8149	3	2474	4381
4	Adi Gudem	3510	4218	7728	4	2196	9229
5	Ara Asegeda	3837	3787	7624	4	3361	6157
6	Hiwane	3704	3869	7573	4	4558	8673
7	Bahir Tsebha	3653	3897	7550	4	2274	6413
8	Metikele	3452	3413	6865	3	3390	7217
9	Fikre Alem	3236	3229	6465	4	5891	5862
10	Amde Woine	3189	3268	6457	4	2045	2337
11	Gonka Seberbera	3236	3130	6366	4	3706	5182
12	Dejen	3086	3144	6230	3	4447	3238
13	Tsehafi	2978	3009	5987	4	9327	7503
14	Muja	2874	2982	5856	4	12352	6535
15	Adi Awona Waza	2830	2929	5759	4	11865	6800
16	Hintalo	2663	2787	5450	3	3365	7613
17	Adi Keyeh	2657	2580	5237	4	2571	9070
18	Adi Meseno	2405	2617	5022	4	2188	3897
19	Mai Nebre	2149	2366	4515	4	3706	5821
Total		61888	63821	125709	72	91208	117469

Table 3 Population and livestock distributions per Tabia within Hintalo-Wajerat Woreda during 1992

The area of the Woreda is nearly 91,000 hectares of which 50% is cultivable, 29% is grazing land, 9% is forest and wooded land and the remainder non-agricultural land. The natural forest area has been depleted by felling of timber for fuel. The main tree species present are *Acacia amythethophyla* (Chea), *Olea Africana* (Awlie), *Acacia etbacia* (Seraw) and *Eucalyptus*. Population increase has exacerbated deforestation through increased demand for cultivable land and fuel.

More than 90% of the population of the Woreda are engaged in subsistence farming. The average holding of arable land is 0.5 Ha per household. The main crops cultivated are barley, wheat, teff, lentils and sorghum. Cattle are used for cultivation while donkeys and camels are used for transportation of fuel and salt. Annual crop yields vary because of the erratic patterns of rainfall. In a good year, an average of 25-30 quintals per hectare of wheat and barley and between 8-10 quintals per hectare of teff can be harvested; quantities that would satisfy a household of 4 people. However, such years are infrequent and in most years, farming communities have to look elsewhere for income, such as selling of livestock, collection/selling of fuel and migration to urban areas to seek employment.

Plate 9 **Intermountain fan delta with irrigated terraces south east of Hiwane**

Plate 10 **Deep gully eroded through black peaty cotton soil into underlying coarse grained alluvium south of Mai Nebri**

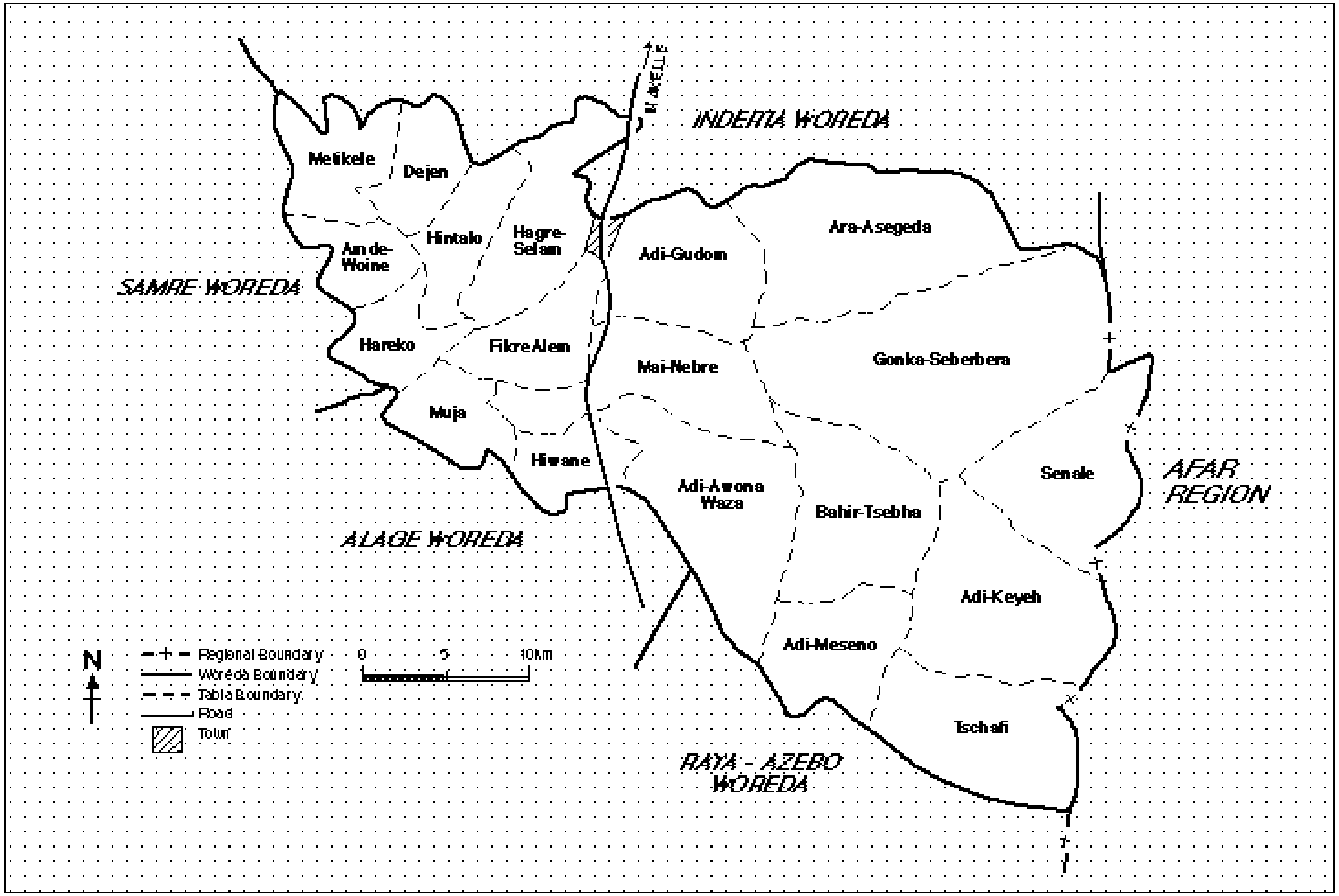

Figure 5 **Map of Hintalo-Wajerate Woreda showing tabia boundaries**

Historically, rural water supplies have consisted of springs and streams. Recurrent droughts have caused some springs to reduce in yield or dry up. During the last five years the Tigray government has implemented an extensive water supply project with the construction of hand-dug wells, boreholes and protected springs. Although these works have improved the water supply situation of the area, some tabias are still situated many hours walk from a water supply often along rugged and steep tracks.

Currently, the Woreda has 66 hand pumped boreholes/hand-dug wells and 5 protected springs. Each hand pump serves an average of 218 people and 2133 livestock, i.e. a hand pump supplies more than one kushet. The average kushet size is 12.6 km^2, therefore households on kushet peripheries, away from the central water source, may have to walk a 3 hour round-trip; a distance also covered by cattle.

The main health problems in the Woreda include a prevalence of malaria, lower respiratory tract infections (e.g. tuberculosis, bronchitis and pneumonia) and diarrhoea. The high incidence of diarrhoea probably related to the use of water sources by both people and livestock.

4. GROUNDWATER AVAILABILITY

Since surface water supplies in the Hintalo-Wajerat Woreda are mainly ephemeral, groundwater forms a significant sustainable water resource, and the only water source for a significant number of the population during the dry season and periods of drought. Groundwater availability is dependent upon the nature of the underlying rocks. As described above, these comprise sequences of Mesozoic sediments and Tertiary volcanics, which exhibit different hydrogeological properties. The primary porosity of both the sedimentary and volcanic formations is probably low and groundwater is most likely to be found in these rocks where they are fractured, baked and/or weathered to significant depths (Chernet and Eshete 1982).

The Adigrat Sandstone is well-cemented, cropping-out in small areas in the east. This formation occurs at depth beneath younger deposits and is unlikely to form a groundwater resource. The Antalo Limestone is generally a fine-grained, crystalline rock but contains thin karstic features that permit groundwater flow limited to the weathered zone. The Agula Shale forms a poor aquifer, except where fractured or baked by igneous intrusion. Limited groundwater resources are contained in the Amba Aradam Formation where faulted and at contact with the overlying Trap Volcanics.

The dolerites and basalts contain little primary porosity, groundwater being stored in columnar joints, fractures, palaeosol horizons, lacustrine deposit interbeds and scouriacious horizons. Dolerite intrusions may act as aquicludes preventing vertical groundwater movement.

Numerous springs were observed in the area. These occur in two main settings.

(i) Along incised river channels that have eroded through black cotton soil deposits into the underlying alluvium. The soils slowly release water from storage to the basal alluvial deposits during the dry season.

(ii) At the contact between basalt/dolerite intrusions and sandstones and/or limestones. These zones were often observed to be associated with steep fault controlled gullies.

This description of groundwater occurrence within the Hintalo-Wajerat Woreda has resulted from limited field observations and information from available reports. The geology of large parts of the area has yet to be proved by drilling. There is little understanding of how groundwater occurs within the different lithologies present. Insufficient data have been collected during drilling programmes, with poor recording of borehole geology and aquifer parameters. Apart from crude air-lift tests borehole test pumping is not generally carried out, and aquifer parameters are rarely assessed.

Groundwater levels and groundwater chemistry are tested at the time of pump installation. However, there is no subsequent monitoring of seasonal water levels, rainfall, groundwater quality, or borehole abstraction rates. Recharge assessments and safe aquifer yields cannot be determined nor resource sustainability considered.

A baseline survey conducted by the Ethiopian Orthodox Church of safe community water supplies within the area showed that in all but one tabia less than 50% of the population had access to safe water supplies. Of these in 8 tabias less than 20% of the population had access to safe water. The EOC estimate that some 56 protected springs, 66 hand dug wells and 30 boreholes need to be installed during the 4-year life of a proposed project (Table 4).

No.	Tabia	No. of Kushets	Water sources needed	Existing hand-pumps	% with access to safe water
1	Hagre Selam	4	5Sp, 3Hd, 1Sw	8	48
2	Senale	4	7Sp, 5Hd	2	13
3	Hareko	3	2Sp, 4Hd, 3Sw	3	19
4	Adi Gudem	4	5Sw, 3Sp, 3Hd	4	25
5	Ara Asegeda	4	3Hd, 4Sw	6	41
6	Hiwane	4	2Sp, 3Hd, 1Sw	5	34
7	Bahir Tsebha	4	4Sp, 4Hd, 1Sw	4	27
8	Metikele	3	3Sp, 4Hd, 3Sw	2	15
9	Fikre Alem	4	2Sp, 3Hd, 3Sw	5	40
10	Amde Woine	4	3Hd, 1Sw	3	24
11	Gonka Seberbera	4	3Sp, 5Hd	2	16
12	Dejen	3	2Sp, 3Hd, 3Sw	2	17
13	Tsehafi	4	6Sp, 5Hd	1	9
14	Muja	4	4Sp, 2Hd, 2Sw	1	11
15	Adi Awona Waza	4	2Sp, 3Hd, 1Sw	3	27
16	Hintalo	3	1Sw	8	75
17	Adi Keyeh	4	3Sp, 3Hd	3	26
18	Adi Meseno	4	5Sp, 4Hd	1	10
19	Mai Nebre	4	3Sp, 3Hd	3	34
Total		72		66	

Table 4 **Existing beneficiaries of safe water and list of water sources needed in Hintalo-Wojerat Woreda (from Ethiopian Orthodox Church, 1999)**

5. CURRENT PRACTICE - METHODS AND APPROACHES

The traditional water sources in the Hintalo-Wajerat Woreda during the wet seasons are rivers, ponds, hand-dug wells and springs. These sources are frequently contaminated by surface runoff of effluent and many also form breeding grounds for mosquitoes. During the wet season, diarrhoea and malaria are the major causes of mortality. During the dry season when surface water virtually disappears, springs and hand-dug wells form the main water sources.

The proposed EOC/WaterAid project aims to adopt the concept of cost sharing with villagers in order to emphasise the achievement of a feeling of community ownership of rural water sources during project implementation. Projects are initiated with the involvement of the village and its component sub-villages. Water committees are established to liase with WaterAid and its partner organisations. The villages are required to set up funds to cover at least part of the costs of the project and the ongoing maintenance of water supply points. Before the installation of hand pumps, sanitation and hygiene awareness and education programmes are carried out.

Field visits were made to a number of kushets in the Adi Gudom, Mai Nebri, Bahir-Tsebha, Senale, Hiwane and Muja Tabias. The short length of time available limited the number of places visited and meant that only sites within a reasonable distance (up to a few hours drive) of Makelle were seen. However, the conditions observed during the visits are characteristic of most of the region.

East of Makelle (N13º28.406' E39º29.728) is a well field of six production boreholes equipped with electrical submersible pumps that provide part of Makelle's water supplies. These boreholes have been drilled into a limestone aquifer overlain by waterlogged black cotton soil. Nine additional abstraction boreholes have recently been drilled but these have yet to be placed in operation. The groundwater is of acidic character, as indicated by the need to replace galvanised iron riser and delivery pipes annually due to corrosion. Excess water from the water logged area (a spring zone) is channelled away for irrigation. Local domestic water supplies are obtained from shallow hand dug wells equipped with Afridev pumps.

At Hiwane, south of Mai Nebri, a solar powered borehole pump was noted, from which water was pumped to a 4-tap stand. This borehole was drilled into alluvial sediments deposited within the local ephemeral river channel. Investigation core drilling undertaken as part of a bridge foundation study into the riverbed proved 15m of alluvium within the channel. Groundwater continues to flow through this river alluvium during the dry season.

At Hidmo (N13º12.879' E39º31.553') a shallow borehole equipped with an Afridev pump was noted (Plate 11). This borehole is located within a linear shallow valley with ridges either side upon which the village is located. Women usually collect water using traditional clay pots (an Einera) that have a capacity of 15-20 litres and are carried on the back. The shallow valley is floored with black cotton soil into which deep gullies have been eroded.

The village of Debub (N13º04.653' E39º37.832') has a variety of water sources. The main source appears to be a spring issuing from the base of gully eroded into black cotton soil (Plate 12). This is a source of domestic supply and water for livestock. About one kilometre from the village is a spring at the contact of a rafted sandstone and basalt flows with interbedded soil horizons also used for domestic supply and watering livestock. Within the village there are several stone lined hand-dug wells excavated through black cotton soil into underlying alluvium and weathered bedrock, mainly within family compounds. One well downstream of the village is disused being thought to be contaminated (Plate 13). A piped water system, installed in the village during the past year, is out of action due to unspecified maintenance problems. This supplied water from a shallow borehole

Plate 11 **Local women pumping water from an Afridev equipped shallow borehole east of Adi Gudom**

Plate 12 **River-side spring from alluvial gravels and boulder beds beneath black cotton soil at Debub**

Plate 13
Disused, apparently contaminated, hand dug well at Debub

Plate 14 **Borehole equipped with an electrical submersible pump supplying local domestic reticulation scheme at Mai Nebri**

equipped with a diesel engine powered mono pump via a small header tank to several sets of water supply taps. Apparently, the community is refusing to pay a mechanic to service the pump engine.

At Senale (N13º04.002' E39º42.172') several spring zones were noted issuing into a deep river channel eroded through black cotton soil into underlying zeolitic basalt. The largest spring, protected as a holy spring by the local church, is used for domestic supply and watering livestock. Downstream of the village, another spring zone issues from a contact of conglomeratic sandstone and basalt. This is a source of domestic supply.

At Mai Nebri (N13º08.061' E39º29.755') there are two main sources of water. The perennial river that flows to the west, south of the village receives much of its flow from the alluvial base of an extensive deposit of black cotton soil that covers most of the local plain. This plain is the site of intensive irrigation throughout much of the year, water being obtained from a local dam and from several stream sources. The second source is a shallow borehole equipped with an electrical submersible pump used to supply domestic water by reticulation to water points at various parts of the village (Plate 14). The borehole receives much of its water from the local river gravels.

Sofu (N13º07.956' E39º28.446') is located on a hillside bench to the south of Mai Nebri. Several small springs issue from a faulted dolerite/limestone contact. The main spring is located at the top of the hill. This was the only example of a protected spring seen. Water is channelled from the eye of the spring to a reservoir box fitted with about 6 outlet taps. Overflow water is piped to a cattle trough. Any excess water is channelled away for irrigation. The community draws water from the cattle trough for their domestic purposes since they are frightened of breaking the taps on the reservoir tank that have been locked (Plate 15).

Further along the track towards Muja, a spring was noted adjacent to a church at a dolerite/limestone contact. A large pillar like travertine formation has developed at the spring.

At Shiket (N13º08.679' E39º24.998') two springs were noted. The first was located on a faulted limestone/dolerite contact zone downstream of a dry waterfall coated with travertine. Water is used for stock watering and domestic purposes. The second spring is located adjacent to a church dedicated to St John the Baptist. The thickly vegetated spring eye is protected as a holy site. Visitors are requested to remove their shoes when visiting the spring eye. The water is used for drinking.

Muja (N13º07.717' E39º24.609') is located upon a wide bench, that is green with irrigated crops, located above a deeply incised valley (Plate 16). The water is derived from a spring at a faulted dolerite/limestone contact. Water flows from the spring at the rate of several litres per second. The eye of the spring is located within a protected, venerated area of dense vegetation. The village area is backed by a series of high sandstone cliffs up to 2850 mamsl.

Boreholes are located east of Makelle and at Hiwane, Hidmo, Debub and Mai Nebri. Within the proposed EOC/WaterAid programme borehole siting and installation would be carried out in stages. The aim is to install one borehole for each sub-village, the current policy is for one borehole for a maximum of 300 people. If the population of a sub-village is greater than 300, two boreholes are installed. Each village water committee specifies three potential borehole sites, in order of preference. These sites are surveyed using the resistivity geophysical method to investigate the vertical distribution of soils, weathered and solid rock types. The data obtained are used to recommend one or more sites for drilling, with specified drilling depths.

Boreholes are installed using a truck-mounted drilling rig with a compressor. During drilling, samples of cuttings are taken at 1m intervals and at major changes in lithology. Following the installation of casing, screen and gravel pack in a successful borehole air lifting is carried out to develop the borehole and give a basic indication of borehole yield. Information collected during drilling of successful boreholes is forwarded to the Water, Mines and Energy Bureau of Tigray. On completion

Plate 15 Protected spring at Sofa west of Mai Nebri

Plate 16 Cliff top irrigated area fed by spring on dolerite/limestone contact zone at Muja

Afridev hand pumps are emplaced in boreholes more than 20 m deep. A concrete surround and apron is constructed at the head of the well. A chain link fence or stone wall is constructed around the pump and apron to keep livestock away from the well.

Issues

(i) Geological and hydrogeological data need to be collected from all boreholes, even those that are apparently dry on completion. Such boreholes should be allowed to stand overnight to determine if sufficient water has seeped into the borehole to warrant their use or abandonment. The locations of **all** boreholes need to be determined using a GPS. These data can then be entered into a GIS database so that regional and lithological unit specific parameters can be assessed. By doing this, patterns of groundwater yield may be recognised and successful borehole siting improved. BGS left a hand-held GPS with the EOC hydrogeologist that can be used to locate boreholes and village centres to within an accuracy of between 100 to 250 m.

(ii) The yield/drawdown characteristics of boreholes yielding only 0.3-0.5 l/sec need to be assessed, especially during the dry season. Given the shallow water tables usually encountered within the region simple Whale pump systems powered by 12 volt DC car batteries could be used to determine aquifer characteristics.

(iii) During drilling, geological samples should be taken at 0.5 or 1 m intervals to allow recognition of geologically significant factors, especially within the weathered zone. Sample colour should be described, according to standard colour charts, since water-bearing horizons in the weathered zone are often recognised using colour.

6. AVAILABLE INFORMATION AND DATA COLLECTION

WaterAid Ethiopia facilitated the BGS visit to Ethiopia and arranged visits to organisations and institutes in Addis Ababa. At each meeting, the nature of the KAR project was described using methods developed during the Oju/Obi project in Nigeria (Davies and MacDonald 1999), including the groundwater development map of that area (Annex E). WaterAid’s main NGO partners are the Ethiopian Orthodox Church/Development and Inter-Church Aid Commission. They are the lead NGO for groundwater resource development at community level in the Hintalo Wajerat Woreda. EOC were able to furnish representative data and facilitate field visits to a number of kushets where WaterAid and EOC plan to work.

Published topographical maps at 1: 250,000 and 1:50,000 scale are available from the Ethiopian Mapping Authority in Addis Ababa. Digitised local maps are being produced in Makelle by the BPED. Aerial photographs of the area are noted on the 1:50,000 topographic maps but acquisition may be difficult due to the ongoing state of emergency.

The Geological Survey of Ethiopia at Addis Ababa has carried out geological and hydrogeological mapping of the Makelle Region at 1:250 000 scale, accompanied by two memoirs. The availability of aeromagnetic survey data is not known.

The Bureau of Planning and Economic Development, is responsible for regional planning and development. The Makelle regional office holds copies of 1:50,000 topographic maps, land use maps, data and reports of land use, agriculture and water supply for the Tigray Region. BPED is developing its own ArcView GIS database.

The Water Resource Development Department of the Water, Mines and Energy Bureau of Tigray in Makelle includes hydrogeologists, geologists and geophysicists. The department oversees water supply, water quality, drilling and geophysical survey within the region as well as holding borehole completion forms recording borehole drilling and construction details.

The Department of Geology at Makelle University College showed interest in attaching students to the KAR project study.

The Tigray Waterworks Construction Enterprise, Makelle, were formerly part of the Water, Mines and Energy Bureau but is now the largest private drilling organisation in Tigray.

GOH Tours and Travel Agency of Makelle provided 4-wheel drive transport at 1200 EBr per day including the services of a driver and fuel.

7. RECOMMENDATIONS

The Hintalo-Wajerat Woreda is a good candidate to use as a case study for the project. The area is one of the poorest in Ethiopia and it is presently affected by drought conditions. Limitations include:

- Lack of funds
- EOC/WaterAid proposals have yet to be approved
- Difficult transportation to, from and within the area
- The availability of coring and other drilling equipment
- The ongoing tensions between Ethiopia and Eritrea

For the project to have any long-term impact, links must be develop with all stakeholders identified in this report. Much interest and support was generated from WaterAid, its partner organisation EOC and University College in Makelle. WaterAid and EOC are keen to improve their ability to provide safe water for the villages where they work, with a long-term view towards expanding their programmes into other areas. The Bureau of Planning and Economic Development and the Water, Mines and Energy Bureau of Tigray expressed much interest in becoming involved at counterpart level in order to improve the experience of their staff. At Makelle the Tigray Waterworks Construction Enterprise staff stressed their need for strong professional contacts.

REFERENCES

Chernet, T and Eshete, G, 1982. Hydrogeology of the Makelle Area (ND37 - 11). Memoir No.2, Ethiopian Institute of Geological Surveys.

Davies, J and MacDonald, A M, 1999. Final Report: The groundwater potential of the Oju/Obi area, eastern Nigeria. British Geological Survey Technical Report, Overseas geology Series, WC/99/32.

Ethiopian Orthodox Church (EOC/DICAC) 1999. Hintalo-Wajerat Water Supply, Sanitation and Hygiene Education Project Proposal, July 1999

Ezana Mining Development Plc, 1999. Hydrogeology and water resources of Agulae and Genfel catchments. Report for the Bureau of Water, Mines and Energy Resource Development, Makelle, Northern Ethiopia.

Mohr, P A , 1971. The Geology of Ethiopia. Haile Sellassie I University Press

Tefera, M, Chernet, T and Haro, W, 1996. Explanation of the Geological Map of Ethiopia (scale 1:2,000,000), 2nd edition. Bulletin No. 3, Ethiopian Institute of Geological Surveys.

ACKNOWLEDGEMENTS

The authors of this report are indebted to Mr Habtamu Gessese of WaterAid for facilitating their first visit to Ethiopia and to Mr Paulos Masresha of the Ethiopian Orthodox Church for introducing them to the fascinating scenery and people of the Hintalo Wajerat Woreda.

ANNEX A INTRODUCTION TO THE PROJECT

ANNEX B ITINERARY

March

6 Flight ET711 London to Addis Ababa, depart 20-15.

7 Arrived at Addis Ababa at 8-30. Met by counterpart from Ethiopian Orthodox Church (EOC) and driven to the WaterAid office where met the country representative Mr Habtamu Gessesse and Mr Paulos Masresha the EOC hydrogeologist with whom discussed programme for visit. Described works undertaken in Nigeria and visits made to Zambia, Ghana and Tanzania as part of the present KAR project. Paulos described the area south of Makelle underlain by limestone, sandstone and shales. Boreholes tend to dry up after two years of operation. To the EOC office where looked at 1:50 000 and 1:250 000 topographic maps and 1:250 000 hydrogeological map of the Makelle area. To the travel agent where organised purchase of tickets to Makelle.

8 With Gessese to the DFID office at the British Embassy where met Dr Nicholas Taylor. Described work undertaken in Nigeria and in other countries visited as part of the KAR project. Discussed visit to the south Tigray region. To the Ethiopian Map Agency to purchase maps of Ethiopia and Addis Ababa. With Asfaw from EOC to Friendship Travel to purchase tickets to Makelle. To the Geological Survey of Ethiopia HQ where found that the GM had gone to Tanzania. On to the hydrogeology unit which found with some difficulty on the other side of the city. There met the chief hydrogeologist with whom discussed the geology and hydrogeology of the Hintalo-Wajerat area.

9 To the WaterAid office where collected a photocopy of the Geology of Ethiopia book. To the airport with Paulos who had bought photocopies of reports. Flight ET14 to Makelle. At Makelle met by travel agent with hire vehicle and driver. Driven to Makelle where checked into hotel. To the Bureau of Water, Mines and Energy where met Ato Abebe Hailemanam the Department Head with whom discussed our experiences in Nigeria, Zambia, Tanzania and Ghana, and problems being experienced within the Hintalo-Wajerat area.

10 To the office of Ato Abebe with whom had further discussions. With him went to meet Ato Zemichel Gebra Medhim, Head of Economic Development and Regional Administration. Discussed planned visit to the Hintalo Wajerat area. Met members of GIS staff at the mapping section with whom discussed the application of Arcview and Arcinfo. Back to the office of Ato Abebe where met Selome Mekonnen and Fethangest W/Mariyam, Bureau geologists who would participate in field visits. Drove to well field east of Makelle where there are six old boreholes and nine new boreholes to supply water to Makelle pumped from dolerite/limestone aquifer. Saw Afridev hand pump on hand dug well. On to Adi Gudom looking at limestone and shale formations on the way. Met district officer at Adi Gudom. Drove to the south along the main road. Looked at core drilling rig and core derived from bridge site. Noted Upper Sandstone with fault zones, basalt intrusions and sandstones. Noted springs along basalt/sandstone contact zones, from which water is channelled to valley bottom irrigated terraces. Returned to Makelle.

11 Drove to the area east of Adi Gudom. Inspected a shallow borehole equipped with an Afridev hand pump. Looked at the occurrence of agglomerate bands, purple/green gypsum rich layers, the effects of faulting on gypsum bands, formation of selenite, dolerite dykes with sandstones and horizontal interbedded basalts with baked horizons above and below. Only small sections of sandstone with horizontal bedding, some contorted, increased intrusion of basalts with columnar jointing into the sandstones further to the east. Rugged area with poor roads. At Debub the next main village saw springs developed on contact zone between basalt and sandstone, local hand dug well and out of use borehole. The borehole is equipped with a Mono pump powered by a three cylinder Lister diesel engine. The local community refused to pay for the maintenance of the engine therefore the

village water reticulation scheme is out of use. On to Senalle village saw more springs along a riverbed and at a conglomeratic sandstone/zeolitic basalt contact. Returned to Makelle.

12 Took the road south of Makelle towards Adi Gudom. Stopped to inspect well bedded limestones at the end of the Makelle runway stream section and the rain gauge site in the next village where limestone blocks were being collected for the local stone breaking plant for road building. Some of these limestones proved to be shelly. At Mai Nebri stopped at the village borehole, equipped with a submersible pump. Crossed the Mai Nebri River, much pebbly river gravel exposed. On the south bank noted well defined example of gullying into black cotton soil in side valley. Noted contact between well bedded limestone with increased sandy partings and overlying basalt. Travelled to the west along the Mai Nebri valley. Noted a good example of a boxed in spring at the top of the hill. Excess water being used for irrigation. Noted several other springs at contacts between sandstone and basalt. Also noted the occurrence of patchy oyster rich beds in the limestones and the occurrence of lacustrine red and green mudstones at the transition between marine limestone and fluvial sandstone facies. Passed large hill-top exposures of limestones with circular slip blocks. At Muja stopped at a school from where walked down to a contact zone spring with a large rate of discharge (approximately 2 ls^{-1}). Water is channelled away to the local fields for irrigation. Returned to Makelle.

13 Visited the University of Makelle but nobody from the Department of Geology was available. Returned to Makelle. Called at the Bureau of Water, Mines and Energy Resources where met with Ato Abebe. Collected Fethangest with whom went to the Tigray Waterworks Construction Enterprise. There met with Hydrogeologist Ato Aradom Kidany with whom discussed the drilling capacity of his firm. Explained who we were and what we were about. Discussed the drilling capabilities of the firms in Tigray with Fethangest, especially EZANA who had acted as hydrogeological consultants to the Bureau. Paid hotel and car hire bills. To the Bureau where met Ato Zemicheal and Ato Abebe. Reported on our visits to the field and offices in Makelle. To the University where met Kifle W/Aregay. Showed him a set of slides designed to illustrate what we have done to date on the project, the methodologies we plan to use and what we want to achieve. He was most interested in attaching students to the project should it happen. Back to the hotel.

14 Drove from the hotel to the airport from where flew on the morning flight to Addis Ababa. To the WaterAid office where met Habtamu Gessesse. To the British Embassy to report to Dr Nicholas Taylor the findings of our visit.

15 To the Geological Survey of Ethiopia to meet with the Director. Discussed the findings of our visit and the results of studies conducted in Nigeria. Arranged for permits to transport rock samples to the UK. Obtained copies of relevant maps and reports. To the WaterAid office for a final meeting with Mr Habtamu Gessesse the country representative. Drove to the airport from where flew via Rome on Ethiopian Airways flight ET730 to London Heathrow, where arrived at 22:00.

ANNEX C PEOPLE MET AND OTHER CONTACTS

Addis Ababa

Department for International Development (DFID), British Embassy, Addis Ababa PO Box 858, Ethiopia. Tel 251-1-612354, Fax 251-1-610588, e-mail: n-taylor@telecom.net.et
Dr. Nicholas Taylor, Development Administration Officer

Geological Survey of Ethiopia (formerly: Ethiopian Institute of Geological Surveys), P O Box 2302, Addis Ababa, Ethiopia. Tel 251-1-615685, Fax 251-1-615686, 712033 e-mail: Geology-Institute@telecom.net.et. Ketema Tadesse, General Manager,
Gebretsadik Eshete, Head, Hydrogeology Engineering Geology and Geothermal Department, P O Box 40069, Addis Ababa, Ethiopia. Tel 251-1-202851/58, Fax 251-1-513877/712033, e-mail: Geology-Institute@telecom.net.et

Ethiopian Orthodox Church/ Development and Inter-Church Aid Commission, P O Box 503, Addis Ababa, Ethiopia. Tel 251-1-553566/206, Fax 251-1-551455:
Asfaw Azezew, Water Unit Co-ordinator,
Paulos Masresha, Hydrogeologist, P O Box 33980, e-mail: explorethiopia@telecom.net.et

United Nations Emergency Unit for Ethiopia, Addis Ababa: Mr Jim Barton.

WaterAid Ethiopia, Kefitenga 18, Kebele 26, Africa Avenue, PO Box 4812, Addis Ababa, Ethiopia. Tel 251-1 654374, Fax 251-1-661678, e-mail: WaterAid@telecom.net.et
Habtamu Gessese, Country Representative

Makelle

Bureau of Planning & Economic Development, PO Box 280, Makelle, Tigray, Ethiopia. Tel (03) 40-20-09, Fax 251-3-40-43-11: Ato Zemichael, Head of Economy
Teklemedhin Dirar, Department Head, Physical Planning

Water, Mines and Energy Bureau of Tigray, Makelle:
Ato Abebe, Head of Water Resource Development Department
Selome Mekonnen, Geologist
Fethangest W/Mariyam, Geologist

Makelle University College, PO Box 231, Makelle, Tigray, Ethiopia, e-mail: Makelle.university@telecom.net.et :Kifle W/Aregay, Head of Geology Department

Tigray Waterworks Construction Enterprise, Makelle Tel 400150, 400675
Ato Gebrudest, General Manager
Ato Aradom Kidany, Hydrogeologist and Team Leader

GOH Tours and Travel Agency, PO Box 1120, Makelle, Tigray, Ethiopia. Tel 251-4 402368, Fax 251-4 402648: Bisrat Mesfin, Branch Manager
Solomon Etay, Driver

Accomodation Contacts
Ras Amba Hotel, Addis Ababa
Axum Hotel, Makelle

NB - To phone out of Ethiopia to UK dial 00-44.

ANNEX D MAPS AND REPORTS COLLECTED DURING VISIT

1:2 000 000 scale Ethiopia Topographic Map

1:250 000 scale topographic maps
ND 37-11 - Makelle
ND 37-15 - Maychew

1:50 000 scale topographic maps
1239 B1 - Maychew
1339 C2 - Makelle
1339 C4 - Dela
1339 D1 - Kwiha
1339 D2 - Ab-Ala
1339 D3 - Adi Gudom
1339 D4 - Haridan

1:2 000 000 scale Ethiopia Hydrogeological Map

1:2 000 000 Geological Map of Ethiopia, second edition 1996

1:250 000 Geological maps
ND37-7 Adigrat, 1977
ND37-11 Makelle, 1971

1:250 000 Hydrogeological maps
ND37-11 Makelle, 1978

Russo, A , Fantozzi, P L and Solomon, T , 199?. Geological map of Makelle Outlier (western sheet). Scale 1:100 000. Italian Co-operation, Addis Ababa University, R Valera, Department of Geology and Geophysics. Correspondence to: Dr Pier Lorenzo Fantozzi, e-mail: fantozzip@unisi.it and disperati@unisi.it , computer graphic and GIS by Deapartment of Earth Sciences, University of Siena (Universita degli Studi di Siena, Dipartimento di Scienze dela Terra)

Other reports and references obtained

Aberra, T , 1990. The hydrogeology and water resources of the Ansokia Highlands springs, Ethiopia. Memoirs of the 22nd Congress of IAH, Lausanne, vol 22, pp 670-680.

Chernet, T and Eshete, G, 1982. Hydrogeology of the Makelle Area (ND37 - 11). Memoir No.2, Ethiopian Institute of Geological Surveys.

Chernet, T , 1992. A hydrogeological map of Ethiopia (scale 1:2,000,000). Hydrogeologie, No. 1-2, pp 29-35.

Garland, C R , 1980. Geology of the Adigrat Area, Memoir 1. Ministry of Mines, Energy and Water Resources, Geological Survey of Ethiopia.

Mohr, P A , 1971. The Geology of Ethiopia. Haile Sellassie I University Press.

Mohr, P A, 1973. Ethiopian flood basalt province. *Nature*, 303, 577-584.

Vernier, A , 1993. Aspects of Ethiopian Hydrogeology. Geology and mineral reources of Somalia and surrounding regions, 1st Agron. Oltremare, Firenze, Relaz. e Monogr., vol 113, pp 687-698.

Report details noted from Ethiopian Institute of Geological Surveys library catalogue

Anonymous The Antalo Limestone Formation, Mineral Intelligence Report No.44 Catalogue: Tigre 050/201/01

Belachew T 1974 Borehole siting for drought relief – Tigre and Wollo Provinces. Unpublished Report No. 7. Cat: 860-201/06

Belachew T, Chernet T, Eshete G T and Hadwen P Imperial Ethiopian Government, Geological Survey of Ethiopia, Unpublished Report No. 7 – Groundwater Appriasals and borehole siting in Tigre and Wollo provinces Cat: 880-201-06.

Eshete G, Hailemeskale M and Last B J 1976 Geophysical groundwater investigation in Wollo and Tigrai, May 1976 Cat: Wollo 840-251 01

Hunting Geology/Geophysics Ltd, Ethio-Nippon Mining SC Photogeological interpretation map (Eritrea and Tigre Provinces) Cat: ND37-6/7.

Rernier A 1985. A groundwater investigation in the Tigrai Region (Makelle) Cat: Tigrai 880-201.

Shumburo M N 1968 The Amba Aradam Formation. Mobil Petroleum Ethiopia Inc. Cat: Tigre ND37/11

Zelekachew M 1976 Borehole siting in Wollo and Tigre administrative regions. Unpublished report No.35, Jan 1976. Cat: 860-251 04

Report details noted from Bureau of Water Mines and Energy Resource Development, Makelle

Ezania Mining Development plc 1999 Hydrogeology and Water Resources Development of Agulae and Genfel catchments

ANNEX E SIMPLIFIED GROUNDWATER DEVELOPMENT MAP AND SUMMARY TABLE FOR THE OJU/OBI AREA, NIGERIA