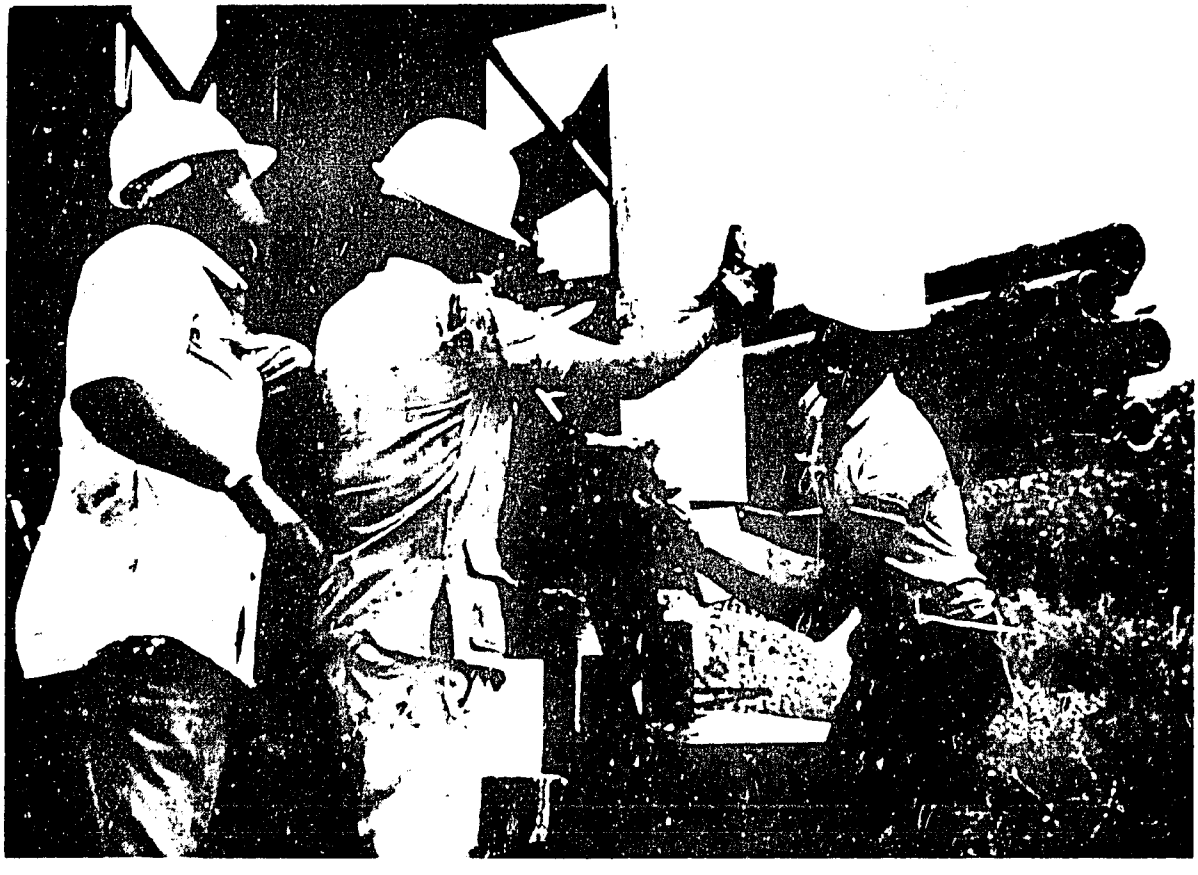
PD BAW032

SOMALI DEMOCRATIC REPUBLIC
MINISTRY OF MINERAL AND WATER RESOURCES
Water Development Agency

COMPREHENSIVE GROUNDWATER DEVELOPMENT

Project 104



FINAL REPORT

VOLUME II

Hydrology

LOUIS BERGER INTERNATIONAL, INC.
ROSCOE MOSS COMPANY

MARCH 1985

VOLUME II

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1. GEOGRAPHY

1.0 GEOGRAPHY

1.1 Location and Physical Features

The Bay Region and the Central Rangelands of Somalia have been the areas of work and study for the Comprehensive Groundwater Development Project (CGDP). The Bay Region is a broad plain lying between the Juba and Shabelli Rivers in southern Somalia. The Central Rangelands Region includes Hiran, Galgudud and Mudugh Provinces lying northwest of the Shabelli River. Both areas comprise 189,000 square kilometers between latitude 3°-8°N and longitude 42°-49°E. This is about 28% of the total land area of Somalia which is 687,000 square kilometers.

The hydrogeological provinces located in these areas as identified in the 1973 UNDP Report are the Mudugh Plateau, the Oddur-Bardera Plateau, and the Bur Area. The Mudugh Plateau in the Central Rangelands is an undulating plain occupying the central portion of Somalia. There are wide shallow valleys, flat-topped broad hills, and a drainage system of shallow emphemeral channels that course southeastward to the coast.

The Oddur-Bardera Plateau centers near the town of Baidoa and is referred to in this report as the Limestone Plateau or the Baidoa Plateau. It occupies the central part of the inter-basin area of the Juba and Shabelli Rivers as a broad plain of moderately fractured and karstified limestone beds. The Bur Area, lying about 100 kilometers west of Mogadishu, is an extensive plain underlain by metamorphic and igneous rocks of the basement rock complex. Erosional processes have reduced this basement complex to a plain with remnants that form inselbergs. These hills are called "burs" and rise abruptly from the plains with spectacular relief. The topographic surface is cut by shallow dry channels that course southward. The soils are derived from alluvium and the weathering of metamorphic and igneous rocks. Much of the area is vegetatively covered by Acacia thickets. The Bay Region of this report includes all of the Bur Area and the southeastern portion of the Oddur-Bardera Plateau.

1.2 Culture and Land Use

The Bay Region is the principle dry land farming region of Somalia. The dark clay soils and relatively high rainfall allow sorghum and other crops to be grown extensively. The 1975 census reported a population of 386,000 people of which 70% were engaged in nomadic herding. Many families are engaged in farming with some family members assigned to herding often at long distances from their home. The animal population is estimated to be .87 million.

The Central Rangelands is populated with an estimated 544,000 inhabitants. Grazing of livestock is almost exclusively the principal source of livelihood. The animal population has been estimated at 9.95 million for the Central Rangeland. These figures include sheep, goats, camels and cattle.

TABLE 2.1

Rainfall Records for Bay and Central Rangelands Regions

Region	Station	Years of Completed Record	Period	Mean Annual Rainfall (mm)	Annual Rainfall Range (mm)	Information Source
BAY	Baidoa	32	1923-1940	585	315-1217	Idrotecneco
	Bur Acaba	14	1922-26;30, 31,34,54-56, 59-61	516	247-1048	"
	Dinsor	4	1954-57	403	302-609	"
	Bardera	37	192 -39,43, 48, 53-64	388	85 -878	"
	Average (Including Baidoa)	87		482	85-1217	
HIRAN	Beled	39	1926-76	248	44 -553	RMR
	Mataban	5	1953-58	136	44 -247	"
	Average	44		235	44 -553	
GALGADUD	Cadaado	5	1953-58	123	28 -327	RMR
	Teelbur	28	1930-76	191	20 -408	"
	DhusaMareb	5	1953-58*	126	15 -250	"
	Mareer Guur	4	1953-58*	109	58 -182	"
	Average	42		167	15 -408	
MUDUGH	Beyra	5	1953-58*	220	93 -373	RMR
	Galinsor	6	1953-58*	115	21 -221	"
	Galkacyo	15	1933-58	154	33 -448	"
	Hobyo (Coast)	15	1954-76	224	81 -447	"
	Average	41		182	21 -488	

*From data Idrotecneco, 1976; R.M. Parsons, 1970; USAID, 1979; and CGDP documents.

2. HYDROLOGY

TABLE 2.2

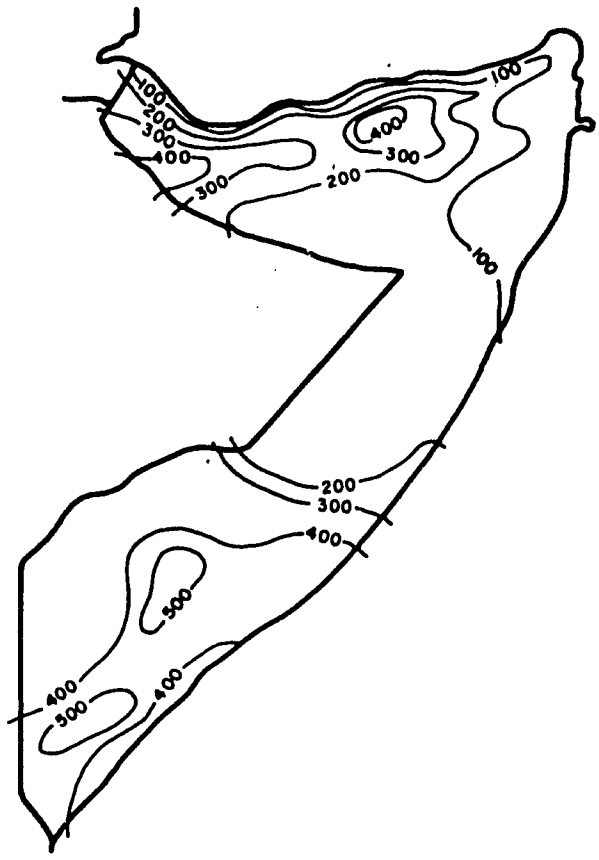
Mean Annual Flows of the Juba and Shabelli Rivers

River	Site	Years	Mean Flow (m^3/)	Reference (Km)
Juba	Lugh Ganana	1951-78	192	0
Shabelli	Belet Ven	1951-79	68.3	--
	Bulo Burti	"	66.4	161
	Maladdei Ven	"	58.8	349
	Balad	"	46.9	477
	Afgoi	"	46.1	547

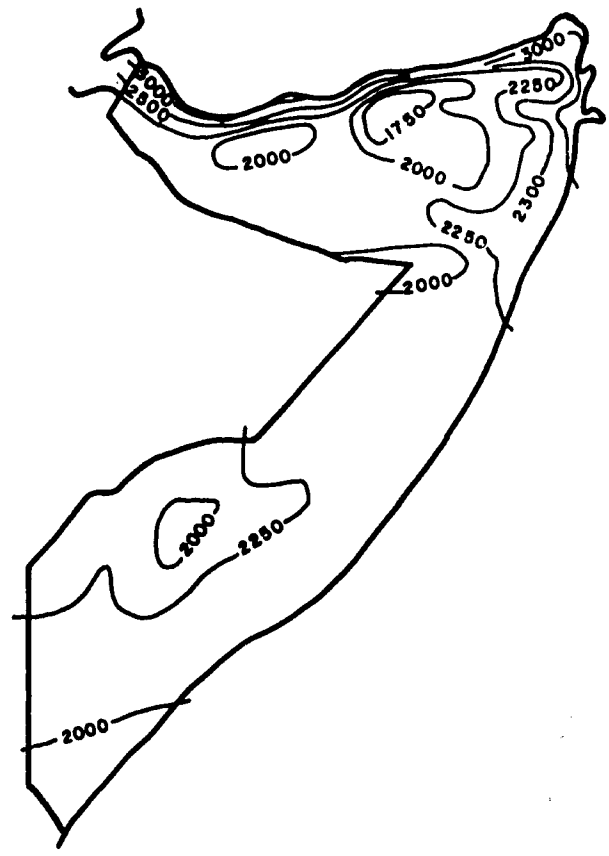
(from FAO, 1979)

Fig. 2.1

RAINFALL AND EVAPOTRANSPIRATION
SOMALIA



MEAN ANNUAL RAINFALL (mm)



MEAN ANNUAL REFERENCE EVAPOTRANSPIRATION (mm)

*(from, AID, Country Environmental Profile : Somalia, 1979)

2.0 HYDROLOGY

2.1 Climate

Southern Somalia has a tropical, arid to semi-arid climate with a range of 100 mm of annual rainfall in the northern part of the Central Rangelands to 585 mm in the Bay Region at Baidoa. The mean daily maximum temperature is 34°C and the mean daily minimum temperature is 24°C in these two regions with lows and highs of 18° and 41°. The high temperatures occur during February and March and low temperatures between July and August. The rainfall is concentrated in two wet seasons, the "Gu," April through June; and the "Der," October through December. Table 2.1 lists rainfall data from the study areas and Figure 2.1 shows the rainfall and evapotranspiration isohyets.

2.2 Evapotranspiration, Runoff, Infiltration

By subtracting the rainfall data from the mean annual reference evapotranspiration data, it is found that a potential annual water deficit of no less than 1,500 mm exists throughout the area. Annual evapotranspiration varies from 2,000 to 2,250 mm.

Some researchers have estimated that as much as 5 to 10% of the annual rainfall infiltrates the groundwater system, but this estimate may be high. Extensive thornbush cover indicates that high evapotranspiration losses occur and limit deep infiltration of water over much of the area. Groundwater recharge must therefore occur mainly by surface runoff into karst holes, fracture zones, and coarse alluvium of wadi channels.

2.3 Surface Water

The Juba and the Shabelli Rivers are the only two perennial streams in Somalia. They run from their headwaters in Ethiopia through Somalia and discharge into the Indian Ocean near Kismayo. The Juba River flows southward passing to the west of the Bay Region. The Shabelli flows almost parallel to the Juba, passing through the southern part of the Central Rangelands in the Hiran Province, and then turning southwest until it joins the Juba River in an area of swamps.

The mean annual flows of these rivers are shown in Table 2.2 for six sites. A discussion of the rivers impact on the groundwater supply of the project areas is treated in Section 4 on groundwater movement.

Intermittent streams (wadis) are found throughout both areas. The wadis flow only during the rainy season and convey water relatively short distances before they become dry from evaporation and infiltration into the alluvium.

Wars, surface water reservoirs, are designed to collect and store rainwater. Wars have traditionally been constructed throughout Somalia and serve effectively to provide water during the rainy seasons. The water supply generally does not last through the dry season due to heavy use and to the 2000-2250 mm per year evapotranspiration rate. Modern wars, designed and constructed with heavy equipment, have also been constructed in selected locations. Figure 4.1 shows the location of modern wars built throughout the Bay Region.

2.4 Water Requirements and Availability

Approximations of the quantities of water necessary to fulfill existing and future needs can be made using estimates of the human population, and the numbers of camels, cattle, sheep, and goats grazing in the two areas. These estimates place the human population at 0.93 million and the number of animals at 10.77 million.

The total water consumption requirement is obtained by multiplying the population figure times a potential improved rate of 20 liters per day for humans, 35 liters per day for camels and cattle, and 15 liters per day for sheep and goats. A weighted average consumption figure for animals for 20 liters per day was used. The calculated water demand for humans is therefore about 7M m^3 and 78 M m^3 for animals on an annual basis. This totals 85M m^3 of annual water demand for the project area.

Water consumption by rural inhabitants depends primarily upon their proximity to the water source. Consumption increases markedly if the distance traveled to obtain water is less than one half kilometer, otherwise consumption is normally less than 15 liters per capita per day (lcd). This has been been shown to be true in water studies throughout the world and has been confirmed by limited studies in Somalia (see Sociology Chapter).

One goal of the CGDP is to improve the accessibility of water to rural inhabitants and thus increase their consumption of water of improved quality. Clearly, the only way to accomplish this goal is to place the well as close as possible to as many people as possible or, in some instances, expect the people to move to the new water source. Since the occurrence of groundwater is dependent on the geologic conditions, it is not always possible to uniformly locate wells where populations are concentrated. Indeed, finding any potable water has been shown to be most improbable in specific areas within the project boundaries. For the above reasons it is difficult to determine water requirements based on potential water consumption.

Complete quantitative studies have not been made of water production from existing water point sources such as drilled wells, hand dug wells, springs, and wars. This will require a comprehensive one-year inventory by two full-time field survey teams. Such a survey has been planned as a joint USAID-UN effort using UN volunteers and Water Development Agency (WDA) personnel during the proposed project extension. This survey is planned not only for the project area but for the rest of Somalia as well.

Water availability within the project area varies enormously from zero to reasonably productive wells at specific locations. The actual quantity of water produced depends on the geology, the well construction, the pump, and the length of time that pumping is undertaken. Except for the geology the other aspects of well production on the CGDP have been sized to fit the demand of the project site and do not necessarily represent the maximum possible production. Thus, pumping data from existing wells, were it available, would not provide a complete picture of water availability.

Potential aquifer recharge can be estimated by adopting a factor of 5% for deep percolation of rainfall. This conservative value is based on studies from other areas of the world but varies considerably from site to site. It is noted that average potential evapotranspiration is about 2,250 mm annually and that the average rainfall for the Central Rangelands and the Bay Region is only about 200 mm annually. Assuming a 5% recharge of 200 mm of rainfall provides only one centimeter of groundwater recharge. However, this represents 1,900 million cubic meters of potential aquifer replenishment annually over the entire project area which is more than 22 times the calculated demand (85 M m^3). While this indicates that total groundwater availability is theoretically sufficient to meet demand, it does not mean that it is distributed evenly nor at the specific locations where it is most needed. It is evident that many more wells will be needed to obtain the figure of 20 lcd for rural dwellers within the project area. Field observations during a short drought in the spring of 1984 indicated severe hardships for many rural Somalis to the extent that many animals and a few humans died as a result of traveling long distances to obtain water.

These calculations do not consider the requirement for irrigated agriculture. Presently, irrigation projects exist mainly in the Juba and Shabelli River valleys where about 200,000 hectares are irrigated using river water. Only marginal amounts are supplied by supplemental groundwater. Large pump stations along the rivers pump as much as 80-100 cubic meters per hour during the cropping seasons.

Large-scale irrigation projects are not feasible in either the Bay or the Central Rangeland Regions using groundwater resources that have been presently proven. Small irrigation ventures might be possible, but would need to be developed on a site-specific basis where local drilling and testing shows unusually large amounts of water to be available. Most water has been found in fracture and fault zones of the limestones where karstic development has taken place. Some modest amounts have been found in wadi gravels, alluvium, and weathered basement rock, but never in a amount to support large irrigation projects. Large, areally extensive aquifer systems have not been identified at this time. In view of the need to overcome the critical water deficit in the supply for human and animal needs it is considered more appropriate to drill wells for this purpose and to delay planning for irrigated agriculture projects.

3. GEOLOGY

3.0 GEOLOGY

The CGDP conducted extensive groundwater drilling operations in the Bay Region west of Mogadishu and limited drilling operations in the Central Rangelands. The geology of the regions, as determined both through field operations and previous research, is described in the following sections.

3.1 Bay Region

The geology of the Bay Region is conventionally divided into two areas. Precambrian metamorphic rocks and their intrusions underlie about two thirds of the area and is referred to as the "Basement Complex". The remainder consists of Jurassic marine sediments and their weathered products and is known as the "Limestone Plateau."

The crystalline metamorphic and intrusive complex is located in the central and eastern parts of the project area. Outcrops of bedrock and residual weathering products covering most of the "Basement Complex" are of no significant hydrogeological importance. A well-developed drainage system, however, directed southeastward, disappears under the younger fluviatile of the lower Shabelle River valley. Small amounts of groundwater are stored in fine to coarse-grained channel sediments even during extended dry periods.

The southern, western, and northern parts of the project area consist of Jurassic limestone forming a plateau with typical karst drainage. This "Limestone Plateau" is separated from the exposed Basement Complex, by a major fault. Southeast of the fault interface, eroded remains of marine sediments overlie the crystalline basement, and this, by some investigators, has been called the "Limestone Depression" (Johnson, 1977).

The areal distribution of the crystalline basement and the Mesozoic sediments are shown in Figure 3.1.

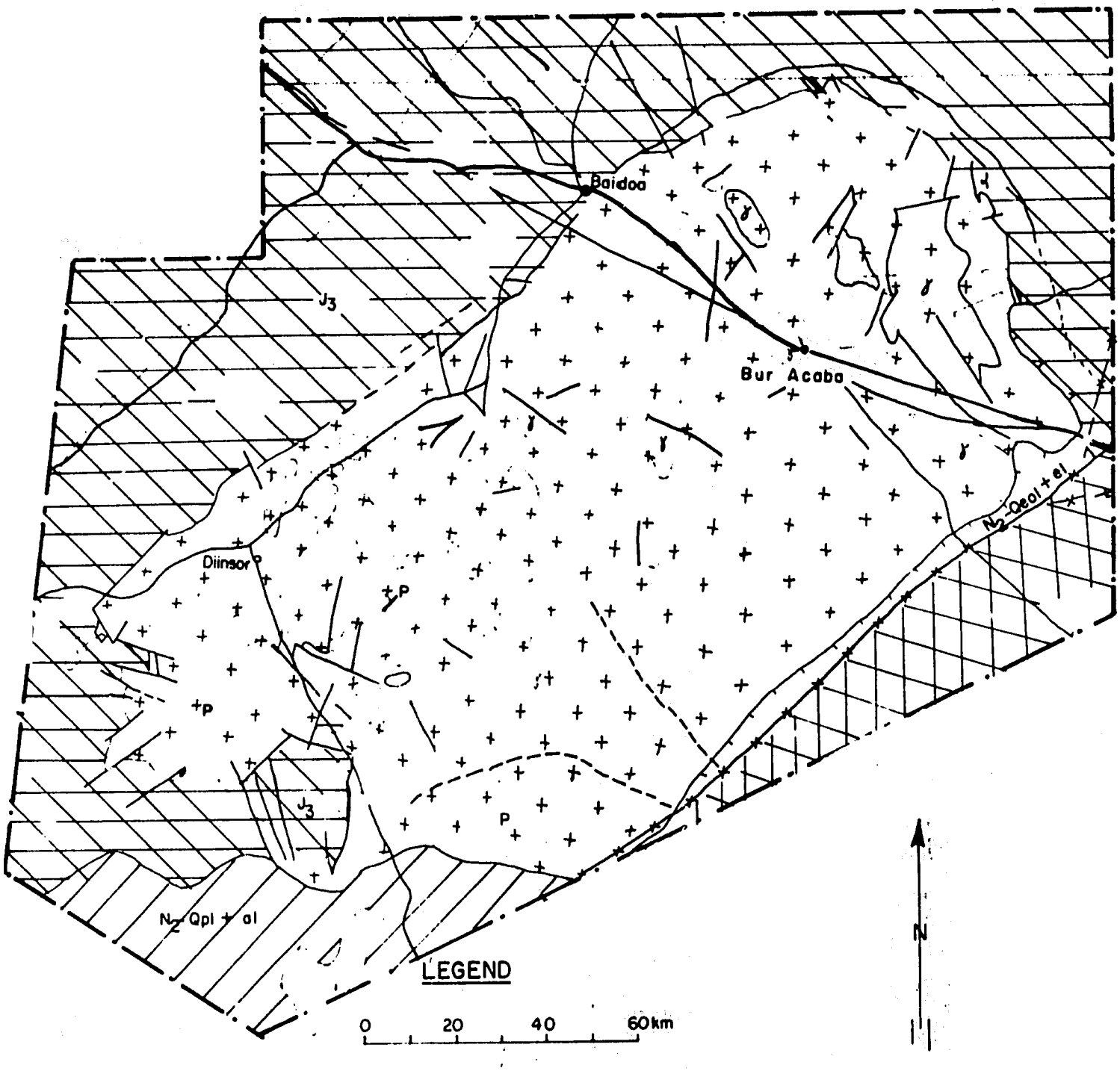
3.1.1 Tectonics

The geologic structures of the Bay Region, divided into the Limestone Plateau, Limestone Depression, and Basement Complex, are described in the following sections.

3.1.1.1 Limestone Plateau

In Jurassic time a trench opened west of the presently exposed Basement Complex and was filled first with sandstones and shales, and later with mainly limestone. The sedimentation stopped during the Cretaceous period and the sediments were uplifted above present sea level. The axis of the trench trends northeastward and is called the Luugh-Mandera basin (Beltrandi and Pyre, 1973).

GEOLOGICAL MAP OF BAY REGION



LEGEND

	J_3	Jurassic : limestone, marl, sandstone
	N_2-Qpl + al	Pli-Qua ternary, proluvial-alluvial sediments
	P	Precambrian : gneiss crystalline schist, quarzite, granite

From UNDP, 1971

LBII/RM

Fig 3.1

Faults with northwest strikes on the Limestone Plateau are commonly widened by karstification. Such faults provide paths for groundwater movement and thus offer good locations for siting wells.

3.1.1.2 Limestone Depression

Eroded remnants of marine sediments at the northern rim of the Limestone Plateau overlie crystalline basement. Major faults clearly separate these sediments from the Limestone Plateau. The escarpment zone, however, consists of tilted strata which form a prominent cliff along most of the contact (Johnson, 1977). The sediments of the Limestone Depression are deeply weathered and do not show fault patterns. The area is covered by a thin layer of surficial material, probably alluvium and colluvium of the Limestone Plateau.

3.1.1.3 Basement Complex (Bur area)

The uplifted Basement Complex is defined by northeast trending lineaments on its south and north borders. The southwestern part of the area has a northeast trending tectonic pattern with marine sediments extending over the basement area and inliers of basement exposed within the sediment area. The northeastern interface of the Basement Complex and the Limestone Plateau shown an extension of the Baidoa Fault. The center of the Basement Complex does not show obvious fault patterns. The predominant drainage channel system directed southeastward does not follow major tectonic features, but rather follows the land surface gradient.

3.1.3 Lithological Description

The lithology of the Bay Region is described in the following subsections for the Limestone Plateau and the Basement Complex.

3.1.2.1 Limestone Plateau

In the northern Bay Region strata of Aalenian to Oxfordian-Kimmeridge age, the Iscia-Baidoa and Anole Formations, are exposed forming a plateau to the north and west of the Basement Complex. A description of the members of these formations and their members is given in the succeeding paragraphs.

<u>Iscia Baidoa Formation</u>

<u>Uanei Member</u> (Jurassic Aelenian)

The lowest part of the marine sediments of the Uanei Member consist of green sandstones, dark marls, limestone and varicolored shales deposited unconformably over the Basement Complex. The upper parts are dark-red shales several tens of meters thick with a layer of limestone at the top. The total thickness of the Uanei Member is about 90 meters, as logged in borehole no. 11, Ministry of Agriculture Housing Compound, Baidoa.

No outcrops of the Uanei Member have been found as the interface of the Basement and Limestone Plateau is covered with limestone from the overlying strata. In borehole No. 45, drilled in the Ministry of Agriculture Compound in Baidoa, the Uanei Member was investigated as a potential aquifer because of its sandstone and limestone layers. However, due to the large amount of marls and shales as frequent inter-layers, the borehole produced only small amounts of groundwater.

Baidoa Member (Jurassic Aalenian)

Limestone layers overlie conformably the Uanei Member. The Baidoa Member consists mainly of gray limestone with a few interlayers of black marl and shale. In the town of Baidoa, it reaches a thickness of about 90 meters. Outcrops of its hard limestone are frequent along the Baidoa escarpment. The limestone layers of the plateau are deeply weathered and karstified, and form a good aquifer which has been tapped by local drilled and hand dug wells.

Goloda Member (Jurassic Callovian to Oxfordian)

The Goloda Member consists of light gray crystalline limestones, with oolitic beds and coquina layers. Thin interlayers of the black marl and shale are common. Regionally, dolomite beds, white to light gray, are present. The uppermost beds of the Goloda Member are resistant, forming hills in the area.

The Goloda Member attains a thickness of 650 meters. As in the underlying Baidoa Member, the Goloda Member is deeply karstified with numerous karstholes and dolines. It forms a good aquifer with relatively high specific yield. Most karstholes and dolines follow a joint pattern that has a northwest trend.

Parts of the middle of the Goloda Member, exposed in the Qansax Dheere area, have undergone more intense weathering and show a covering layer of caliche of several meters thickness, the top layer consisting of terra rossa with brown limonite concretions shaped like coffee beans. This middle part of the Goloda Member is less karstified with increasing depth and yields less water to wells in the Qansax Dheere area.

Anole Formation (Jurassic Oxfordian to Kimmeridgian)

The Iscia Baidoa Formation is overlain conformably by the Anole Formation of 300 meters thickness. It consists mainly of black marl and shale with interlayers of blue compact limestone.

The softer marl and shale layers do not occur as outcrops as they weather to light-brown clay. The limestone layers show few signs of karstification, but south of the village of Berdale they are weathered to caliche.

Residual Soils

Large parts of the Iscia Baidoa Formation are covered by residual clay soils, forming a strip from Baidoa to the southwest along the escarpment, and north of Awdiinle to southwest of Qansax Dheere.

The bedrock limestone of the Baidoa and Goloda Members decomposes to fine gravel of weathered white limestone. An overlying dark brown soil reaches a thickness of up to 30 meters. After the first rainfalls, the clay soil swells, closing all cracks and forming an impervious cover with little runoff but many rainwater-filled depressions.

Due to the low infiltration rates of the underlying limestone there are fewer springs along the escarpment south of Baidoa. These springs in the south yield more highly mineralized groundwater than the springs north of Baidoa. The weathered zone may contain some groundwater in the lower parts consisting of limestone fragments.

Basalts (Cretaceous and Tertiary)

In the extreme west of the project area, at the Juba River, black basalts are exposed filling a 300-meter wide joint in limestones of the Anole Formation. These basalts extend from east of Luugh in the north to Baardheere in the south. They are harder than the surrounding rocks and prevent the Juba River from meandering to the east. These basalts are of Cretaceous to Tertiary age and weather from coarse blocks to gravel size. The basalt should be investigated more closely for its capacity to store groundwater, or to form impervious barriers.

Figure 3.3 shows a generalized geological cross section of the project area extended from the Indian Ocean in the east to the Kenyan border in the west. The cross sections in Figures 3.4 and 3.5 show the geological profile of the Limestone Plateau. The profile in Fig. 3.4 runs from Baidoa, in the east, to Qansax Omane in the west and in Fig. 3.5 from Robay Gaduud in the east to Durei Ali Galle in the west.

3.1.2.2 Basement Complex

In the interriver area, between the lower Juba to the west and the Shabelli River to the east, crystalline basement covers about two-thirds of the Bay Region.

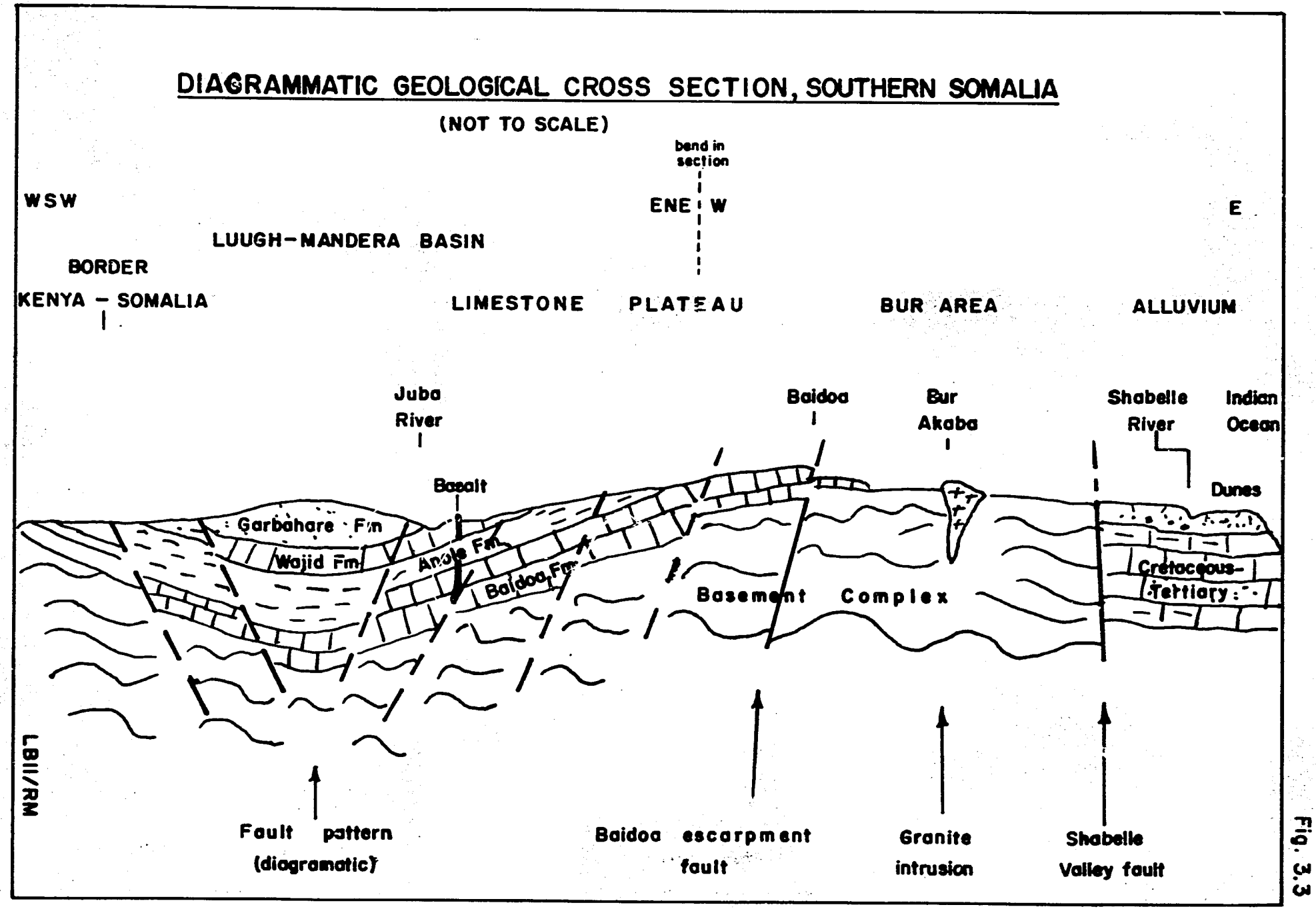
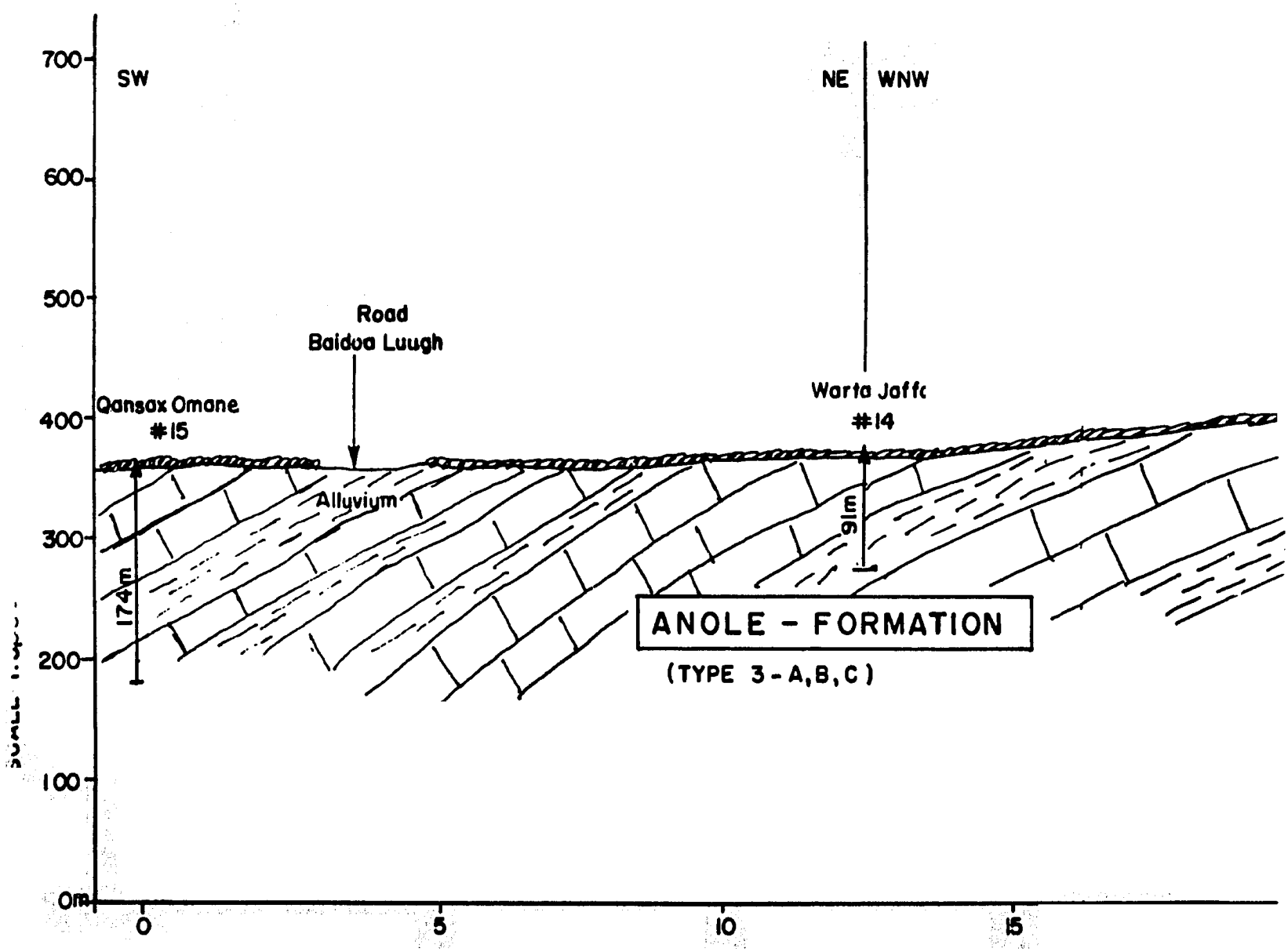
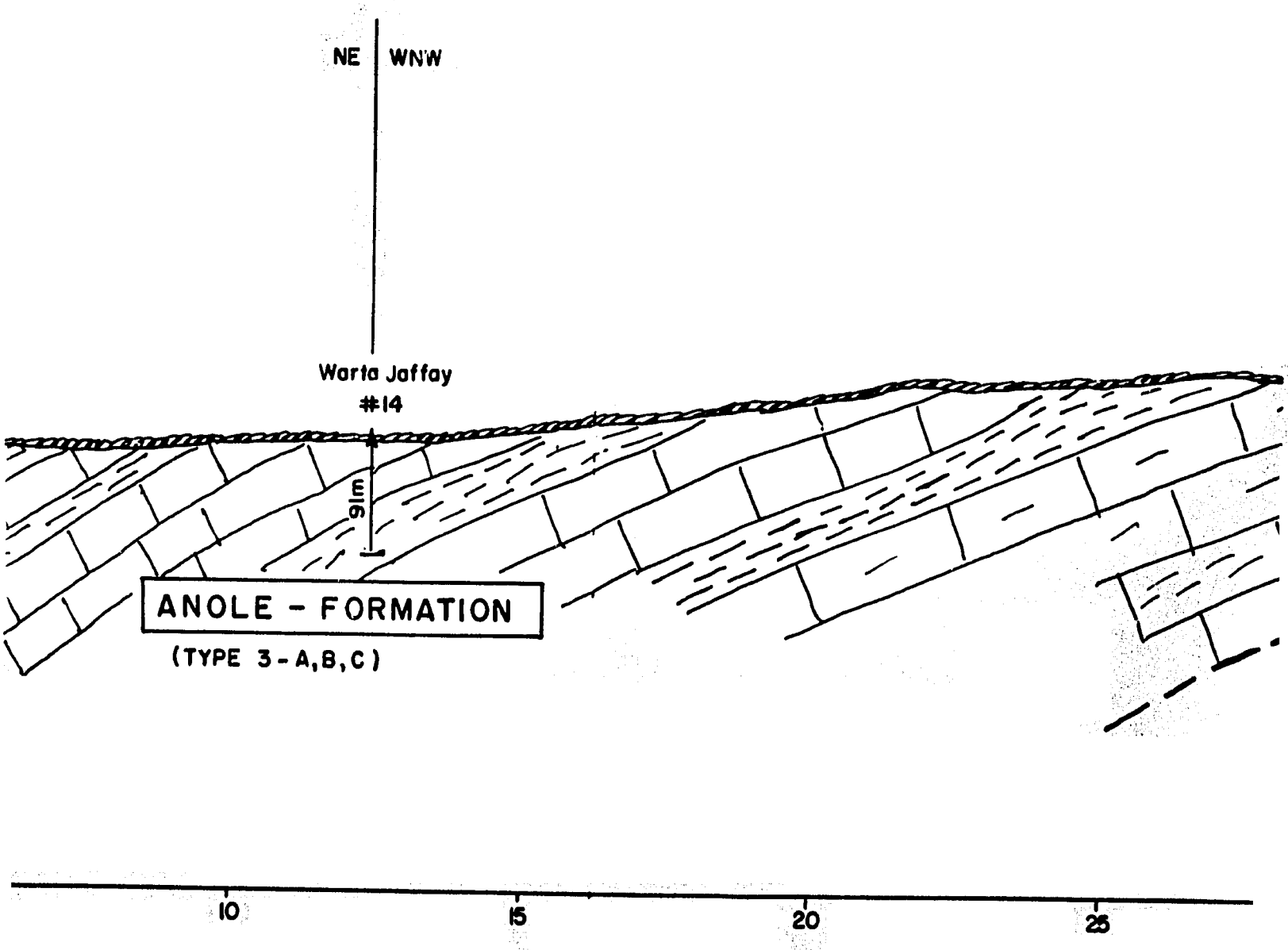

DIAGRAMMATIC GEOLOGICAL CROSS SECTION, SOUTHERN SOMALIA
(NOT TO SCALE)
bend in section
WSW
ENE
W
E
LUUGH-MANDERA BASIN
BORDER
KENYA - SOMALIA
LIMESTONE PLATEAU
BUR AREA
ALLUVIUM
Juba River
Baidoa
Bur Akaba
Shabelle River
Indian Ocean
Basalt
Dunes
Garbahare Fm
Wajid Fm
Anole Fm
Baidoa Fm
Basement Complex
Cretaceous-Tertiary
Fault pattern (diagramatic)
Baidoa escarpment fault
Granite intrusion
Shabelle Valley fault
LBII/RM

Fig. 3.3

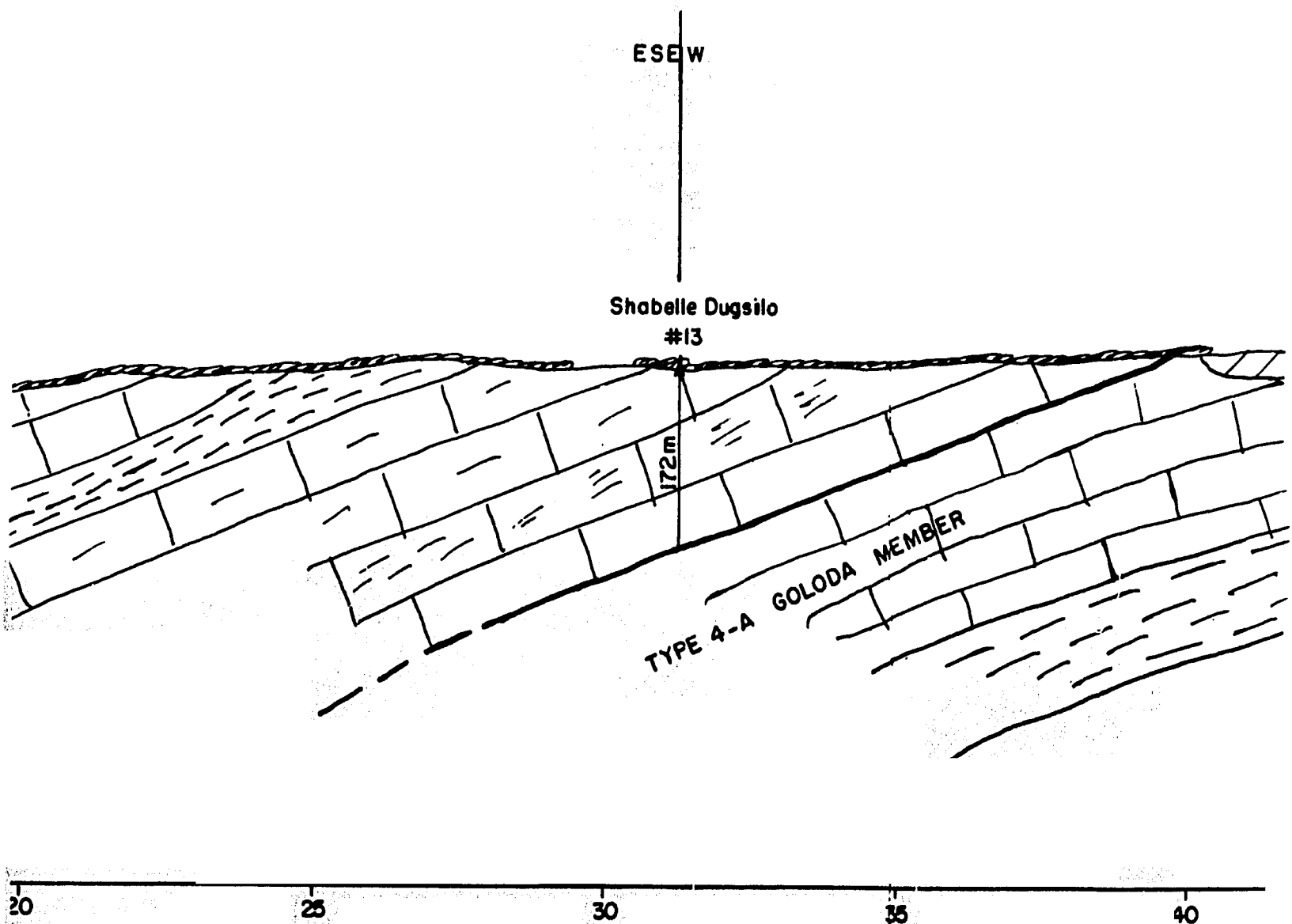
A


700
600
500
400
300
200
100
0m
SW
NE
WNW
Road
Baidoa Luugh
Qansax Omane
#15
Warta Jaffe
#14
Alluvium
174m
91m
ANOLE - FORMATION
(TYPE 3-A,B,C)
0
5
10
15

A

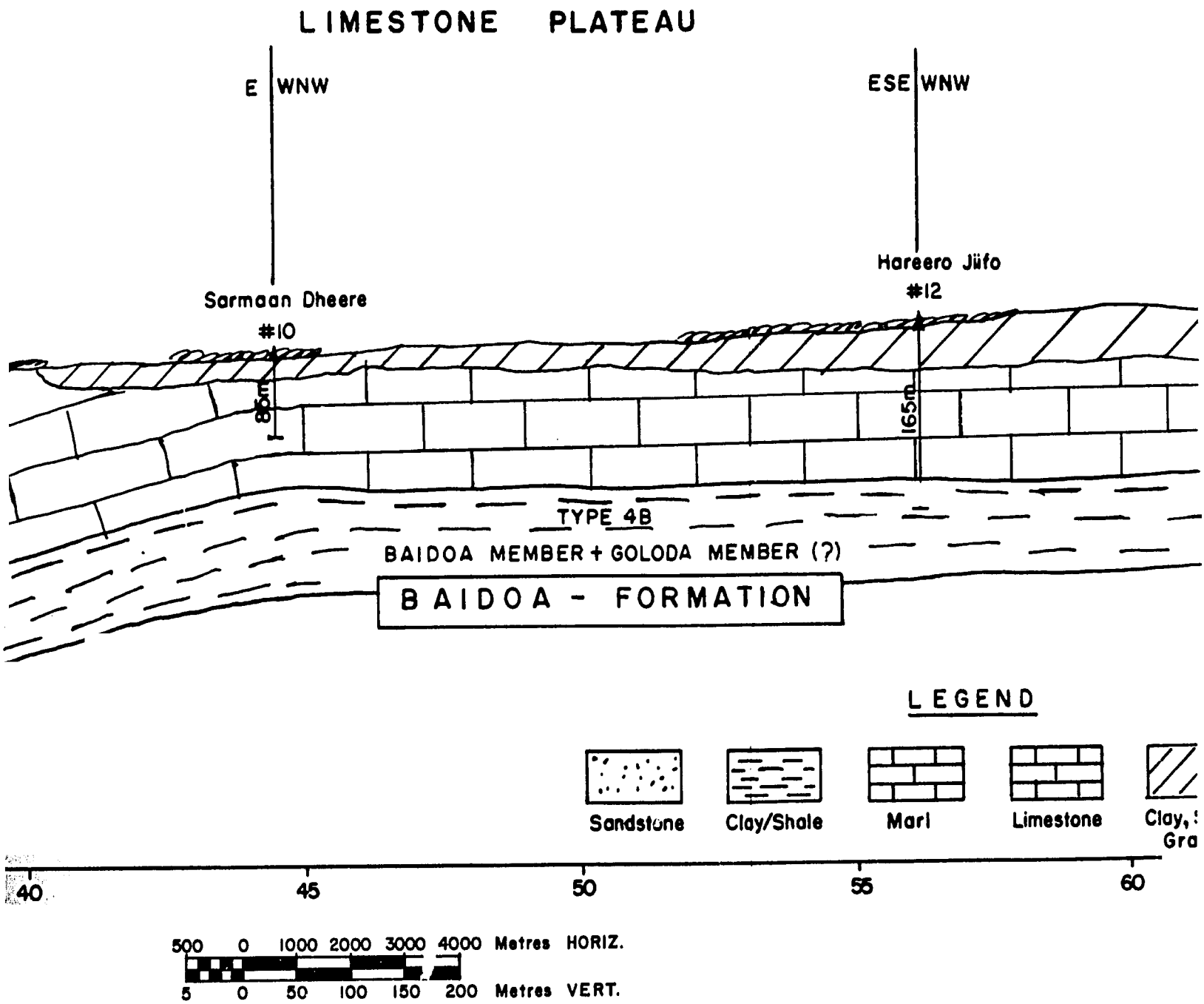

NE
WNW
Warta Jaffay
#14
91m
ANOLE - FORMATION
(TYPE 3-A,B,C)
10
15
20
25

GEOLOGICAL CROSS



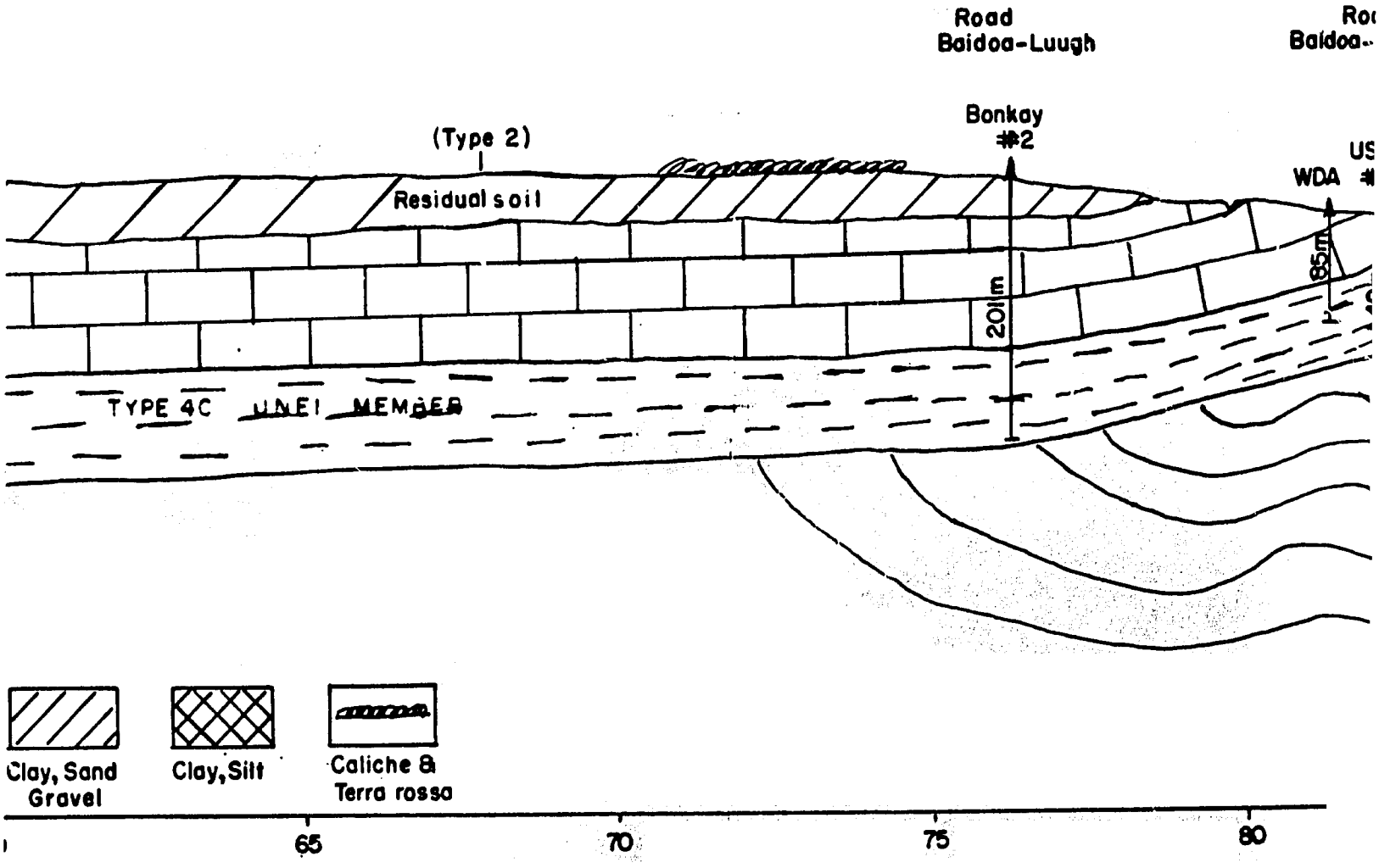
ROSS SECTION WARTA JAFFAY (QANSAX OMANE) - TUGEREW

SECTION A-A'



EW (BAIDOA)

A'


Road
Baidoa-Luugh
Bonkay
#2
(Type 2)
Residual soil
WDA
201m
85m
TYPE 4C
Clay, Sand
Gravel
Clay, Silt
Caliche &
Terra rossa
65
70
75
80

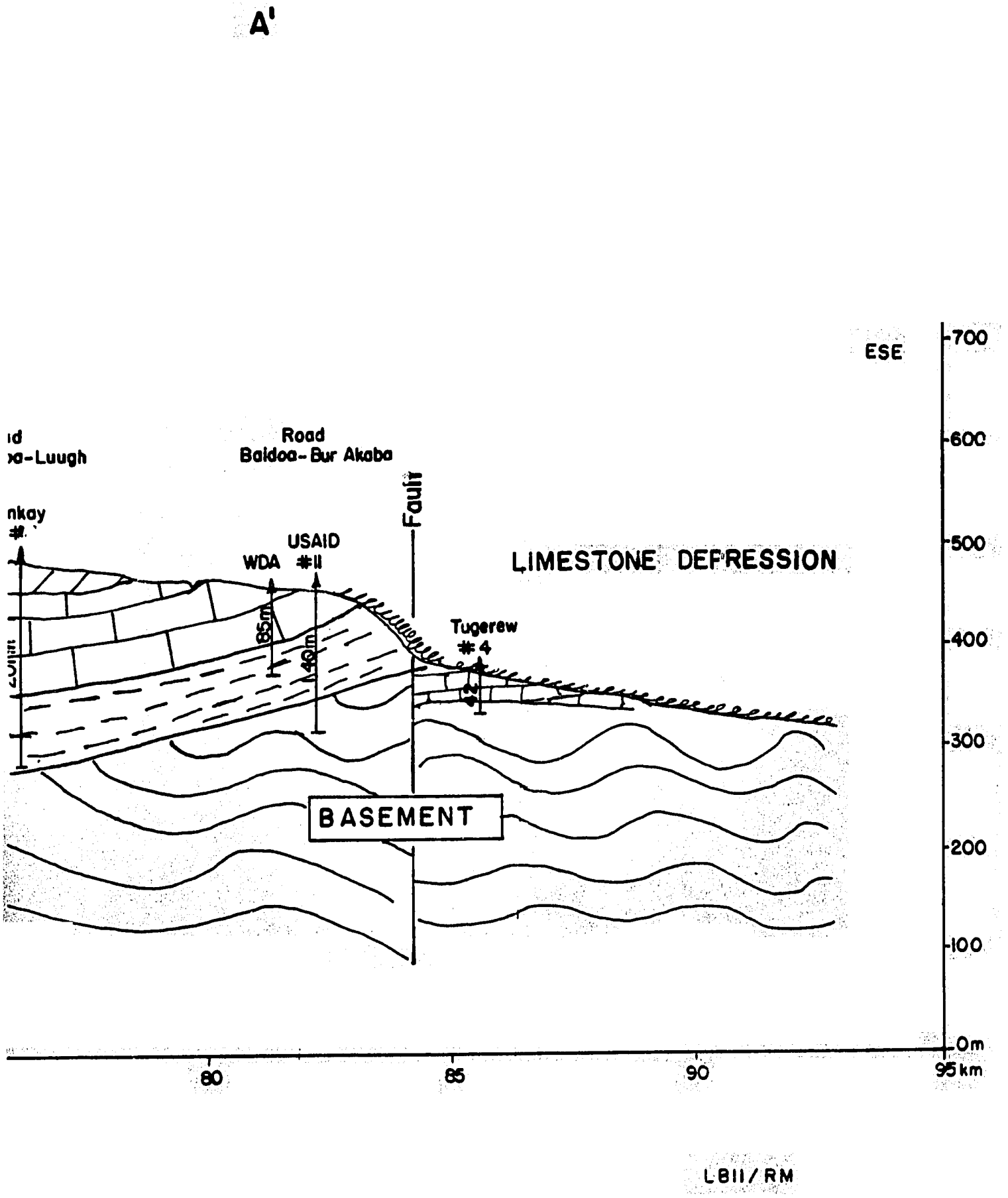
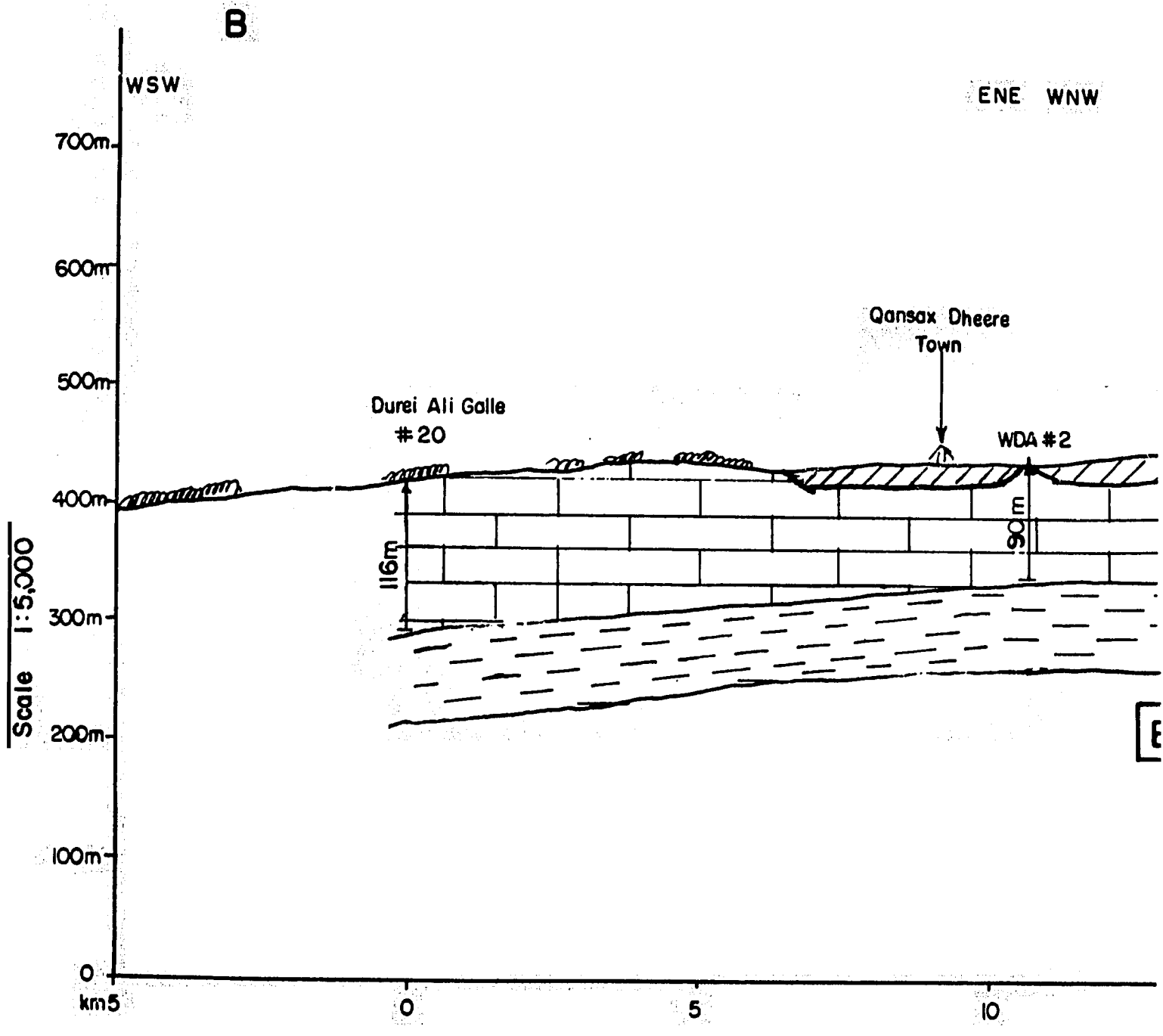

A'
ESE
700
600
500
400
300
200
100
0m
Road
Baidoa-Bur Akaba
Fault
USAID
WDA #11
LIMESTONE DEPRESSION
Tugerew
#4
85m
BASEMENT
80
85
90
95 km
LBII/RM

Fig. 3.4

27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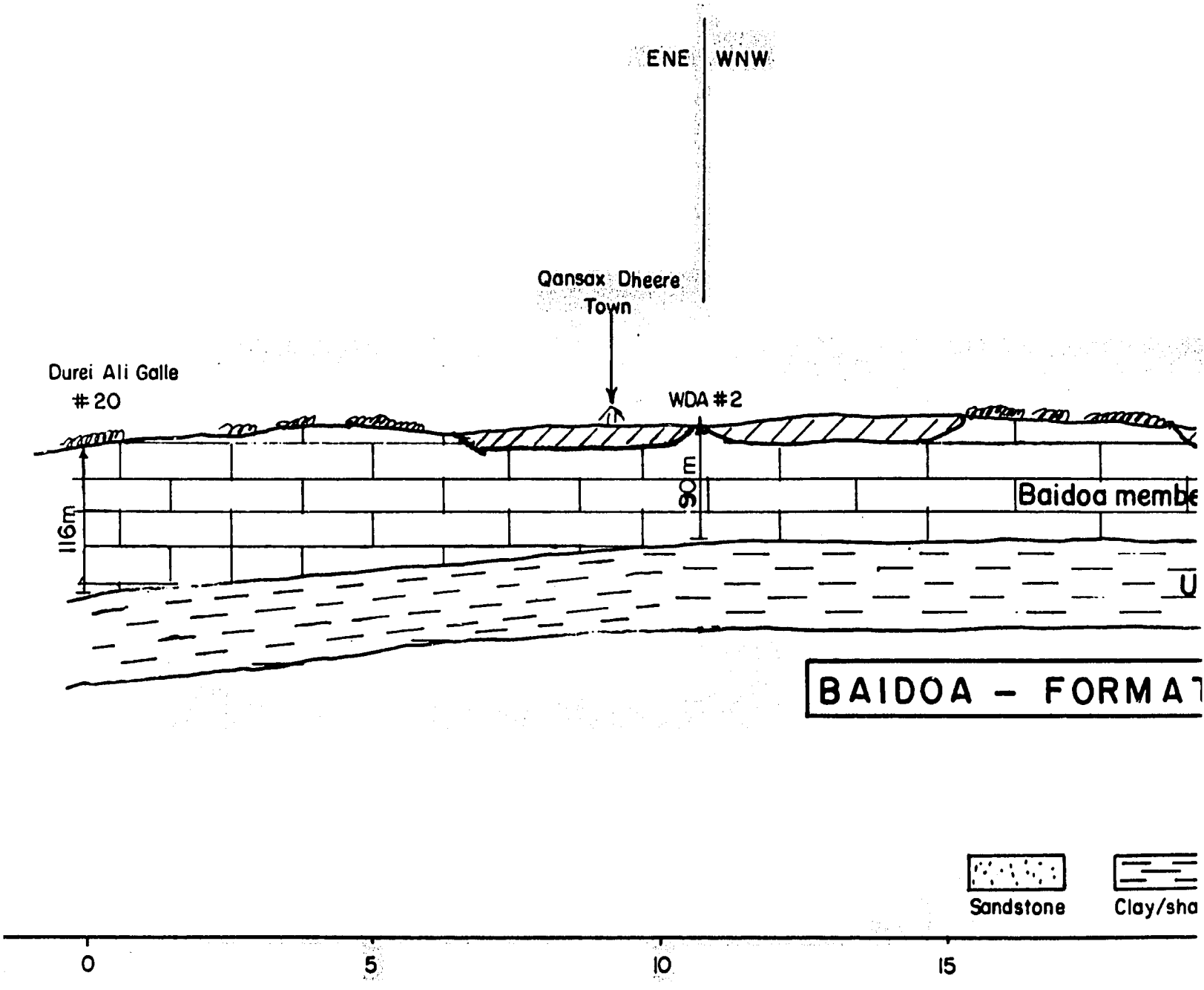
GEOLOGICAL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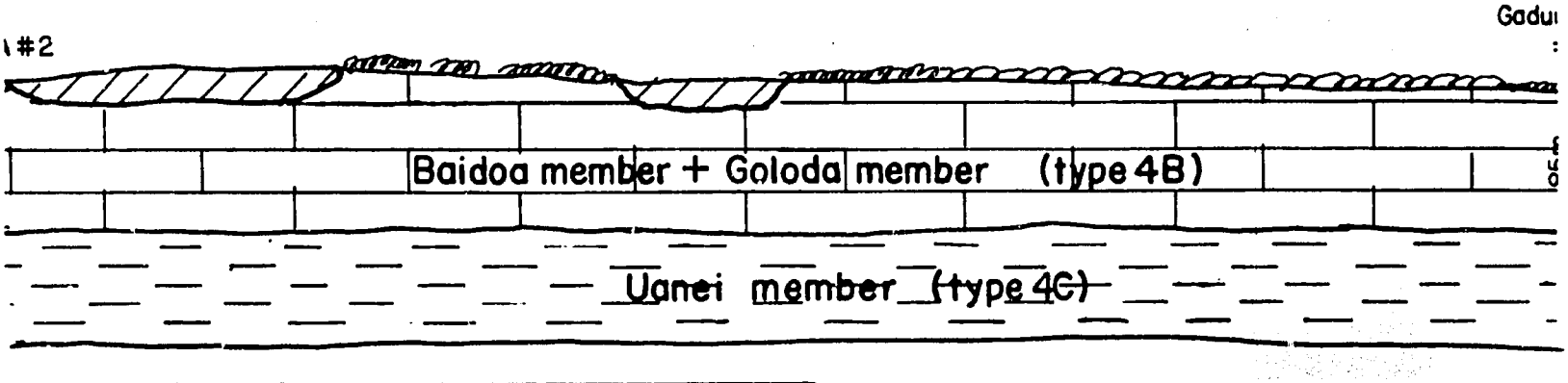
GEOLOGICAL CROSS SECTION DUREI

SECTION B-B'



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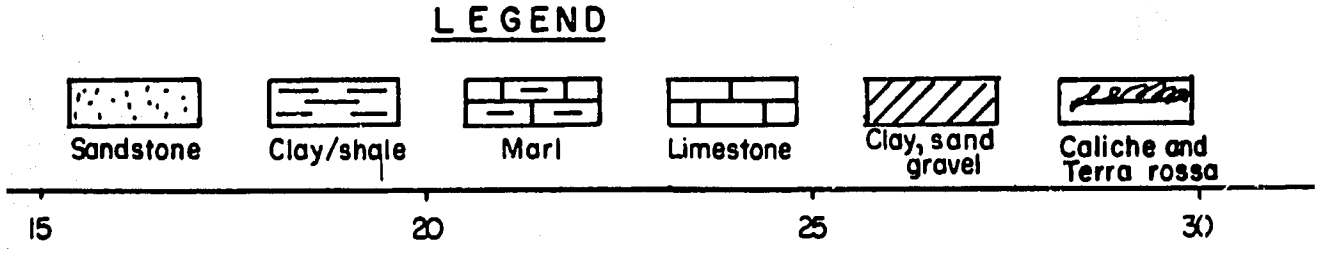

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·ION DUREI ALI GALLE - ROBAY GADUUD

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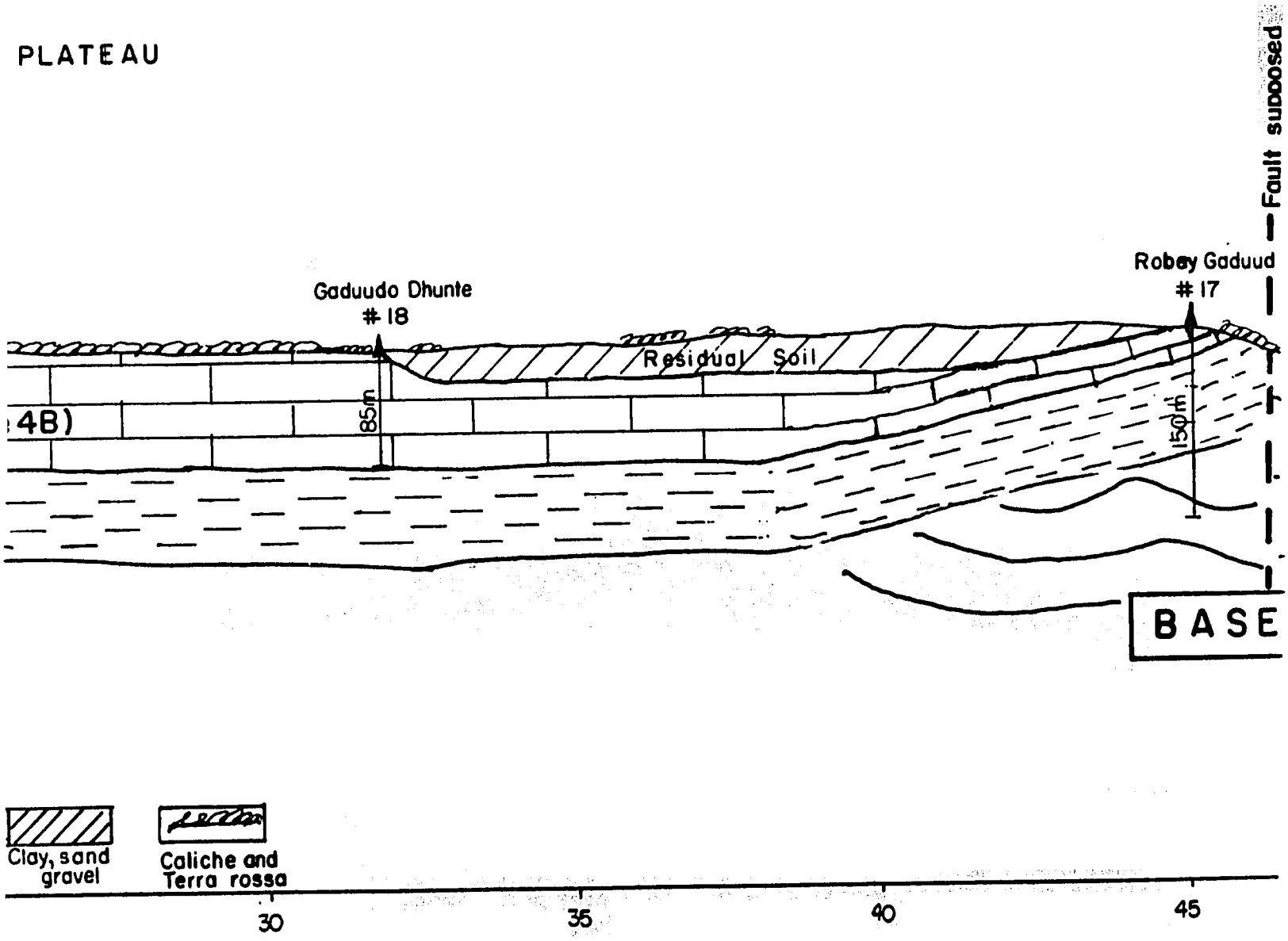
PLATEAU



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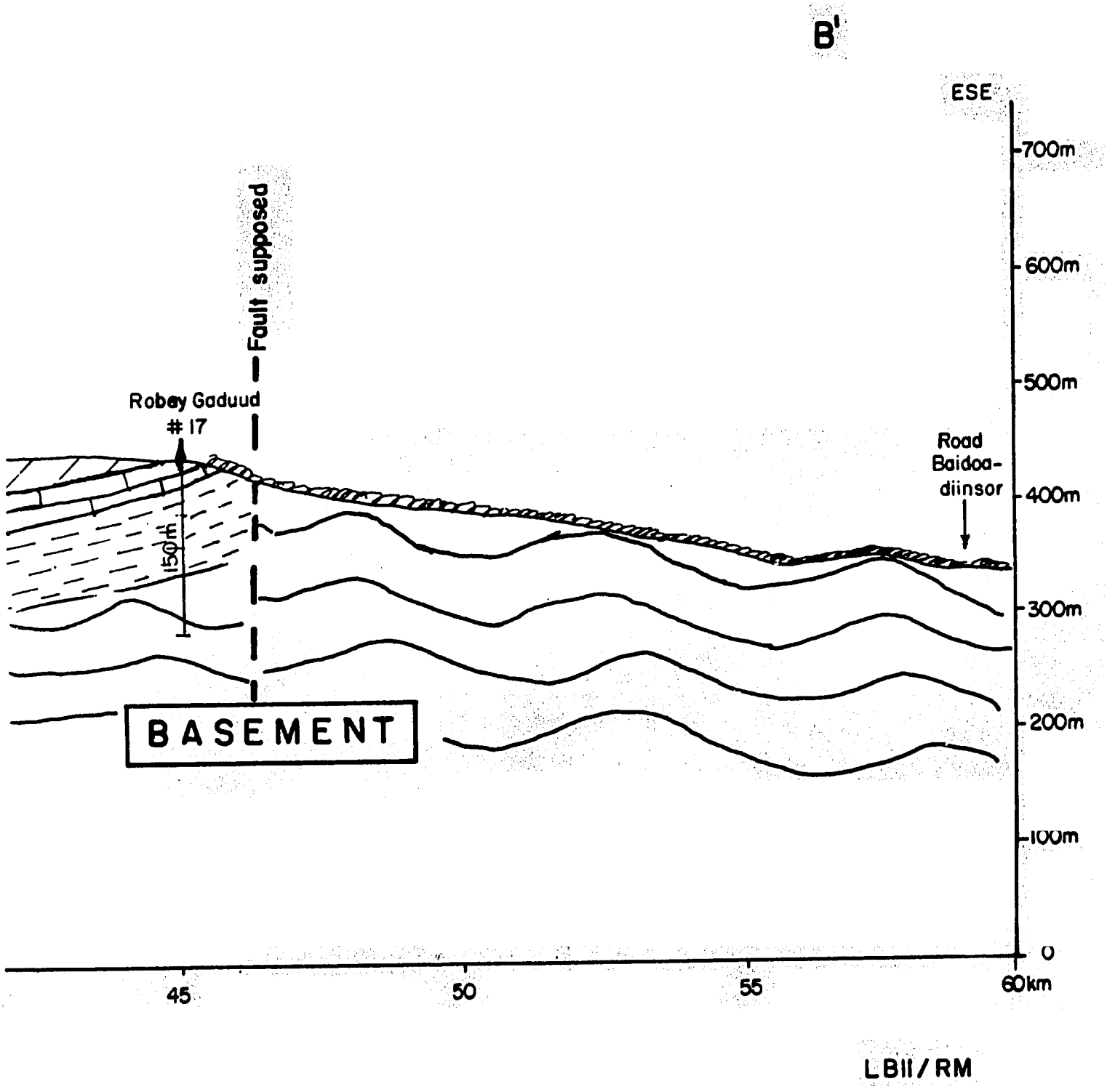
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BASEMENT
45
50
55
60km
LBII/RM

Fig. 3.5

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Exposed since Jurassic time, it forms a peneplain with residual weathered igneous and metamorphic rocks. Outcrops of granitic and syenitic intrusions occur above the plain, forming inselberg hills that are called "burs," in the Somali language, giving the name of "Bur Area" to the entire Basement Complex.

Italian and Somalian geologists (Hilal, Pavan, & Robba, 1982) established the following groups of rocks for the Bur Area; quartzites of Egherta, gneiss of Bur Mun, gneiss of Bur Meldac, marbles of Buulo Gasei, migmatites of Lamma Lavet, and granites and syenites of Jacdumi and Bur Sigirre. The youngest metamorphic phase with intrusions is dated at 600 million years during the Early Paleozoic.

The Bur area has a well-developed drainage system directed southeastward. These channels are filled with coarser alluvium and form fair aquifers, collecting the runoff of the surrounding area, storing the water in alluvium and draining to the lower Shabelli River. Numerous shallow wells have been dug by nomads in these drainage channels.

3.2 Central Rangelands Area

The Central Rangelands extend northeast of the Shabelli River to the Nogal Valley in northeastern Somalia. Marine sediments of mainly Tertiary age and continental sediments of sub-recent age cover the surface as part of a large basin. The basin extends through the Ogaden and down to the Indian Ocean parallel to the Shabelli Valley east of Belet Uen to Jowhar. The deepest part of the basin, the Obbia Embayment, is located near Obbia on the coast of the Indian Ocean east of Gaalkacayo (Barnes, 1976). There have been several transgressive and regressive phases of the sea over the Horn of Africa, and sedimentation thicknesses generally decrease inland.

The areal distribution of the geological formations in the Central Rangelands is shown in Figure 3.6 and explained in Table 3.1. Figure 3.7 shows a cross section of the project area and the the northern part of the basin near the coast of the Gulf of Aden.

3.2.1 Lithological Descriptions

The lithology for the Central Rangelands is described in the following subsections.

Belet Uen Formation (Cretaceous Coniacian to Campanian)

The Belet Uen Formation, the oldest formation related to the investigation of the CGDP project, reaches a thickness of 145-200 meters. It is formed of a lower part of interlayered limestone and gypsum beds, overlain by limestones with sandy and marly beds. The upper part of the Belet Uen Formation contains alternating gypsiferous limestones, marls, sandstones, and a few gypsum beds.

Table 3.1

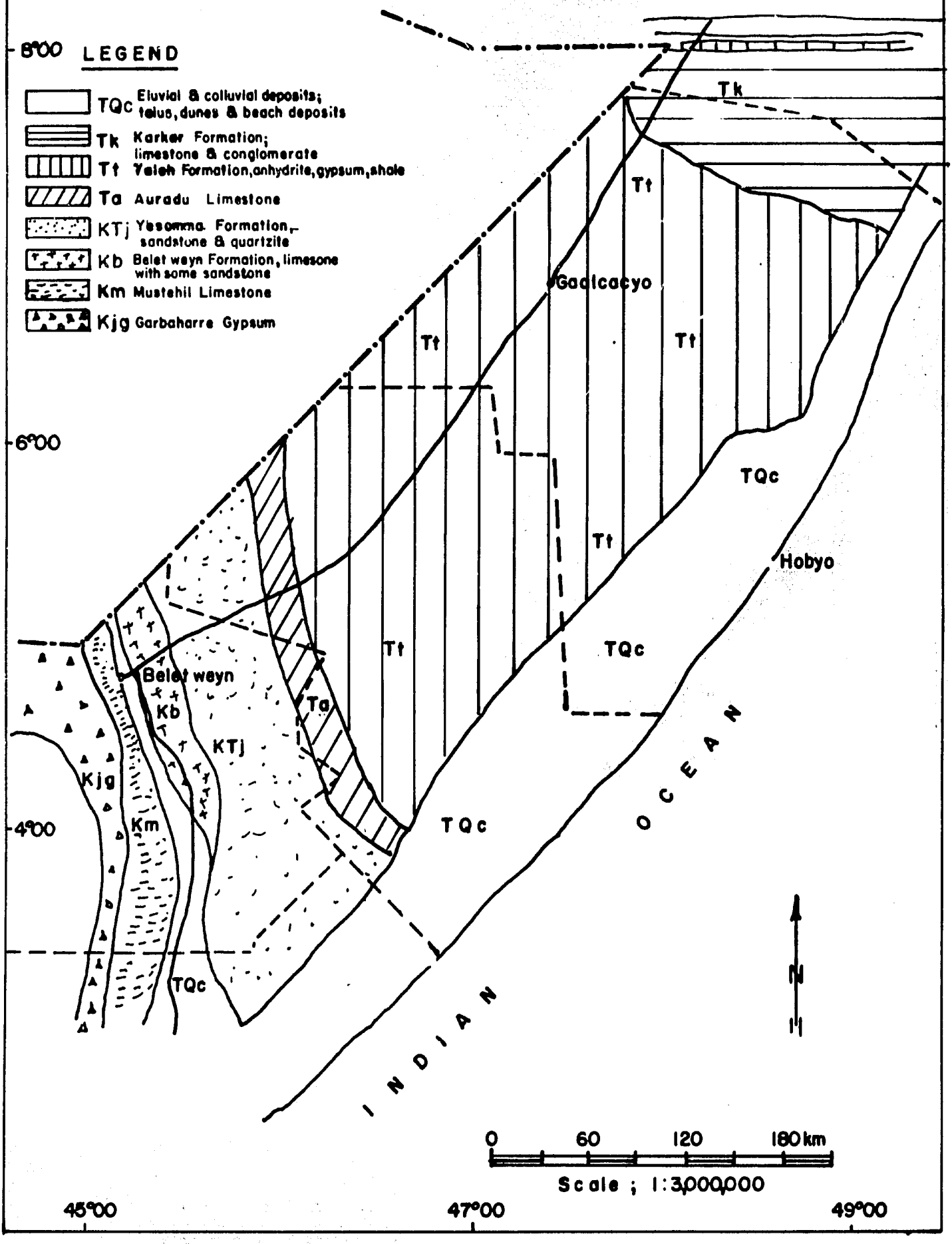
Central Rangeland

Formation Descriptions and Estimated Depth to Water

	Estimated Thickness (meters)	Estimated Depth to water from the top of the Formation Meters
TQc- Eluvial and colluvial Deposit including the Mudugh Beds, talus, dunes and beach deposits. Groundwater occurs in pore spaces of soft unconsolidated formations. Sediments of ephermeral streams also act as temporary aquifers.	30-40	5
Tk- Karkar Formation limestone, marl, calcareous siltsone and mudstone, some gypsiferous. Water occurs mainly along bedding planes and in fissures. There appears to be two separate aquifers	80-230	20-30 150-180
Tt- Taleh Formation - anhydrite, gypsum, interlayers of dolomite and mudstone, commonly gypsiferous. Water circulation along karst hollows is predominant.	350	20-80
Ta- Auradu Limestone - massive limestone, calcareous dolomite interbedded with siltstone. Water occurs in veins (within tectonic fractures), in fissures, and along bedding planes elsewhere. In many cases there are two identifiable aquifers in this series	15-20 40-60	3-6 40-60
Ktj- Yesomma Formation - sandstone with subordinate layers of consolidated clay. Groundwater occurs along bedding planes and in fissures.	200	50-70
Kb- Belet Uen Formation - limestone with some sandstone groundwater is found along bedding planes and in fissures	300	5-20
Km- Mustehil Limestone - The water is found along bedding planes and in fissures.	500	5-20
Kjg- Gabra Harre Gypsum - This formation contains karst water	300	10-40

Fig. 3.6

GENERALIZED GEOLOGICAL MAP OF CENTRAL RANGELAND



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Shabelle river valley

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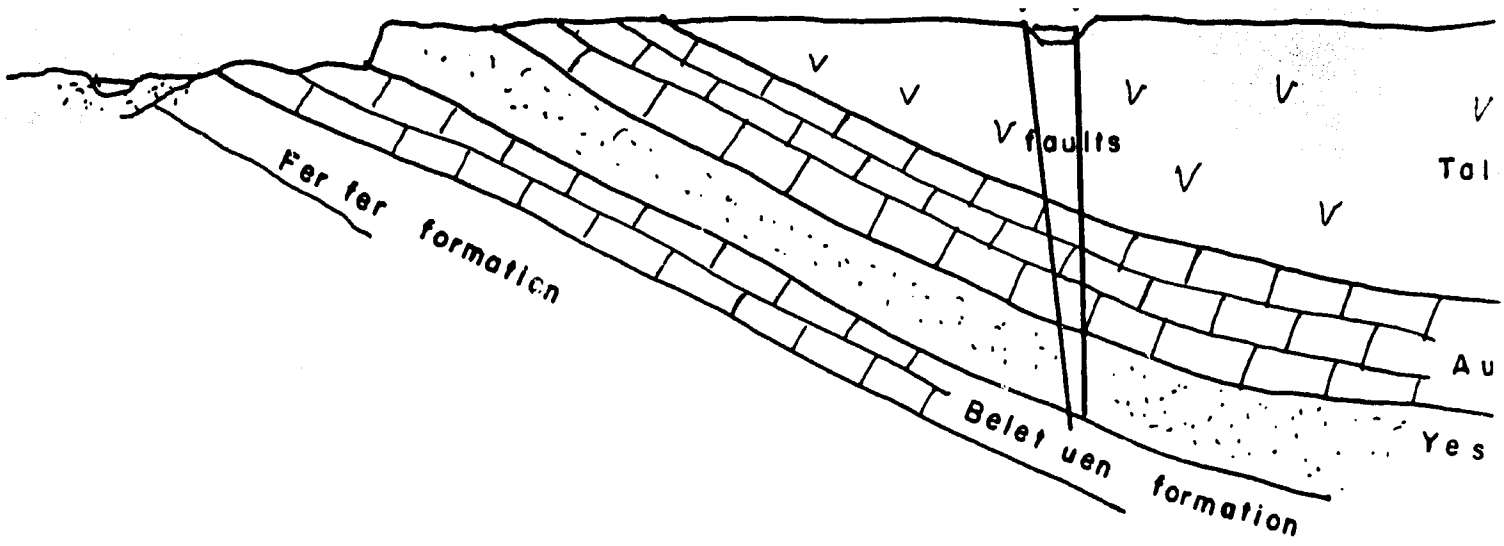
MUDUGH PL

"Mudug Beds"



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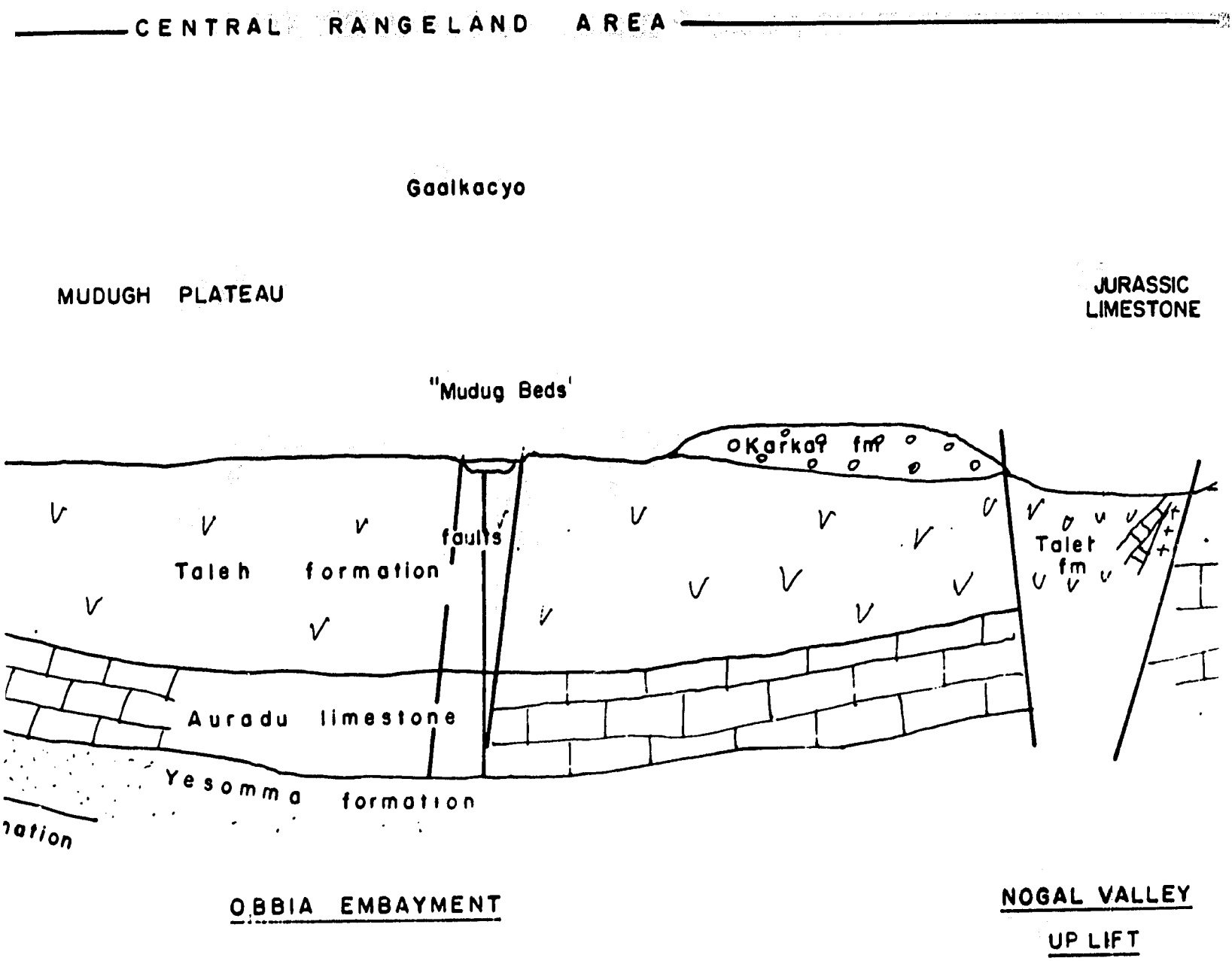
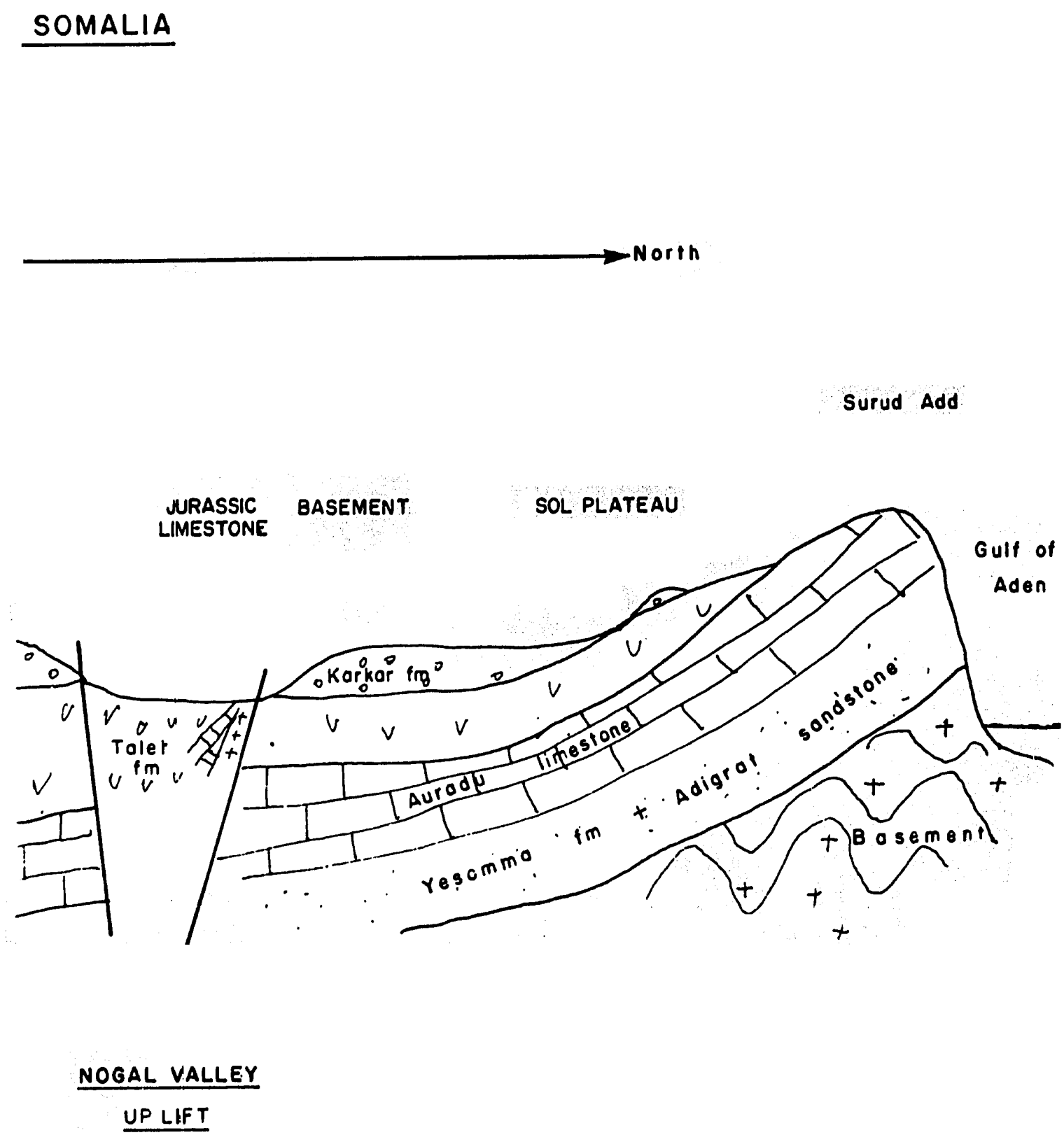
:AL CROSS SECTION : CENTRAL AND NORTHERN SOMALIA



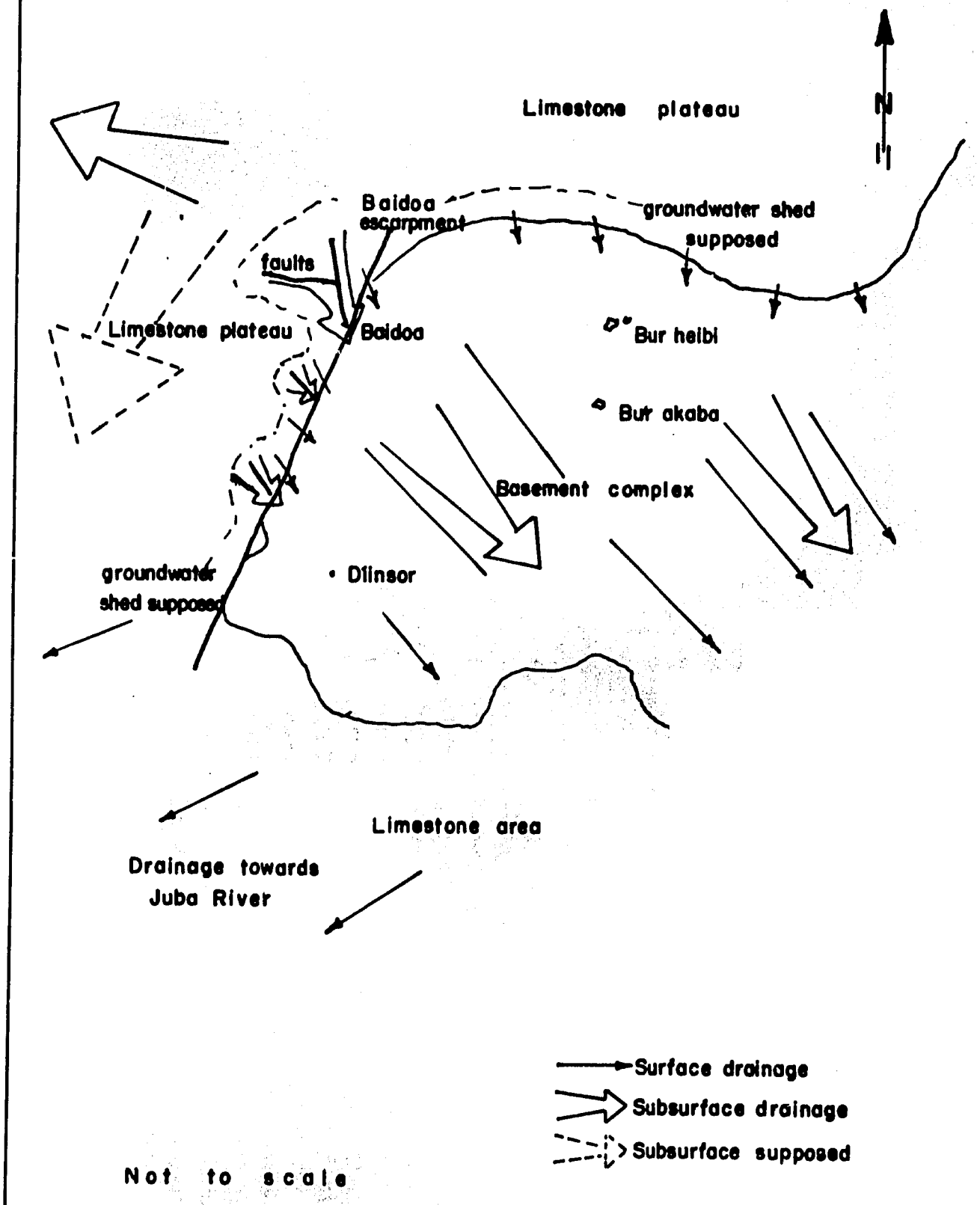


LBII / RM

Fig. 3.7 38

Fig. 3.8

DRAINAGE PATTERN BAY REGION



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Yesomma Formation (Cretaceous Companion to Thanetian)

The Yesomma Formation consists of varicolored quartzitic, poorly cemented, hard sandstone beds. Dominant colors are white, yellow, brown, and dark red. Crossbedding is common and interpreted to be of fluviatile origin. Limestone layers may occur and the top weathered zone of uncemented sandstone contains subsurface calcareous concretions.

At the village of Yesomma, east of Buulo Burti, the Yesomma Formation has a thickness of 300 to 400 meters and overlies the Belet Uen Formation unconformably. The unconformable contact, however, is seldom seen as the Yesomma sandstone weathers deeply and forms a cover of several meters of loose sand over the first cemented layers. Sand washed down to the valley of the valley of the Shabelli River covers large areas of the underlying Belet Uen Formation.

The Yesomma Formation in the Hiran region with interlayered sand and sandstone beds requires more test drilling to determine if it is a potential aquifer. Drilling is difficult due to the tendency of loose sand beds to cave into the boreholes. The sands, and also fractured sandstone beds, may contain groundwater of good quality and show high transmissivities in pumping tests (GTZ wells III b and IV, Burco).

Auradu Limestone (Tertiary Thanetian to Priabonian)

After a transgression, the Auradu Limestone was deposited over the Yesomma Formation. Outcrops are found in a band extending through the western part of Galgudud region to the coast of the Indian Ocean via Duusa Mareeb and Ceel Dheere.

The lower sections consist of dark-brown, fine, crystalline, compact, coarsely-banded limestone. The upper sections show a finer and clearer banding and lighter colors. The Auradu Limestone reaches a thickness of 400-500 meters in the western parts of the area and up to 2,000 meters at the Indian Ocean.

Outcrops may show some karstification. The limestone beds are commonly fractured and offer a good potential for groundwater storage and yield. Wells in the Auradu limestone yields good quality water and frequently in large quantities. If overlain by impervious layers, artesian groundwater is found such as in the southeast near Duusa Mareeb. Flowing artesian drilled wells exist in the Ceel Bur area.

Taleh Formation (Tertiary Priabonian to Lattorfian)

The evaporite sediments of the Taleh Formation were deposited during a regression of the sea from the horn of Africa. The Taleh Formation overlies conformably most of the central and northeastern Somalia and consists of gypsum and dolomites.

Along the coast of northeastern Somalia, the entire Formation is represented by dolomites, thus indicating a deeper sedimentary environment. The Taleh Formation reaches a thickness of 200 to 400 meters in the project area, with a maximum of 450 meters in the Nogal Valley. It often displays intense karstification with large dolines and sinkholes which trap the scarce rainfalls, and reduces the drainage system to short segments on gypsum-anhydrite plateaus. Groundwater is found in fractured karstified zones, but is generally of bad quality.

Karkar Formation (Tertiary Rupelian to Chattian)

The Karkar Formation overlies conformably the Taleh Formation and consists of limestones and marly limestone with a few gypsum lenses similar to those found in the Nogal Valley and in the north of the Central Rangelands area. Large exposures may consist of weakly cemented coarse pebble conglomerates. The Karkar reaches a thickness of 200 to 400 meters. Lateral changes in facies occur from the northeast of Somalia, where it is represented by gypsiferous marls, to Obbia and Merka in the south, where shales and sandstone beds were found in oil well drilling attempts (Barnes, 1976).

The Karkar Formation is the uppermost marine deposit on the central Somalian Plateau and does not have much importance as an aquifer in the area. Springs on both sides of the Nogal Valley along the interface of the Karkar and Taleh Formations, however, may indicate that an aquifer exists, even in the absence of dug or drilled wells. Infiltrating rainwater may be stored in the Karkar Formation above the impervious beds of the Taleh Formation.

Mudugh Beds (Tertiary Miocene)

Satellite photographs of the Central Rangelands area show a well developed regional fault pattern with strikes ranging from NW-SE to NNW-SSE. In the Central Rangelands late Tertiary streams carved shallow river beds, draining the Ogaden Plateau. Two distinct former drainage areas are developed, the Ghelinsor-Dhusa Mareb-Ceel Bur System and the Gaalkacayo System to the north. Into these drainage areas sediments of continental lacustrine conglomerates, fluvial sandstone, and clay and marl were deposited when the climate became more dry. These miocene sediments contain uranium minerals at Dhuusa Mareeb and in the area of Ceel Bur where large deposits of che sepiolites are mined for the magnesium-silicate clay mineral "meerschaum."

The surfaces of the Mudugh Beds are intensely karstified with sinkholes, caves and large dolines. They store groundwater of low quality, but of easy access, as groundwater is only a few meters below the surface. Towns and villages in the area are supplied by dug or drilled wells in the Mudugh Beds. Deeper drilling, however, may reach fractured zones of the Auradu Limestone and encounter an artesian aquifer with groundwater of relatively low mineralization.

Basalts (Cretaceous and Tertiary)

Basalts frequently are encountered in deep drilled wells northeast of the Shabelli river. These basalts may serve as aquifers where they are fractured or scoriaceous, and as confining layers where they are dense and impermable. Artesian water has been struck when deepening boreholes through basalts in some areas.

Recent boreholes undertaken by GTZ encountered olivine basalts as a sill in Auradu limestone near Dhuusa Mareeb and Ceel Bur. The basalt sill near Dhuusa Mareeb is impervious.

Basalts which outcrop southwest of the Shabelli River near Bur Weyn need further investigation to determine their potential as aquifers.

4. HYDROGEOLOGY

4.0 HYDROGEOLOGY

As in the previous section, the Bay Region and the Central Rangelands area are described separately. Groundwater in the Bay Region occurs mainly in limestone and in the Central Rangelands in limestone, sandstone, and loose sand.

4.1 Bay Region

The Limestone Plateau west of Baidoa is the eastern part of a marine Jurassic trench fill in southwest Somalia and northeast Kenya. The plateau dips 4 degrees west-southwest and groundwater drains in the same direction toward the Juba River. The Basement Complex as well as the eroded remaining area of marine sediments on the western and northern Baidoa fault interface, and springs along the escarpment of the Limestone Plateau, drain southeastward to the Shabelli Valley. The watersheds for groundwater and surface water on the Limestone Plateau are not clearly defined. Faults that may drain parts of the plateau are few and vary in length (Figure 3.8). The different types of aquifers described below are ranked according to their groundwater potential.

4.1.1 Limestone Plateau

The Limestone Plateau west of the Baidoa escarpment is divided hydrogeologically into areas of exposed outcrops, and a larger area with a thick cover of residual soils. Outcrops of karstified limestone and dolomite are encountered west, north, and northeast of Baidoa. Karstholes are common and provide access for abundant groundwater recharge during the rainy seasons. In boreholes, the karstification was found to occur to depths of 30 to 50 meters, but deeper karstified and fractured zones may exist such as at the site of Marti Moog (well No. 55). Usually the upper most aquifer has a free water level, although rises of borehole fluid levels frequently were recorded after drilling penetrated the karst zone immediately below the uppermost aquifer.

Wells in these types of aquifers generally yield groundwater having conductivities below 2,500 micromhos. Pumping tests recorded specific capacities of 0.2 to 63.0 m^2/hour. Analyzed as aquifers in idealized unconsolidated sediments, equivalent transmissivities of 2.0 to 2021 m^2/day were calculated. A pumping test in a well at the Ministry of Agriculture Compound in Baidoa indicated a specific yield of about 10 percent from highly karstified limestone, and an equivalent transmissivity of 487 m^2/day.

Following the gentle surface gradient of the Limestone Plateau and the dip of the strata, about 4 degrees northwestward, together with a decrease in altitude of the plateau southward, the movement of groundwater is toward the west and south. This is indicated on the sketch of groundwater flow, Figure 3.8. It remains unclear if a single water table aquifer with regional extent was encountered in the karstified zones, or if small, independent systems were developed. The latter would mean lesser groundwater storage capability and greater changes in static water levels over dry and wet periods. Small karstified outcrops on the Limestone Plateau are found along the Baidoa escarpment.

Large areas of the bedrock limestone in the zone of Awdiinle to Qansax Dheere, are covered with caliche and terra rossa. Cavities in the bedrock were encountered in some boreholes, and prove that karstification exists even if surface evidence, such as karstholes, is absent. Wells in the area vary considerably in regard to their yield and chemical quality of water.

Closely spaced drilled wells of approximately equal depth may show large differences in chemical quality as exemplified by two WDA wells supplying the town of Qansax Dheere. WDA well No. 7 yields water having a conductivity of 2,000 umhos and WDA No. 8 has water of 4,000 umhos.

Wells in the caliche zone drilled under the CGDP are Taflow No. 16, Durei Ali Galle No. 20 and Buulo Fuur No. 42 with equivalent transmissivities of 20.45 and 36.03 m^2/day for wells No. 20 and No. 42 respectively.

Large areas of the Limestone Plateau are covered by residual clayey soils. Clay swelling after the first rainfall creates an impervious layer causing ponding in small depressions on the plateau. These ponds are frequently sites for the construction of wars. Groundwater recharge from these clay-soil areas, along the escarpment and from Berdale to Qansax Dheere in the southwest, remains questionable. WDA wells previously drilled near Baidoa, yielding water from lower parts of the residual soil cover or upper weathered bedrock, were not functioning during the project period.

Drainage from the part of the Limestone Plateau immediately west of the escarpment toward the Basement Comples feeds through a network of faults into numerous springs at the base of the escarpment. The larger fault systems are those west and north of Baidoa and the Baidoa springs: the fault at the Manas Springs and the fault near Robay Gaduud and the Dimer Spring. Smaller faults are developed north of Baidoa. The springs south of Baidoa, with the recharge area below the residual soils, yield mineralized groundwater with high chloride content. Springs north of Baidoa, originating from bedrock outcrops, yield water of low mineralization. Baidoa is supplied water from four drilled wells that yield water with high chloride values in dry seasons and low values after rain periods.

In addition to the upper water table aquifers, one or several deeper aquifers of high mineralization exist. Confined groundwater with a pressure head of about 120 meters was encountered in project boreholes Nos. 2, 3, and 50 in the Bonkay farm area. A water sample taken from well No. 50 showed a mineral content similar to samples collected from the Manaas Springs, suggesting an extensive lower aquifer with a few discharge points at wells along the escarpment unconnected to the near surface karstic aquifer.

In the wells west of the Bay Region groundwater with high degrees of mineralization were encountered in interlayered marls, shales, and limestone of the Anole Formation. These were not transformed into production wells due to the poor water quality of the groundwater which has conductivities higher than 20,000 micromhos. Single, thick limestone beds, with caliche-type weathering, form small-scale groundwater aquifers serving as sources of water for hand dug wells south and southwest of Berdaale.

4.1.2 Limestone Depression

The area east and northeast of the Baidoa escarpment and south of Dolondole to Bur Heibi is covered with deeply weathered remnants of marine sediments. On false color satellite imagery the area is shown to have a relatively dense cover of vegetation. This has lead to the assumption that a groundwater system may be present. Previous studies by the World Bank formulated plans for intensive use of the area by assuming the existence of groundwater reserves.

Of eight project boreholes in this area, however, only borehole No. 4 at Tugerew could be transformed into a slightly yielding production well; it was equipped with a hand pump. The extensive vegetation seen on the satellite imagery may be supplied water by the numerous small springs along the base of the escarpment that drain the Limestone Plateau. In the area of Dolondole, a streamlet fed by karst springs flows down the escarpment and disappears in a quicksand area. It is concluded that the Limestone Depression may be excluded from further investigation as an exploitable groundwater resource.

4.1.3 Basement Complex

The Basement Complex consists of impervious crystalline metamorphic and plutonic rocks. Groundwater storage and circulation is only possible under specific circumstances. Groundwater potentially occurs either near outcrops of granite (burs), within deep residual soils, or in ephemeral stream beds. Burs, or outcrops of granitic plutonics, overlie the Basement Area and have been exposed since Jurassic time to weathering. These inselbergs may reach an altitude of 250 meters above the surrounding plain. Fault or joint traces are

frequently covered by vegetation, indicating the presence of groundwater. A few springs, or wells, are known to be fed by this type of aquifer, such as the spring supplying the village of Bur Heibi. There are many hand dug wells in the alluvium around these outcrops, such as at Bur Akaba and Kananax, yielding fresh water. Faults or joints in granite covered by a thin layer of residual soil or talus also may store groundwater, as are found in the springs along the road north of Bur Heibi.

The residual soils of the Basement Complex consist mainly of clayey material from decomposed feldspar and mica, as well as other silicates, with much quartz sand and weathered feldspars. These soils cover most of the Basement Area. Wells in these soils all yield highly mineralized water of more than 20,000 micromhos. CGDP wells drilled in the area had to be abandoned, as this type of groundwater cannot be used for human or animal consumption.

The Basement Area has a well developed drainage system directed southeastward. These drainage channels may reach up to four kilometers in width and contain 20 to 30 meters in thickness of sand, gravel, and finer alluvium. Numerous hand dug wells in streambeds supply nomads and villagers with small amounts of groundwater of acceptable quality.

At Yaaq Brave, a village located near a drainage channel, the aquifer has been developed in a different way. The drainage channel is filled with coarse sand and crossed by a natural dam consisting of a grantic dike. In normal years the impervious dike forces groundwater to come to the surface, and flow over the dike as a steamlet. Dug wells built on residual soils in the village reach groundwater seven meters below surface, thus deeper than the static groundwater level in the wadi, only tens of meters away. The well water is of high mineralization, about 3,000 micromhos, and is polluted by animals.

4.2 Central Rangelands

The Central Rangelands area from the Shabelli River in the southwest to the Nogal Valley in the northeast consists mainly of aquifers in sandstone, limestone, and gypsum-anhydrite. Aquifers in unconsolidated material are of local significance, as in the dune belt along the coast of the Indian Ocean and alluvium in dry river beds.

No perennial surface drainage occurs northeast of the Shabelli River. Numerous wadis (dry river beds), however, show that the Central Rangelands area is part of a drainage system with a directed south eastward. Larger wadis commonly have vegetation growing in strips across the dry channels, the "brousse tigree."

The low precipitation of the area, with annual rainfall ranging between 100 millimeters in the north and about 200 millimeters in the south, may partially infiltrate the karstified limestone and gypsum anhydrites. Groundwater flow near the surface follows a southeast direction. A deeper large-scale regional groundwater flow occurs from recharge areas in the Ogaden northwest of Somalia. This confined aquifer has static water levels of 100 to 150 meters below the surface along the border of Ethiopia and Somalia, and is presumed to be present in the area southeast of Ceel Bur.

The upper water-table aquifer systems show a direct relation to the chemical composition of the outcrops and are highly mineralized. Groundwater from the deeper aquifer, probably consisting of the Auradu Limestone, is of lower mineralization and is characteristically undersaturated in sulfates. The coastal dune belt has groundwater of high sodium content which rapidly diminishes in concentration inland.

A description of groundwater conditions in the Central Rangelands is given in the following sections. The principal zones, as indicated in Figure 3.6, are discussed including the Coastal Dune Belt, Belet Uen and Yessomma Formations, Auradu Limestone, Taleh Formation, and Mudugh Beds. Table 3.1 summarizes the formation descriptions.

4.2.1 Coastal Dune Belt

Lenses of fresh groundwater in dunes of fine unconsolidated white to yellowish-brown sand are recharged by rainfall along the coast and, in certain areas, by groundwater flow from the inland that produces a coastal fresh water-salt water interface. Towns and villages along the coast are supplied by hand dug wells. The groundwater is generally high in sodium and chloride.

Coastal dunes aquifers may be locally important but require detailed studies if plans are made to use them for wells. For example, a testwell in the dunes near Merka, 100 kilometers south of Mogadishu, yielded 20 m^3/h over 24 hours with a minor drawdown. Water was of relatively low mineralization with values ranging between 2000-3000 micromhos. An analysis for tritium content to determine the age of the groundwater showed none present as the water is very old and has insignificant recharge (GKW Groundwater Program, 1978).

4.2.2 Belet Uen and Yesomma Formations

Both formations have a minor importance as aquifers because of their lithological composition. The Belet Uen Formation in the valley of the Shabelli River consists of limestone with

interlayers of gypsum which reduces the quality of the groundwater. The formation may be a part of the groundwater system related to the Shabelli River with infiltrations of river water into the aquifer rather than having groundwater flow from the formation to the river. The Belet Uen Formation has a small recharge area. Surface and near-surface groundwater flow, however, may occur from the Yesomma Formation into the Belet Uen Formation and to the Shabelli River during and after rainy periods (Figure 3.9).

4.2.3 Auradu Limestone

In the Central Rangelands area, outcrops of the Auradu Limestone are exposed in a strip parallel to the Shabelli River. The karstified limestone collects red lateritic soils in dolines, giving the Somali name of "Galgudud" (red depression) to the area. The Auradu Limestone regionally has large-scale karstification with karst-widened joints that store and transmit groundwater, making it an excellent aquifer. Numerous drilled and hand dug wells yield water of relatively low mineralization having conductivities of around 2500 micromhos.

The entire formation dips gently north-northeastward and is found in deep drilled wells under evaporites of the Taleh Formation. Wells penetrating the Auradu Formation, northeast of the outcrops, yield confined groundwater containing sulfates. This suggests that there may be a semi-permeable boundary between the Auradu Limestone and the overlaying evaporites, or that groundwater flows from two different aquifer systems are present.

The deeper groundwater flow may be related to recharge areas in the western Ogaden and the extreme west of Somalia and having a discharge area on the coast of the Indian Ocean. A discharge area for this artesian aquifer, west of Somalia and having a discharge area on the coast of the Indian Ocean. A discharge area for this artesian aquifer, west of the fault parallel to the coast, exists in the area southeast of Ceel Bur. More detailed hydrogeological investigations are recommended to verify the significance of this area.

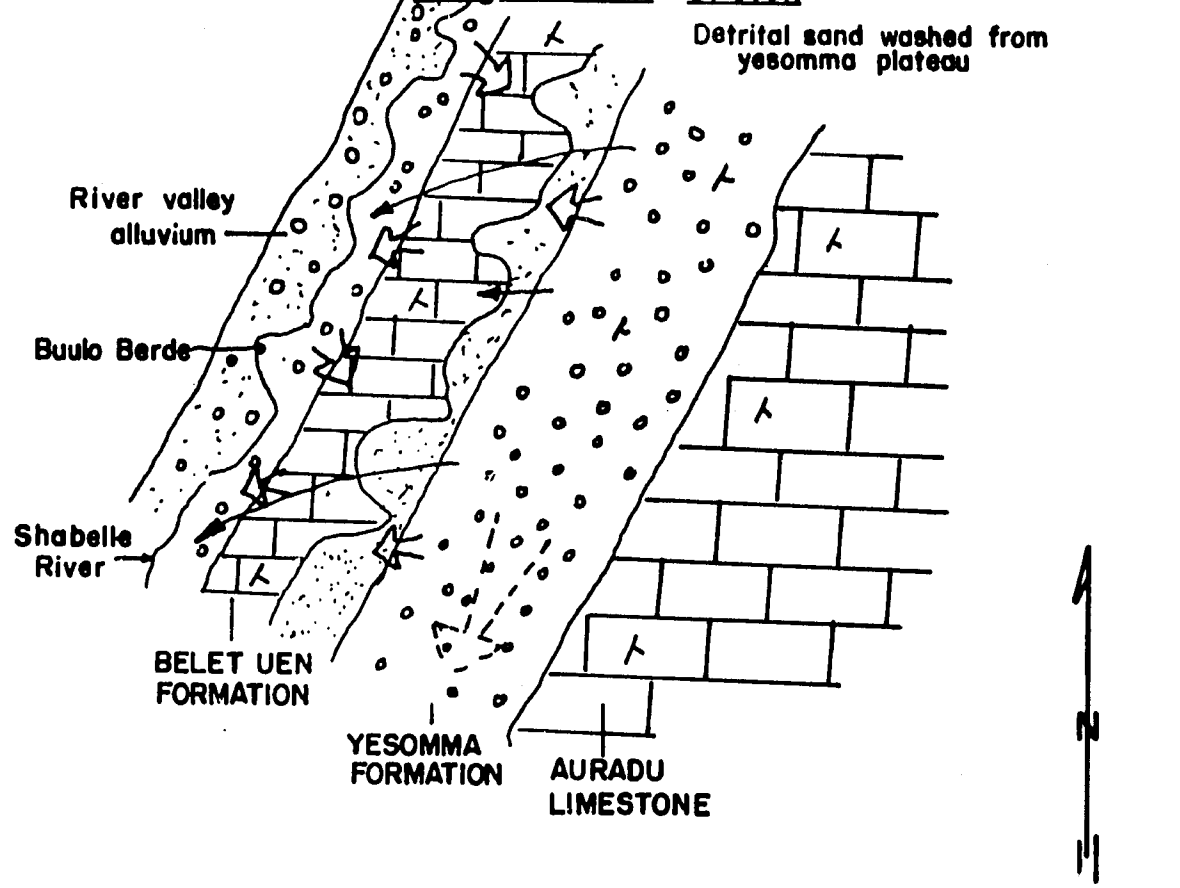
The outcrops of the Auradu Limestone in the project area receives annual rainfall of about 200 millimeters with estimated infiltration rates of 5 to 10 percent. Small-scale isolated near-surface karst systems, such as occur on the Baidoa Limestone Plateau, are inferred rather than a continuous shallow groundwater flow to the coast (Figures 3.9 and 3.10).

Fig. 3.9

SURFACE AND SUBSURFACE DRAINAGE NEAR THE SHABELLE RIVER

CENTRAL RANGELAND REGION

Diagrammatic Sketch



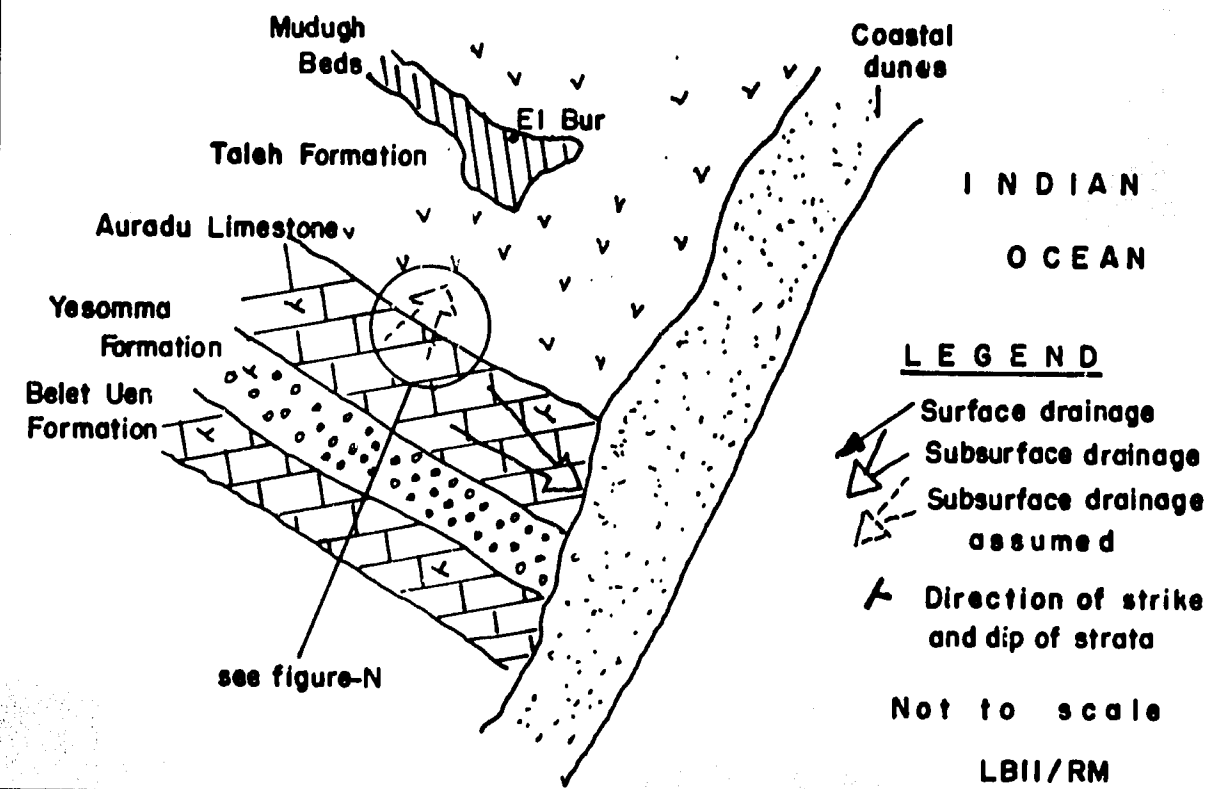
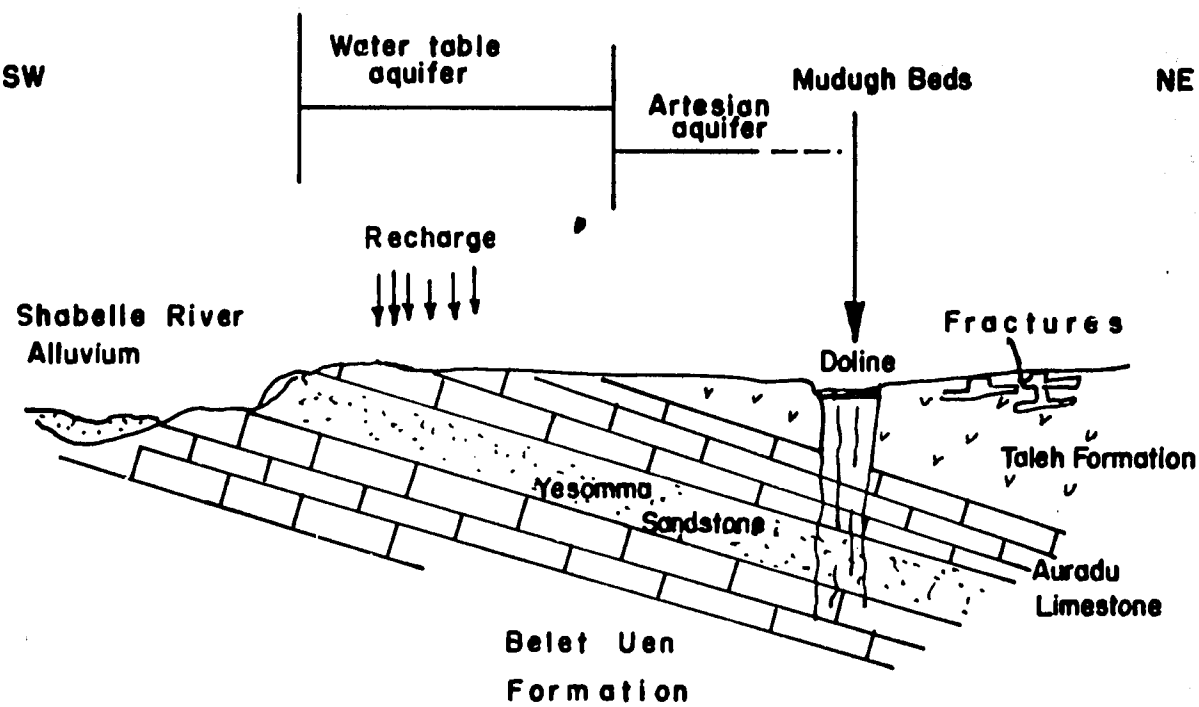


Fig. 3.10

GROUNDWATER MOVEMENT CENTRAL SOMALIA



Sketch Map

Not to Scale

LBII/RM

4.2.4 Taleh Formation

Outcrops of the Taleh Formation occupy about two-thirds of the Central Rangelands project area. Consisting mainly of anhydrite, it decomposes to gypsum on the surface. Gypsum crystal aggregates of large sizes (0.5 cubic meter) may occur, and surface layers are deeply karstified with karstholes and dolines that collect the scarce rainfall. North of the town of Gaalkacyo, a large doline with a diameter of approximately 30-50 meters and a depth to the mud-filled bottom of 15-20 meters, showed no change of water level during the year (1983) from almost full to completely dry. The pond level paralleled the changes of static water levels in the near-surface karst system. An increase of the annual average precipitation of 100 to 200 millimeters per year could lead to an overflow of this shallow system and the reactivation of the surface drainage system down to the Indian Ocean, now consisting of dry river beds filled with calcrete and gypcrete crusts (Mudugh Beds).

Deep groundwater systems may be developed with interlayers of marl and shale (some bituminous). Both types of systems, the shallow one in intensely karstified top layers, and the lower systems, drain to the coast of the Indian Ocean. They are probably not interconnected. The groundwater in shallow and deeper drilled wells is saturated with sulfates that raise the conductivities to as much as 3,500 micromhos.

4.2.5 Mudugh Beds

Mudugh Beds are continental, fluviatile and lagoonal sediments deposited in drainage channels crossing the Mudugh plateau. These beds are of relatively young age (Miocene) and consist of crusts of limestone, gypsum and sandstones. Locally, minerals such as carnotite (uranium, thorium) and sepiolite (meerschaum) may occur.

Shallow wells, which depend on smaller near-surface systems, vary in water quality according to variations in the chemical character of the aquifer. However, wells with sulfate saturated water may draw water from the underlying Taleh Formation.

The system, of Mudugh Beds from Gaalkacyo southeastward, terminates in a former lake, now dry, located west of the fault running parallel to the Indian Ocean (Figure 3.10). This system requires further hydrogeological investigation to determine the quantity and quality of groundwater. There are eroded remnants of Mudugh Beds isolated from the two main accumulations. Further examination of the area southeast of Ceel Bur, the supposed discharge area of the Ghelinsor-Ceel Bur System, is needed.

4.3 Pumping Tests

The pumping test program focused on the measurement of aquifer characteristics such as maximum yield, specific capacity, and transmissivity; and on the establishment of the proper pumping equipment. Pumping tests were completed for 19 wells with the results listed in Table 4.1 and discussed below. The pumping test data are included in the Appendix.

4.3.1 Description of Pumping Tests

Pumping tests with sustained yields were completed at twelve locations. Step drawdown tests were conducted beforehand whenever feasible to determine the optimum pumping rate for 24-hour tests. This data from the 24-hour tests allowed the calculation of specific capacity and of transmissivity.

The yields of wells in the limestone areas varied primarily according to the number of fractures in the rock and to the degree of fracture width through karst solution processes. Since other parts of the limestone are solid and generally impervious, groundwater will flow in bedding planes, joints, fractures and cavities to the well. The aquifers are not homogeneous with isotropic aquifer conditions in all directions. Since transmissivity formulas were originally developed for unconsolidated isotropic aquifers, the values listed in Table 4.1 provide only a comparison with wells drilled under similar conditions.

A standard methodology was employed in calculating equivalent transmissivity. The recorded values of drawdown at a constant pumping rate and of the water level recovery, at pumping completion, were plotted on semilog paper (see Appendix). The drawdown is shown on the linear vertical scale in meters and the time in minutes on the horizontal logarithmic scale. For the recovery curve on the logarithmic horizontal scale the quotient t/t^1 represents the total time of the pumping test drawdown and recovery, divided by the time of recovery. When the points for drawdown and recovery form lines, the difference in water level over one logarithmic cycle can be read from the graph and used in the equation:

$$T = 0.183 \times \frac{Qm^3/hr}{(S_2 - S_1)m}$$

T = Transmissivity in m^2/hr

Q = Average discharge by pumping m^3/hr

S_1 = Water level at beginning of test, m

S_2 = Water level at end of test, m

Table 4.1

Pumping Test Data

Well No.	Location	Transmissivity m2/day	Specific Capacity (m2/hr)	Pumping Rate (m3/hr)	Test Length (hrs)
10	Sarman Dheere	2,021.	63.4	26.6	24.
11	Min. Agric CMPD Baidoa	487.	6.4	13.3	11.
12	Hareero Jiffo	1.9	0.22	11.4	5.
16	Taflow	20,45	1.69	15.6	24.
17	Robay Gaduud	-	0.20	11.4	0.67
18	Gaduudo Dhunte	10.12	0.90	11.4	24.
20	Durei Ali Galle	-	0.34	11.4	0.33
21	Min. Agric CMP Baidoa				24.
42	Buulo Fuur	36.03	1.72	11.4	24.
45	Min. Agric CMP Baidoa	-	0.20	10.9	0.42
46	Qansax Dheere Rod well	10.51	0.68	11.4	24.
47	Awshiini	22.32	0.71	11.4	24.
50	Bonkay Seed Farm	-	0.20	11.4	0.33
51	Mintaan	23.67	0.68	15.6	12.
52	Maleel	294.	23.77	25.2	11.5
54	Isgeed	7.06	0.77	17.0	24.
55	Marti Moog	11.21	0.83	22.7	24.
57	Hagarka	-	0.23	11.4	0.18
59	Shawka	-	0.23	11.4	0.17
63	Bonkay Seed Farm	-	0.10	9.1	1.33

During drawdown, conditions such as dewatering of the aquifer and equilibrium of pumping with flow of groundwater to the well become apparent with a change in line slope on the graph. If the slope flattens, as occurred in the drawdown for well No. 54, the well has reached a state of semi-equilibrium. If the slope steepens abruptly, as in well No. 51, the aquifer is of limited extent and rapid dewatering occurs. The graph line slopes for recovery and drawdown data should be similar although recovery data are more accurate since water level measurements can be made without interference from pump vibration and without being affected by intermittent variations in pumping rates.

The theoretical final position of the recovery curve should be through the initial water level. However, an intercept above this is evidence of recharge to the aquifer and a lesser intercept is caused by a reduction in specific yield. An incomplete recovery is due to limited extent of the aquifer. The reliability of the transmissivity values was enhanced when another method of analysis on a log-log plot gave comparable results.

4.3.2 Well Yields

As indicated in Table 4.1, well #10, at Sarman Dheere is by far the most productive well drilled to date by the CGDP in the Bay Region. It appears that the site is located on a fault with a northwest strike on which numerous sinkholes are found. The specific capacity and transmissivity are greater than any of the other wells tested.

Wells Nos. 11 and 52 have comparatively high transmissivities and specific capacities and appear to be good producers, although they were not pumped for 24 hours.

The wells drilled at Taflow, Gaduudo Dhunte, Buulo Fuur, Qans Dheere, Awshinini, Mintaan and Marti Moog (Nos. 16, 18, 42, 47, 51 and 55) respectively appear to be above-average wells for the Limestone Plateau. Well Nos. 16, 18, 46 and 55 reached a semi-equilibrium state during pumping and although the specific capacities are low, they will sustain long pumping periods.

The well at Buulo Fuur, No. 42, is also above average although the breakdown curve never flattened or reached a state of semi-equilibrium. However, the results for wells No. 47 and 51 are questionable in spite of the fact that the transmissivities are higher than some of the wells described above. Both drawdown slopes steepen before the test completion and the well at Mintaan, No. 51, was only pumped for a 12-hour period. The pumping level in this well should be monitored closely after the installation of a motor pump.

The transmissivities of wells No. 12 and 54 are exceptionally low although No. 54 at Isgeed was able to sustain a pumping rate of 17 m^3/hr for a 24-hour period while reaching a state of semi-equilibrium. The well at Hareero Jiffo, No. 12, had considerable drawdown and was only tested for 5 hours. A motor pump has been installed at this site, but the pumping rate is set for less than 11.4 m^3/hour and the villagers have been instructed to limit the daily use of the pump. Water levels should be monitored closely at this site.

Those wells listed in Table 4.1 with no transmissivity values were able to sustain yields of 9.1 m^3/hr to 11.4 m^3/hr (40 to 49 gpm) for short periods of time. Although the specific capacity for well No. 63 was very low the well recovered quickly as did the well at Robay Gaduud, No. 17.

4.3.3 Pump Recommendations

In determining the most suitable pumps to be used in permanent well installations several criteria were considered. In recognition that the wells are intended for village and stockwater use and often located in remote areas, the single most important criteria is reliability. A pump that is simple, efficient, requires low maintenance and capable of delivering 3.2 liters per second (11.4 m^3/hr, 50 gpm) at 150 meters of head was required.

In meeting these criteria a positive displacement, helical rotor, mono pump was recommended. The pump is driven via lineshaft, by a single-cylinder air-cooled diesel engine. In order to meet requirements and also in an attempt to standardize with some existing pumps in Somalia mono pumps driven by Lister engines were purchased. The problem of standardization is impossible to resolve because there are about 20 models from different manufacturers currently in use in Somalia. However, there are many mono pumps in operation and the equipment uniformity established by the CGDP should help to improve the maintenance and spare parts situation.

For those locations where the well yield or water demands do not warrant the use of a motorized pump, hand pumps have been installed. Helical rotor type pumps known as Moyno pumps, were procured from the Robbins and Meyers Company. The Moyno pump has passed comparative tests under conditions similar to rural Somalia and is rated at approximately 2 m^3/hr (0.3 liter/sec, 4.4 gpm) up to depths of 90 meters.

It is believed that windmills offer potential advantages and two test windmills have been ordered but have not yet been placed in production. Wind conditions are generally marginal within the CGDP areas during part of the year but specific sites may prove effective.

5. WATER QUALITY

5. WATER QUALITY

The quality of groundwater in Somalia has been a concern of the CGDP since the inception of the project. Groundwater in the project areas is generally very high in dissolved solids. Salinity has been found to be a limiting factor in many wells drilled under the CGDP. This has necessitated the adoption of water quality standards by the WDA which allows a compromise between the World Health Organization (WHO) recommended international standards and the realities of water conditions in Somalia. The water quality conditions for the Bay Region and Central Rangelands, respectively, are presented in the following subsections.

5.1 Water Quality in the Bay Region

The assessment of the water quality in the Bay Region is based on analyses of water samples collected by the CGDP from 1982-1984; UN Technical Report No. 3, 1971; and results published by Idrotecneco (IDT), 1976. The water samples collected by the CGDP are primarily from deep wells in the Limestone Plateau. Most of the samples in the IDT and UNDP reports are from hand dug wells in the Basement Complex. The analytical results from the three organizations have been consolidated and are provided in the Appendix, (Table A5.1). The geographical locations of these water sources are shown in Plate 4 in the Appendix. Table 5.1 provides the chemical analyses of the CGDP wells in the Bay Region.

5.1.1 Mineral Content

The mineral content of water is expressed as total dissolved solids (TDS) or electrical conductivity (EC). TDS and EC are generally well correlated (Figure A5.1, Appendix) as well as the sum of cation and the sum of anions to the EC (Figure A5.2ab). The variations of the EC in three areas of the Bay Region are shown in Figure A4.8.

There are three main sources of highly mineralized water. These areas are:

1. Karstic channels containing water of high conductivities in the Limestone Plateau. The directions of the channels coincide with the direction of faults.

2. Along part of the edge of the Limestone Plateau between Baidoa and Dinsor.

3. The Anole Formation.

5.1.1.1 Chlorides

The variations of the chloride concentration in wells of the Bay Region is shown in Figure A5.9. The figure shows the

TABLE 5.1

Chemical Analysis of New CGDP Drilled Wells

LBI No.	UN No.	Idro-tec	WDA No.	Location	Sampling Date	Long	Lat	pH	EC x 10^6 (mmhos)	TDS (mg/l)	Total Hardness as $CaCO_3$	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	Remarks
2				Bonkay II	12/4/82	43°:39.00	3°:07.00	7.8	2,300	-	353	77	39	260	16	229	648	397		pre-completion sample-PCS
3				Bonkay III	10/9/83	43°:39.00	3°:07.00	7.0	3,100	2,216	716	229	35	135	3	533	12	427		PCS
4				Tugerew	4/8/82	43°:42.45	3°:07.06	7.3	1,100	868	472	138	31	58	5	243	31	489		PCS
8				Tugerew	2/2/84	43°:41.66	3°:06.86	7.4	1,700	1,348	729	218	45	98	2	461	55	536		hand pump
8				Tugerew	6/2/84	43°:41.66	3°:06.86	7.0	1,400	1,352	564	157	42	96	6	461	59	536		hand pump
10				Sarman Dheere 1	29/6/82	43°:21.38	3°:16.62	7.1	2,400	3,004	1,071	269	97	102	8	649	47	509		pump test
10				Sarman Dheere 2	29/6/82	43°:21.38	3°:16.62	7.3	2,300	2,912	1,080	256	107	105	5	632	47	489		pump test
10				Sarman Dheere 3	29/6/82	43°:21.38	3°:16.62	7.1	2,300	2,888	1,046	272	89	100	5	632	53	484		pump test
10				Sarman Dheere	18/1/84	43°:21.38	3°:16.62	7.6	3,300	2,964	1,321	308	134	165	3	1,063	118	625		hand pump
11				USAID Compound	15/1/83	43°:38.93	3°:7.29	7.5	3,000	1,868	729	170	74	77	0,6	305	105	388		
12				Bareero Jiffo	10/9/83	43°:25.16	3°:13.95	7.8	2,800	-	888	192	99	180	14	454	92	610		PCS
12				Bareero Jiffo	10/1/84	43°:25.16	3°:13.95	7.6	2,500	-	1,463	205	231	110	7	638	217	482		pump test
12				Bareero Jiffo	26/1/84	43°:25.16	3°:13.95	7.8	3,900	3,554	1,262	311	185	230	3	1,382	257	373		hand pump
13				Shabelle Dugsi-	26/6/82	43°:13.00	3°:17.15	6.8	24,000	19,772	12,211	2,761	1,291	250	34	9,618	284	351		PCS
14				Warta Jaffay	10/9/83	43°:08.47	3°:19.03	7.1	10,000	9,188	3,065	599	381	750	23	3,024	105	445		PCS
15				Qansax Omare	16/6/82	43°:02.36	3°:19.92	8.0	24,000	16,436	5,462	670	920	250	105	8,740	362	1,193		PCS
16				Taflow	10/9/83	43°:11.42	3°:03.88	7.6	1,480	1,528	420	35	81	100	13	265	130	232		PCS
16				Taflow	25/2/84	43°:11.42	3°:03.88	7.5	1,650	1,452	854	205	83	100	11	391	123	631		hand pump
17				Robay Gaduud	27/3/84	43°:18.75	2°:46.25	8.2	1,600	1,408	325	99	19	125	1	355	76	104		pump test #1
17				Robay Gaduud	27/3/84	43°:18.75	2°:46.25	8.2	1,220	1,060	1,408	93	19	113	2	319	73	79		pump test #2
17				Robay Gaduud	4/4/84	43°:18.75	2°:46,25	7.8	1,280	1,024	362	122	14	138	3	355	89	186		hand pump
18				Gaduudo Dhunte	13/3/84	43°:15.75	2°:47.50	7.7	1,900	1,796	894	167	116	114	1	567	99	388		pump test #1
18				Gaduudo Dhunte	13/3/84	43°:15.75	2°:47.50	7.9	3,800	3,380	1,161	234	140	250	2	1,148	102	210		pump test #2
18				Gaduudo Dhunte	13/3/84	43°:15.75	2°:47.50	8.2	3,800	1,932	1,186	231	148	240	2	1,148	204	115		pump test #3
18				Gaduudo Dhunte	21/3/84	43°:15.75	2°:47.50	7.8	3,400	2,812	1,068	228	121	194	2	1,008	79	163		motor pump
42				Buulo Fuur II	10/9/83	43°:05.00	2°:53.75	7.6	2,300	1,800	984	221	105	100	8	214	314	592		PCS
42				Buulo Fuur II	16/4/84	43°:05.00	2°:53.75	7.6	1,950	2,024	766	208	60	106	7	336	267	367		pump test #1
42				Buulo Fuur II	16/4/84	43°:05.00	2°:53.75	7.7	2,000	1,836	831	183	91	106	6	308	258	378		pump test #2
42				Buulo Fuur II	16/4/84	43°:05.00	2°:53.75	7.7	1,950	2,024	903	192	103	106	6	420	249	420		pump test #3
42				Buulo Fuur II	7/5/34	43°:05.00	2°:53.75	7.2	2,150	1,340	1,008	247	95	105	11	336	369	420		hand pump
20				Durei Ali Galle	30/6/83	42°:55.85	2°:49.85	6.8	3,000	-	940	208	107	121	17	789	58	488		PCS
20				Durei Ali Galle	7/3/84	42°:55.85	2°:49.85	8.4	1,800	1,584	617	87	97	125	5	496	109	252		hand pump
20				Durei Ali Galle	29/4/84	42°:55.85	2°:49.85	7.5	2,200	1,964	878	35	192	120	6	448	203	472		pump test, first sample
20				Durei Ali Galle	29/4/84	42°:55.85	2°:49.85	7.5	2,000	1,816	825	159	104	115	7	448	100	430		pump test, last sample
21				USAID Compound	15/1/83	43°:39.65	3°:07.40		2,300	1,928	601	183	35	8	0,1	341	64	243		motor pump

TABLE 5.1 (continued)

LBI No.	UN No.	Idro-tec	WDA No.	Location	Sampling Date	Long	Lat	pH	EC x 10^6 (mmhos)	TDS (mg/l)	Total Hardness as $CaCO_3$	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	Remarks
23				Kurman	24/1/83	42°:51.25	2°:28.95	7.1	900	-	311	80	327	54	6	187	28	244		PCS
23				Kurman	29/2/84	42°:51.25	2°:28.95	7.6	2,400	1,868	824	144	113	167	8	756	132	251		hand pump
25				Dodole	19/1/83	43°:33.93	2°:18.32	7.2	900	660	318	96	19	45	0.4	52	36	384		PCS
25				Dodole	30/3/84	43°:33.93	2°:18.32	8.0	595	744	262	77	17	56	14	84	68	344		hand pump
26				Shidaalow I	20/1/83	44°:16.12	2°:53.57	6.8	33,000	32,092	20,800	1,910	3,900	815	1	10,000	1,250	284		PCS
27				Shidaalow II	10/9/83	44°:16.12	2°:53.57	6.7	1,600	1,288	456	99	50	112	54	210	128	317		PCS
31				Bur Acaba IV	25/1/83	44°:05.10	2°:47.45	7.7	34,000	33,376										
32				Bur Acaba V	10/9/83	44°:05.10	2°:47.45	7.9	800	624	125	32	11	92	86	48	80	232		PCS
32				Bur Acaba V	29/3/84	44°:05.10	2°:47.45	8.2	1,060	836	202	58	14	125	81	224	85	136		hand pump
32				Bur Acaba V	7/5/84	44°:05.10	2°:47.45	7.8	1,140	916	240	58	23	70	179	168	81	304		hand pump
41				Dolondole	10/9/83			7.9	1,040	564	508	135	42	29	20	71	72	634		PCS
45				USAID Compound	14/9/83	43°:38.93	3°:7.29	7.9	-	1,340	460	102	52	221	25	338	452	384		
46				Aabey	15/5/83	42°:57.32	2°:55.45	7.1	1,600	-	912	240	76	83	6	386	82	323		PCS
46				Aabey	19/10/83	42°:57.32	2°:55.45	7.1	2,000	-	774	196	69	89	1.5	390	70	592		pump test
46				Aabey	16/5/84	42°:57.32	2°:55.45	7.3	1,550	1,376	577	58	105	80	4	308	63	378		pump test
47				Aw Shiini	10/9/83	43°:23.52	3°:12.19	7.5	3,200	2,704	1,016	199	126	250	11	601	189	592		PCS
47				Aw Shiini	10/4/84	43°:23.52	3°:12.19	7.7	3,100	2,740	967	202	113	257	11	851	371	294		pump test #1
47				Aw Shiini	10/4/84	43°:23.52	3°:12.19	8.0	2,800	2,604	799	218	62	257	13	815	300	241		pump test #2
47				Aw Shiini	11/4/84	43°:23.52	3°:12.19	8.0	3,000	2,280	887	192	99	250	11	840	251	199		pump test #3
50				Bonkay Seed F.	17/8/83	43°:36.58	3°:11.84	7.2	2,900	-	672	109	97	200	15	263	699	366		pump test
50				Bonkay Seed F.	20/11/83	43°:36.58	3°:11.84	7.0	11,400	8,290	3,705	1,055	260	738	7	4,000	222	478		pump test
51				Mintaan	20/11/83	43°:33.16	3°:20.75	7.1	1,440	756	689	192	51	116	2	213	55	584		hand pump
51				Mintaan	20/11/83	43°:33.16	3°:20.75	6.8	1,400	1,164	666	196	43	57	12	248	40	676		hand pump
52				Maleel	20/11/83	43°:35.20	3°:26.20	7.5	1,000	595	512	90	70	43	3	106	40	531		PCS
52				Maleel	1/3/84	43°:35.20	3°:26.20	8.0	670	608	349	44	58	100	5	112	67	294		hand pump
54				Isgeed	28/1/84	43°:33.16	3°:26.84	7.6	1,200	1,064	671	147	74	57	2	266	53	606		pump test 04.10 AM
54				Isgeed	28/1/84	43°:33.16	3°:26.84	7.8	1,350	992	808	109	130	57	2	283	40	652		pump test 09.50 AM
54				Isgeed	28/1/84	43°:33.16	3°:26.84	7.5	1,500	1,076	792	182	82	73	2	237	52	536		pump test 04.10 AM
54				Isgeed	28/1/84	43°:33.16	3°:26.84	7.6	1,300	1,008	703	186	58	57	2	248	55	723		pump test 10.10 AM
54				Isgeed	28/1/84	43°:33.16	3°:26.84	7.6	1,400	1,008	776	179	80	60	2	284	40	629		pump test 10.00 PM
54				Isgeed	1/3/84	42°:33.16	3°:26.84	7.7	1,525	1,448	905	125	144	94	3	448	63	252		
55				Marti Moog	22/2/84	43°:28.80	3°:34.01	7.1	1,150	1,064	589	170	40	38	2	178	21	631		pump test #1
55				Marti Moog	22/2/84	43°:28.80	3°:34.01	7.0	1,150	960	672	170	60	39	2	178	18	631		pump test #2
55				Marti Moog	22/2/84	43°:28.80	3°:34.01	7.0	1,150	964	579	166	40	36	2	142	21	573		pump test #3

TABLE 5.1 (continued)

LBI No.	UN No.	Idro-tec	WDA No.	Location	Sampling Date	Long	Lat	pH	EC x 10^6 (mmhos)	TDS (mg/l)	Total Hardness as $CaCO_3$	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	Remarks
55				Marti Moog	27/2/84	43°:28.80	3°:35.01	7.8	900	770	618	147	61	41	3	178	13	487		
57				Xagarka	2/3/84	43°:18.68	2°:53.68	8.0	6,400	4,584	1,953	340	268	833	19	1,276	1,814	157		pump test
57				Xagarka	5/4/84	43°:18.68	2°:53.68	7.3	2,000	1,656	758	218	52	194	7	560	187	220		hand pump
58				Bur Acaba	20/3/84	44°:06.79	2°:44.47		48,000							22,700				
59				Showka	4/3/84	43°:31.84	3°:00.52	7.6	12,300	10,536	2,233	439	276	2,710	15	4,816	898	184		pump test #1
59				Showka	4/3/84	43°:31.84	3°:00.52	7.8	13,500	10,224	2,169	410	278	2,000	14	4,760	782	231		pump test #2
62				War Asha	28/4/84	43°:32.63	3°:02.63	7.7	1,250	1,200	625	26	136	44	5	525	41	399		PCS
63				Bonkay Seed F.	6/5/84	43°:36.58	3°:11.84	7.7	2,200	1,476	535	61	93	221	11	420	324	315		pump test #1
63				Bonkay Seed F.	6/5/84	43°:36.58	3°:11.84	7.8	2,100	1,496	487	45	91	207	10	392	317	367		pump test #2
66				Buulo Bawo	25/2/84	43°:06.58	3°:03.68	8.0	1,500	-	482	58	82	90	11	364	124	210		
48				Mori Ari	2/7/83	46°:02.62	3°:51.54	7.0	3,700	-	880	224	78	177	8	488	249	599		PCS

probability of different chloride concentrations. The probabilities of obtaining chloride with concentrations less than the value indicated are:

	Probabilities in Percent			
	50%	77%	93%	
Basement Complex	500	1500	4000	mg/l Cl
Limestone Plateau	500	1000	4000	mg/l Cl
Karstic Springs	100	200	250	mg/l Cl

There are only small differences in the chloride concentrations between wells in the Limestone Plateau and in the Basement Complex. In these two areas there is a 60 percent probability of finding water with a chloride concentration below the recommended WDA water standards of 800 mg/l. The chloride concentrations of the karstic springs are all below 800 mg/l.

The regional variations in the chloride ion concentration are similar to the variations of the EC (Plate 9). There are high (>1000 mg/l) chloride concentration in the wells from the Anole Formation and at both sides of the fault between the Limestone Plateau and the Basement Complex. In the karstic zone there are low chloride concentrations (<300 mg/l). In the Baidoa Formation and in the southern part of the Basement Complex, the chloride concentrations are slightly higher (300-1000 mg/l).

Chloride waters dominante in 75 percent of the wells in the Basement Complex and in 65 percent of the wells in the Limestone Plateau (Table A5.2, Appendix). In the Basement Complex the chlorides are associated with sodium, in the Limestone Plateau with calcium and magnesium.

5.1.1.2 Sulfates

The sulfate concentrations in the Bay Region are often below the highest concentration recommended by WDA (Figure A5.10). The probability of obtaining sulfates with concentrations less than the value indicated are:

	Probabilities in Percent			
	50%	77%	93%	
Basement Complex	90	500	1000	mg/l SO_4
Limestone Plateau	60	250	700	mg/l SO_4
Karstic Springs	10	50	100	mg/l SO_4

Only 5% of the wells in the Bay Region can be considered to have sulfate waters. The few wells with sulfate waters are scattered over the entire area, thus indicating that they may be due to local pockets of gypsum.

5.1.1.3 Bicarbonates

The concentrations of bicarbonates in the Bay Region are high. There is a 50 percent probability of finding a bicarbonate concentration between 500 and 1000 mg/l in the Bay Region (Figure A5.11). Bicarbonate concentrations are similar throughout the region although the dominant anions differ. Bicarbonate waters are primarily found among the karstic springs and in wells west of these springs. These areas coincide with the areas of low chloride concentration (<300 mg/l Cl)(Figure A5.9). It is apparent that the limestone west of the springs are in karstified limestone. Outside this zone, the limestone is more compact and covered with a clay layer which decreases the amount of infiltration and minimizes karstic development. The absence of karstification in other parts of the Limestone Plateau results in waters of higher mineral content.

5.1.1.4 Hardness

On the Limestone Plateau there is a 25 percent probability of finding a hardness below the WHO recommended not-to-be-exceeded value of 500 mg/l $CaCO_3$ (WHO, 1982). The hardness of water is less in the Basement Complex and the karstic springs. In these areas there is a 50 to 60 percent probability of finding water with a hardness below the WHO recommended level (See A4.12).

5.1.1.5 Fluorides and Nitrates

Thirty-seven samples have been analyzed for fluoride in the Bay Region (Table A4.1, Appendix). The range was 0.07 to 3.0 mg/l F, with two of the samples exceeding 1.5 mg/l F, the highest allowable level (WHO, 1982; 1970). Due to the low consumption of water per capita and the low concentration of fluoride, health hazards due to fluoride water intake are unlikely.

Thirteen samples were analyzed for nitrates, most of them from drilled wells. The range was 3 to 40 mg/l NO_3 - N. Nine of the samples had concentrations above the maximum recommended by the WHO (10 mg/l). High concentrations of nitrates are often associated with fecal contamination. Examples of other parameters indicating fecal pollution are phosphate and ammonium. Spot tests of ammonium and phosphate all gave low values. Since the drilled wells are rather deep, it is believed that phosphate is absorbed by the limestone and soil, ammonium is nitrified, and nitrate easily transported down to

the water level. The high nitrate concentrations would then indicate pollution from cattle. Fecal contamination of the old drilled wells has been verified in bacteriological tests.

5.1.2.6 Organic Pollution of Wells

The control of pollution is especially important in the Limestone Plateau, where a network of cracks and fissures allow the transport of contaminated water over rather long distances. Most of the drilled wells in the Limestone Plateau are used as cattle watering points, and defecation by animals around the water points often contaminates the wells. Precautions have been taken with CGDP wells to avoid contamination by arranging the watering point at some distance from the well head and by constructing brush fences around the well. Although moderate contamination from the cattle is not generally believed to be a serious problem, its presence suggests that the water could potentially be infected by human excreta. If the well is located inside a village, the numerous dug septic pits are a potential source for human fecal contamination of the well water.

Bacterial contamination of water is measured by total coliforms, fecal coliforms and fecal streptococci. All these types are found in the intestines of warm-blooded animals. They are thus frequent in feces in high amounts and are used as indicators of fecal contamination. These bacteria are not pathogenic, but their presence in drinking water indicates that epidemics might be transmitted via drinking water. The ratio between fecal coliforms (FC) and fecal streptococci (FS) is used to indicate the origin of the fecal contamination. Ratios above 4.0 indicate human origin and below 0.7 animal origin. According to WHO (WHO, 1970, 1982) the number of fecal coliforms per 100 ml in drinking water should be zero. The sample frequency should be one sample per month when the population is below 5,000.

Bacterial tests undertaken on CGDP drilled wells with motor driven pumps are all uncontaminated, while some of the newly drilled wells with hand pumps are contaminated (Table 5.2). Most of the hand pumps were temporarily installed as emergency watering points during the severe drought in the spring of 1984. Pumps will eventually be changed to motor driven pumps and the surface sealings of the wells will be improved. As a comparison, bacterial tests were performed on some of the earlier drilled wells operated by WDA (Table 5.1). Most of these wells were found to be contaminated. Due to the difficulties of operating testing equipment in the field, (test procedures require an incubation temperature of 35°C but ambient air temperatures usually exceeded this) tests for fecal streptococci could only be completed a few times. The results indicated that the wells are contaminated both from human and cattle feces.

TABLE 5.2

Bacteriological Tests of Drilled Wells in the Bay Region

WDA No.	New Well LBI No.	Date	Location	Source	Fecal Colforms per 100 ml	Fecal Streptococus per 100 ml	FC/FS
2		27/2/84	Dusta	Tap	235	-	-
2			Dusta	Pump house	7	-	-
3		27/2/84	Wabdore	Tap	110	-	-
4		27/2/84	Xawalbarbar	Tap	5	-	-
4		27/2/84	Xawalbarbar	Pump house	6	-	-
6		27/2/84	Lowraar	Tap	53	-	-
7		31/10/83	Qansadhere	Tap	2	0	-
7		31/10/83	Qansadhere	Pump house	0	10	-
7		11/5/83	Qansadhere	Tap	0	14	-
7		11/5/83	Qansadhere	Pump house	16	9	1.8
7		11/5/83	Qansadhere	Water container	500	300	1.7
14		10/5/83	Awdiinle	Tap	94	37	2.5
14		10/5/83	Awdiinle	Pump house	142	59	2.4
14		10/5/83	Awdiinle	Water container	96	809	0.6
14		31/10/83	Awdiinle	Tap	19	12	1.6
18		1/11/83	Gof Gaduud Buuray	Tap	40	30	1.3
18		1/11/83	Gof Gaduud Buuray	Pump house	25	8	3.1
18		31/5/83	Gof Gaduud Buuray	Tap	74	247	0.3
18		31/5/83	Gof Gaduud Buuray	Pump house	15	210	0.1
19		31/5/83	Barbaray	Tap	129	11	11.7
19		31/5/83	Barbaray	Pump house	412	25	16.5
19		1/11/83	Barbaray	Tap	28	40	0.7
19		1/11/83	Barbaray	Pump	19	42	0.5
23		30/6/83	Daymunay	Tap	0	0	-
1		26/2/84	Gof Gaduud Shabelow	Tap	43	-	-
1		28/6/83	Gof Gaduud Shabelow	Tap	0	0	-
	8	27/3/84	Tugerow	Tap	15	-	-
	10	12/3/84	Sarman Dheere	Tap	2	-	-
	-11-	20/3/84	Sarman Dheere	Tap	2	-	-
	-11-	20/3/84	Sarman Dheere	Pump house	0	-	-
	11,21,45	2/11/83	USAID Compound	Tap	30	10	3.0
	11,21,45	30/6/83	USAID Compound	Tap	0	0	-
	11,21,45	27/3/84	USAID Compound	Tap	0	0	-
	16	13/3/84	Taflow	Tap	0		
	17	16/4/84	Robey Gaduud	Tap	0		
	18	16/4/84	Guduudo Dhunte	Pump house	0		
	23	19/3/84	Kurmann	Tap	0		
	25	25/4/84	Dodole	Tap	0		
	32	25/4/84	Bur Acaba	Tap	0		
	51	19/3/84	Mintaan	Tap	7		
	52	19/3/84	Maleel	Pump house	2		
	54	19/3/84	Isgeed	Tap	2		
	55	19/3/84	Marti Mog	Tap	0		
	57	26/4/84	Xagarka	Tap	0		
	12	13/3/84	Hareero Jifo	Tap	0		
	47	6/5/84	Awshiini	Tap	0		
	42	7/5/84	Buulo Fuur	Tap	0		

All of the newly drilled CGDP wells were tested when the pumps were installed. The wells have, to date, been used only for a short period, mainly during the dry season. When the cattle start to gather around these watering points and the rains begin, these newly drilled wells may become contaminated depending on the local geology. The high frequency of pollution among the earlier drilled wells gives support for such an assumption. Regular monitoring for pollution will confirm these conditions.

5.1.3 Water Quality of the Wars

Wars, or surface reservoirs, are utilized extensively in the Bay Region, and must be considered in an analysis of water quality. Since wars are more numerous and therefore more accessible, some wells incur reduced operation schedules during the rainy season. Few wars contain water all year around and people, during dry periods, must rely on deep well water sources. There are a few technically designed and engineered wars in the Bay Region operated by the National Range Agency. These wars are sealed with plastic sheets to minimize seepage and are surrounded with barbed wire fences to prevent animal and human intrusion. The water is pumped outside the war to concrete basins. Figure 5.1 shows the distribution of the wars in the Bay Region.

Samples were obtained from eight selected wars. The variation in water quality was considerable and found to be dependent upon the relative amount of water in the war at the time of sample collection (Table 5.3). Immediately after the rainy season the wars are full and the mineral content is low. In addition to consumption, there are seepage and evaporation losses. Evaporation causes an increase in mineral content of the remainding water as the season progresses.

5.1.4 Summary

High concentrations of dissolved solids, which are generally present throughout Somali, have necessitated the introduction of relaxed water quality standards. Based on electrical conductivity, wells exceeding 3,500 micromonos (umhos) have not been completed for human use. Wells designated only for animal use have a limit of 10,000 umhos. Recommended international standards of water quality, if they were implemented, would condemn over 60% of existing wells.

Poor water quality is found along the escarpment, in suspected fault areas of the Limestone Plateau, in the Anole Formation, and in deeper wells of the Basement Complex. Except for those wells in the karstic limestone north of Baidoa which have concentrations of calcium carbonate, most of the wells are dominated by chlorides.

Fig. 5.1

EEC WAR LOCATIONS IN THE BAY REGION

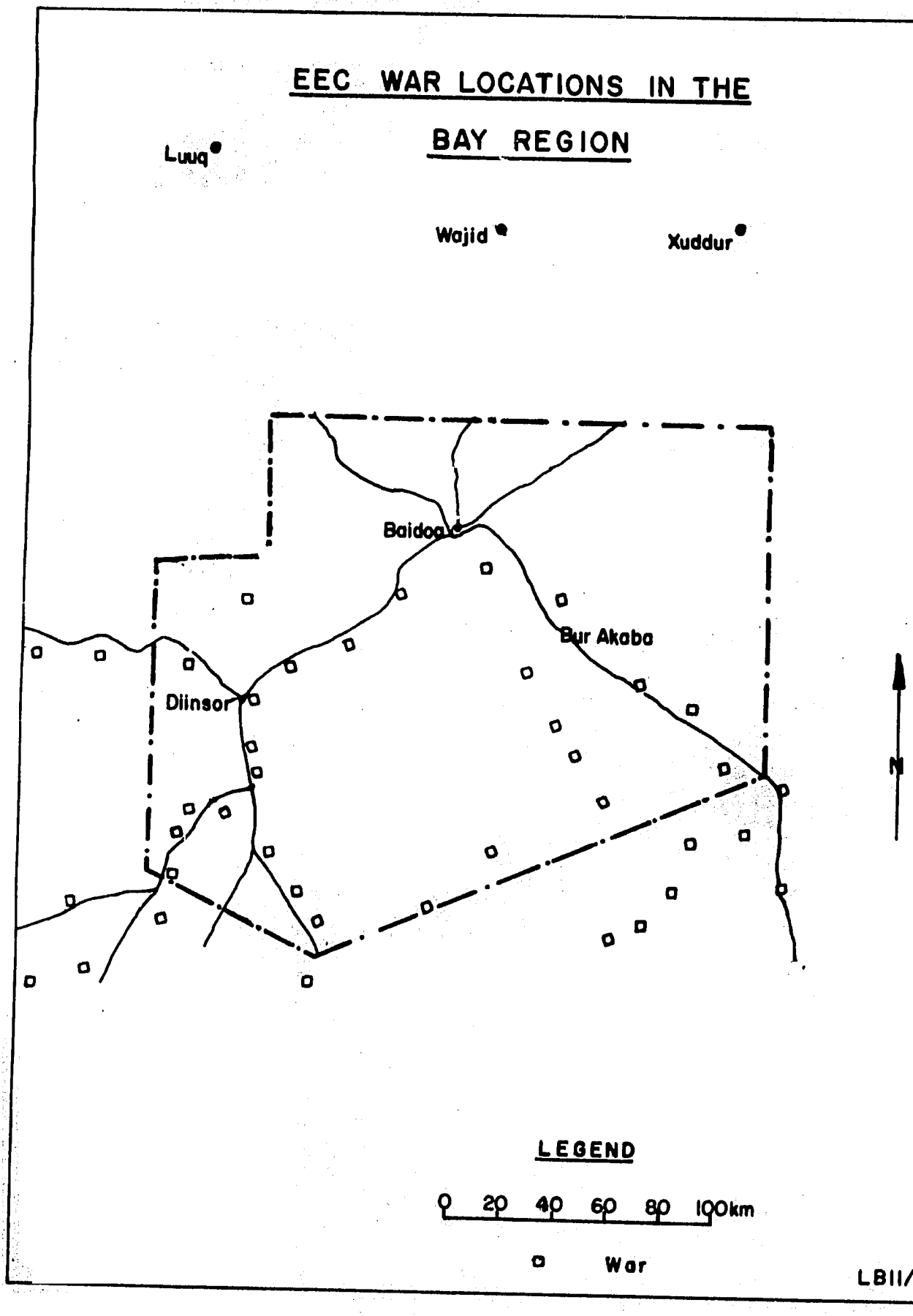


TABLE 5.3

Water Quality of Wars

Location	Sample No.	Sample Date	Water Source	Position Long	Position Lat	EC x 10^6	pH	mg/l Total Hardness as $CaCO_3$	+ NA	K^+	++ Ca	++ Mg	- Cl	— SO_4	- HCO_3	TDS TDS	Remarks
Warta Awa Nabadey	B 514	28/6/82	WAR	43°37'30"	3°16'30 "	700	7.5	385	32	14	90	39	34	193	205	584	Almost empty
UAR Synulow	B 515	28/6/82	WAR	43°30'00"	3°17'00 "	270	7.4	233	22.5	6	29	39	17	9	188	312	Full of water
Cali Mummin	B 516	28/6/82	WAR	43°30'00"	2°58'30 "	1,100	7.[illegible]	440	77.5	8	125	31	43	508	113	1,124	Almost empty
Ariis UAR	B 517	7/7/82	WAR	43°20'30"	2°53'00 "	3,700	7.7	1,733	250	9	577	71	85	2,305	76	3,700	Almost empty
Tcogal Hoosle	B 518	12/7/82	WAR	43°03'30"	2°31'00 "	550	7.2	140	45	5	48	5	52	143	157	460	Half full
Gorisane	B 519	29/6/82	WAR	43°25'00"	2°59'00 "	500											Half full
Buulo Barakay	B 520	29/6/82	WAR	43°22'00"	2°59'00 "	430											Full of water
Safarnoolays	B 521	28/6/82	WAR	43°10'00"	2°41'00 "	170											Full of water

5.2 Water Quality in the Central Rangelands

The assessment of the water quality in the Central Rangelands is based on results published in the UN Technical Report No. 3 (1973) and data obtained from five field trips conducted in May, 1982; February, September, and October, 1983; and February, 1984. The data are compiled in the Appendix (Table A5.3).

5.2.1 Mineral Content

The total mineral content of water is related to Electrical Conductivity (EC) and the Total Dissolved Solids (TDS). The relation between EC and the total mineral content depends on the kinds of ions in the sample. A chloride water with the same mineral content as a sulfate water has a higher EC. However, this is only of importance when the waters are highly mineralized. In the Central Rangelands the majority of wells contain water having high concentration of sulfate or chloride. These relationships are shown in Figure A5.1. Because of these relationships, the total mineral content in the Central Rangelands is discussed as a function of TDS, even though the TDS analyses have a higher risk of analytical errors.

The mineral content of drinking water should, according to the provisional standards adopted by the WDA, not exceed an EC of 3,500 umhos. This corresponds to TDS of about 2,500 mg/l. In Plate 14 areas are indicated where wells have TDS less than 2,500 mg/l. There are only three small areas that meet WDA standards in the project area. Possible explanations for this pattern are discussed in the following subsections.

5.2.1.1 Chlorides

Chlorides in water give a salty taste. The level where people perceive the salty taste varies between individuals, the lowest level being around 120 mg/l and the highest around 1,200 mg/l (Train, EPA). In 1970, WHO stated that for concentrations above 200 mg/l Cl, potability problems may arise and in no circumstances should the chloride concentrations exceed 600 mg/l (WHO, 1970). In 1982, WHO included the chlorides among the aesthetic parameters and gave a guideline value of 250 mg/l Cl. The initial fear about the health hazards of chloride intake via drinking water is apparently not given the same importance as earlier.

In some areas of Somalia people are drinking water containing 2,000 mg/l Cl. It has been observed that in such areas people add salt to tea water if the mineral content is low. The WDA has adopted an upper limit of 800 mg/l Cl as a suitable compromise between the extremes of acceptance.

In Plate 12 the regional variation of chlorides is presented. The chloride concentrations of the wells decrease with the distance from the sea. The high concentrations of chlorides (>1,000 mg/l) the coast are probably not all due to sea water intrusion, however, since the width of this coastal strip is as broad as 30 to 50 km. The chloride isolines in the high range are rather steep, which indicate the influence of geologic materials. The geology of the Central Rangelands can be seen in Figure 3.6. The coastal strip consists of recent geologic deposits (Pliocene to recent age), mainly sand dunes and coral reefs. A modified piper diagram of the analyses from the coastal strip (area TQc on the geological map) is presented in Figure A5.5. These wells have mainly sodium (magnesium) chloride water due to the influence of the recent marine deposits and from sea water intrusion into the wells nearest the coast.

5.2.1.2 Sulfates

Sulfates give a bitter taste to water. The taste threshold value is in the range of 200 to 500 mg/l. High sulfate concentrations in drinking water have a laxative effect and the effect is stronger in combination with magnesium. Magnesium sulfate is a well-known purgative. A study done in the USA showed that 62 percent of a population drinking water containing 1,000 to 1,500 mg/l sulfate reported gastro-intestional disturbances. In the range of 200 to 500 mg/l only 25 percent of respondents reported difficulties (Train, EPA). In 1970, WHO recommended that a concentration of 250 mg/l of sulfate should not be exceeded. In 1982 the organization gave 400 mg/l as a guideline value, mainly based on taste considerations. The provisional standards adopted by WDA for sulfate not to be exceeded is 600 mg/l.

The sulfate concentrations of the wells in the Central Rangelands increase Northwest Ward (Plate 13). The central part of the area is dominated by deposits of gypsum and anhydrite. The thickness of the deposits varies from 200 to 400 meters and increases northward (Hilal et. al, 1977), where the highest sulfate concentrations are found (1,500 to 3,000 mg/l). At the edges of these deposits the sulfate concentrations are lower, which is believed to be due to the thinner layers of gypsum-anhydrite, and to the effects of underlying limestone formations. Along the coastal strip, sulfate concentrations of well water are low.

In Figure A5.6 a modified Piper diagram shows the water types found in gypsum/anhydrite area. The wells yield mainly calcium (sodium) sulfate water.

5.2.1.3 Bicarbonates

The bicarbonates concentration of the wells are rather evenly distributed in the range of up to 1,000 mg/l; one third

in the range of up to 250 mg/l; one third in the range of 250 to 500 mg, and the final one-third in the range of 500 to 1,000 mg/l.

Only about 10 percent of the wells have bicarbonate concentrations higher than 500 mg/l. All of these wells dominated by bicarbonates are of good water quality with TDS less than 2,500 mg/l. The bicarbonate wells are found in the limestone formation west of the Shabelli River and in the zones between the gypsum/anhydrite deposits. There are, however, other water types in these areas, but the locations of the bicarbonate waters support the conclusion that at the thinner edges of the main gypsum deposit, limestone formations influence the water quality.

5.2.1.4 Calcium and Magnesium

Calcium and magnesium are the dominating cations in the gypsum-anhydrite areas, and sodium is the dominating cation in other areas. The calcium concentration in the gypsum areas are a result of the solubility of gypsum which is affected by the ion-pair formation of calcium sulfate, and by its ionic strength. This phenomenon is demonstrated in Figure A5.7, where the logarithms of the true ion concentrations of calcium and sulfate, calculated by taking into consideration the ion-pair formation and the ionic strengths, are plotted against each other. The two straight lines in the figure represent the equilibrium between gypsum and water at two different ionic strengths. The data points between the lines are in equilibrium with gypsum, the data points above the upper line are oversaturated, and the points below undersaturated. In Figure A5.7 most of the samples in the gypsum areas have water in equilibrium with calcium sulfate but 38 percent are undersaturated. This indicates that the contact time between gypsum and water has been rather long and there is recharge from the surface.

According to WHO (1970) magnesium should not exceed 30 mg/l if there are 250 mg of sulfate per liter. If there is less sulfate, a magnesium concentration of 125 mg/l may be allowed. The level at which magnesium-sulfate in water has a laxative effect for an adult is about 1,000 mg/l (about 200 mg/l Mg and 800 mg/l SO_4). In 1982, WHO did not recommend any guidelines specifically for magnesium, however, a guideline value for hardness of 500 mg/l as $CaCO_3$ was given as an aesthetic level. Only 15 percent of the samples analyzed from wells in the Central Rangelands have a hardness of less than 500 mg/l as $CaCO_3$.

In the following table the distribution of the magnesium concentrations is presented. The ranges are based at levels given by WHO in 1970 and the level for the laxative effect of magnesium sulfate. The gypsum area, shown as Tt (Taleh Formation) in Figure 3.6, has been treated separately because sulfate concentrations are high, above 800 mg/l, in this area.

Percentage of Wells in the Central Rangelands with Varying Magnesium Concentrations

	Mg<30 mg/l	Mg<125 mg/l	Mg<200 mg/l
All Central Range Area	18%	59%	77%
Taleh Formation Only	20%	60%	88%

The magnesium concentrations are not extremely high despite the reported presence of dolomite in the central areas. It is thus concluded that the health aspects in magnesium of drinking water in the Central Rangelands are of minor importance.

5.2.1.5 Nitrates and Fluorides

According to WHO (1970) moderate concentrations of fluoride in drinking water cause mottling of the teeth. The effect has been reported occasionally at levels above 1.5 mg/l F. At levels above 3 mg/l skeletal fluorisis may occur, and at levels above 10 mg/l crippling fluorisis may occur. WHO recommends a level below 1.5 mg/l F.

Only a few samples have been analyzed for fluoride in the Central Rangelands; 19 by LBI from April, 1982 and February, 1983, and 19 by GTZ from February, 1982 (Table A5.6). Eighteen (50%) of the samples had concentrations below 1.5 mg/lF and one sample had a concentration of above 3 mg/l F. Since the rural population of Somalia has a low daily consumption of water, higher fluoride concentrations than recommended by WHO might be acceptable. The results reported in Table A5.6 are too few to draw any firm conclusions, but they do not indicate any serious fluoride problems.

High concentrations of nitrates in drinking water may cause methemoglobinemia (blue babies) in bottle-fed infants and cancer among adults. WHO (1970, 1982) recommends that 10 mg/l NO_3-N should not be exceeded in drinking water. Although procedures for nitrate analyses have not yet been established at the MMWR laboratory, 29 samples have been analyzed from the Central Rangelands (Table A5.6). Seven of the samples had a nitrate-nitrogen concentration above 10 mg/l. There are no indications that high nitrate concentrations are a problem in the area but a more extensive review is necessary before firm conclusions can be drawn.

5.2.2 Summary

Areas where water of good quality have been identified in the Central Rangelands and are shown in Plate 14. There is a

high probability that water of good quality can be found inland in a narrow band along the edge of the gypsum deposits, and in the limestone formations west of the Shabelli River. Water from drilled wells in these areas is of the quality that might be used for drinking, irrigation, and cattle. In other areas it will be more likely that water from wells is suitable only for cattle. Good quality water is only found in one-third of the area investigated although the limits of the boundaries are inexact because of limited distribution of available sample points for much of the Central Rangelands. Based upon the preceding discussion of water quality, the proposed use of water from selected drill sites should be carefully evaluated and in many instances alternative water development schemes may have to be considered.

6. GEOPHYSICS

6. GEOPHYSICS

6.1 Surface Geophysical Studies

The procedure for selecting drilling sites involved several steps including, in some instances, the use of geophysical surveys. Initially, a list of villages needing rural water supply were prepared by the Bay Region Agricultural Development Project (BRADP) or the Central Rangelands Project (CRP) and presented to the CGDP. The villages were located on maps and a study was made of aerial photographs and the satellite imagery available. A complete set of satellite images for Somalia is stored at the WDA, Hydrogeological Department, with black and white images in bands 4 and 5 and false color images in band 7. Black and white aerial photographs are available at WDA and detailed single photographs for the areas are stored in the Ministry of Mineral and Water Resources. Satellite imagery and aerial photographs allow possible interpretation of fault traces and drainage patterns, as vegetal cover does not obscure most areas of Somalia.

The study of photographs was followed by field surveys, to identify sinkholes and dolines in the Limestone Area, and possible faults and drainage channels in the Basement Complex. This was often done in conjunction with the village meeting process which is described in the Sociology chapter of Volume I.

In addition, a crew of WDA assistants was trained to run geophysical traverse lines in order to indicate where the best well sites might be located. Hammer seismic and geoelectric tests were utilized.

6.1.1 Hammer Seismic Tests

The available test equipment (Soiltest, Inc.) allowed Seismic depth penetration manually by hammer of 10-15 meters. Numerous trouerses were performed near Baidoa, on the Limestone Plateau, the crystalline Basement Complex, and over their interface. The measurements were processed and plotted by the WDA crew and discussed with the LBI hydrogeologist and thickness of the top layers of overburden were calculated. Rocks in the limestone and basement areas and their overburden of loose residual soils were classified according to their characteristic transmission of shock waves.

The hammer seismic method is intended to be utilized when investigating the drainage channels of the Basement Complex for well sites by measuring the thickness of the overburden and the depth of the static water levels.

6.1.2 Electrical Resistivity Test

A WDA crew was also trained to conduct direct-current electrical with resistivity test with the "Soiltest" equipment and process the data obtained. In using this equipment to site

wells in drainage channels of the Basement Complex, the training was focused on "trenching" using the Wenner configuration. Tests were run on dry channels along the escarpment, as well as on Basement Complex areas covered by residual soils.

The interpretation of these profiles normally requires intensive training, in a class room, using model curves for different layer configuration, that were not furnished with the equipment. The extreme drought of 1983/84 made electrical resitivity tests difficult as the top soils were dried out, including the clayey areas on the Limestone Plateau. Water had to be carried to the test sites and work would be done for periods of several hours only. The electrodes could not be fixed in the cracked clay soil, making tests impossible. It is recommended that future resistivity tests for well sites in the drainage channel should be performed shortly after a rainy period.

6.2 Downhole Geophysical Studies

In the course of drilling operations conducted by the CGDP, geophysical logging trucks outfitted with "Mineral Logging Systems" equipment have been used to provide downhole logs. Present equipment capabilities allow electrical resistivity, spontaneoeus potential (SP), gamma ray, caliper and flowmeter logs of the boreholes. Single-point resistivity, SP, and gamma ray logs are obtained simultaneously with a single tool, the ore-logging tool. A caliper or flowmeter log is obtained by a separate pass of the borehole for each log, using the caliper, or flowmeter tool, respectively.

6.2.1 Resistivity

The single-point resistivity log is a record of resistivity values within a radius of about 15 inches of the probe; it can provide depth measurement of stratam boundaries. The equipment is calibrated prior to running the log at each borehole, allowing quantitative comparison of logging print-outs. The values recorded are influenced by the borehole fluid and indicate the resistivity in ohm-meters of the mineral/ rock and the formation water contained in the rock when the borehole fluid is uniform. Resistivity and gamma logs of most CGDP boreholes are shown together with a representation of the geologic logs of the boreholes for comparison in the appendix.

As an example of the use of resistivity logs, in the vicinity of the town of Baidoa, resistivity logs (in conjunction with gamma ray log) display marker layers of clay/shale which allow the determination of the tilt of the underlying lithological layers. By comparing the depth or altitude of characteristic layers, a determination can be made of the dip or slope of rock formations and therefore the depth that drilling must reach at a distant location.

As another example, Buulo Hawo, Borehole #66, was originally drilled to a total depth of 133 m. An electric log was then run. From the measurements of the resistivity log, complemented by the record of sample drill cuttings, the main composition of the formations below 85 meters were found to be calcareous shale with poor water quality. To prevent these formations from degrading the water of good quality obtainable from shallower depths, the borehole was backfilled to 85 meters and plugged at that depth with cement.

6.2.2 Spontaneous Potential

The SP log is a record of the natural electrical potential between the geologic formation and the fluid in an incased borehole. The SP measurement requires the use of a borehole fluid with a different electrical conductivity than the formation water. The Ingersoll Rand TH-60 rigs use air only, or air with water and foam injection, for drilling in karst areas to reduce the problem of lost circulation that results when drilling with mud. Drilling without mud does not allow use of a SP log.

There were only a few holes drilled with mud during the project and these were in the Central Rangelands Region. An ideal SP log will allow interpretation salt-water formations, fresh-water formations, and interbedded clay/shale layers. The quality of the formation water may be determined from observing the deflection of the SP log. In SP logs obtained from mud-drilled boreholes in the Central Rangelands, interpretation was not possible because borehole fluids were not of uniform conducitivy, probably due to uneven mixtures with formation water.

6.2.3 Gamma Ray

The gamma ray log is a record of radioactivity emitted by radioactive minerals or the differences in the background radioactivities of different geologic materials. Clay, for example, has greater background radioactivity than sandstone or limestone. Granites of the Basement Complex have a higher radioactivity than limestone and quartz sandstone because they are more dense and because granite contains small amounts of a radioactive potassium isotope in potassium feldspar.

Together with the resistivity log, the gamma ray log identifies borehole sections composed of granite in the basement area and clay shale sections in the sedimentary cover, as well as marly rock sections containing clay materials. The amount of gamma radiation is measured in counts per second (CPS). In the sedimentary layers of the project area, limestone and sand show values below 10 CPS. Marly rock sections are indicated by values around 10 CPS. Clay shale sections are indicated by values of 30-40 CPS.

In basement rock, values ranged between 30-50 CPS and more. In contrast to sedimentary cover, basement rock has both high gamma ray output and high electrical resistivity. This allows a clear distinction between sedimentary clay and shale layers and basement rock sections.

6.2.4 Caliper

The caliper log is a record of the borehole diameter versus depth. This log is easy to interpret, and in uncased holes indicates depths at which the boreholes walls are swelling, have collapsed, or have passed through large fractures. In cased holes, a caliper log can indicate total depth of the casing, casing joints, casing joints which have separated, and casing sizes. The caliper log has been used frequently in all of the above-mentioned circumstances.

6.2.5 Flowmeter

The flowmeter log is a record of relative fluid flow within the borehole. The fluid flow may occur naturally, as between two aquifers, or in an artesian well. Fluid flow may also be caused by pumping. The flowmeter is usually positioned at the point of maximum fluid flow in the borehole and logged. The tool is then moved to other depths in the borehole, held stationary and the relative fluid flow at this new point recorded. Alternatively, the flowmeter may be raised or lowered at a constant rate through the borehole for a continuous curve of relative fluid flow. Interpretation of a flowmeter log will indicate borehole sections where groundwater is entering or leaving the well.

7. CONCLUSIONS AND RECOMMENDATIONS

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In Somalia, semi-arid conditions of low rainfall, high evapotranspiration rates, areally limited aquifers and poor quality water, particularly in the Basement Complex and the Central Rangelands areas, have created conditions of limited groundwater resources. Surface water resources are also minimal with only two perennial rivers existing in Somalia, the Juba and the Shabelli.

Somalia will need a continuous effort to develop the meager water resources to their fullest potential by drilling wells, digging wells, constructing wars, developing springs, harvesting rainfall in sisterns, and re-cycling water where feasible.

From results of this project it is evident that existing groundwater reserves are insufficient for large-scale agricultural development in the areas studied. Village water supplies for people and animals will continue to be primary goals for development. The recommendations for continued drilling for future groundwater supplies are based on the 69 boreholes drilled during this Project and on data from earlier research and from other development projects

The chances of success in finding usable water at a specific site varies from area to area, and contains elements of risk. Based on drilling results to date probabilities of future success can be projected. In the Limestone Plateau area of the Bay Region the number of successful wells drilled was 74%; in the Basement Complex, 15%; in the Limestone Depression, 12%; and in the Central Rangelands, 29%. A summary of these areas based on a scale of good, moderate, and low probability of finding usable water during development drilling is as follows:

7.1 High Probability, Limestone Plateau

This area comprises the Iscia Baidoa Formation limestones west of the Baidoa escarpment and east of the first outcrops of the Anole Formation. The best conditions for borehole wells are encountered in karstified limestones. Well sites are located through analyses of satellite and aerial photographs that allows main fracture zones and faults, enlarged by karstic chemical solution processes, to be traced. The remote sensing has to be combined with field surveys, assisted by information obtained from the local farmers or herders who are familiar with the area. In areas covered by a caliche layer of several meters of thickness or by residual clay soil, remote sensing and field surveys may not reveal faults and fractures. Several

test boreholes in an area may be required before obtaining a satisfactory site for a production well.

The water quality should be from good to acceptable with specific conductivity values ranging from 800 to 2,000 micromhos.

The limestone aquifers transmit significant quantities of groundwater only from fractures and fissures in the rock. The apparent transmissivity may range from zero in solid rock to more than 2,000 m^2/day in karst-widened fissures. The Karstic Limestone ranges in specific yield from about 2 to 10 percent. Large seasonal and annual fluctuations occur. During rainy periods, aquifers may be filled and overflow. In years of no precipitation, normally productive wells may become dry.

The Limestone Plateau can be subdivided into three areas where relative probability of success is high. These are:

Outcrops of Karstified limestone

- Areas north, northeast and northwest of the town of Baidoa, north of the clay soil area (Labatan Jirow), and outcrops of uppermost member of the Baidoa formation (Berdaale, Sarmaan Dheere).
- Limestone-Basement interface along the Baidoa escarpment (Baidoa, Robay Gaduud, Kurman).
- Outcrops of limestone bedrock in areas generally covered by clay soils or caliche (Buulo Hawo, Gaduudo Dhunte).

Areas covered with Residual Clay Soils or Caliche and Terra Rossa

- Baidoa agricultural area (down to Robay Gaduud)
- Gel-gel and Qansax Dheere agricultural area
- NE-SE striking band from Audinle to Qansax Dheere and southwest of it (Buulo Fuur, and Durei Ali Galle)

7.2 Moderate Probability, Basement Complex

The only areas worth considering in the Basement Complex correspond to drainage channels and the patches of thicker alluvium consisting of sand and gravel covering the basement in a few places.

In contrast to the limestone areas, the Basement Complex has a well-developed drainage system beginning at the Limestone Plateau in the Northwest and disappearing as abraided channels in young alluvial sediments in the Southeast. This indicates a rate of high surface-water runoff. Zones of coarser alluvium alternate with zones having a greater clay content, reducing the alluvium's permeability and frequently storing saline groundwater with specific conductivity values up to 48,000 micromhos.

The groundwater level is generally shallow and in dry seasons groundwater quality may be degraded due to evaporation of groundwater rising by capillarity to near land surface. Electrical conductivity values may range from 1,000 to 5,000 micromhos according to the season and capillary conductivity of the alluvium.

As an alternative to drilling shallow wells in this zone, large diameter hand dug wells offer some advantages over drilled wells.

7.3 Low Probability, Exposed Basement Rock and the Anole Formation

The exposed basement and its residual cover consisting mainly of clay, can be expected to have only slight yields, and groundwater with high electrical conductivities. In Diinsor, water of 22,000 micromhos was measured and in Yaaq Braawe, 35,000 micromhos. The outcrops of basement (burs) sometimes facilitate the collection of water in the alluvial material at their base.

The Anole Formation, overlying the Iscia Baidoa Formation west of a contact running through the village of Berdaale with a northeast trend, is composed up of shales, marls, and clays containing groundwater with electrical conductivities ranging from 10,000 to 20,000 micromhos. Overlying soils and alluvium also bear groundwater of unacceptable quality. Single layers of limestone, deeply weathered and forming a caliche surface may contain groundwater of acceptable quality, but the wells in this material have low yields.

Some additional exploratory drilling should be conducted in the Diinsor area. The limestone area southwest of Diinsor is covered with residual clay soils which allows farming. The drilling results collected in this area under the CGDP do not agree with older reports which assume sedimentary cover of only several tens of meters over impervious basement. The drilling site at Buulo Gaddud encountered 190 m of limestones and shales that could not be correlated with basal members in the Iscia Baidoa Formation. Numerous shallow wells in the area with

groundwater of acceptable quality, but high in chlorides, leads to the probability that one or more aquifers may be developed there. Before drilling operations are continued, a survey of satellite and aerial photographs of the Dinsoor area is recommended as the groundwater recharge area may be too small to allow exploitation of groundwater of significant quantity.

7.4 Central Rangelands

The Central Rangelands is a large area and the GCDP has undertaken an insufficient number of wells to make any firm recommendations as to probability of success. The few wells drilled in the southern part of the Central Rangelands were primarily unsuccessful. A drilling program in the Hobbio district has been recently begun with a successful first well. Research will be continued at sites selected by the CRP.