special report 02:78.3
UDK 551.49(1)

GROUNDWATER STORED IN LARGE FRACTURE AND FAULT SYSTEMS - A HIDDEN WATER RESOURCE. A CASE STUDY FROM BOTSWANA

Presented at
NORDIC HYDROLOGICAL CONFERENCE,
1978, Helsinki, Finland

Åke Möller Ph.D. (Civ.Eng.)
VBB Div. for Water, the Environment and Geotechnology
Carl-Fredric Müllern M.Sc.
Geological Survey of Sweden

VBB

5038 · S-102 41 STOCKHOLM 5 · Sweden · Cable VATTEN Sthlm · 10477 VATTEN S
Swedish Consulting Group

GROUNDWATER STORED IN LARGE FRACTURE AND FAULT SYSTEMS - A HIDDEN WATER RESOURCE. A CASE STUDY FROM BOTSWANA

Åke Möller & Carl-Fredric Müllern

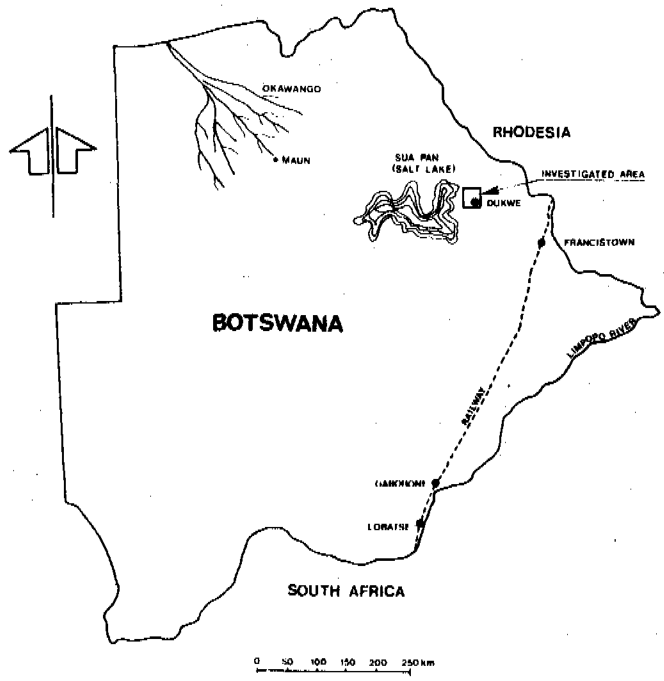

FIGURE 1 SIMPLIFIED MAP OF BOTSWANA SHOWING THE LOCATION OF THE INVESTIGATED AREA
SWECO

ABSTRACT

During a groundwater investigation in northeastern Botswana a large fault and fracture system with abundance of groundwater was discovered. The fault separate an arkose filled graben and the Precambrian basement. There is no evidence from surface topography or air photos of this large structure. Through various geophysical investigations and test-drillings this remarkable structure was outlined and its groundwater potential calculated. Wells yielding as much as 50 to 60 l/sec could be drilled more or less anywhere along the fault zone. This capacity should be compared with the average yield of 2-3 l/sec in wells located outside of the fault system in the arkose formation. However, the total yield from the aquifer as a whole is limited as presently no or very little recharge seem to take place and all groundwater extracted is through mining. There is strong evidence that similar structures exist elsewhere in Botswana.

INTRODUCTION

The studied area is situated in northeastern Botswana and covers part of the border zone between Precambrian gneisses, schists and amfibolites to the east and sedimentary rocks of Paleozoic and Mesozoic ages to the west. The border between these rock types is to a large extent controlled by faulting.

The ground surface of the area rises gently from about 920 metres above mean sea level in the west to about 1,000 metres in the east at the foot of the Matopo Hills, a distance of 35 kilometres. This gives a slope of about 0.2 %, which is almost horizontal to the eye. The ground is covered by dense bush vegetation.

Except for the Matopo Hills, a NNE-SSW trending mylonitic shear zone, only a few geomorphological features can be traced on aerial photographs. The most important are drainage patterns. Other features that can be traced are WNW trending dolerite dykes, the general borderline between the crystalline and sedimentary rocks, the strike of foliation in the gneiss area, alluvial deposits, ancient shore lines and some faulting. The latter is mainly indicated by differences in vegetation over the structures. The difficulty experienced in tracing fault lines is partly due to the fact that most of the faulting took place before the deposition of the Ntane sandstone which now covers most of the faults, and partly to the extremely low relief of the area.

GEOLOGY

The studied area covers, as mentioned briefly in the introduction, two completely different types of rock. In the eastern area remnants of the Precambrian basement crops out while in the western area the crystalline basement is covered with sedimentary rocks of Paleozoic and Mesozoic age, see Figure 2 and 3. The succession of the rocks is given in Table 1.

Table 1. Succession of rocks in the Dukwe area

Alluvium Calcrete and Silcrete			Recent Recent
	Erosion Faulting?		
Dolerite Intrusious			Post-Karroo Intrusions
Ntane Sandstone		Stormberg Series	
	Erosion Faulting?		
Tlapana Mudstone: Non-Carbonaceous		Beaufort	
	Erosion Faulting		
Tlapana Mudstone: Carbonaceous		Upper Ecca Middle Ecca	Karroo Supergroup
Mea Arkose			
	Erosion Uplift		
Dukwe Mudstone Dukwe Formation		Upper Dwyka? Lower Dwyka	
	Major Hiatus		
Mosetse River Gneiss			Pre-Cambrian complex

A brief description of the main formations is given below:

Dukwe Formation

This formation consists of sediments deposited under glacial conditions and comprises sandstones, siltstones, shales, tillites and varved shales.

Dukwe Mudstone

The Dukwe Mudstone consists of different red and black shales and grey mudstones. The maximum encountered thickness was about 31 metres.

Mea Arkose

This formation was deposited following uplift and erosion of the Dukwe Mudstone. The Mea Arkose is a white, gritty arkose. Major minerals are quartz of usually rather high angularity and feldspar that is frequently weathered to kaolin.

The grain size varies from fine sand to pebbles. According to the geological log of the core from borehole N47, the distribution of "very coarse", pebbly and conglomeratic beds was as follows:

From the top of the Mea Arkose

0 - 26 m,	none
26 - 58 m,	five horizons, total thickness 15 m
58 - 94 m,	none
94 -109 m,	two horizons, total thickness 4.5 m

The presence of high permeability zones within the upper half of the Mea Arkose formation has also been indicated by geophysical well logging and pumping tests. Consequently, where this upper part has been eroded the possibilities for groundwater extraction seem to be highly reduced.

Tlapana Mudstone

This formation is divided into a lower dark grey to black carbonaceous part, and an upper light grey to yellowish non-carbonaceous part. The contact between these two rock types is very distinct and has served as a good key horizon between boreholes.

The Tlapana Mudstone has a very low permeability and serves as a confining layer to the groundwater in the underlying arkose formation.

Ntane Sandstone

After the deposition of the Tlapana Mudstone, some faulting may have taken place, followed by erosion, after which the Ntane

Sandstone was deposited. The unconformity is clearly shown in section A-A[1] on the geological map.

The permebility of the Ntane Sandstone is generally very low but can in certain locations be very high and yield large amounts of groundwater, as indicated at wellfield 8, wells E1, E3 and E7.

TECTONICS

Section A-A[1] shows the general decline of the basement (pre-cambrian) level towards west due to faulting. At least four different fault zones have been identified along this profile. The faults show a step-wise nature and it is most likely that there is more than one step in each fault zone.

The downthrow between boreholes 2017 and 616 is in the order of 100 m. The area between borehole 2017 and somewhere between boreholes E2 and N122 constitutes a graben. The area west of this graben to borehole N123 constitutes a remaining horst. The area west of the horst may be downfaulted some 160 m compared to the horst, see Figure 3 and 4. The strike of all of these major faults is NE-SW. There are indications of some N-S striking faults, probably shear zones, in the area of wells E1, E3 and E7.

HYDROGEOLOGICAL CONDITIONS

Geophysical Investigations

An intensive geophysical study was carried out including magnetometry, electrical resistivity soundings and traversing, gravity and horizontal loop electromagnetics. It was unfortunately not possible to carry out seismic profile investigations due to the lack of suitable equipment within the country. The combination of resistivity traversing, spontaneous potential and magnetic measurements proved to be the most useful techniques in locating sub-surface anomalies.

Well Inventory and Drilling

During the well inventory data from some 23 drilled wells were found. Valuable information about the geological conditions was obtained from well-logs at the archive at the Geological Survey. However, very little information about the depth to water table, drawdown, capacity etc was available. Some of these wells were pump tested and water samples for chemical analyses obtained. In addition to these wells another 22 test wells were drilled and tested. Geophysical well logging was also done in some of these wells. The following parametres were recorded: a) caliper, b) bulk density, c) neutron (porosity), and d) natural gamma.

Aquifers

The study clearly showed that the Mea Arkose was the only suitable formation with potable and extractable amounts of groundwater. It also became clear that wells drilled in the arkose formation but outside of the large eastern fault zone yielded very little water, about 2-3 l/sec, compared to as much as 50-60 l/sec for wells drilled in this zone. However, in the southwestern parts of the study area the capacity of wells penetrating the full thickness of the arkose formation but located outside of any known fault zone were almost dry. The occurrence of dolerite dykes in this area, as shown on aerial photos, seems to be more pronounced and it is possible that these intrusions act as groundwater barriers and reduce the movement of groundwater along the fault zone.

Geohydrological conditions

During the study 16 wells were tested, in some cases with both step-drawdown and constant discharge tests. However, as only a few observation wells were drilled, it was only at a limited number of places where calculation of the storage coefficient could be made.

As an example of the drawdown in a well located in the large eastern fault zone the data from the step-drawdown test of well 3173 is shown on Figure 5. It was not possible to conduct any similar pumping tests in the wells located outside of this fault zone as the capacities were too low.

The transmissivity for the tested wells is listed in Table 2.

Table 2. Transmissivity

Well No.	T, m²/s	S
604	$6 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
616	$1 \cdot 10^{-2}$	$1 \cdot 10^{-3}$
1239	$7 \cdot 10^{-3}$	$2 \cdot 10^{-5}$
1662	$8 \cdot 10^{-5}$	-
2146	$7 \cdot 10^{-5}$	-
2157	$7 \cdot 10^{-5}$	-
3112	$2 \cdot 10^{-5}$	-
3116	$2 \cdot 10^{-5}$	-
3127	$2 \cdot 10^{-4}$	$7 \cdot 10^{-5}$
3128	$1 \cdot 10^{-4}$	$6 \cdot 10^{-5}$
3130	$1 \cdot 10^{-2}$	$2 \cdot 10^{-3}$
3131	$1 \cdot 10^{-4}$	-
3155	$6 \cdot 10^{-5}$	-
3173	$3 \cdot 10^{-2}$	$4 \cdot 10^{-3}$
3179	$2 \cdot 10^{-2}$	$1 \cdot 10^{-3}$
3181	$1 \cdot 10^{-2}$	$5 \cdot 10^{-3}$
E3	$5 \cdot 10^{-3}$	-

As an example of the transmissivity in areas outside the fault zone west of the high yielding wells 3179 etc wells nos 3112 and 3155 can be used. Here the T-value is around 10^{-5} compared to 10^{-2} m²/s for wells located in the fault zone. In the area further north, wells 3127 and 3128, the T-value is about 10^{-4} m²/s.

GROUNDWATER QUALITY

The water samples taken in the various wells indicate that there is a general tendency for the groundwater to become more salty (high sodium-chloride content) towards west and north west with the best water in central area around the eastern fault zone. The TDS in the western areas is around 1600 ppm compared to about 900 ppm in the wells along the fault zone. The chloride content in the same wells were about 700 ppm and 200 ppm.

WATER POTENTIAL

It is clear from the general geological framework that most of the Mea Arkose formation is under confined conditions. Recharge areas for this aquifer is to be found in the area east of the graben zone where the confining formations have been eroded. However, it is believed that during the present climatic conditions very little precipitation, if any, recharges the aquifer. This is partly indicated by the large depth to the groundwater table in the recharge areas, e.g. east of wells 3131 and 3066 the depth to the water table is between 35-40 metres.

In studies made by Mazor et al (1974) and Hutton and Loehnert (1977) the recharge mechanism in selected areas in Botswana was analysed by means of isotopic methods. These studies indicate that the groundwater at Dukwe (as well as in most other areas in Botswana) was recharged during cooler climatic conditions.

Unfortunately no continous water level measurements were carried out during the study due to various reasons. Therefore, at present nothing is known about the true recharge conditions and the calculation of the groundwater potential was based on the assumption that no recharge takes place.

The conclusions of the water potential calculations were that some 30 to 40 l/sec could continously be pumped for at least 15 years before the water level should have dropped to the top of the Mea Arkose formation or before more saline water from the western areas had moved to the fault zone with a deterioration in the water quality as a result. The calculation is rather conservative and it is thought that more water can be extracted. However, further pumping tests with higher capacity pumps and more observation wells are needed for better and more safe calculations in this respect. The positive result of the study was however, that groundwater, in limited but important amounts, could be found in an area where previously it was thought that no such groundwater resources existed.

REFERENCES

Mazor, E., Verhagen, B., Sellschop, J., Robius, N. and Hutton, L. 1974 Kalahari Groundwaters: Their Hydrogen, Carbon and Oxygenen Isotopes. Isotope Techniques in groundwater hydrology, IAEA, Vienna.

Mazor, E., Verhagen, B., Sellschop, J., Jones, M., Robins, N., Hutton, L., Hutton, S. and Jennings, M. 1974 Northern Kalahari Groundwaters: Hydrologic Isotop and Chemical Studies at Orapa, Botswana. Geological Survey Department, Botswana. (unpublished report.)

Hutton, L. and Loehnert. 1977. Hydrochemical surveys of selected Karroo areas in Botswana. International Association of Hydrogeologists, report at congress in Birmingham, England, 1977.

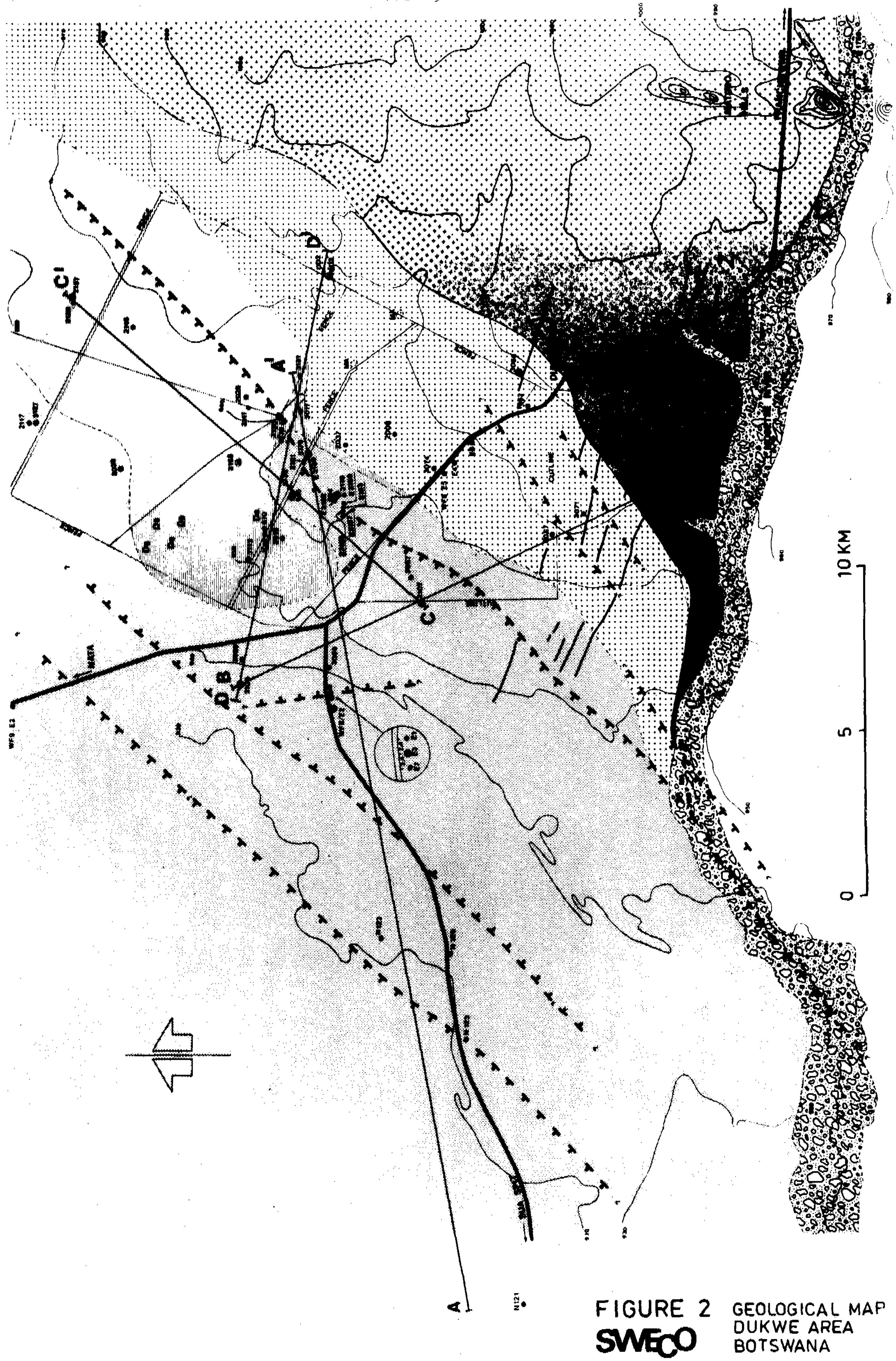

FIGURE 2 GEOLOGICAL MAP
DUKWE AREA
BOTSWANA

SWECO

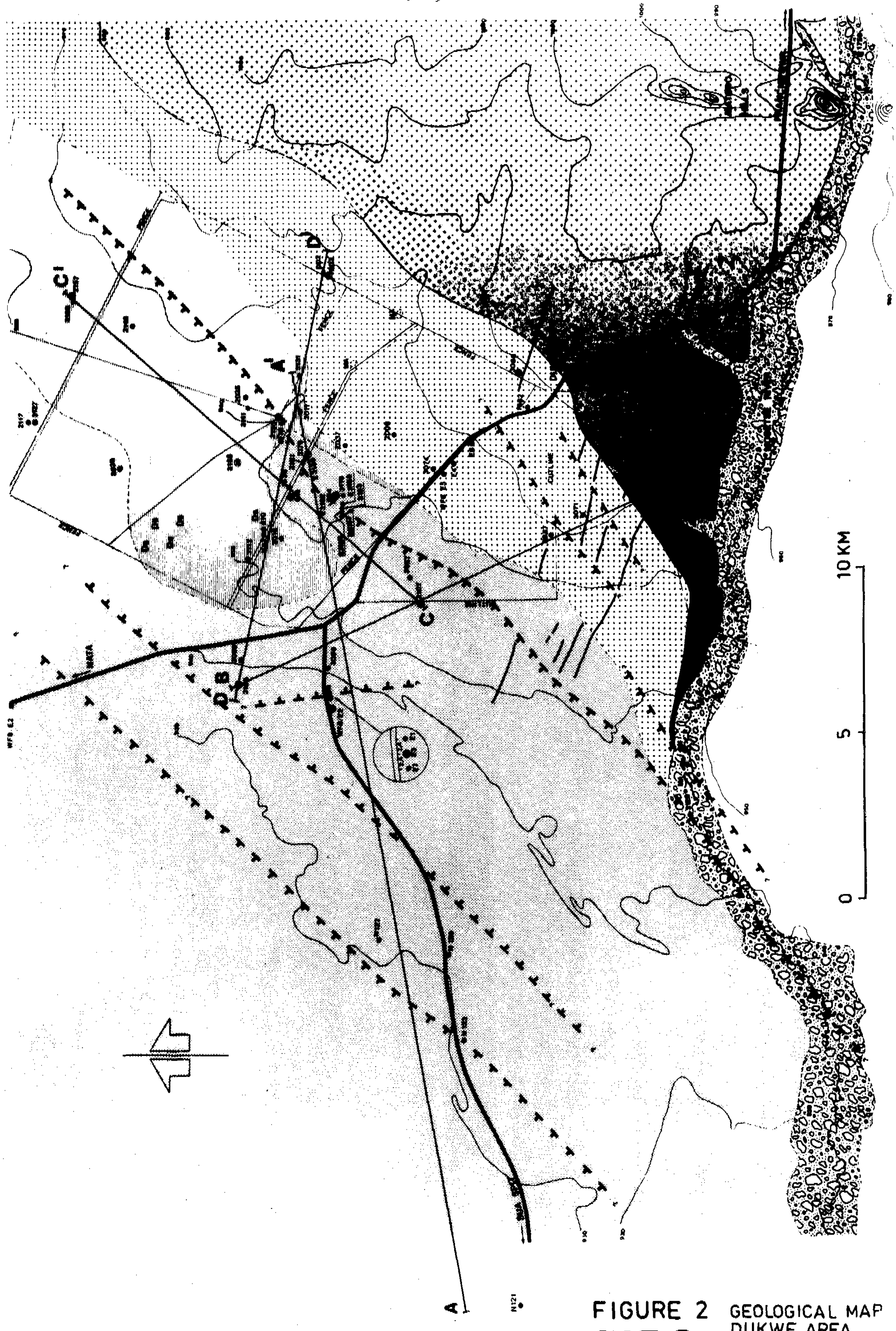

FIGURE 2 GEOLOGICAL MAP
DUKWE AREA
BOTSWANA
SWECO

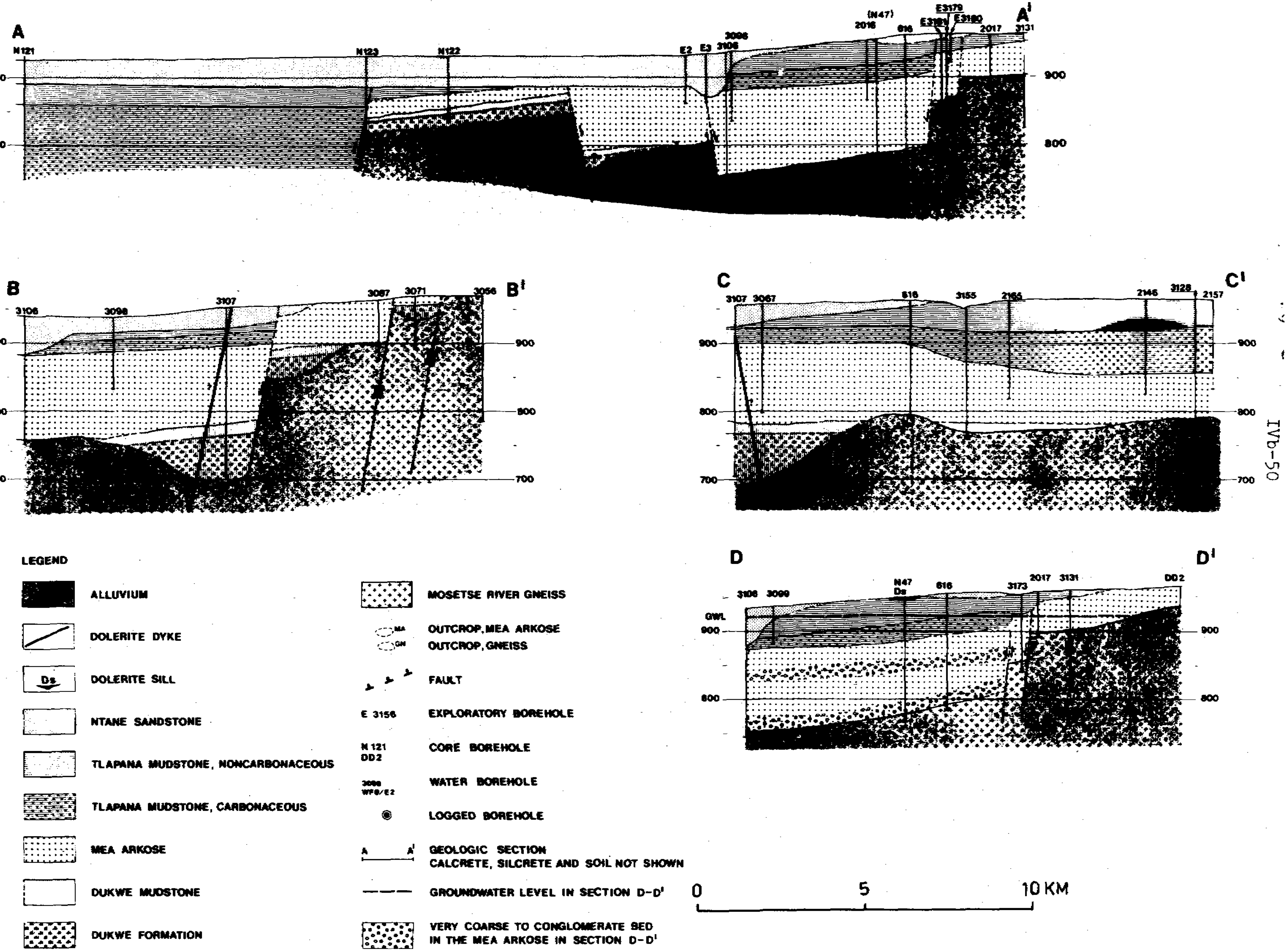

FIGURE 3 GEOLOGICAL PROFILES
DUKWE AREA
BOTSWANA

SWECO

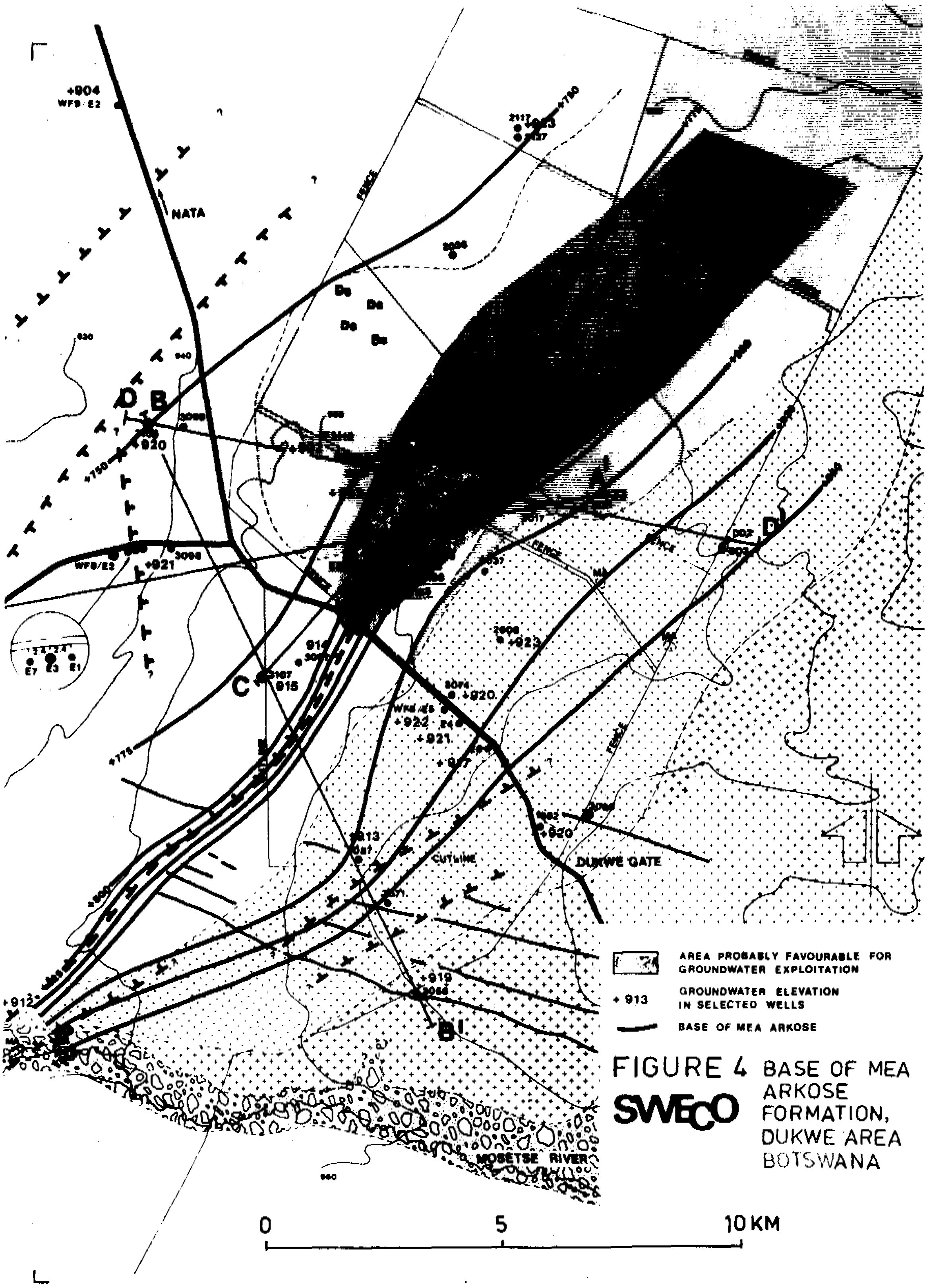

FIGURE 4 BASE OF MEA ARKOSE FORMATION, DUKWE AREA BOTSWANA

SWECO

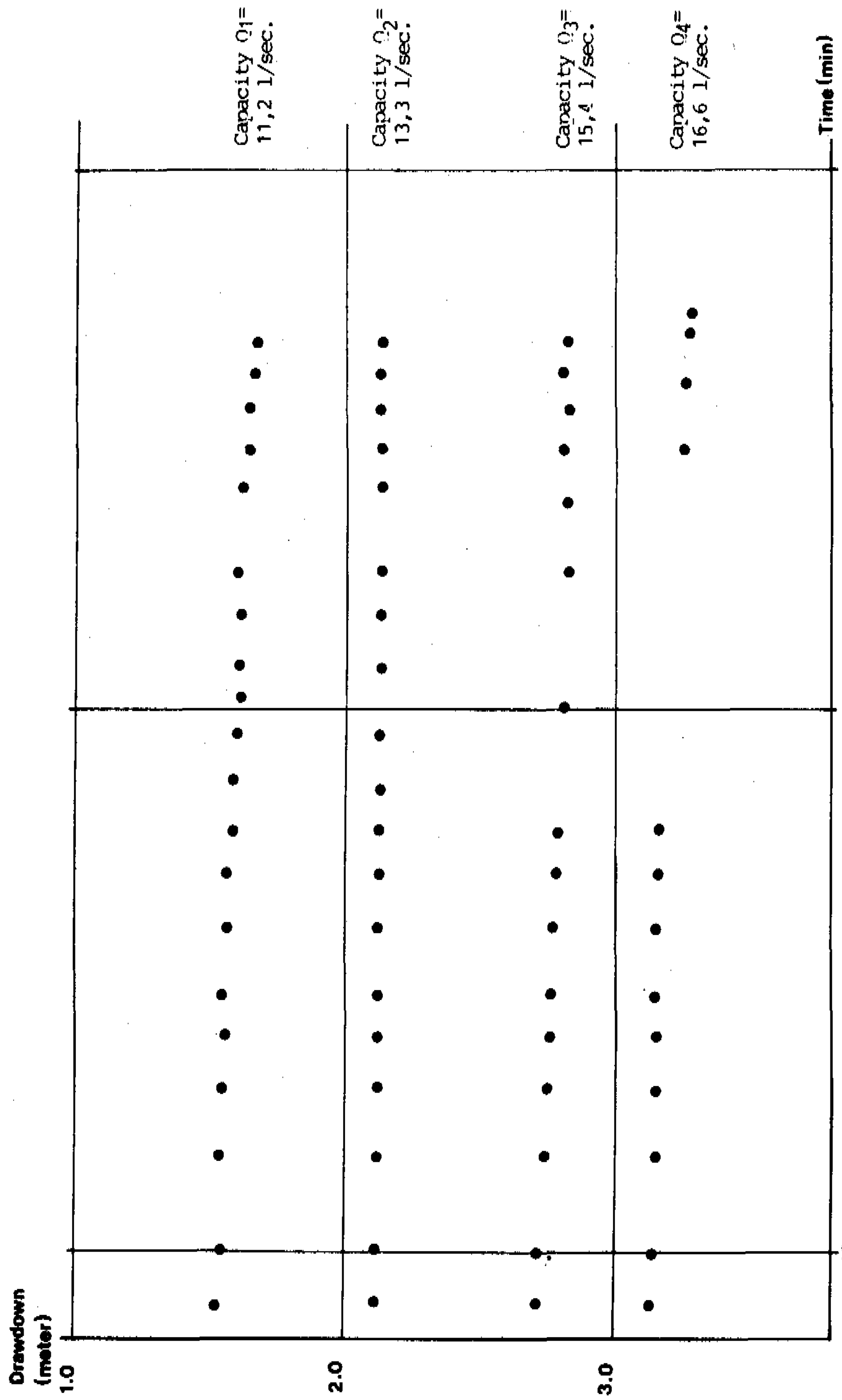

FIGURE 5
TEST PUMPING OF WELL 3173

SWECO