A GEOHYDROLOGICAL EVALUATION OF THE COASTAL AREA BETWEEN BUSHMANS RIVER MOUTH AND CAPE PADRONE, EASTERN CAPE, SOUTH AFRICA.

by
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CHAPTER 1

INTRODUCTION

The study area, situated in the South-Eastern Cape, is roughly midway between Port Elizabeth and East London (see Figure 1). The area extends from Bushman's River Mouth to Cape Padrone, a distance of some 25kms, with an inland extent of about 3kms. Included in the area are the holiday resorts of Bushmans River Mouth, Richmond (alternatively known as Boknes) and Cannon Rocks.

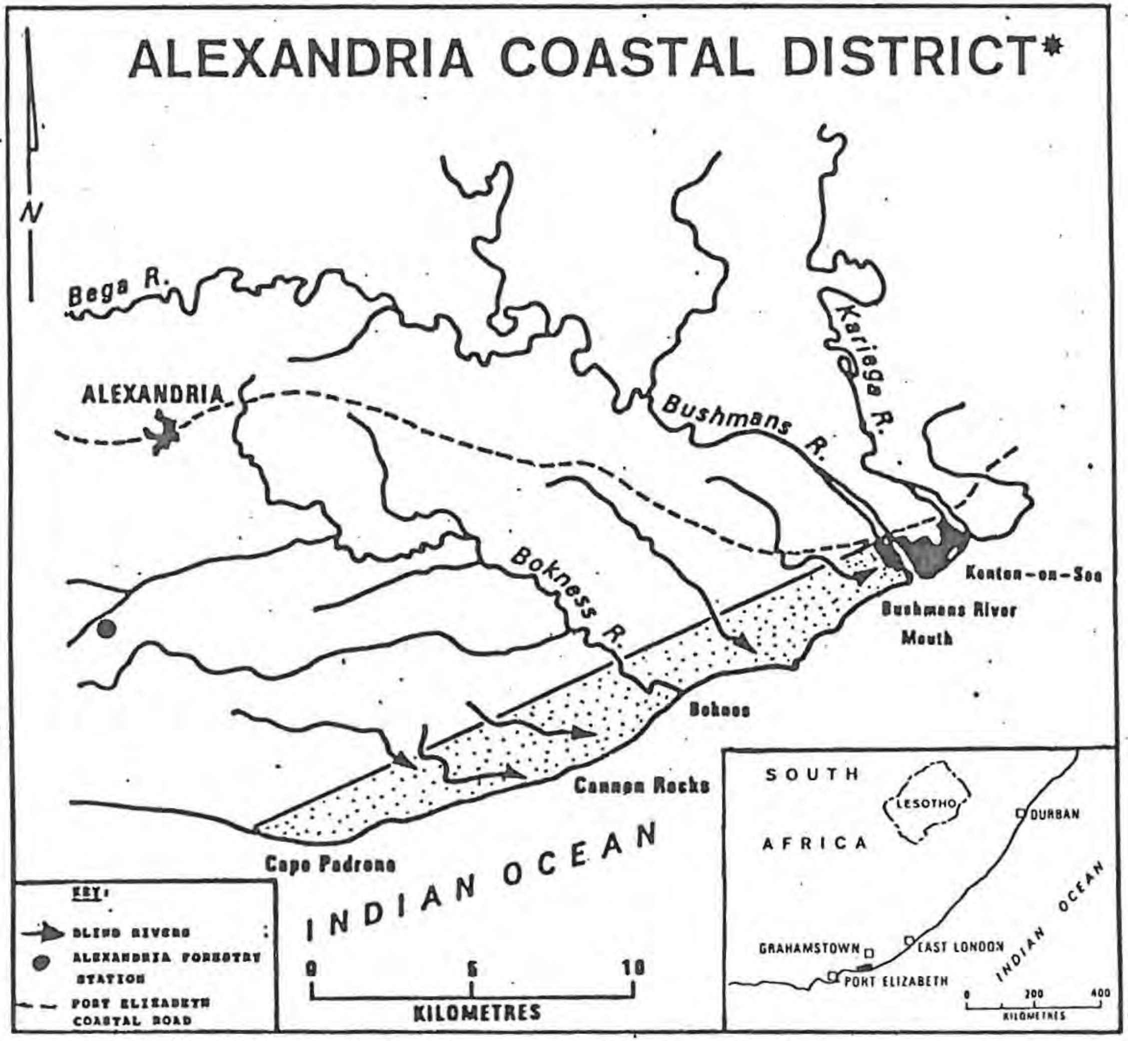
The coastal resorts of the Bushmans River - Cape Pardrone study area are faced with water shortage problems, especially during the holiday periods when domestic water demand is at a peak. The water supply problems of the study area were brought to the notice of the Department of Water Affairs in 1972 by the Town Clerk of Bushman's River Mouth. No overall assessment of the groundwater potential had been undertaken prior to this study (1981) and there existed considerable uncertainty about the area's hydrogeology. The demand for housing has continued to increase and considerable expansion is planned for the region e.g. Cannon Rocks (50 erven), Merry Hill extention of Kenton-on-Sea (220 erven) and Extention 1 of Bushmans River Mouth (432 erven). It is imperative that the geohydrology of the area is more clearly understood so that the available groundwater supplies can be evaluated with a view to extraction for possible municipal supplies.

Within the study area the provision of adequate supplies from surface water is limited because:

(1) the rivers are either tidal (Bushmans River) or high in total dissolved salts (Boknes River);
(2) dam storage is hampered by rapid infiltration rates in the unconsolidated and consolidated sands which comprise the surface cover of much of the area.
(3) dam storage above the tidal range is impractical because of the low total flow.

The only other practical supply source is that of groundwater from boreholes, wells or springs. Groundwater is used throughout the study area as a source of both domestic supply and supply for stock watering. The resorts in the area rely on groundwater for their water supply. In terms of the provision

FIGURE 1



* THE STUDY AREA IS DELINEATED BY THE STIPPLED ZONE ON THE LARGE SCALE MAP AND BY THE RECTANGLE ON THE INSET

of water for reticulation schemes, the provincial requirement in the Eastern Province is 900 l/erf/day. Much of the demand is seasonal, but the proportion of permanent residents in coastal settlements is on the increase. Present and future demands at the Bushmans River Mouth, Boknes, Cannon Rocks and Kenton-on-Sea resorts, based on a maximum usage of 900 l/erf/day over the peak tourist season, is as follows:

TABLE 1 WATER DEMANDS IN THE BUSHMANS RIVER MOUTH, KENTON, BOKNES AND CANNON ROCKS RESORTS

1. BUSHMANS RIVER MOUTH	: PRESENT	= 900 l/erf/day	x 260	erven	= 234 m^3/day
	: FUTURE	= 900 l/erf/day	x 917	erven	= 825 m^3/day
2. CANNON ROCKS	: PRESENT	= 900 l/erf/day	x 237	erven	= 213 m^3/day
	: FUTURE	= 900 l/erf/day	x 600	erven	= 549 m^3/day
3. RICHMOND (BOKNES)	: PRESENT	= 900 l/erf/day	x 172	erven	= 154 m^3/day
	: FUTURE	= 900 l/erf/day	x 592	erven	= 532 m^3/day
4. KENTON-ON-SEA	: PRESENT	= 900 l/erf/day	x 512	erven	= 460 m^3/day
	: FUTURE	= 900 l/erf/day	x 1591	erven	= 1431 m^3/day
			TOTAL PRESENT		= 1061 m^3/day
			TOTAL FUTURE		= 3337 m^3/day

In order to satisfy the increasing demand it is particularly important that a study of aquifer yield potential and reliability is undertaken as a basis for the implementation of groundwater schemes.

1.1 STUDY OBJECTIVES

The objectives of any study are the broad intentions, whereas the aims are the specific goals. The objective of the Bushmans River/Cape Padrone study is to determine the availability of groundwater supplies in the study area. The specific aims are:

(1) To identify and delineate the different aquifers present.
(2) To determine the hydraulic and hydrochemical properties of the aquifers.
(3) To develop conceptual model(s) of the aquifer(s).
(4) To assess the groundwater resource potential in terms of exploitable yield and water quality.

CHAPTER 2

THE STUDY AREA

2.1 CLIMATE

The study area has an equi-seasonal rainfall with a marginal predominance during spring and autumn. Rainfall events are mostly associated with cyclonic conditions. Rainfall resulting from convection storms contributes a minor amount (less than 10%) to the yearly total. The average annual rainfall measured at the Alexandria Forest Station for the period 1956 to 1981 was 888 mm.

The mean monthly rainfall figures are shown in Table 2.

TABLE 2 MEAN MONTHLY RAINFALL (IN MILLIMETERS) AT THE ALEXANDRIA FOREST STATION (1956-1981)

JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
62.5	56.7	91.1	71.1	94.1	76.7	65.1	85.4	75.4	83.6	67.3	59.0

2.2 PHYSIOGRAPHY

The relationship between rivers, pans and permeable sands is significant when it comes to the localization of infiltration, while the surface geology is expected to influence the chemistry of any runoff recharging the aquifer(s). The principle topographic characteristics of the study area may be considered in terms of three morphological zones occuring from the shore inland. The zones are represented in Figure 2.

DUNE BELT

The dune belt, not fixed by vegetation, can be subdivided into two separate zones:

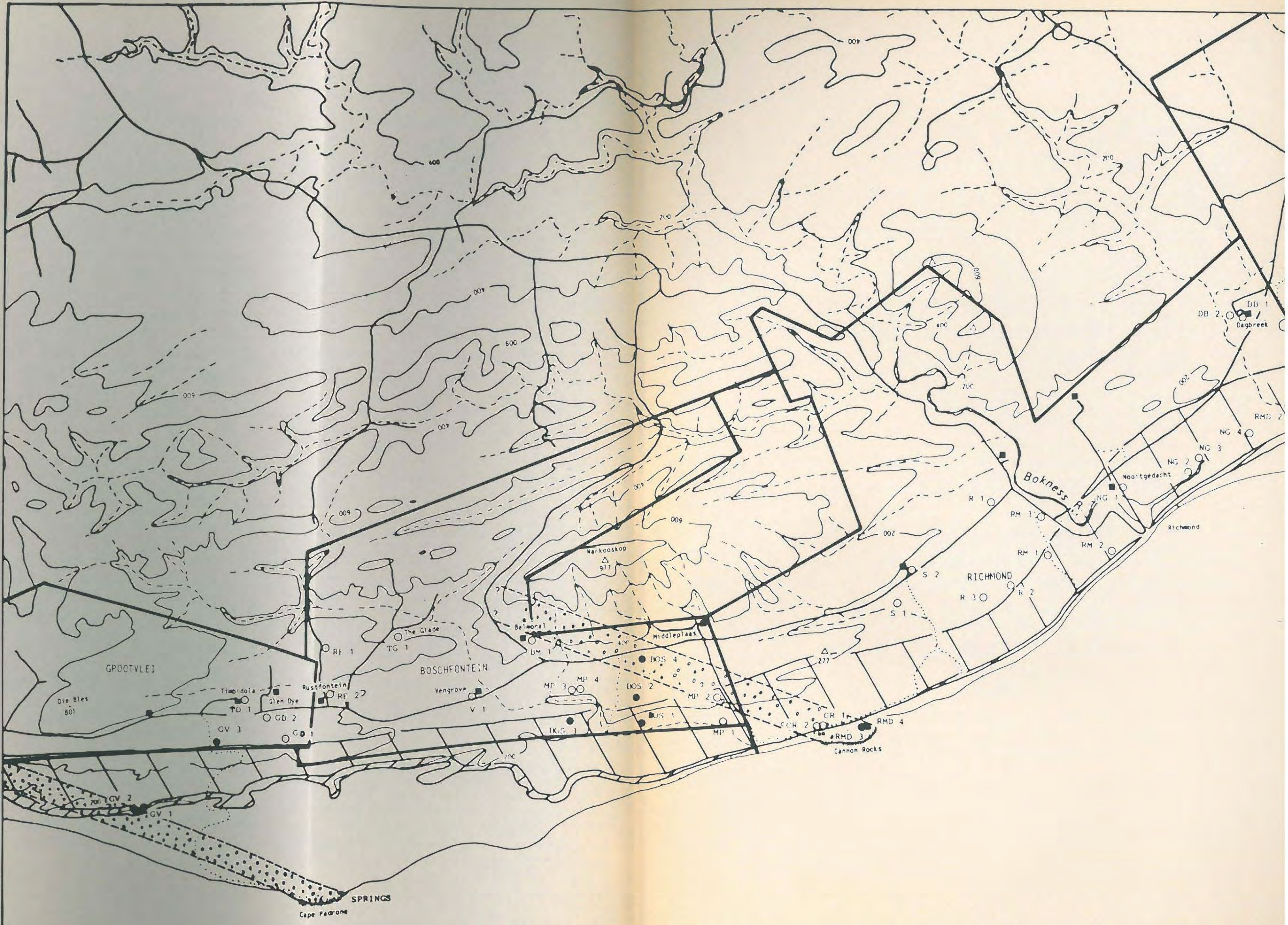
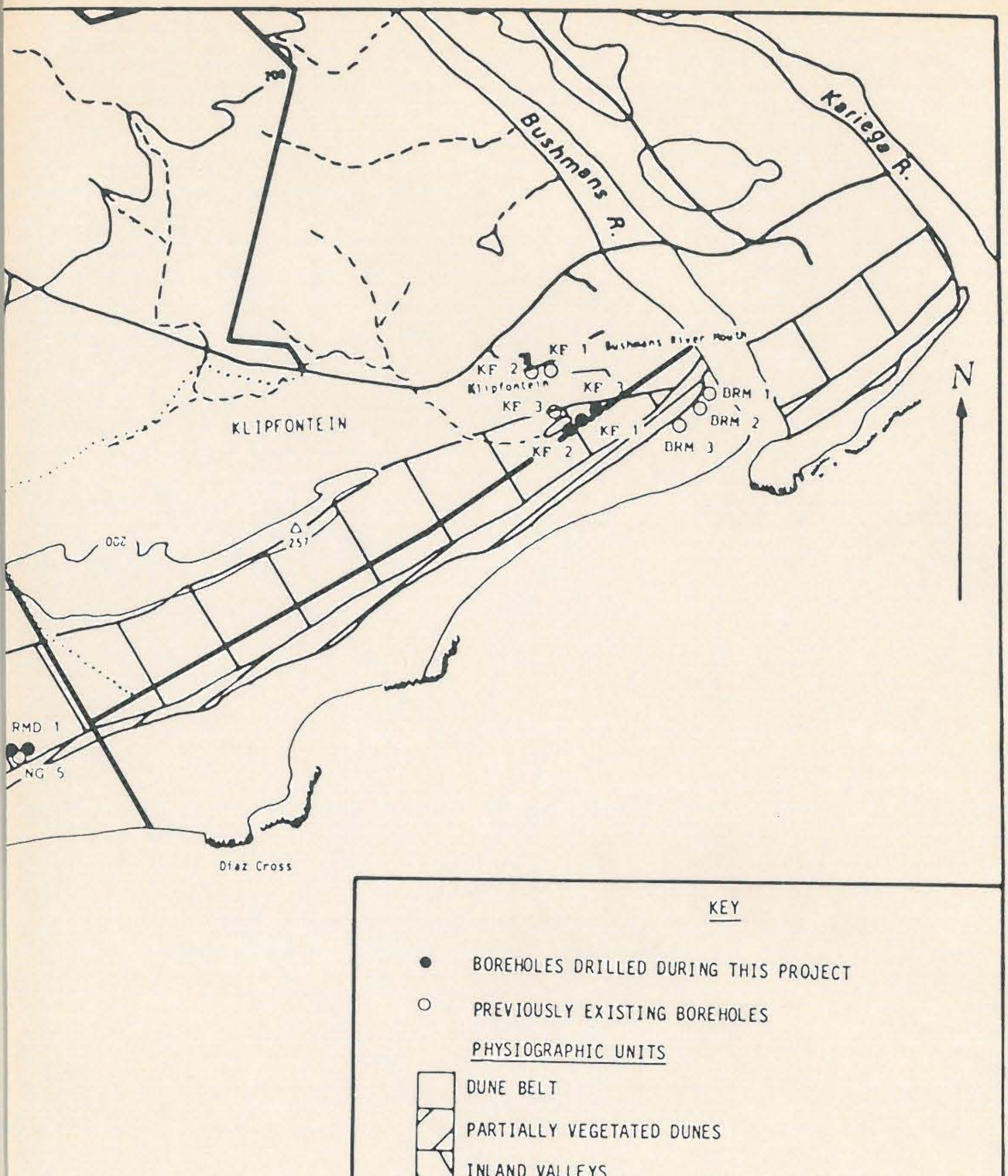


FIGURE 2 : PHYSIOGRAPHIC UNITS, BASEMENT GEOLOGY AND BOREHOLE SITES


Bushmans R.
Kariega R.
KLIPFONTEIN
Klipfontein
Bushmans River Mouth
KF 1
KF 2
KF 3
BRM 1
BRM 2
BRM 3
RMD 1
NG 5
257
200
Diaz Cross
N
KEY
BOREHOLES DRILLED DURING THIS PROJECT
PREVIOUSLY EXISTING BOREHOLES
PHYSIOGRAPHIC UNITS
DUNE BELT
PARTIALLY VEGETATED DUNES
INLAND VALLEYS
BASEMENT GEOLOGY
BOKKEVELD SHALE
BOKKEVELD SANDSTONE
FARMSTEADS
ROADS
TRACKS
NON-PERENIAL RIVERS
TRIGOMETRIC BEACONS
CADASTRAL BOUNDARIES
ROCK OUTCROPS
200 FT. CONTOUR INTERVALS
1 000
0
1 000
2 000
3 000
4 000
5 000 Meter

(1) Marine shoreline beach zone.

(2) Aeolian mobile dune zone.

The Cape Padrone and Diaz Cross areas have the widest dune belts, while the Richmond to Cannon Rocks zone is the narrowest, being only 100-200m wide (see Figure 2). The largest zone of mobile dunes is in the southern limit of the study area at Cape Padrone where the zone is a kilometer wide. Grain size analysis of the semi-consolidated sands obtained from borehole BOS 1 shows a mean grain size of 0.25mm and a sorting value of 0.073, with a skewness of 0.143. All these values are typical of a shoreline depositional environment. (Blatt, Middleton and Murray, 1972). The percentage of the deposit with a grain size of less than 0.0625 mm (i.e. silt) is 1%.

PARTIALLY VEGETATED DUNES

The inland extent of the mobile dunes is fixed by a ridge of unconsolidated sand which in some areas may be as thick as 60m. The ridge is normally vegetated on the top and northern faces but not on the southern face. The position of these ridges is fixed although the character of the southern face changes depending on the wind direction.

INLAND VALLEYS

The first valleys inland from the mobile dunes are probably former dune ridges, which are now completely vegetated. The valleys vary in width and depth, but the majority are at least 200m wide. The widest of these valleys is 2km wide, situated on the farm "Stillwater" near Cannon Rocks. The valleys trend in a NE-SW direction, parallel to the coast. The alternation of valley and ridges continues inland throughout the study area. Sands, which form the surface geology in the inland valleys, thin out with distance inland, eventually becoming replaced by Bokkeveld rocks

Cutting through the inland valleys but stopping short of the partially vegetated dune ridge are a series of "blind valleys". During periods of heavy rain these valleys become flooded just behind the dune ridge forming temporary vleis. For example, the Klipfontein stream dams up behind the Bushmans River Mouth resort. In July and August of 1979, after exceptionally high rainfall, the vlei overflowed through the streets of Bushmans River Mouth. It appears likely that the collection of runoff in the blind valleys plays an important role as a focus of recharge into the unconsolidated sands.

2.3 GENERAL GEOLOGY

An understanding of the geology of an area is essential because the lithology is probably the major influence on variations between aquifers. The main rock groups of the area are presented in Table 2 and are briefly described on a stratigraphic basis.

TABLE 3 GEOLOGICAL FORMATIONS OF THE STUDY AREA (AFTER MOUNTAIN, 1962)

LATE TERTIARY TO RECENT	Wind-blown sand, soil and weathering residues, alluvium and river-gravel, unconsolidated beach deposits, semi-consolidated sand, calcareous tufa, calcareous sandstone
ALEXANDRIA FORMATION	Massive, crystalline limestone, sandy limestone and minor pebble beds
BOKKEVELD GROUP	Sandy, micaceous and carbonaceous shales, and sandstone bands

BOKKEVELD GROUP (EARLY DEVONIAN AGE)

The Bokkeveld shales when fresh are dark grey but on weathering become yellowish or brown. There is a distinctly uniform regional strike in the study area of 10-20 degrees south of east (Mountain, 1962). The Bokkeveld erosional surface slopes seawards at an angle, according to Mountain (1962) of 1^{0}, while according to du Toit (1954) the angle is between 0.45^{0} and 0.75^{0}. (see Section 7.1.2 for results from this study).

The Bokkeveld sandstone is dark black in colour and more resistant than the Bokkeveld shale. In the area around Cape Padrone where the largest outcrop of Bokkeveld sandstone in the study area occurs, the sandstone strikes west-northwest and dips at between 9 and 15 degrees northwards.

ALEXANDRIA FORMATION (MIO-PLIOCENE AGE)

There is considerable debate about the lithology of the Alexandria formation from Bredasdorp to Zululand. Mountain (1962) defines the Alexandria formation as a massive, creamy, crystalline limestone and mentions that its greatest thickness is 6m. Mountain (1962) together with Schwartz (1908) have excluded dune rock/aeolianite from their definition of the Alexandria formation. Truswell (1977) considers the Alexandria formation to consist of a thin basal marine sequence (a shelly conglomerate) succeeded by calcareous aeolian sands of up to 200m in thickness. The inclusion of the marine sequence is also mentioned by Mountain (1962). The latest South African Committee for Stratigraphy Handbook (1980) states that the Alexandria formation comprises only sediments of marine origin, and aeolianites are therefore to be excluded from the classification.

LATE TERTIARY TO RECENT DEPOSITS

The Late Tertiary to Recent deposits grade upwards from dune rock to unconsolidated sands. The aeolianite deposits which are discontinous in occurrence overlie the "pebble bed" of the Alexandria formation. Occurring between the dune rock and the unconsolidated sand deposits are calcareous, semi-consolidated sands rich in calcareous nodules.

(1) DUNE ROCK (AEOLIANITE)

The dune rock consists of cross-bedded calcareous sandstones, rich in shell fragments and cemented by secondary calcite. Two well know coastal features which are comprised of this type of rock are Kwaaihoek (Diaz Cross) and the Kenton Rocks. The occasional occurrence of horizontally bedded deposits similar to the dune rock is thought to be a result of deposition under localized lagoonal conditions. The upward transition from the marine Alexandria formation through lagoonal deposits to dune rock could be explained by the regression of the sea level. Where the Alexandria formation does not exist the aeolianite overlies the Bokkeveld directly.

(2) SEMI-CONSOLIDATED CALCAREOUS SANDS

Above and usually grading from the dune rock are semi-consolidated sands ranging from chalky-looking sandstones to hard calcretes (Mountain, 1962). Using Netterberg's (1980) classification system for South African calcretes, the semi-consolidated sands could be classified as either;

(1) calcified dune sands with calcrete nodule inclusions, or

(2) nodular calcretes.

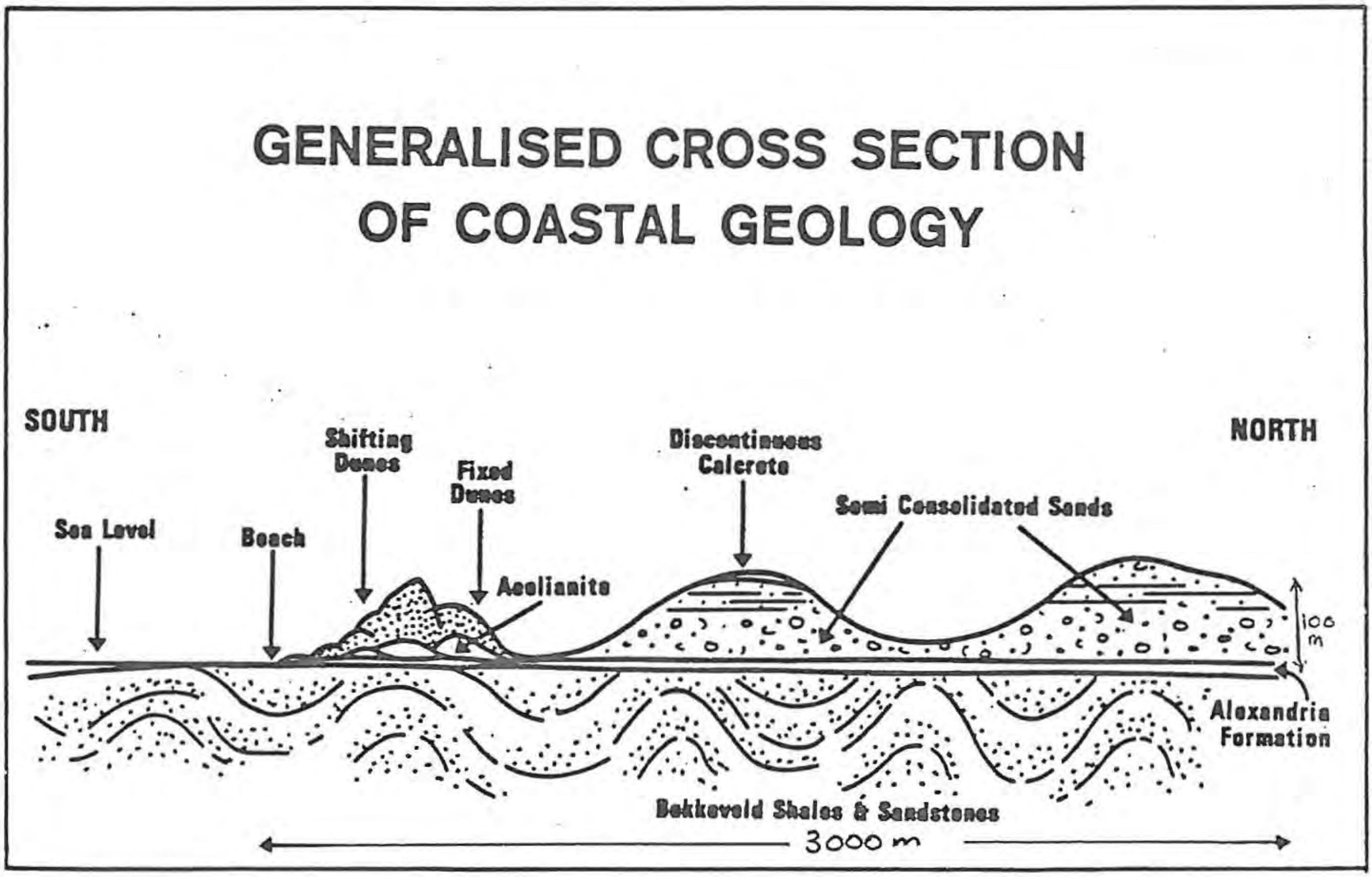
Thin section analysis of two calcrete nodules showed the chemical composition as - 60% quartz, 26% calcite, 2% plagioclase and 2% shell fragments (also calcite). The calcite occurs as grains and as the cement (which causes a low porosity and limited permeability).

(3) UNCONSOLIDATED DEPOSITS

These comprise; - wind blown sand, beach sand, river alluvium and weathering residues, the latter two being of limited hydrogeological importance. In the southwestern extent of the study area (Cape Padrone), the beach and wind blown deposits extend 2 km inland and in places comprise dunes of 100m in height.

A cross-section showing these different formations is contained in Figure 3.

FIGURE 3


GENERALISED CROSS SECTION
OF COASTAL GEOLOGY
SOUTH
NORTH
Shifting Dunes
Fixed Dunes
Discontinuous Calcrete
Semi Consolidated Sands
Sea Level
Beach
Aeolianite
100 m
Alexandria Formation
Bokkeveld Shales & Sandstones
3000 m

CHAPTER 3

GEOHYDROLOGY - BASED ON PAST RESEARCH IN THE AREA

The initial understanding of the aquifer system, prior to fieldwork, was based essentially on previous work undertaken by the Geological Survey, the Division of Geohydrology and by private companies (i.e. Bowler, van Heerden and Partners, and Ninham Shand Inc.). It was from the previous work undertaken that the study hypotheses were formulated.

The summary of the previous work undertaken is included to show the reasoning behind the hypotheses formulated. From the previous work undertaken in the area it appears that four physical attributes play a role in the area's hydrogeology.

(1) The basement rocks.
(2) The Alexandria formation.
(3) The semi-consolidated sands.
(4) The relief.

THE BASEMENT ROCKS

Hydrogeologically, the most important facets of the basement rocks are: (1) they slope seawards and (2) they are relatively impermeable. According to Rust (1980) the groundwater flow direction is critically controlled by the slope and topography of the basement rocks.

The Bokkeveld basement is comprised of both shales and sandstones, each forming a different aquifer system. Shales contain little in the form of useful groundwater supplies, most supplies being high in dissolved solids (Bond, 1946). Bokkeveld sandstones which comprise less basement area than shales, produce higher yielding boreholes with a less mineralized groundwater. Three boreholes penetrating sandstones were tested at Cannon Rocks and gave the following yields:

(1) 230m^3/day (Dippenaar and Marais, 1965)
(2) 1400m^3/day (Bowler, van Heerden and Partners, 1969)
(3) 1600m^3/day (Meyer, 1967).

The average yield for other boreholes penetrating shales in the Cannon Rocks area is under $100m^3$/day (Seward, 1979). The basement rocks outcrop at (or just below) sea level, and coupled with the basement's slope towards the coastline reduces the likelihood of any saltwater intrusion inland (Rust, 1980).

ALEXANDRIA FORMATION

The pebble bed of the Alexandria formation appears to be hydrogeologically important. Stratigraphically the pebble bed is found between the sands and Bokkeveld basement rocks. The pebble bed is laterally discontinuous in the study area. The formation is highly porous and permeable (Meyer, 1971) and is thought to be a conduit zone for groundwater seepage. At Cape Padrone groundwater is emitted as springs from the pebble bed. The collective yield of these springs was estimated at 736 m^3/day in 1962 (Marais, 1962). In 1982 the springs, which are all linked together by a french drain system, supplied the Alexandria municipality with $927m^2$/day.

Drilling results (Meyer, 1971) showed that 9% of boreholes drilled into shales had a yield of over $56m^3$/day, while 42% of boreholes where Alexandria formation overlay the shales had a yield of over $56m^3$/day. In many boreholes water levels rose slowly after water was first struck (the first strike often being at the top of the pebble bed). This could be indicative of semi-confined conditions.

SEMI-CONSOLIDATED SANDS

Rust (1980) in his report on the Bushmans River area states that the sandy sediments overlying the Bokkeveld shale is the only water-bearing zone in the area. In Rust's study he is dealing with unconsolidated sands and a poorly defined pebble bed horizon. According to the Town Clerk of Bushmans River Mouth, two wells situated in the dune sands at Bushmans River Mouth yield $300m^3$/day together, a fairly substantial supply. The high permability of the unconsolidated sands permits rapid infiltration of rainfall - favourable conditions for aquifer recharge. The supply potential of the Post Holocene deposits only appears important in areas where runoff accumulates in blind valley situations, or where unconsolidated sands are recharged by direct precipitation.

RELIEF

The relief of the study area appears to aid aquifer recharge. The immediate hinterland behind the dunes has a poorly developed surface drainage system and is characterized by valleys with "sink hole"-type hollows. After heavy rains it is not uncommon to find that these poorly drained areas become flooded, often for months afterwards (Marais, 1962). Rust (1980) mentions that the blind valley behind the Bushmans River Mouth wells, which is flooded periodically by the Klipfontein river, is important in concentrating recharge. Blind valley sand aquifers only occur where recharge occurs as a result of the accumulation of runoff into pans.

All the groundwater investigations undertaken in the area so far have been as a direct result of either specific demands from township developers or local representatives from Cannon Rocks, Boknes and Bushmans River Mouth. The work has been highly localized and areas of study have been directed by the clients themselves. No basic study of the whole area has as yet been undertaken. The result from previous investigations can be summarized as follows - groundwater does exist in boreholes yielding from less than 0.13 l/s (100 g.p.h.) to about 18 l/s (14 000 g.p.h.) and in varying qualities. The general observation is that both yields and quality are better in sandstones than in shales, while supplies in unconsolidated sands are highly variable in quality and quantity being dependent on recharge sources.

Chapters 2 and 3 have outlined the conditions and problems of the area and the objectives of the study. The following chapter (4) summarises the methodology of groundwater investigations and chapter 5 considers the theoretical basis of the techniques used in the study.

CHAPTER 4

METHODS OF INVESTIGATION

This chapter outlines procedures appropriate to a regional groundwater investigation and a description of procedures undertaken in this study.

The science of groundwater hydrology is concerned primarily with "the evaluation of the occurrence, availability and quality of groundwater". (Hazel, 1975, pp.1). This definition may serve as a very basic guide line to what a groundwater resource evaluation programme should encompass. Typical programmes include some or all of the following:

(1) Desk study
(2) Geological and hydrogeological mapping
(3) Inventory of existing water points
(4) Geophysics programme
(5) Drilling programme
(6) Aquifer testing programme
(7) Hydrochemical survey

Walton (1970) states that the cause/effect relationship in an aquifer can only be understood after completion of full analysis of the hydrogeological system. All seven categories of study as outlined above have formed part of this investigation. The following section will attempt to explain why the above seven categories of study are essential for a comprehensive groundwater evaluation of the area.

The Desk study

The desk study is often underestimated in value. The major objective of fieldwork is to collect data, and an effective programme of field operations should be formulated in the light of previous investigations. The Desk Study for this investigation involved a study of all existing literature on the area (see Table 3) and also included analyses of aerialphotos, orthophotos and geological maps.

Mapping

Gray (1975) states that geology is the most important influence on the

TABLE 3 STUDIES PREVIOUSLY UNDERTAKEN IN THE STUDY AREA

YEAR	STUDY BY WHOM	STUDY DIRECTION AND RESULTS
1962	Marais (Geol.) Survey) for Alexandria Municipality	Evaluation of Springs, concluding that the supply was sufficient for Alexandria's Municipal uses.
1965	Dippennaar and Marais (Geol. Survey) for Cannon Rocks Pleasure Resort	Pumping test at Canon Rock where the yield estimated was 227 m^3/day
1967	Bowler, Van Heerden and Partners for Kenton and Bushman's Resorts	To see if Spring's water could also supply Kenton/Bushman's. Concluded that extension would be unwise unless further springs were added to the present scheme
1967	Meyer (Water Affairs) for Cannon Rocks Pleasure Resort	Pumping test at Cannon Rocks yielding 63.6 m^3/day
1969	Bowler, Van Heerden and Partners for Cannon Rock Pleasure Resort	Pumping test at Cannon Rocks for two boreholes 30 m apart yielding 1396.8 m^3/day singly or for both holes combined
1971 and 1974	Bowler, Van Heerden and Partners for Richmond Strand	Pumping tests on boreholes at Richmond to assess a possible supply for development schemes at Bushman's River Mouth. High piping costs resulted in the abandoning of this scheme
1979	Seward (Water Affairs)	Geohydrological Survey of Bushman's River Mouth area with the conclusion that the implementation of dune wells in other areas could work
1980	Rust (as a Consultant of Ninham Shand) for Albany Water Board	Investigation of ground water potential of the Bushman's River Mouth area. Rust suggested that a well field be developed with interconnecting french-drains.

occurrence, magnitude and quality of subsurface waters. There is great value therefore in producing a lithological map of the formations existing in the study area. The distribution of permeable, semi-permeable and impermeable rock, although often more difficult to map than stratigraphy, is the prime factor influencing hydrogeological variations between different formations (Gray, 1975). Field mapping was undertaken to differentiate between Tertiary deposits and Bokkeveld Group rocks, and also between Bokkeveld sandstones and Bokkeveld shales.

The field inventory of existing water points

The high costs of drilling make it essential to make the greatest possible use of existing boreholes. The inventory helps to formulate ideas on the depth at which water is struck, the geological formations in which water exists and the yields obtained from the different formations (i.e. the water bearing properties of the different formations). The field inventory (or borehole report) is contained in the Appendix and contains data for all springs and boreholes in the study area.

Geophysics Survey

The survey is used to obtain information on:

(1) The horizontal and vertical distribution of rock units (i.e. layering).
(2) Variations within a formation (i.e. weathering and fracturing)(Shiftan, 1970).

The results from the geophysics can be used to help in the location of drilling sites. Shiftan (1970) points out that although geophysics is usually an integral part of regional groundwater surveys, the geophysics must be carried out in close co-ordination with drilling procedures. This is because the analysis of geophysics data usually requires borehole information from which the geophysics results could be calibrated for further interpretation.

The relationship between the amount of geophysics and amount of drilling is usually cost controlled. Geophysics is usually cheaper and less time consuming than drilling.

The geophysics data obtained from the survey was used to obtain information on:

(1) The horizontal and vertical distribution of rock units, especially the depth to the Bokkeveld basement.
(2) Variation within a formation (i.e. weathering and fracturing).
(3) The slope of the Bokkeveld basement.

The results from the geophysics were also used to help in the location of drilling sites. During the project 44 vertical electrical soundings (V.E.S.) were undertaken using the C.S.I.R. resistivity apparatus.

The Drilling Programme

The drilling both complements and supplements the geophysics, drilling being the only method that provides a means of access to the aquifer. Exploratory drilling may be undertaken for two reasons (Johnson Divsion, 1972); - (1) as part of an overall groundwater survey, (2) to produce production boreholes. In this study the former is the case. The holes are drilled to verify or supplement information collected in the other phases of the evaluation programme. The 14 exploration holes drilled were part of an overall data collection project and were not intended to be used as production boreholes. Drilling was undertaken by the Drilling Services subdivision of the Department of Water Affairs and involved the use of cable-tool percussion (jumper) drilling rigs.

Aquifer tests

Once an aquifer is defined it is necessary to determine the reaction of the aquifer to extraction. During an aquifer test data on water level drop for specific extraction rates in an aquifer is collected. From this data the hydraulic properties (i.e. storage capacity and ability to transmit water) for the aquifer can be calculated. According to the Johnson Division (1972) an aquifer test is the only reliable means of calculating the hydraulic characteristics of aquifers. Differentiation may be made between two types of tests, each with a different objective.

(1) Pumping test, which determines the performance and efficiency of the borehole (yield, drawdown and specific capacity).
(2) Aquifer test, which provides data from which aquifer performance is calculated (transmissivity and storage). The aquifer test has become one of the most important tools in practical groundwater investigations (Jones and Rushton, 1981). The aquifer tests (step drawdown and constant yield

varieties) were undertaken so that the hydraulic properties (transmissivity and storage of the aquifers) could be calculated. During this project ten tests were undertaken:

6 - stepdrawdown tests (4 x 100 minute steps)
4 - constant yield tests (1 x 48 hours and 3 x 24 hours).

HYDROCHEMICAL SURVEY

The hydrochemical survey may have two objectives;

(1) To collect hydrochemical data which will aid in the understanding of the geochemical and hydrological relationships in the aquifer.
(2) To determine the suitability of groundwater supply for domestic, industrial or agricultural uses.

Water samples were collected during both drilling operations and aquifer testing operations. Twenty-six samples were analysed by the Hydrological Research Institute at Roodeplaat Dam, Pretoria. The samples collected were from thirteen of the fourteen boreholes drilled and included samples from aquifer tests of BOS 4, GV 1, RMD 1, RMD 3 and RMD 4. Laboratory analyses of the samples included the determination of pH, conductivity (mS/m), and the concentration (in mg/l) of the following: Total alkalinity (TAL), NH_4, Ca, Cl, NO_3, Na, Mg, F, Si, K, SO_4 and P.

CHAPTER 5

THEORY OF GROUNDWATER EVALUATION

The five sections contained in this chapter discuss the theory of the groundwater procedures used in this investigation. According to Chow (1952) groundwater exploration involves:

(1) The location and delineation of aquifers,
(2) The determination of the quality and quantity of water that can be yielded by the boreholes that penetrate them.

The following sections attempts to explain the principal methods involved with the location, delineation and evaluation of the aquifers. In this project these methods are:

(1) Geophysical surveys, using electrical resistivity apparatus.
(2) Drilling - a limited programme to obtain lithological and hydraulic information from a variety of hydrogeological situations in the study area.
(3) Aquifer tests to obtain aquifer characteristics.
(4) Hydrochemical analysis to evaluate water quality variations.

5.1 PRINCIPLES OF GEOPHYSICS

Geophysics techniques, according to Dobrin (1960), involve the collection of data from the earth's surface which will help decipher the physical properties of the material within the earth's crust. Of all geophysical prospecting methods (viz. gravimetric, seismic, magnetic and electrical resistivity methods) electrical resistivity methods are the most frequently used for groundwater prospecting (Linsley, Kohler and Paulhus, 1975; Kosinski and Kelly, 1981). The resistivity methods help to obtain a more detailed knowledge of subsurface conditions, such as:

(1) Type and depth of different rock layers.
(2) Depth of bedrock.
(3) Groundwater quality variations - only discernable where geological formation characteristics are constant over the entire survey area.

(4) Depth to groundwater - usually only discernable in a homogeneous formation, and even then the water level is shown by a transitional zone of gradual resistivity decrease.

It is essen .ally the data from the above four situations that is required in the delineation of the aquifers' geometry.

The basic principles of the electrical resistivity method (Keller and Frischknecht, 1966; Van Zijl, 1977) are outlined below. Resistivities (ρ) of a specific rock formations can be determined by passing a known current (I) into the formation using two current electrodes (A and B) and measuring the potential difference (ΔV) between two potential electrodes (M and N). The basic resistivity system can be seen in Figure 4.

Based on Ohm's Law, viz, "The electrical resistance, R, of a length of wire is ... $R = {}^{\Delta V}/I$ where ΔV is the potential difference between the ends of the wire and I is the intensity of the current which flows in the wire in the direction of decreasing potential" (Van Zijl, 1977 p.3). The apparent resistivity (ρa) of the volume of earth between the electrodes can be determined from:

$\rho a = K^{\Delta V}/I$

where K is a coefficient, called the geometric factor, calculated from any specific array of four electrodes from:

$$K = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BN} - \frac{1}{BN}\right)}$$

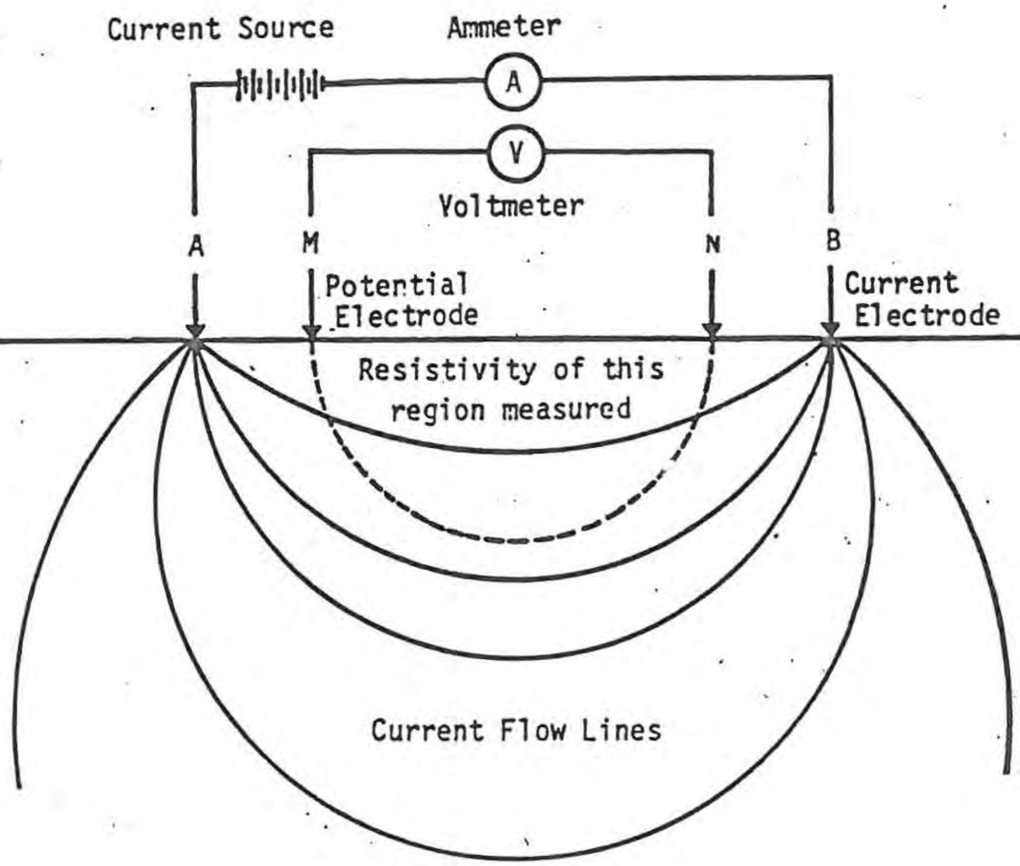
The value ρa, the apparent resistivity, is a measure of the resistivity (not the true or the average resistivity) of a specific volume of earth dictated by;

(1) The electrode spacing,
(2) Local geological conditions.

The apparent resistivity measured, is only equal to the true resistivity, if the volume of earth being measured, is homogeneous. Apparent resistivity is only used for comparative purposes since values are not absolute.
During this project the vertical electrical sounding (V.E.S.) technique has been used. The electrode spacing about a fixed point (0) is increased, thus giving a variation of ρa values related to the increasing electrode separation

Figure 4

A Generalized Resistivity System.



and hence depth below the surface. The data are plotted as a curve depicting variations of ρa with current electrode spacing. V.E.S. soundings can be undertaken using a variety of electrode configurations, the most popular being

(1) The Schlumberger configuration (Schlumberger, 1939) and
(2) The Wenner configuration (Wenner, 1916).

These two are shown in Figure 5. In both these configurations ρa is calculated from the previously defined equation:

$\rho a = K^{\Delta V}/I$.

In the Schlumberger configuration the coefficient K reduces to $K = \pi (^{AM.AN}/MN)$, while in the Wenner configuration K reduces to $K = 2\pi a$ (where 'a' is the electrode spacing in meters). The major difference between these two arrays is in the method of increasing the separation of the electrodes. In the Wenner array all the four electrodes are moved simultaneously keeping the spacing between the electrodes equal, while for the Schlumberger array the ratio AB:MN is $AB < 5MN$. During this project the Schlumberger array was used because the curves on the graphs produced using the Schlumberger method are far less distorted than those from Wenner arrays (Van Zijl, 1977), giving greater accuracy in interpretation. The lesser distortion using a Schlumberger array is related to the fact that the MN electrodes are moved a lesser distance outward from the centre point than for a corresponding AB distance using the Wenner array. Distortion problems caused by moving the M and N electrodes (known as MN effects) are therefore less in Schlumberger arrays than Wenner arrays.

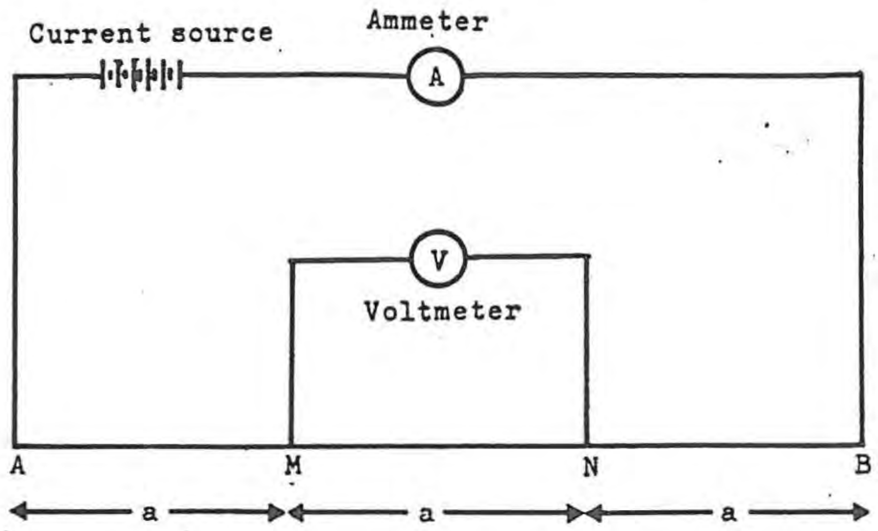
The curves obtained from the resistivity soundings can be interpreted to give a vertical sequence of electrical resistivity beneath a fixed point. The actual interpretation is performed in three steps;

(1) Interpretation of the field V.E.S. curves using master curves (i.e. Orellana and Mooney, 1966 : Joubert, 1977).
(2) Correlating the interpreted results with actual geological conditions.
(3) Re-interpretation of the field curve, if calibration with geological data shows this to be necessary.

Graphical interpretation relies on the application and matching of theoretically computed master curves to the field curves (During this project the curves drawn up by Joubert in 1977 were used). Since curve matching involves personal choice, it is possible to obtain a series of similar results

Figure 5

The Two Resistivity Arrays(after Scintrex,1976)

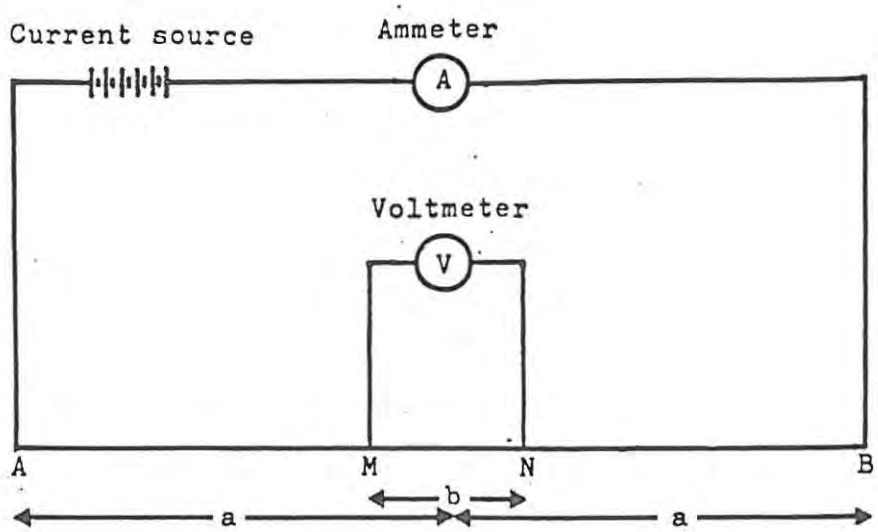


WENNER ARRAY (above)

a=a=a

SCHLUMBERGER ARRAY (below)

b<0.2a

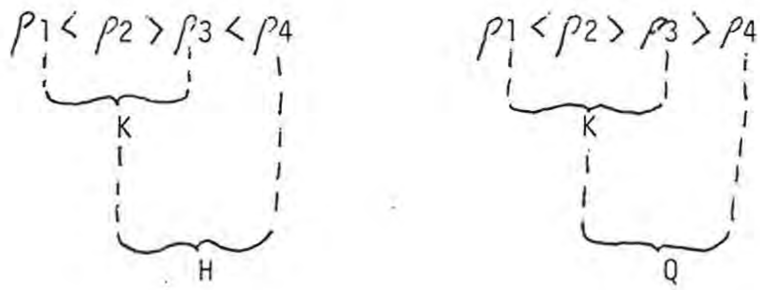


from the same curve. The type of curves that can be found are (Van Zijl, 1977):

(1) Two layer curves with $-\rho 1 < \rho 2$ (ascending type)
$-\rho 1 > \rho 2$ (des .nding type)

(2) Three layer curves with $-\rho 1 > \rho 2 < \rho 3$ (H type curve)
$-\rho 1 < \rho 2 > \rho 3$ (K type curve)
$-\rho 1 > \rho 2 > \rho 3$ (Q type curve)
$-\rho 1 < \rho 2 < \rho 3$ (A type curve)

(3) Curves of four or more layers - these are expressed in terms of three layer types e.g. KH, KQ etc:



These different curves are shown in Figure 6.

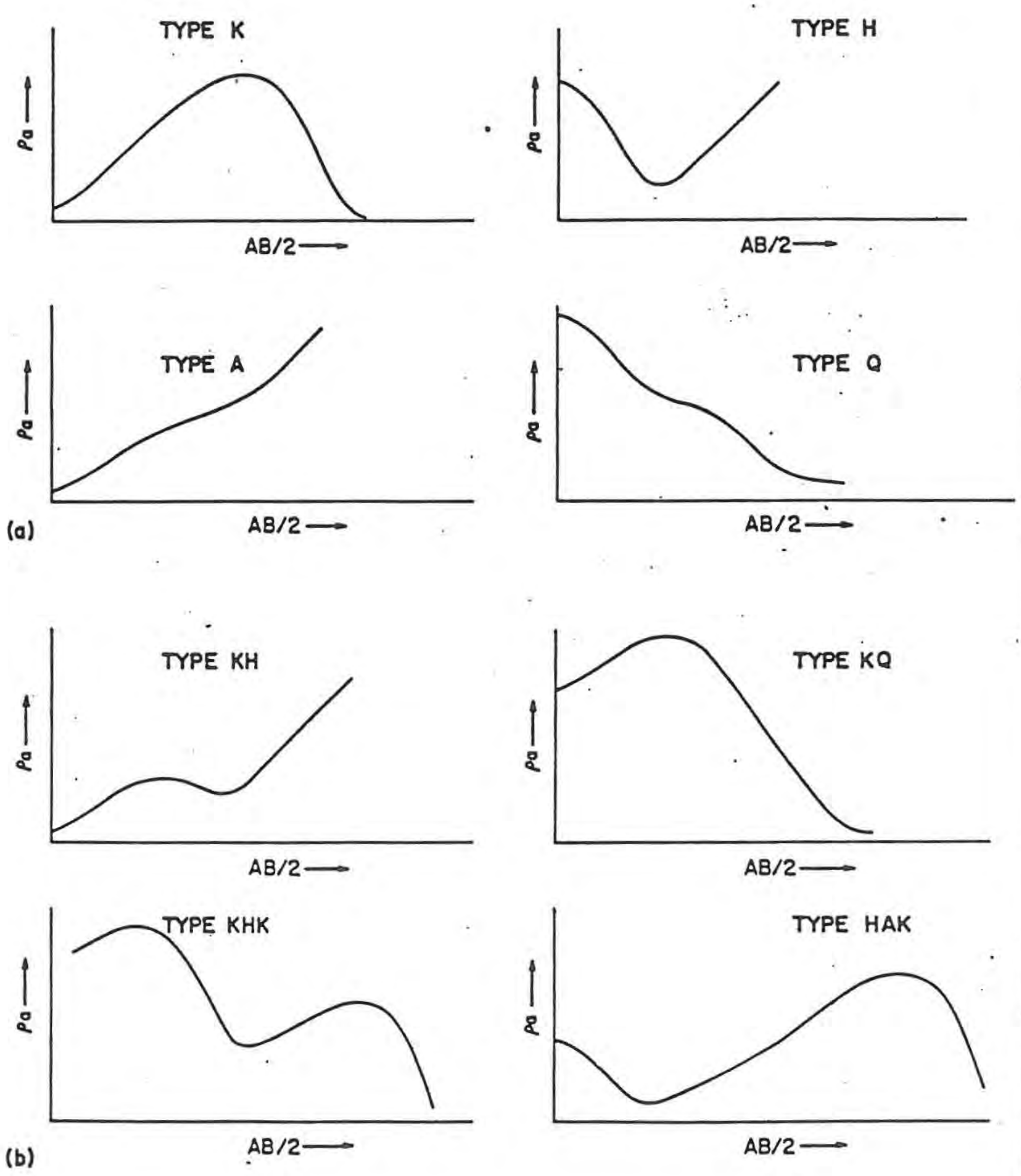
The curve matching process makes use of two values, known as the Dar Zarrouck parameters, in calculating the apparent resistivity and depth of each geoelectrical formation existing. The Dar Zarrouck parameters are (Smith, 1982):

(1) S - The longitudinal conductance
(2) T - The transverse resistance

In H, A, KH, HA and all other similar rising curves, the rise in the end section of the curve results from a resistive basal layer. To calculate the total S, a two layer master curve is matched to the final rising limb of the field curve. The left cross of the two layer master curve (co-ordinates $\rho a = 1$, $^{AB}/2 = 1$) is marked onto the field curve and the co-ordinantes of this cross on the field curve are ascribed to S. The total S value calculated is for the total volume of rock above the substratum corresponding to the final rising limb. Thus

FIGURE 6

CLASSIFICATION OF SOUNDING CURVES



(a) Three-layer cases (b) n-layer cases, n>3

$S_T = S_1 + S_2 + S_3$ ... where S_1, S_2, etc are the S value for each geoelectric formation. S can also be calculated from
$S = {}^{h}/_{\rho}$, where h and ρ are the thickness and resistivity respectively for a particular formation. S_T can therefore be calculated from
$S_T = h1/_1 + h2/ + h3/_3$, where the h's and ρ's are the respective thicknesses and resistivities for different formations.
The calculation of S_n for any rising portion of the curve can be calculated in the same way as for S_T.
Three or more layer curves containing a K or Q type section will have a maximum point of inflection in the curve. The value T, the transverse resistance of the resistive layer which causes the maximum value, can be calculated by matching a three layer K or Q type master curve to the field curve. The transverse resistance is given by van Zijl (1977) as:

$$T_n = h_{n-1} \times \rho_{n-1} \times \rho n/\rho_{n-1} \times hn/_{hn-1}$$

$$(\text{i.e. } T_2 = h_1 \times \rho_1 \times \rho_2/\rho_1 \times h_2/h_1)$$

where hn = Ordinate of the left cross of the master curve transferred to the field curve

ρn = Absissa of the left cross of the master curve transferred to the field curve

$\rho n/\rho_{n-1}$ = Resistivity ratio of the master curve used in the matching process.

$hn/_{hn-1}$ = Thickness ratio of the master curve used in the matching process.

Given calculated values of T and S for a multi-layer system, combined with estimated resistivity values obtained from curve matching, it may become possible to calculate resistivities and depths for all geo-electric layers present.

Curve matching is necessary because it has been found that empirical methods of curve interpretation do not give sufficiently accurate results (Van Zijl, 1977). This is mainly because depths from experimental drilling have proved that the depths estimated from the $^{AB}/2$ ratio are inaccurate; basically because the depth of penetration varies greatly with difference in geo-electric conditions. Usually curve matching is undertaken in the field and then the results checked by computer at a later date. Computer programmes exist which calculate theoretical curves from the field interpretation, thus checking the field interpretation. It must however be realized that although the computer interpretation may fit the field data, the results still only represent one of many solutions. It will also be up to the geologist or geophysicist concerned to decide whether or not the computer results indicate whether modifications are required. Any modification will be based on;

(1) Geological knowledge of the study area,
(2) Results from other sounding curves. In all cases a single sounding curve is of little value if it is not compared with other nearby soundings. The other soundings show similarities or progressive changes which help with the interpretation.

Once the geo-electric profile has been established the geological profile must be interpreted from the geo-electric conditions. To do this there must be comparisons made between geological logs and the corresponding geo-electric log from the sounding. In most cases, drilling is the only method of obtaining an accurate geological log.

5.2 PRINCIPLES OF DRILLING

Reasons for drilling into aquifers involve more than exploitation of groundwater resources. Drilling may be undertaken for the following reasons (Johnson Division, 1972):

(1) To produce a production borehole.
(2) To collect data from which the aquifer potential could be evaluated (not necessary involving any interest in developing the well for production purposes).

During this study drilling was for the purpose of data collection.

The exploration boreholes are required to complement and to verify the data collected during other phases of the evaluation programme. Drilling plays an important complementary role with resistivity surveys. Shiftan (1970) in his paper on the "Integration of geophysics and hydrogeology in the solution of regional groundwater problems" suggested that although geophysics surveys are often integral parts of groundwater surveys, the geophysics should be carried out in close co-ordination with drilling. Resistivity surveys require lithostratigraphic borehole logs from which the interpreted resistivity data can be calibrated. The relative time spent on drilling and geophysics in a particular study depends on;

(1) The depth to the aquifer.

In areas where the drilling becomes difficult drilling becomes a particularly expensive method of data collection and geophysics methods play a more dominant role. The actual depth at which drilling becomes difficult is dependant on the lithology of a specific formation. For example, it may be more expensive and complicated drilling shallow holes in unconsolidated sands than deeper holes in a soft, consolidated formation.

(2) The purpose for which the data are required.

As previously mentioned there is both the scientific/academic aspect and the commercial production aspect of drilling. More geophysics work is undertaken in scientific projects. The exact objectives of a particular study will dictate the methods of data collection.

During drilling the following should be obtained (U.S. Dept of the Interior, 1977);

(1) Measurements of water levels, when first encountered and variations throughout drilling thereafter.
(2) Geological samples.
(3) Water samples.

From these three the following information can be obtained;

(1) Lithostratigraphic profile of the borehole.
(2) Evidence of water-bearing formations and their thicknesses and depths.
(3) Water chemistry data for different formations.

Comparison of the above three for various boreholes in any study can help in discerning regional patterns in the geohydrology.

The drilling techniques used in a groundwater study places constraints on the type of data collected. Of the three drilling methods used in groundwater exploration (cable-tool, air driven and rotary) the cable-tool method is best suited for medium depth holes (less than 100m) in unconsolidated sediments

(Johnson Division, 1972), and for this reason was used in the Bushman's River Mouth/Cannon Rocks project. Samples collected using the cable-tool method are disturbed, but a relatively undisturbed sample can be obtained by using a drive-core barrel.

The method of drilling, design and development of a borehole can have a profound effect on the borehole yield (Hancock, -). Well design, using the correct gravel packs and screens, is however costly and often no design occurs unless the borehole is to be used for production purposes. In many exploration drilling projects no gravelpacks or screens are used, only perforated casing is used, thus the borehole is incorrectly developed and would probably yield below the maximum potential.

5.3 AQUIFER CLASSIFICATION

An aquifer can be defined as a "groundwater - bearing formation sufficiently permeable to transmit and yield water in usable quantities." (Bower, 1978 pp.3) Aquifer types, as defined by Kruseman and De Ridder (1970, pp. 18 and 19), are;

(1) Confined Aquifer - "A completely saturated aquifer whose upper and lower boundaries are impervious layers."
(2) Leaky Aquifer - "A completely saturated aquifer that is bounded above by a semi-pervious layer and below by a layer that is either impervious or semi-pervious."
(3) Unconfined Aquifer - "A permeable bed only partially filled with water and overlying a relatively impervious layer."

In the study area both unconfined, leaky and possibly even confined aquifers exist. The unconfined aquifers exist

(1) where unconsolidated sands overlie an impervious basement (the aquifer being the saturated sands) and
(2) in the partially saturated weathered Bokkeveld sandstones. The leaky aquifer occurs where semi-consolidated sands overlie an aquifer comprised of weathered Bokkeveld and Alexandria pebble beds. Confined aquifers occur where impervious calcretes overlie the weathered Bokkeveld and Alexandria pebble beds.

5.4 PRINCIPLES OF AQUIFER TESTS AND PUMPING TEST ANALYSES

Once the drilling of a borehole has been completed further information on the aquifer can be obtained by undertaking a pumping test on the borehole. Essentially a pumping test, more correctly known as an aquifer test, involves the controlled extraction of groundwater from the borehole coupled with the measurement of the variation in water level or piezometric surface with relation to time in the pumped borehole or in observation boreholes. Once pumping has started a "cone of depression" develops, causing lowering of the water table (in unconfined conditions) or the piezometric surface (in confined conditions) around the borehole. The cone develops as a result of the hydraulic gradient caused by the groundwater extraction. The development of the cone shape is related to the hydraulic properties of the aquifer and the rate of extraction. Knowledge of the behaviour of the cone of depression, gained from aquifer tests, can help in calculating the aquifer's hydraulic parameters. Controlled extraction of water from a borehole can give both:

(1) An aquifer test, from which the aquifer's hydraulic characteristics are calculated.
(2) A pumping test, which tests the performance of the borehole. (results being expressed in terms of yield and drawdown.)

Figure 6 shows some of the indices measured during aquifer tests. These indices help in the calculation of the hydraulic properties of the aquifer.

The important hydraulic properties of an aquifer are:

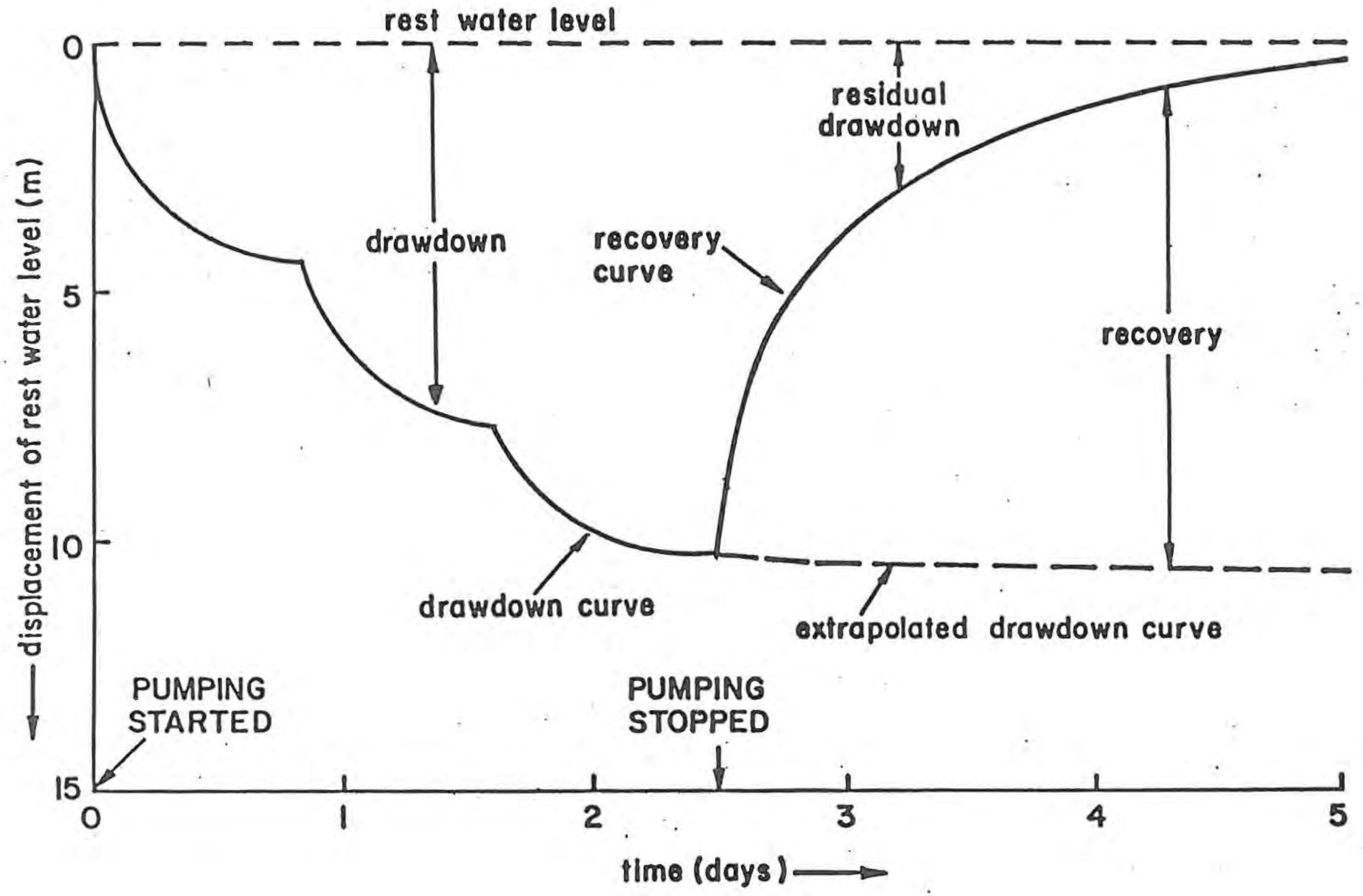
(1) Hydraulic conductivity (K) and transmissivity (T), which define the ability of an aquifer to permit groundwater flow.
(2) The storage coefficient (S), which defines the storage ability of the aquifer.

The relationship between T, S and the cone of depression is as follows : with all other parameters remaining constant (i.e. extraction rate) the cone of depression is steeper for low values of transmissivity and for low storage coefficients. The values of T and S are dependant on the permeability and the amount of pore space in a rock.

The analysis and calculation of T and S from aquifer tests is based on the following assumptions (Bower, 1978);

FIGURE 7

RELATIONSHIPS BETWEEN DRAWDOWN, RESIDUAL DRAWDOWN AND RECOVERY



(1) The aquifer is homogeneous, isotropic and of an infinite horizontal extent.
(2) The water removed from storage is discharged instantaneously with decline in water level (some analyses do however take into account delayed yield).
(3) Groundwater flow is horizontal in accordance with the Dupuit-Forcheimer assumptions.
(4) The only flow in the aquifer is that caused by pumping.
(5) Pumping is at a constant rate.
(6) The volume of water extracted from the actual borehole is negligible compared to the volume extracted from the aquifer.
(7) The borehole totally penetrates the aquifer.

Tests may be categorized in two ways;

(1) Steady state tests, where pumping is continued until equilibrium is reached between extraction rate and water level.
(2) Non-steady state (or transient) tests, where equilibrium is not reached, but drawdown is measured in relation to time.

During the Bushman's Rivèr Mouth/Cape Padrone study only transient state test were undertaken. The reason being that the attainment of steady state conditions can often be a very lengthy process. During any aquifer testing programme the specific tests undertaken depend on what data is to be collected and on what type of aquifer exists. The principles of aquifer tests are essentially based on the work of Thiem (1870) and Theis (1935). Kruseman and de Ridder (1970) and Walton (1970), inter alia, give full descriptions of the principles of aquifer testing and descriptions of the variety of tests available.

Two methods of aquifer testing were used in the Bushman's River Mouth/Cape Padrone study.

(1) The step drawdown method of multi-rate tests.
(2) Constant discharge rate tests.

STEP DRAWDOWN TESTS

During a step drawdown test the drawdown in a pumped borehole is monitored with time, while the discharge rate is increased in steps. The basis of step drawdown tests is that the increase in discharge at the start of each test may be considered equivalent to a new pump added to the system. This basic assumption makes the analysis of each step possible. The analysis method of step drawdown tests was devised originally by Jacob (1946) to determine borehole losses and to calculate the effective radius for a pumped borehole. In any pumped borehole the drawdown is made up of a borehole loss component and an aquifer loss component. Jacob (1946) suggested the following:

Drawdown (Sw) = Aquifer loss (BQ) + Borehole loss (CQ^2)

The borehole loss is approximately proportional to the square of the discharge rate.

During the Bushman's River Mouth/Cape Padrone project the step drawdown test was used to evaluate B and C in Jacob's equation, and from these to calculate the borehole efficiency, defined as the ratio of the aquifer loss to the total drawdown (Clark, 1977).

$$\text{Borehole efficency} = \frac{BQ}{BQ + CQ^2} \times 100 \text{ (in percent)}$$

During this project analysis was undertaken using a computer program devised by Seward (1982) and based on the Bierschenk and Wilson (1961) method of analysis.

Borehole loss calculations obtained from step drawdown tests may be used in the analysis of testing procedures. Once the borehole loss component of drawdown is known the true drawdown can be calculated, thus allowing more accurate analysis of constant discharge tests. Values of transmissivity which do not take into account borehole losses are usually underestimates.

CONSTANT DISCHARGE RATE TESTS

During constant discharge rate tests the pumping continues at a constant rate with drawdown being measured throughout the test. Drawdown is measured in nearby observation boreholes (if they exist) or in the pumped hole. The duration of tests vary, but most tests are usually in excess of 24 hours, so that the results obtained are representative of the aquifer. Drawdown during constant discharge tests is usually measured in observation holes. Observation boreholes are however not always available, because of the extra costs involved, and this can reduce the scope of interpretation.

The aquifers encountered in this project were found from the drilling to be of all three varieties - confined, semi-confined and unconfined. The relevant methods of analysis that could be used were therefore:

(1) Confined Aquifers - Theis (1935) Solution, Chow (1952) Solution and Cooper - Jacob (1946) Solution.
(2) Semi-confined aquifers - Walton (1962) method, Hantush (1956) method.
(3) Unconfined Aquifers - Boulton (1963) Solution and variations of the three solutions used for confined aquifers.

RECOVERY TESTS

Recovery tests are normal extentions to the constant discharge rate tests. Recovery tests can often be the most reliable since there are less human influences, viz., no fluctuations in pumping rate. Worthington (1978) states that under conditions with no observation boreholes the recovery method is more reliable than where drawdown is measured in the pumped hole. Immediately on completion of pumping the water level will rise. This recovery of the water level is monitored with time since the end of pumping. Theis (1935) has presented analyses of recovery tests.

5.5 PRINCIPLES OF CHEMICAL ANALYSIS

The quality of water is just as important as the quantity available in terms of water resource evaluation. It is the chemical, physical and bacterialogical character of the water that determines its usefulness for domestic, industrial or agricultural supplies. Chemical analysis of the groundwater can therefore comprise an important part of a water resource evaluation study. The factors determining the quality of the groundwater can best be explained in terms of the hydrological cycle. The processes whereby water quality changes could occur are:

(1) Condensation in the atmosphere (Whitehead and Feth, 1964; Charlston and Rodhe, 1982).
(2) Interaction with the soil and vegetation (Fitzpatrick, 1974).
(3) Interaction with the soil horizons (Bear, 1964).
(4) Interaction with the rock formations (Davis and de Wiest, 1966; Hem, 1970).
(5) Contamination by existing groundwater sources (Lawrence, et al., 1976).
(6) Contamination as a result of saltwater intrusion (Glover, 1964; Henry, 1959).

The overriding influence on groundwater quality is probably the nature of the soil and rock formations encountered during infiltration, flow and storage in the aquifer. Most rocks are complex mixtures of both soluble and insoluble minerals. The soluble minerals are most important in influencing groundwater chemistry. Table 5 shows the major minerals found in groundwater and their respective sources in sedimentary rocks.

Special mention must be made of sedimentary deposition under marine conditions, because of increased concentration of certain ions otherwise not found. The following have high concentrations in marine rocks - chloride, sodium, sulphate.

TABLE 5 SOURCES OF ION CONCENTRATIONS IN GROUNDWATER (after Davis and de Wiest, 1966)

CONSTITUENT	MAJOR SOURCES
SiO_2 (Silica)	Feldspars, Ferromagnesium and Clay minerals
Fe (Iron)	Oxides, Carbonates and Sulphates of Iron Clay minerals
Mn (Manganese)	Solution from soils and sediments
Ca (Calcium)	Feldspars, Gypsum, Pyroxenes, Aragonite, Calcite Dolomite, Clay minerals
Mg (Magnesium)	Pyroxenes, Clay minerals, Dolomite
Na (Sodium)	Clay minerals, Evaporites (i.e. Halite)
K (Potassium)	Feldspars, Feldspathoids
CO_3 (Carbonate)	Limestones, Dolomites
HCO_3 (Bicarbonate)	Clay minerals, Dolomites
SO_4 (Sulphates)	Evaporites, Oxidation of Sulphate Ores
Cl (Chloride)	Sedimentary rocks (Evaporites)
F (Flouride)	Fluorite
NO_3 (Nitrate)	Atmosphere, Legumes, Plant debris

A number of authors have proposed a cycle of chemical changes in groundwater (Chebotarev, 1955; Johnson, 1974). The cycle involves a change from young HCO_3 concentrated groundwater to Cl concentrated groundwater with increasing age. It must however be realized that this hypothesized cycle was evaluated under specific conditions and is not universally applicable. High chloride concentrations in marine deposits must not necessarily be equated with old age in terms of the Cl/HCO_3 cycle.

Once the chemical analysis of the water samples has been completed there is a variety of techniques which can be used in the actual interpretation of the results, each method having its own particular use. The standard techniques used to analyse the chemical results are (Hem, 1959);

(1) Inspection and comparison of different samples or groundwater regimes using ratios and averages.
(2) Classification of the water according to the combinations of ions (i.e. Palmer's classification, 1911).
(3) Graphical techniques (i.e. scatter diagrams, pie diagrams, Shoeller graphs, Stiff diagrams, Piper diagrams and Durov diagrams).

The Piper diagram was found to be extremely useful during the Bushman's River Mouth/Cape Padrone project, because of its wide range of uses. The diagram can be used to help interpret:

(1) Groundwater movement.
(2) Differences between separate aquifers.
(3) Sources of recharge and abstraction.
(4) Relative ages of groundwater.
(5) The detection of possible fault or contact zones.

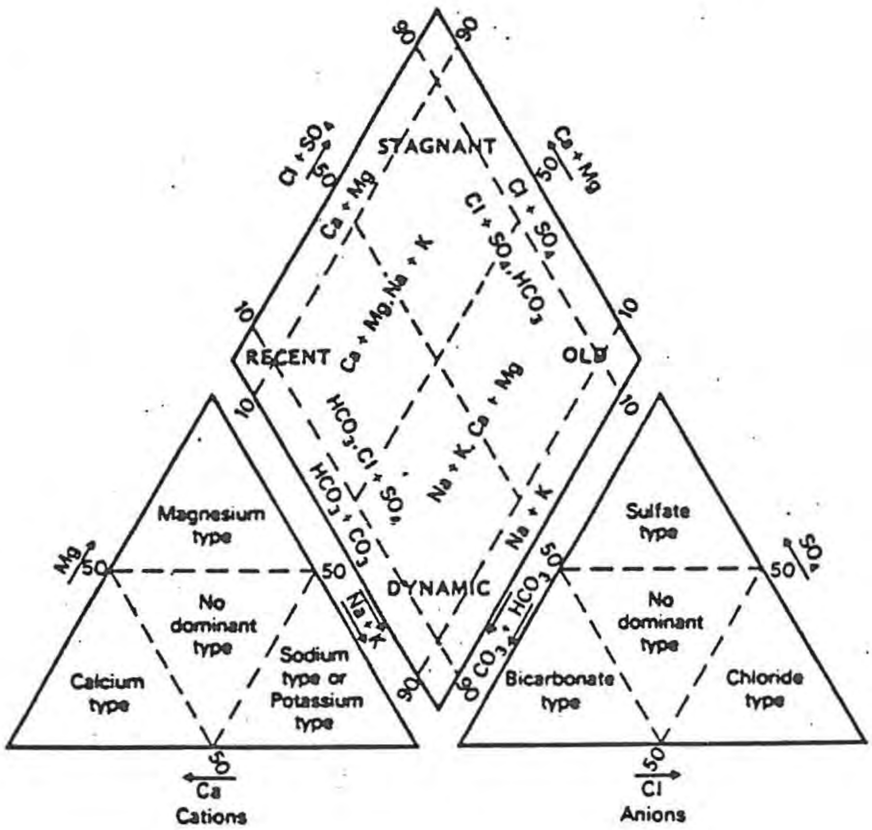
Papers by Johnson (1974), and van der Linde and Hodgson (1977) give examples of the different uses. The basis of the Piper diagram is as follows (Piper, 1953). The diagram combines three distinct fields for plotting (see Figure 8). The two lower triangles contain three cation groups (Ca, Mg, Na+K) and three anion groups (CO_3 + HCO_3, SO_4, Cl) respectively. The concentrations of the cations and anions are marked in their respective triangles and then projected into the diamond shaped quadrangle to show the overall chemical character of the groundwater as one point. Mixtures of any two waters will plot along a line joining their respective points in each of the three diagrams (Piper, 1953). Use of Piper diagrams to prove that mixing has occured is however rather simplistic, the process of mixing being very complex and difficult to interpret.

Graphical methods, like the Piper diagram, are often extensively used because of their visual unambiguity, and are used in many groundwater chemistry projects.

FIGURE 8

PIPER DIAGRAM SHOWING HYDROCHEMICAL FACIES IN PER CENT OF TOTAL EQUIVALENTS PER MILLION

(after Back, 1966)



CHAPTER 6

HYPOTHESES

In order to provide a scientific framework for the investigation a number of hypotheses have been formulated. The hypotheses are based on the finding of previous work and on theoretical hydrogeological concepts.

AQUIFER GEOMETRY AND LITHOLOGY

1. A single aquifer system occurs comprised of the weathered and fractured rocks at the top of the Cape Supergroup, the Alexandria formation and the overlying Quarternary sands.
2. The base of the aquifer is formed by the unweathered bedrock horizon of the seaward inclined slope of the pre Cretaceous erosion surface.

HYDRAULIC PROPERTIES OF THE AQUIFERS

3. Higher yielding supplies result from boreholes penetrating Bokkeveld sandstones, rather than Bokkeveld shales.
4. The aquifer(s) is laterally anisotropic.

HYDROCHEMISTRY OF GROUNDWATER

At any one point in the aquifer system groundwater quality may be influenced by one or a combination of factors.

5. Groundwater quality in the blind valley sand aquifers will be affected by the quality of the surface water in the area.
6. Bokkeveld sandstone aquifers will have a less mineralized groundwater than Bokkeveld shale aquifers.

FLOW REGIME

7. Rates and vectors of subsurface flow are controlled by bed rock configuration and recharge rates.

CHAPTER 7

DATA COLLECTION AND RESULTS.

7.1 RESISTIVITY

The following sections contain the data and results from the seven sections in the previous chapter. Only the data used during actual discussion of results is contained in this chapter. The other data (i.e. V.E.S curves) is given in the Appendix.

The V.E.S. sites are shown in Figure 9. The basis used for siting of the soundings was:

(1) Firstly, near suitable boreholes with known geological logs, so that the geo-electric curves could be calibrated.

(2) Secondly, in transect lines from the coast inland in order to produce geo-electric profiles. The siting of the profiles was limited by the relief and the vegetation thickness. Thick bush, steep slopes and uneven terrain made it impossible to undertake soundings in some areas. Once obtained, the geo-electrial profiles were used as a basis for the selection of possible borehole sites.

During the fieldwork final $^{AB}/_{2}$ distances were usually in the vicintiy of 200m, although in some cases were as high as 500m. The distance between successive soundings in a profile was dependant on relief, varying between 200m and 500m. Data were obtained during the sounding in accordance with standard C.S.I.R. procedures.

The majority of sounding curves produced were combinations of K, Q and H type curves, A type curves being rare. Many curves had KQH character, showing the existence of five different lithologies.

7.1.1 CALIBRATION

Before any geological interpretation could be made from the geo-electric profiles it was necessary to calibrate the geo-electric data against known vertical variations in lithology from boreholes. Four curves have been selected which were calibrated against boreholes drilled at the site of

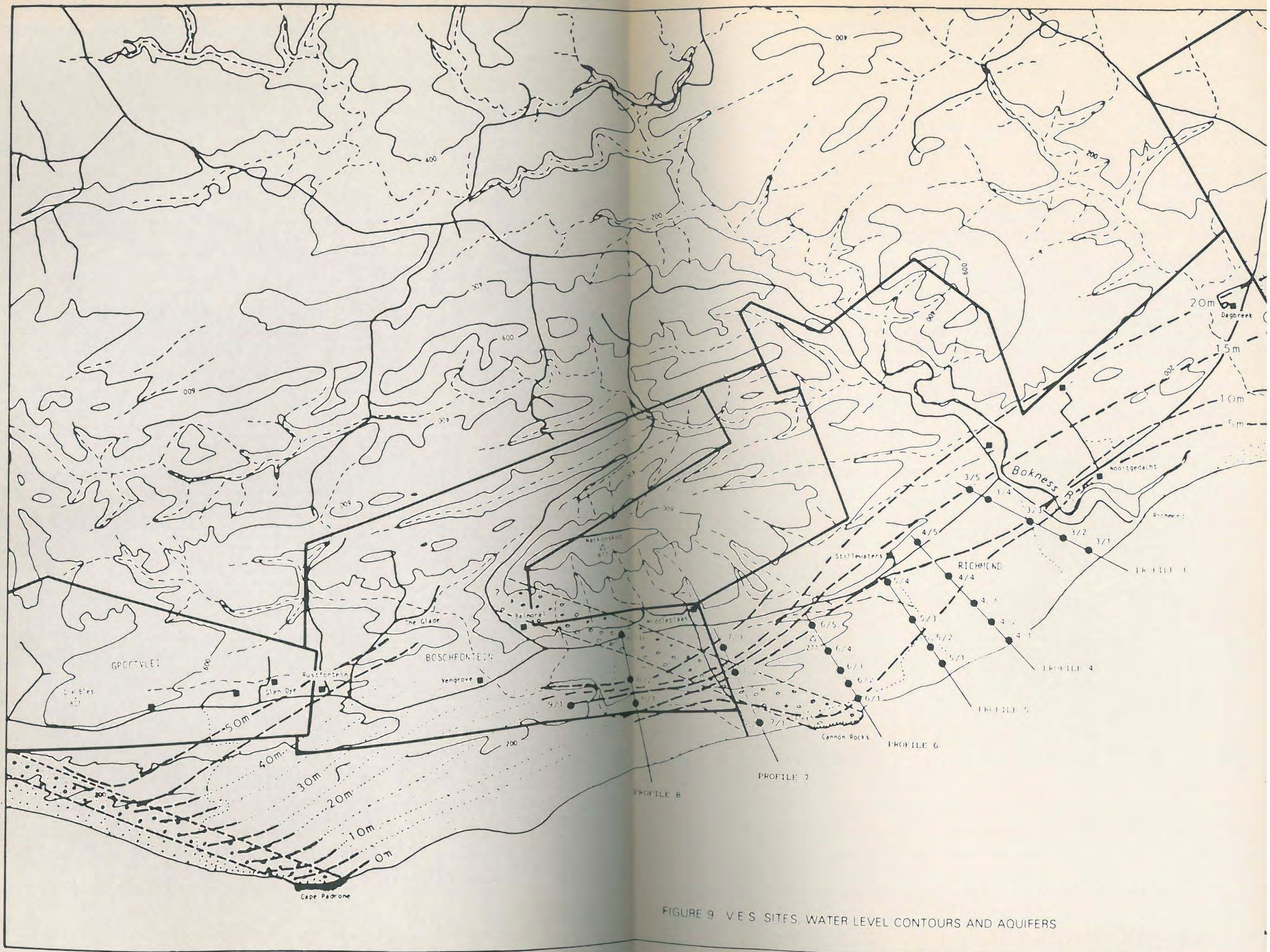
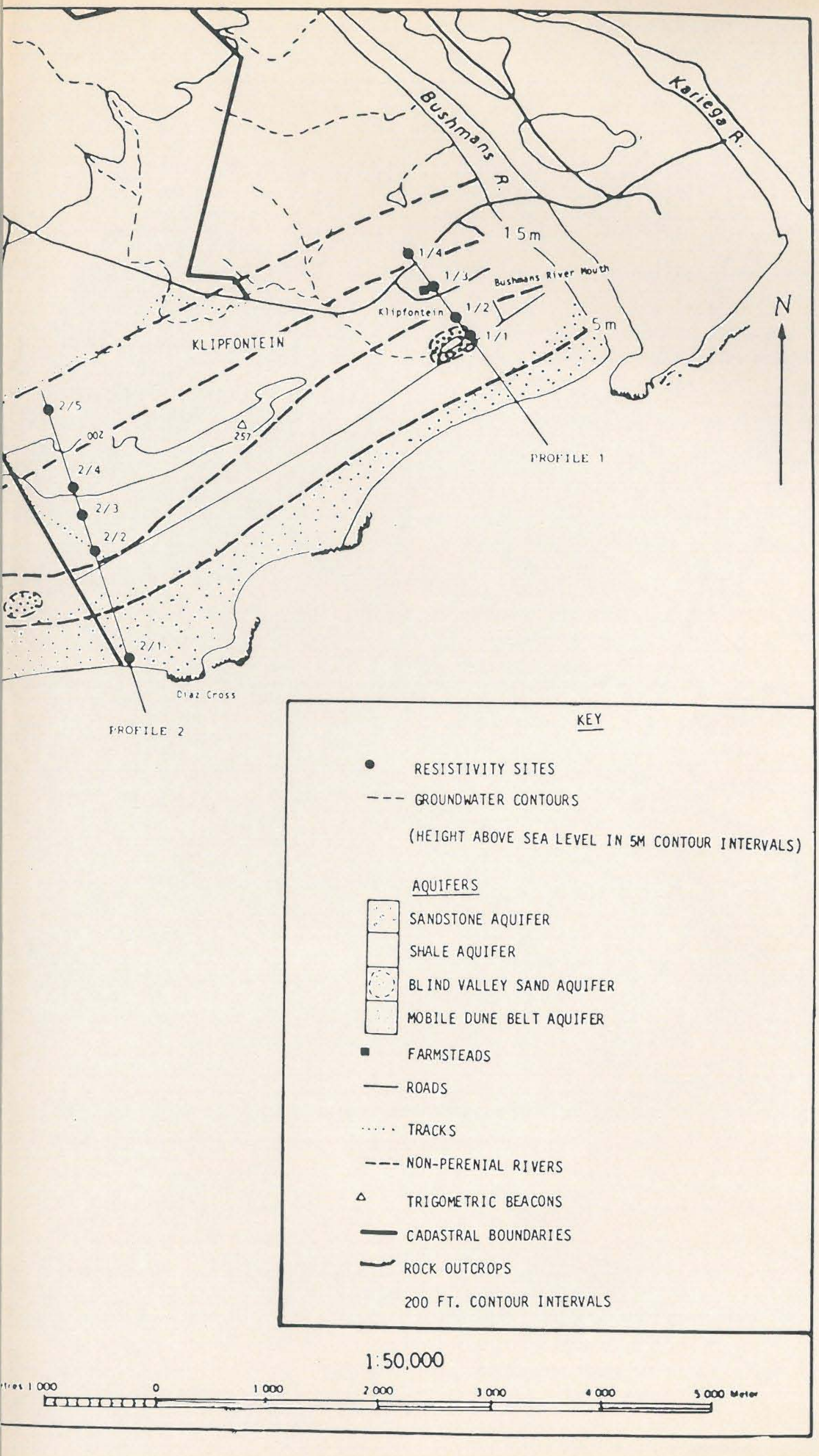


FIGURE 9 V.E.S. SITES, WATER LEVEL CONTOURS AND AQUIFERS


Bushmans R.
Kariega R.
15m
5m
1/4
1/3
1/2
1/1
Bushmans River Mouth
Klipfontein
KLIPFONTEIN
2/5
2/4
2/3
2/2
2/1
257
002
PROFILE 1
PROFILE 2
Diaz Cross
N
KEY
RESISTIVITY SITES
GROUNDWATER CONTOURS
(HEIGHT ABOVE SEA LEVEL IN 5M CONTOUR INTERVALS)
AQUIFERS
SANDSTONE AQUIFER
SHALE AQUIFER
BLIND VALLEY SAND AQUIFER
MOBILE DUNE BELT AQUIFER
FARMSTEADS
ROADS
TRACKS
NON-PERENIAL RIVERS
TRIGOMETRIC BEACONS
CADASTRAL BOUNDARIES
ROCK OUTCROPS
200 FT. CONTOUR INTERVALS
1:50,000
1 000
0
1 000
2 000
3 000
4 000
5 000 Meter

resistivity soundings. The V.E.S. numbers of the four calibration boreholes are:

BOREHOLE	V.E.S NUMBER
Boschfontein 2 :	8/2
Boschfontein 3 :	9/1
Klipfontein 1 :	1/1
Richmond 1 :	6/1

For these V.E.S. curves the geo-electric interpretations and geological logs are given in figures 10, 11, 12 and 13. The results from the calibrations are summarized below for the post Tertiary sands and for the Lower Devonian age basement rock.

(1) SANDS

The sands can be subdivided into 2 different geo-electric categories, each with characteristic resitivities

CATEGORIES	RESISTIVITY RANGE (ohm.m)	MEAN (ohm.m)
Dry unconsolidated sands:	118-130	126
Nodule rich calcareous semi-consolidated sands:	210-340	275

Under shallow water level conditions (less than 10m) it also appeared possible to distinguish between saturated and dry sands, the saturated sands having low resistivities i.e. 4 ohm.m at RMD 1. In some areas calcretes develop due to extreme calcification.

These calcrete horizons have resistivities ranging from 900 to 1000 ohm.m. In most soundings, other than where calcrete caps the surface, the surface horizon is comprised of a sandy soil with characteristic resistivities in the range 57-500 ohm.m, depending on moisture content.

(2) BASEMENT ROCKS

Mapping and geophysics have shown that Bokkeveld shales comprise over 95% of

SOUNDING: 8/2 BOREHOLE: BOS 2

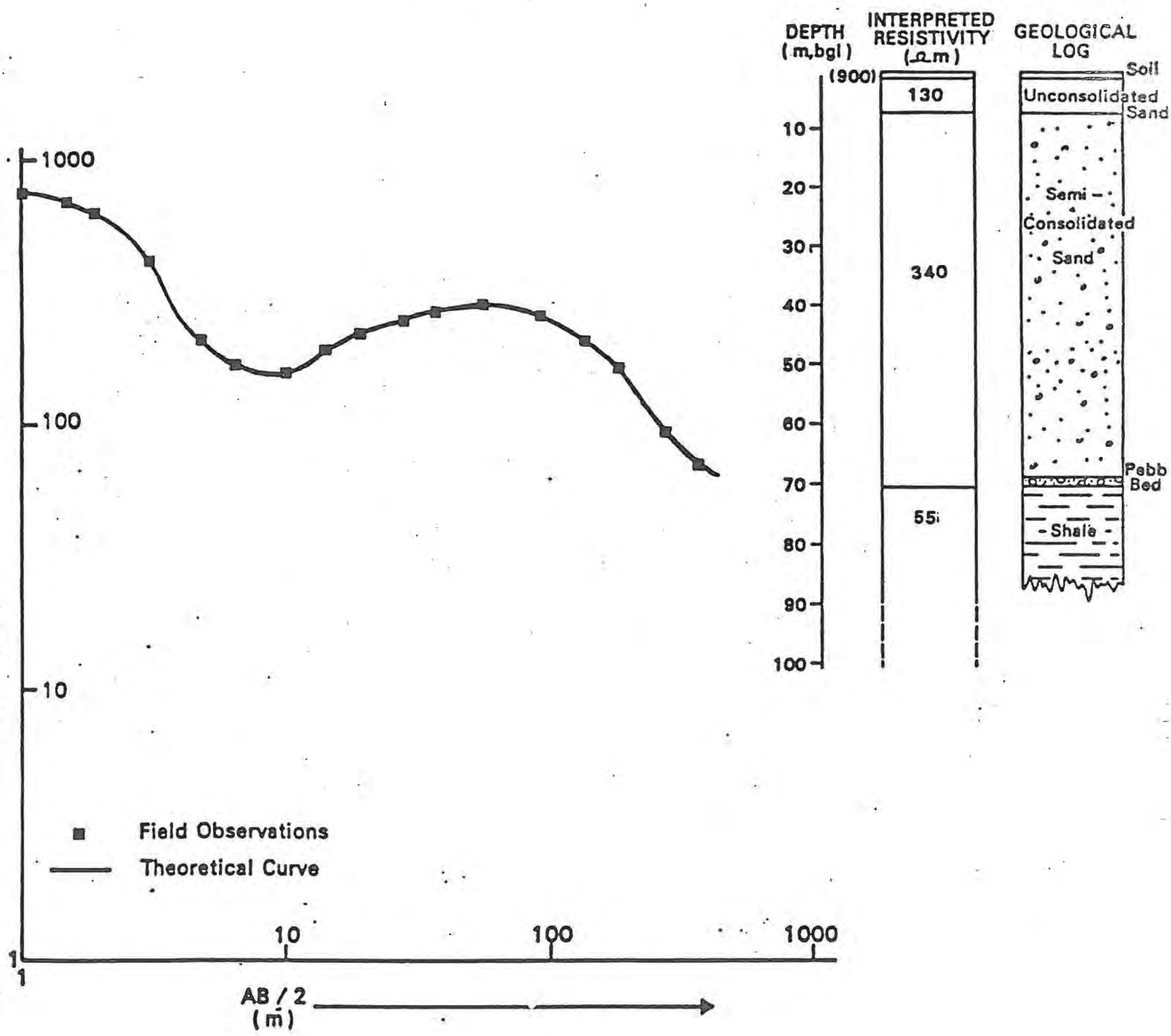


FIGURE 10

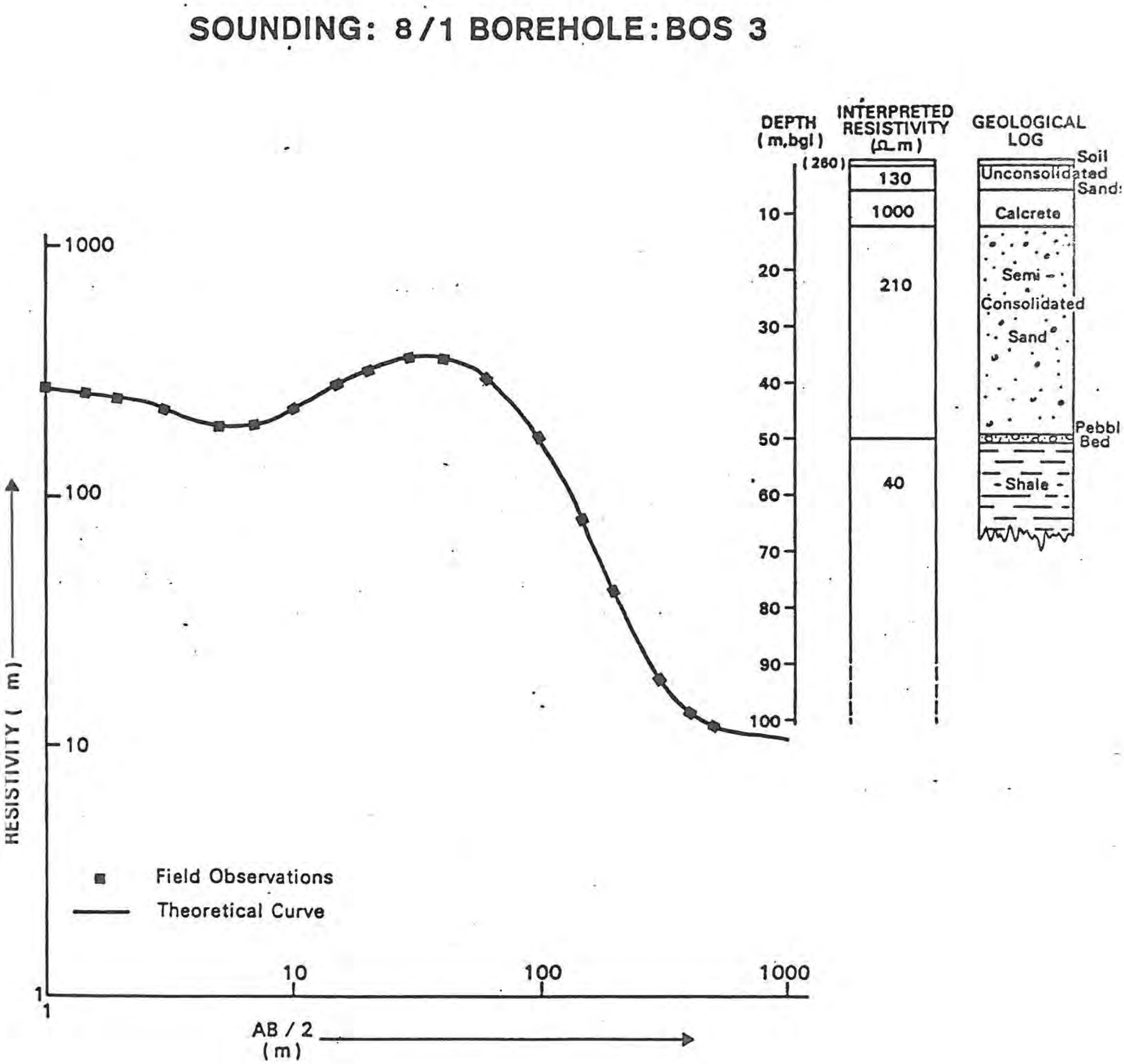

SOUNDING: 8/1 BOREHOLE: BOS 3
DEPTH (m,bgl)
INTERPRETED RESISTIVITY (Ω.m)
GEOLOGICAL LOG
(260)
130
1000
210
40
Soil
Unconsolidated Sand
Calcrete
Semi-Consolidated Sand
Pebbl Bed
Shale
10
20
30
40
50
60
70
80
90
100
1000
100
10
1
RESISTIVITY (m)
Field Observations
Theoretical Curve
1
10
100
1000
AB / 2 (m)

FIGURE 11

SOUNDING: 1/1 BOREHOLE: KF 1

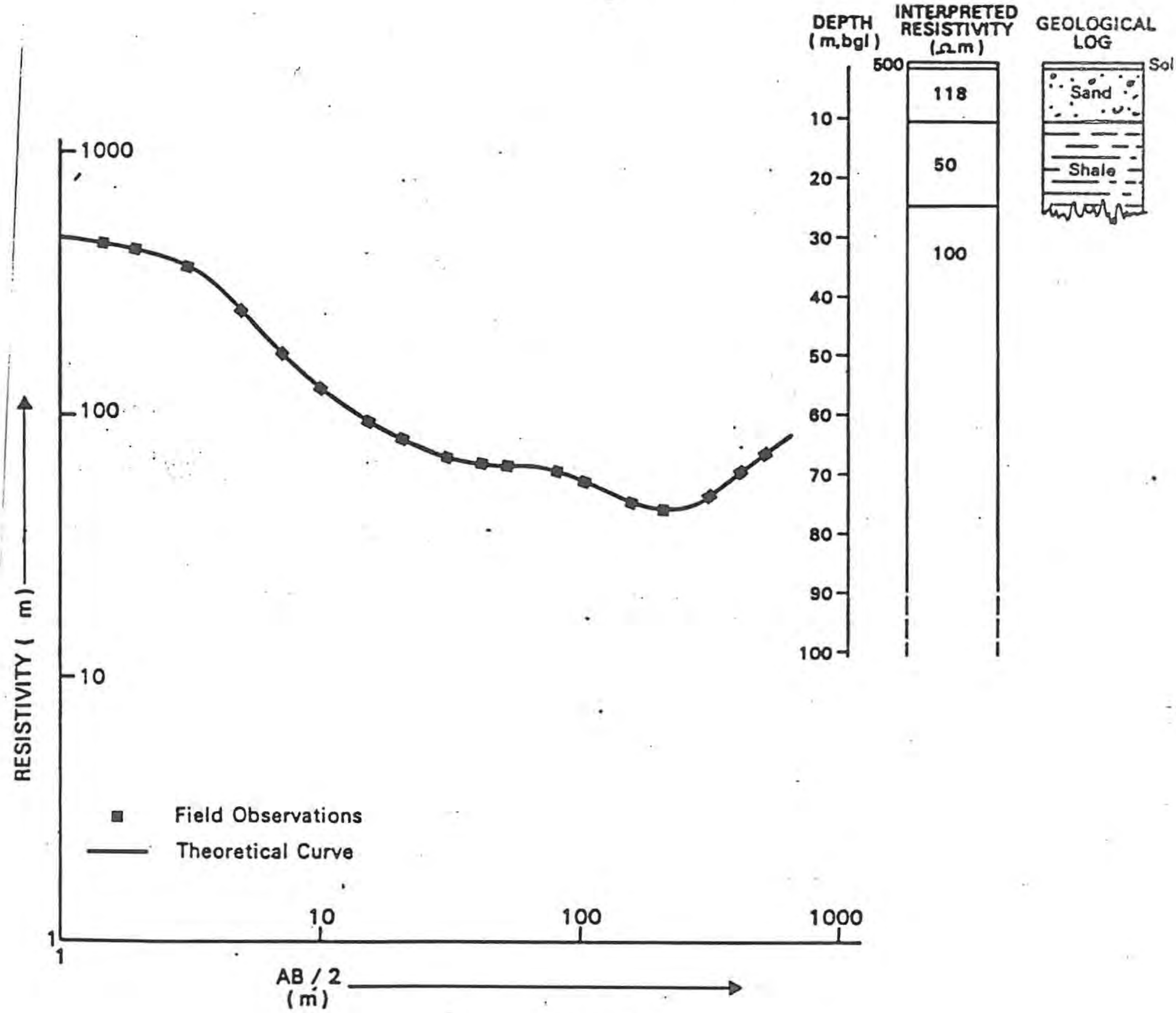


FIGURE 12

SOUNDING: 6/1 BOREHOLE: RMD 1

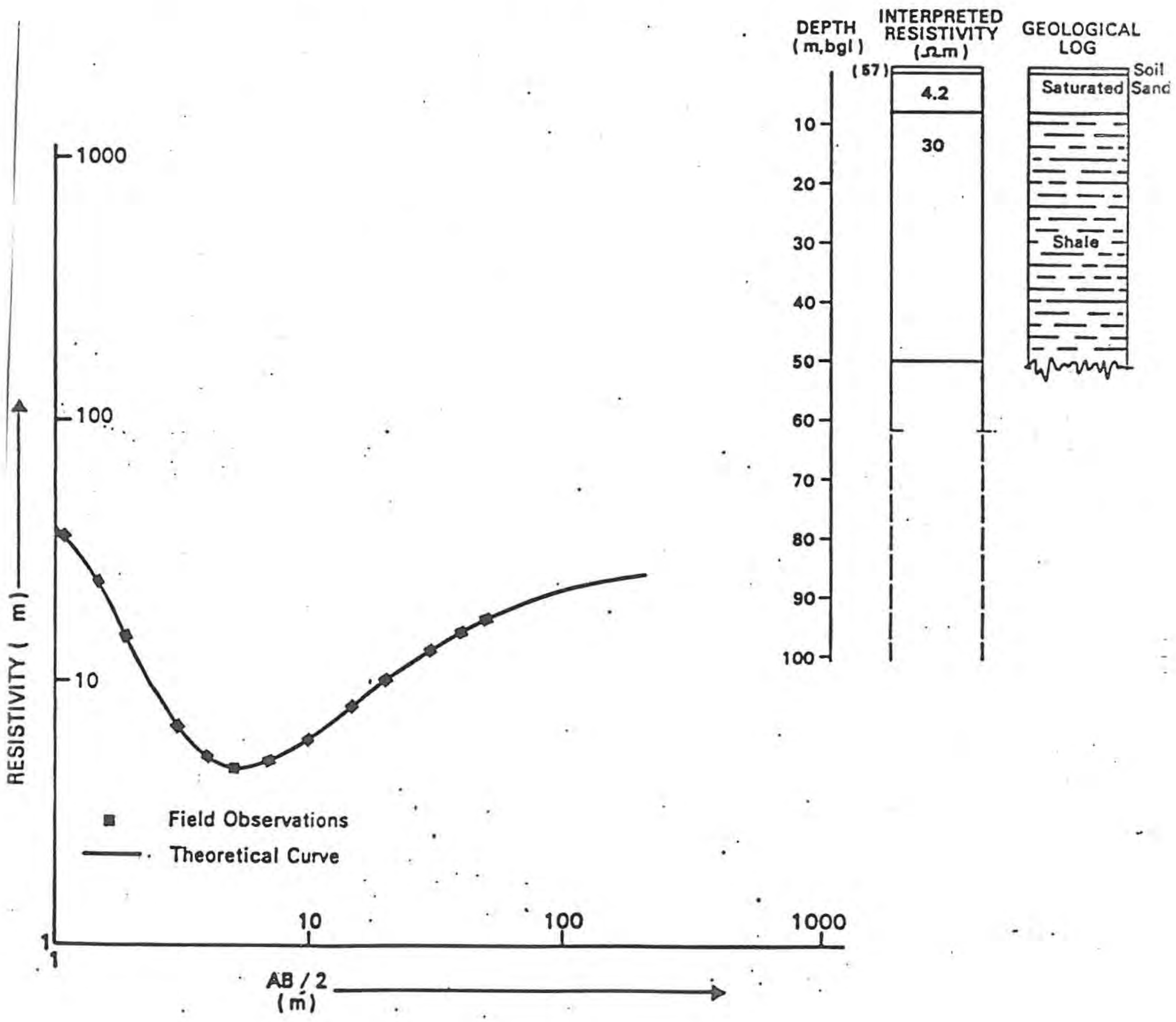


FIGURE 13

the basement in the study area. The remaining 5% is comprised of Bokkeveld sandstone (see Figure 2).
The shales are characterized by low resistivities with a mean of 40 ohm.m and ranging from 6-50 ohm.m. It was impossible to undertake soundings at any of the boreholes drilled into sandstones because of unfavourable relief. A few soundings could however be undertaken in areas where it was definitely known that the basement was Bokkeveld sandstone. From these soundings resistivities were calculated as : range of 130-275 ohm.m, with a mean of 215 ohm.m.

Using the calibration curves it was possible to construct probable geological sections from the resistivity profiles undertaken in the area. The sites of the profiles are shown in Figure 9, while the interpreted sections are contained in the Appendix.

7.1.2 INTERPRETATION OF GEOLOGICAL PROFILES

The interpreted geological sections clearly distinguish between the basement and the overlying sands.

(1) BASEMENT

The sections indicate a seaward sloping Bokkeveld basement overlain by unconsolidated and semi-consolidated calcareous sands - a fact pointed out by Mountain (1962), Seward (1979) and Marais (1962). The slope of the basement varies between 1.5 and 0.5 degrees SSE with an average of 0.95 degrees (i.e. sloping down towards the coastline). The slope of the weathered base of the Bokkeveld surface appears to be the primary control over groundwater flow direction (see the groundwater contours - Figure 9). The basement either outcrops at sea level along the coastline (i.e. Cannon Rocks and Cape Padrone) or is within 3m of the surface (see Appendix D). In all cases outcrops above the sea-level consist of Bokkeveld sandstones, while the Bokkeveld shales because of their apparent lower resistivity to weathering, occur below sea level. Minor variations in the Bokkeveld erosion surface (channels, etc) could not be identified from the resistance because their size is not within the limit of accuracy of the interpretation of the V.E.S. curves.

(2) TERTIARY SANDS

The overlying sands vary in thickness in the study area between zero coverage where Bokkeveld outcrops occur to a thickness of over 110m along the high fixed dune area inland of Cape Padrone.

The near surface sands are semi-consolidated and unconsolidated, being dissected in some areas by hard calcrete horizons. Calcrete is especially evident in the Cape Padrone area and on the hillcrests north of Cannon Rocks. The role played by the calcretes in the hydrological system is not fully understood. The soil horizon overlying the sands consists only of a thin veneer and is therefore not shown in the geological cross-sections. The existence of the Alexandria pebble bed horizon could not be substantiated using resisitivity, probably for two reasons:

(1) It is impossible using resistivity techniques to distinguish a thin horizon (usually under 2m) at depth similar to those at which the horizon is found in the study area (i.e. over 60m depth).
(2) The horizon is also thought to be laterally discontinuous (Mountain, 1962) - probably only existing in hollows on the Bokkeveld erosion surface.

7.2 DRILLING RESULTS

The individual borehole logs are contained in the Appendix, while Figure 2 shows the location of the boreholes. A summary of the fourteen boreholes drilled is as follows:

TOTAL METERS DRILLED	:	615
- IN SAND	:	427.1
- IN PEBBLE BED	:	8.2
- CLAYS	:	4.0
- SHALE	:	105.7
- SANDSTONE	:	70.0
HOLES DRILLED INTO SHALE BASEMENT	:	9[1]
HOLES DRILLED INTO SANDSTONE BASEMENT	:	4
HOLES DRILLED ONLY IN SAND	:	1
HOLES PENETRATING SHALE AQUIFER	:	4
HOLES PENETRATING SANDSTONE AQUIFER	:	4
HOLES PENETRATING SAND AQUIFERS	:	5[2]

1. Although nine holes were drilled down deep enough to strike the shale basement, in five of the cases the aquifer consisted of the sands above the shale and not the shale itself.
2. One borehole was not completed due to drilling difficulties at a depth of 110m (borehole GV3) and it was impossible to identify with certainty the lithology of the aquifer.

A SUMMARY OF EACH INDIVIDUAL BOREHOLE'S IMPORTANT DETAILS IS SHOWN IN TABLE 6

TABLE 6 SUMMARY OF BOREHOLE CHARACTERISTICS

Borehole	BOS 1*	BOS 2	BOS 3	BOS 4	GV 1	GV 2	GV 3	KF 1	KF 2	KF 3	RMD 1	RMD 2	RMD 3	RMD 4
Depth (m)	55.0	80.0	67.0	81.5	29.2	35.2	112.1	25.0	18.0	12.0	50.0	25.0	25.0	25.0
Water depth below the surface (m)	38.5	69.0	51.3	70.17	17.50	17.35	102.1	3.39	1.50	4.58	2.33	2.63	10.65	12.33
Level water struck (m) yield	40.0	70.0	51.3	70.2	26.5	24.0	110.1	3.4	2.0	4.6	2.3	2.6	10.7	12.3
Casing (m x mm)	44 x 152	21 x 203	6.1 x 152	54.0 x 152	27 x 152	26 x 203	** None	15 x 152	14 x 203	9.0 x 203	28.0 x 203	25 x 152	17 x 152	9 x 177

* The borehole numbering is related to the cadastral area in which the borehole was drilled.

** Casing was extracted

The details of depth and formation in which the water was struck are as follows:

TABLE 7 DEPTH AND FORMATION WHERE WATER WAS STRUCK

BOREHOLE	FORMATION IN WHICH WATER WAS STRUCK	DEPTH (M) BELOW SURFACE	DEPTH (M) TO WHICH THE WATER ROSE BELOW THE SURFACE
BOS 1	Shale/pebble bed/sand zone *	40.00	38.50
BOS 2	Shale/pebble bed/sand zone *	69.00	69.00
BOS 3	Shale/pebble bed/sand zone *	51.30	51.30
BOS 4	Sandstone	70.17	70.17
GV 1	Sandstone	26.50	17.50
GV 2	Shale/pebble bed/ sand zone*	26.00	17.35
GV 3	Semi-consolidated sand/ calcrete contact	110.10	102.10
KF 1	Semi-consolidated sands	3.39	3.39
KF 2	Semi-consolidated sands	1.50	1.50
KF 3	Semi-consolidated sands	4.58	4.58
RDM 1	Semi-consolidated sands	2.33	2.33
RDM 2	Semi-consolidated sands	2.63	2.63
RMD 3	Sandstone	10.65	10.65
RMD 4	Sandstone	12.33	12.33

* Due to drilling method and thinness of the pebble bed it was not possible to ascertain if the water was struck at the base or top of the pebble bed, although the latter is suspected.

The data shown in Tables 6 and 7 is discussed below:

(1) In areas of shale basement (see Figure 9) the water was struck in the borehole in the shale/pebble bed/sand zone, often with a rise in water level thereafter. The rise in water level, although fairly fast, was not instantaneous, being therefore indicative of semi-confined conditions, not confined conditions. Deeper drilling into the shales after the first strike of water failed to cause a further rise in water level or any increase in yield in any of the shale boreholes (see Section 7.4).
(2) In areas with a sandstone basement (see Figure 9) the water was struck below the pebble bed/sand contact in the weathered upper portion of the sandstone with no rise in water level. Exceptions to this are GV1 and GV2, where a water level rise of 9.0 m occurred. Both GV1 and GV2 (75 m from GV1) have been drilled in an area where the sands are dissected by impermeable calcretes. These calcretes may provide a greater confining influence than the semi-consolidated sands.
(3) The drilling data obtained from boreholes KF1, KF2, KF3, RMD1 and RMD2 must be analysed with caution. All these boreholes were drilled near pans (within 100 m) which were flooded at the time because of heavy rains. Water levels in the boreholes drilled show a decline with distance away from the pans, thus showing that the pans are the source of groundwater in the sands. Even if the pans are totally full, it is still expected that areas distant from the pans will have no ground water supply in the unconsolidated sands. As the pan levels dropped during the study period, so the water levels in the boreholes dropped, until they remain constant at the shale/sand contact (no discernable pebble bed existed, only a thin shelly horizon).

In terms of the hydrogeological properties of the rock units four aquifer types may be distinguished.

(1) the weathered sections of the Bokkeveld sandstone basement.
(2) a zone containing weathered basement shales and the Alexandria pebble bed horizon.
(3) the semi-consolidated and unconsolidated sands in those areas where flooding has occurred (ie. near pans in blind valley environments). The existence of these aquifers is periodic, being closely related to periods of high rainfall.

(4) the unconsolidated sands of the mobile dune belt - these sands are recharged by direct precipitation onto the dune belt and through groundwater flow along the more permeable zones in the seaward sloping basement (i.e. sandstone formations).

Both the sand aquifers and the weathered section of the sandstones are only partially saturated and thus according to Kruseman and De Ridder's (1970) definitions of aquifer types, both the sands and the sandstone aquifers must be defined as unconfined. The shale aquifer is saturated, and is confined above by the semi-confining consolidated sands. The shale aquifer is therefore probably defined as being semi-confined.

7.3 WATER LEVEL FLUCTUATIONS

Two automatic water-level recorders were installed in the study area. The water level fluctuations and rainfall for the period 15th July 1981 to 15th June 1982 are shown in Figure 14. Both boreholes (one at Cannon Rocks and the other inland of Bushmans River Mouth) show a very slight decline in water level over time, with no apparent fluctuations related to rainfall events. The rainfall is spread fairly evenly throughout the year, so seasonal variations in water-level would not be expected. The lack of fluctuations in the water levels could be expected from an aquifer which is covered by a thickness of sands. These sands would absorb infiltration and thus have a dampening effect on peak rainfall values. To determine whether the water level trends shown in Figure 14 are related to long term fluctuations in rainfall, a longer period of data collection would be necessary and some knowledge of the borehole geological log would be required. Recommendations for the relocation of the water level recorders are made in the conclusion (section 9.4).

7.4. AQUIFER TEST ANALYSES AND RESULTS

Of the ten tests undertaken only seven had data suitable for analysis in the calculation of transmissivity and storage capacity. The remaining tests could only be analysed in terms of yield and drawdown. The deviation from expected behaviour of many of the tests, and the unsuitability of the data for analysis are a result of:

(1) Pump breakdown.
(2) Fluctuations in extraction rate.

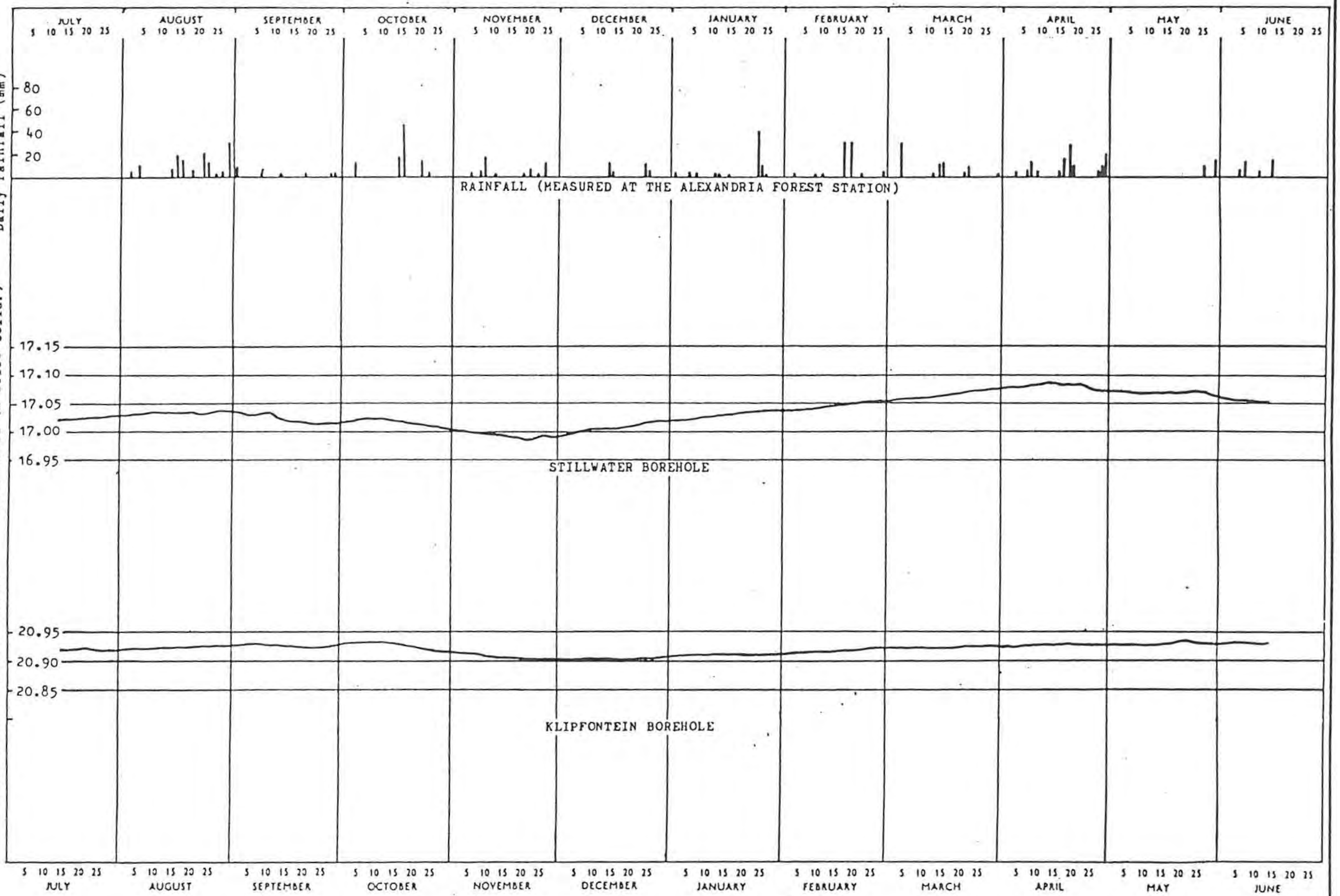


FIGURE 14 WATER LEVELS RECORDED DURING THE PERIOD JULY 1981 - JUNE 1982

(3) Decrease in yield, as a result of clogging of the hessian cover (biddum) around the slotted casing.
(4) Inadequate development of the boreholes prior to the tests, resulting in aquifer development during test pumping.
(5) Boundary influences, especially prevalent near the contacts between shale and sandstone formations in the aquifer i.e. BOS 4, GV 2, RMD 3 and RMD 4.

In only one case was reliable observation borehole data obtained (from the constant yield test at RMD 3 on 5/11/81), thus severely limiting the reliability of results obtained from the analyses.

The tests are discussed in terms of the aquifer categories mentioned in section 7.2 viz:
(1) Bokkeveld sandstone aquifers.
(2) Shale/pebble bed aquifers
(3) Blind valley semi-consolidated sand aquifers.
(No aquifer tests were undertaken on the dune aquifer).

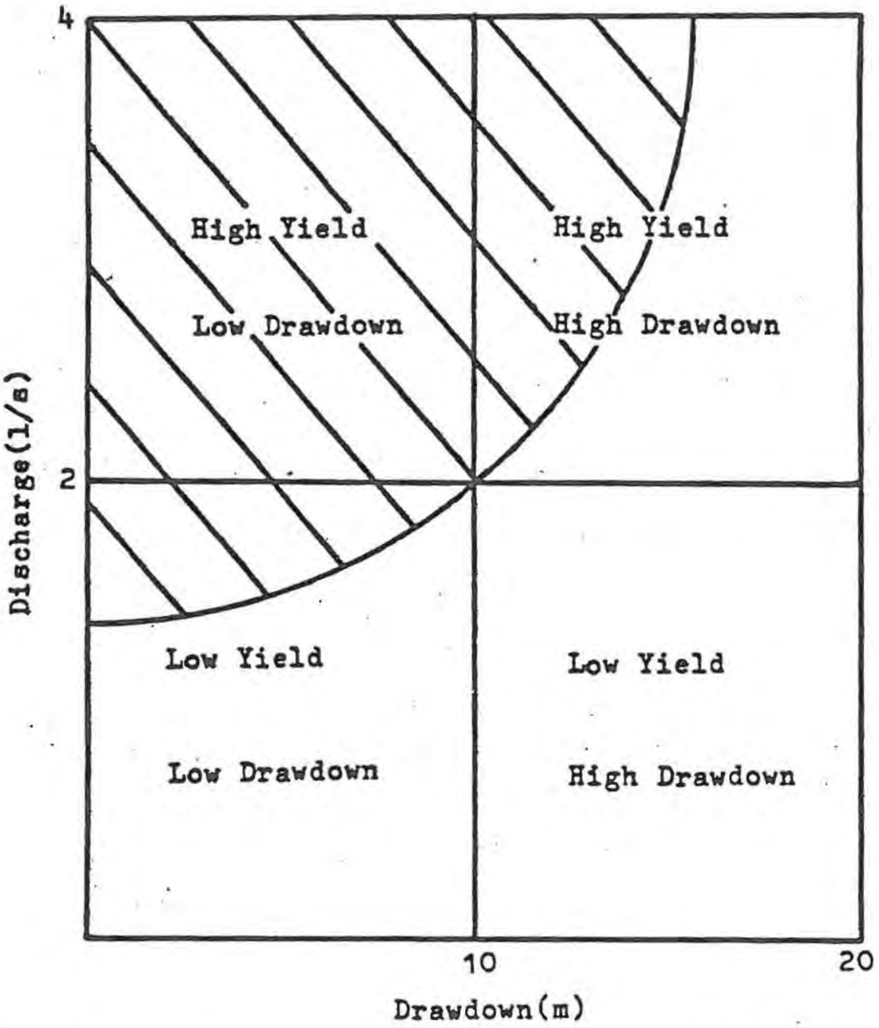
7.4.1 YIELDS AND DRAWDOWNS

Table 8 contains yield and drawdowns after 100 minutes of pumping during each test. A one hundred minutes time period was used in the analysis because this was the duration of the steps in the step-drawdown tests undertaken. Since each step in the step drawdown tests was 100 minutes, a period longer than 100 minutes would have meant that the step drawdown data could not have been used in the comparisons between the different aquifers, because this would have involved water level readings taken during a change in extraction rate. For comparative purposes a parameter was used which consists of the ratio of water level drop per unit of extraction rate (specific drawdown), for the same period of 100 minutes. This drawdown/yield parameter will give an indication of the ability of the aquifer to transmit water. The higher the value the greater the drawdown for the same amount of extraction. For the same extraction rate differences in drawdown could be the result of variations in:
(1) Transmissivity of the aquifer.
(2) Amount of storage the aquifer possesses.
(3) Borehole losses.

High values of the parameter will therefore indicate low transmissivity conditions, while low values will indicate high transmissivity conditions (see Figure 15).

FIGURE 15

SPECIFIC DRAWDOWN RELATIONSHIPS



Shaded area : Boreholes plotted in this area show the best potential in terms of exploitation in the Bushmans River Mouth - Cape Padrone study area

The results show a striking difference between the three aquifers. Even though only one value exists for shale aquifers, this value is adequate to distinguish shales from sandstones. The sandstone boreholes show a far greater potential than the shale boreholes in terms of specific drawdown (i.e. greater yield and lower drawdown).

TABLE 8 YIELDS, DRAWDOWNS AND DRAWDOWN/YIELD RATIOS FOR THE DIFFERENT AQUIFERS

BOREHOLE	AQUIFER TYPE	DRAWDOWN * IN PUMPED WELL (m)	YIELD * (l/s)	DRAWDOWN/YIELD PARAMETER * m (l/s)
Bos 4	Sandstone	0.066	2.061	0.032
Bos 4	Sandstone	0.271	5.952	0.046
GV 2	Sandstone	3.55	1.800	1.972
GV 2	Sandstone	4.280	3.405	1.257
GV 2	Sandstone	1.105	0.800	1.382
RMD 4	Sandstone	3.06	0.666	4.596
RMD 3	Sandstone	7.52	2.842	2.656
RMD 3	Sandstone	10.95	2.900	3.775
			mean ($\bar{X}$) =	1.963
KF 1	Shale	15.56	0.046	338.261

* Drawdown and yield shown in this table were measured after 100 minutes. Data for BOS 1 could not be included since the duration of the test was only 35 minutes.

7.4.2 CALCULATION OF TRANSMISSIVITIES AND STORAGE CAPACITIES

The test pumping data (the curves are contained in the Appendix) was analysed using the Jacob-Cooper straight line method (Cooper and Jacob, 1946), the Theis Recovery method (Theis, 1935) and the computer analysis derived by Seward (1982) for step-drawdown tests. The results are shown in Table 9.

The analyses show a great contrast between sandstone aquifers, and sand or

TABLE 9 CALCULATED HYDROGEOLOGICAL PARAMETERS FOR THE DIFFERENT AQUIFERS

BOREHOLE	AQUIFER	TEST TYPE	TRANSMISSIVITY (m^2/day)	STORAGE CAPACITY	WELL EFFICIENTY	REMARKS
BOS 4	Sandstone	Step drawdown	-	-	B = 2.87 X 10^{-4} C = 4.73 X 10^{-7} 53% efficiency For Q = 6 l/s	1
BOS 4	Sandstone	Recovery	323	-		
BOS 4	Sandstone	Recovery	290	-		
RMD 3	Sandstone	Const. Yield	178	1.72 X 10^{-3}		
RMD 4	Sandstone	Step drawdown	-	-	B = -1.07 X 10^{-3} C = 1.07 X 10^{-3}	2
GV 2	Sandstone	Recovery	68	-		
GV 2	Sandstone	Step drawdown	77*	-	B = 1.57 X 10^{-2} C = 1.54 X 10^{-6} 97% efficiency. for Q = 3 l/s	
KF 1	Shale	Recovery	1.3	-		
BOS 1	Shale	Constant Yield	5.7	-		
RMD 1	Sand	Step Drawdown	9.9*	-	B = 1.23X 10^{-1} C = 1.48 X 10^{-3} 57% efficiency. for Q = 0.7 l/s	
RMD 1	Sand	Recovery	2.4	-		

* Transmissivities calculated using Clark's (1977) approximation of $T = {}^{1.22}/_{B}$.

1. Hysteresis of the capillary fringe occurs.
2. Negative B value indicates positive boundary conditions.

shale aquifers. The sandstone aquifers have transmissivities of above 50m^2/day, while the sands and shales have transmissivities of below 10m^2/day. The transmissivities calculated for the sands must however be examined with caution. The casing in borehole RMD 1 extends through the sands into the underlying shales, so that the groundwater extracted from the borehole is derived from the weathered shale. The groundwater extracted has the chemical properties of the sand aquifer, but the transmissivity calculated cannot correctly be assigned to the sand aquifer. The calculated transmissivites of 9.9 and 2.4 are probably underestimates, although a medium grained sand would be expected to have a low transmissivity i.e. about 50 m^2/day.

The overall yield results show the major aquifer to be the sandstones, with the sands having lesser value, while the shales yield a very limited supply.

During the aquifer testing the lowest yield obtained from a sandstone borehole was 0.6 l/s, whereas the shale borehole tested yielded only 0.046 l/s (see Table 6). Data collected during the borehole survey shows a range for shale boreholes from 0.12 l/s to 3 l/s with an average of 0.2 l/s. Most of the yields obtained during the borehole survey were estimated during short term pump tests undertaken after drilling and are probably gross over estimates. Previous workers (Mountain, 1962; Meyer, 1971; Marais, 1962: Seward, 1979) have commented that yields of over 0.5 l/s are unusual from shales. High yields obtained from shales are probably associated with a thick Alexandria formation pebble bed.

Meyer (1971) gives data showing that 42% of successful boreholes penetrating the Alexandria formation have a yield of 0.5l/s while the similar figure for successful holes where no Alexandria formation was found is only 9.1%.

Transmissivities vary greatly between the aquifers. The average values for the respective aquifers are; (see Table 9) Sandstones = 187m^2/day
Shales = 3.5m^2/day
Dune and blind valley sands = 6.2m^2/day (underestimate i.e 50m^2/day).

7.4.3 ABSTRACTION POTENTIAL

Although the previous section outlined yields obtained from the different boreholes, no clear outline was given on the abstraction potential of the different aquifers. For the purpose of this section the abstraction potential is defined as the maximum rate at which water can be abstracted from an aquifer, without causing a long term depletion of the supplies in the aquifer.

(1) SANDSTONE AQUIFERS

The two sandstone aquifers are those striking inland from Cannon Rocks and Cape Padrone. The discharge into the sea from these two aquifers is calculated as:

(1) CAPE PADRONE

Q = Aquifer width (W) x Transmissivity (T) x Hydraulic gradient (I)
= 500m x 187 m^2/day x 1/103
= 907 m^3/day or 10.5 l/s

8.5 l/s is at present being abstracted from the springs at Cape Padrone, so the possibility of further abstraction is limited.

(2) CANNON ROCKS

Q = WTi
= 70m x 187m^2/day x 1/119
= 1099m^3/day or 12.7 l/s

A collection system similar to that at Cape Padrone could be developed with a possible extraction rate of 12.7 l/s. The present abstraction from the Cannon Rocks aquifer consists of 300 m^3/day (3.47 l/s) from two boreholes drilled into the sandstones.

The yield of boreholes drilled into both these aquifers varies between 1 and 6 l/s, depending on the degree of fracturing and weathering of the sandstone. The total volume of storage for the sandstone aquifer in the Cannon Rocks area is;

Water Storage = 10% (aquifer width x length x saturated thickness)
= 10% x 112 x 10^5 m^3
= 1.12 x 10^6 m^3

This figure is based on the assumption that 10% of the aquifer (by volume) contains groundwater.

(3) SHALE AQUIFERS

Flow rates in the shale aquifers are much lower than in the sandstones. The flow rate for a 100m wide zone extending between boreholes BOS 3 to BOS 1 (both drilled into shale) is:

$$Q = WTi$$
$$= 100 \times 3.5 \times 1/200$$
$$= 1.4 \ m^3/day$$

For the 4km zone from Boknes to Stillwater, it is estimated that only $110m^3$/day seeps out to sea.

The supply that could possibly be derived from drilling into the shale aquifer is also of little value in terms of municiple supply, since most shale boreholes yield under 0.01 l/s.

(4) BLIND VALLEY SAND AQUIFERS

Two of these aquifers exist - at the Klipfontein and Richmond pans. The concentrated infiltration in these two areas results in a greater hydraulic gradient from the pans to the coastline, in comparision with other shale areas where no infiltration from the pans occurs. i.e. 1/67 from blind valley aquifers to sea level, while 1/160 from shale aquifers adjacent to blind valley pans to sea level. Seepage from the 300 m long Klipfontein pan into the mobile dune is calculated as : $Q = WTi$

$= 27.5 \ m^3/day$ (probably an underestimate, since the transmissivity has been underestimated)

This is considerably higher than a 300 m section of shale basement. The aquifer yield, although greater than 0.5 l/s at the Richmond pans, is probably not adequate for any long term supply, because of the fluctuations in storage between wet and dry periods.

(5) MOBILE DUNE AQUIFER

The inputs and outputs in the dune aquifer system are;

- precipitation directly onto the dunes
- flow from the dune aquifer out to sea
- evaporation
- runoff

Recharge from precipitation has been calculated using data for precipitation and evaporation from the Hydrological Research Unit (Wits) report No. 12/81 (1981). From this report it was calculated that on average 11% of M.A.R. contributed to aquifer recharge (this calculation assumed zero runoff in the dune environment).

Outflow to sea from the dune belt seaward of the Klipfontein pans (i.e. Bushmans River wells) is calculated from the equation;

$$Q = WTi.$$
$$= 1000m \times 6.2m^2/day \times 1/166$$
$$= 37m^3/day$$

Thus for an area 1000 m x 500 m in the Bushman's River Mouth dune belt, the water balance is:

Input: Recharge by rainfall = 1000 m x 500 m x (11/100 x 0.888 mm)
= 48840 m^3 p.a. (i.e. 133 m^2/day)
: Inflow from shale and Klipfontein blind valley environment
= (7x1.4 m^2/day) + 27.5 m^3/day
= 37.3 m^3/day

Output: 37m^3/day leakage out to sea.

Thus inflow equals outflow, so that the only recharge is by actual precipitation. The higher the M.A.R. the higher the recharge to the dune aquifer. During 1982 for example, the total rainfall was 1193 mm and infiltration was calculated as 33% of the figure. Based on average M.A.R. figures, it appears that 48 840m^3 of groundwater could be extracted yearly from a 1000 m x 500 m area, without depleting supplies.

7.5 HYDROCHEMICAL ANALYSIS

7.5.1 AVERAGES OF ION CONCENTRATIONS, pH AND CONDUCTIVITY

A summary of the ionic determinations for all the boreholes drilled is presented in the Appendix. In the case of boreholes sampled on more than one occasion (during pumping for example) the analysis of the first sample collected is presented. Data of the average ion concentrations for samples from the different major aquifers are summarized in Table 10. From this

TABLE 10 AVERAGE CHEMICAL ANALYSES OF THE PRINCIPAL ROCK FORMATION*

Aquifer Type	No of samples	T.D.S. (mg/l)	T.A.L. (mg/l) (% of TDS)	Ca (mg/l) (% of TDS)	Cl (mg/l) (% of TDS)	Na (mg/l) (% of TDS)	Mg (mg/l) (% of TDS)	K (mg/l) (% of TDS)	SO_4 (mg/l) (% of TDS)
Bokkeveld sandstone aquifer	5	1264	236.1 (18.7%)	56.5 (4.5%)	441.4 (34.9%)	322.4 (25.5%)	22.9 (1.8%)	7.1 (0.6%)	33.2 (2.6%)
Bokkeveld shale aquifer	6	1871	232.9 (12.5%)	88.9 (4.8%)	726.1 (38.8%)	480.4 (25.6%)	34.8 (1.8%)	4.9 (0.3%)	95.8 (5.1%)
Blind valley sand aquifer	3	4762	123.5 (2.6%)	292.0 (6.1%)	2658.4 (55.8%)	1245.1 (26.1%)	174.8 (3.7%)	19.7 (0.4%)	240.9 (5.1%)
Dune sand aquifer	2	1600	235.9 (14.7%)	78.2 (4.8%)	664.2 (41.5%)	413.0 (25.8%)	43.8 (2.7%)	7.8 (0.5%)	86.7 (5.4%)

* All results, except T.D.S. (which was calculated from conductivity values) are rounded off to the nearest one decimal place.

data, distinct differences occur which support the different aquifer subdivisions mentioned previously.

Analysis of total dissolved solids can be used to differentiate between the different aquifers. The groundwaters from the sandstone and shale aquifers would, according to Swenson and Bardwin's (1965) T.D.S. classification, be slightly saline, while the sand aquifer supply would be moderately saline.

In both blind valley sand aquifers (Klipfontein and Richmond) the T.D.S. of the groundwater is fairly high, varying from 2539 mg/l behind Bushman's River Mouth to 8129 mg/l inland of Diaz Cross. In both cases the T.D.S. of the rivers feeding the pans in the Blind valleys, matches closely the T.D.S. in the groundwater. The T.D.S. of the respective surface supplies are:

inland of Diaz Cross = 8100 mg/l
inland of Bushmans River Mouth = 2400 mg/l (Klipfontein River).

Concentration by evaporation in the pans probably also serves a role in the accumulation of certain ion concentrations in the groundwater.

The groundwater seeping out along the coastline seaward of the blind valleys has a much lower T.D.S. content than the blind valley sand aquifer concentrations. This is probably a result of dilution of blind valley sand aquifer groundwater by the groundwater contained in the mobile dune belt. It is theorized that a considerable quantity of "fresh" groundwater exists in this mobile dune belt - the groundwater being recharged mostly by precipitation directly onto the dune belt. Recharge of the dune belt by groundwaters flowing seawards through the low transmissivity shale aquifer is of less importance.

The average T.D.S. contents from five sandstone and six shale aquifers penetrated during drilling was 1264 mg/l and 1871 mg/l respectively, while the range in T.D.S. within each aquifer was;

Sandstones:	1049 mg/l to 1585 mg/l
Shales:	1641 mg/l to 2105 mg/l.

Examination of the concentration of the various ions (as a percent of T.D.S.) shows only subtle differences between the hydrochemistry of the two Bokkeveld aquifers. The only ions showing noteworthy differences are Cl, K, T.A.L. and SO_4.

The difference between the two Bokkeveld aquifers are probably a result of the following:

(1) Weathered and fractured shales have a lower permeability than weathered, fractured sandstones and are thus subjected to less flushing by moving groundwaters. The shale groundwater will thus have a greater ion concentration than the sandstone groundwater.
(2) Greater mineralization of the shale rocks than of the sandstones - during weathering of the rocks more salts are taken into the groundwater from shales than from sandstones.

These factors are also responsible for higher concentrations of Cl, Ca, K and SO_4 in shale groundwater. The differences between the blind valley sand aquifer and the dune sand aquifer is best seen in the following concentrations : T.D.S., Ca and Cl. The differences are a result of;

(1) The higher $CaCO_3$ content of the inland semi-consolidated sands than that of the dune sands (the $CaCO_3$ is the cement in the semi-consolidated sands). This gives the blind valley groundwater a higher Ca character than the dunes. Associated with a high Ca content is a low T.A.L. (T.A.L. being a measure of carbonate and bicarbonate ions in the water). When high calcium concentrations exist, then the bicarbonate can be removed from the grounwater by the precipitation of calcium carbonate.

(2) The high Cl concentration in the blind valley aquifer is related to a more saline recharge source - runoff from a catchment with shale surface geology, and also to the further concentration, by evaporation, of salts in the pans, which recharge the blind valley aquifers.

7.5.2 PIPER DIAGRAM ANALYSIS

1. Trend for the study area's groundwater

Figure 16 contains the plots of the different borehole samples in the study area. The grouping of the plots allows for the following classification of the groundwater quality in the study area;

(1) Cation Triangle - Na type groundwater.

FIGURE 16

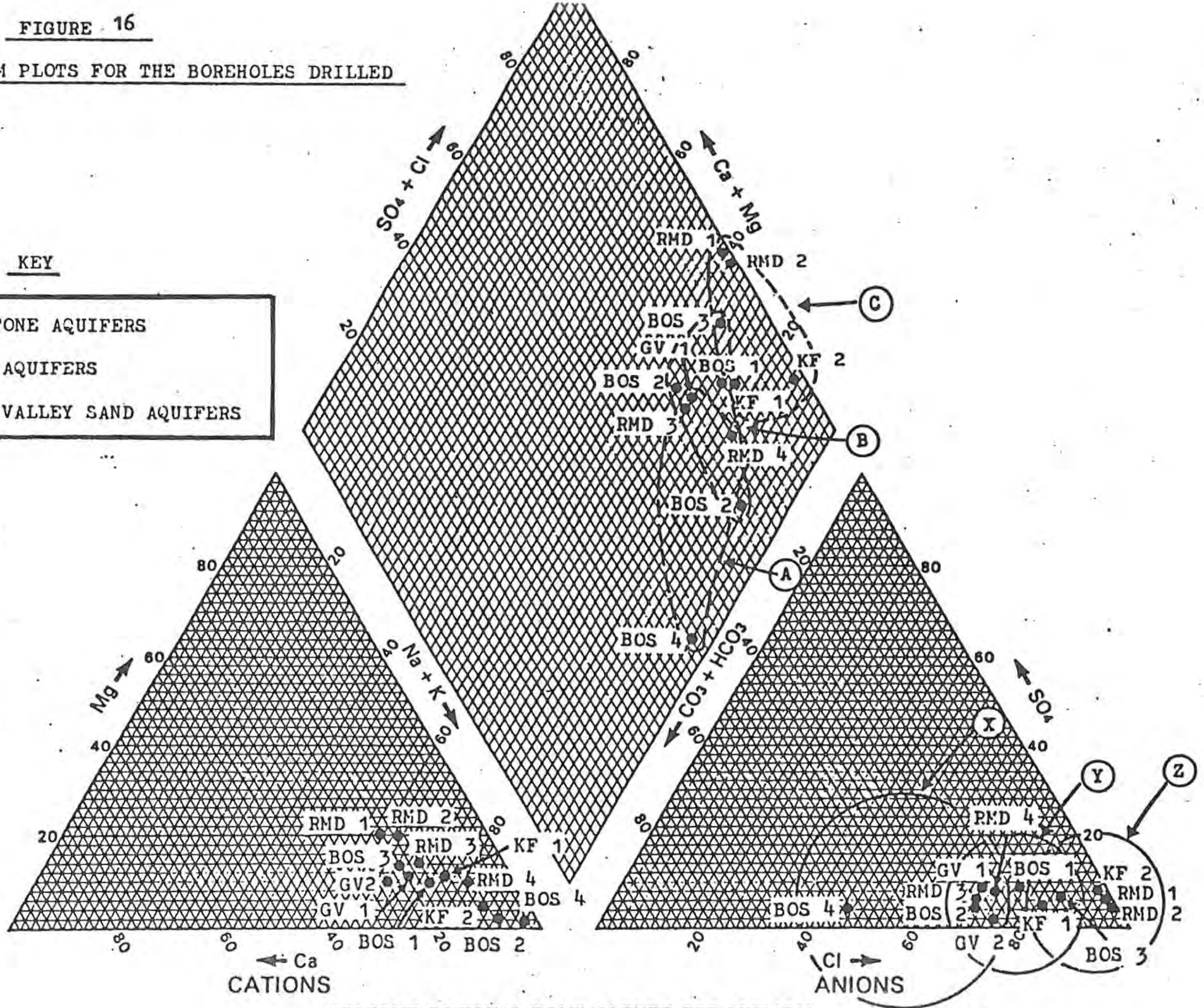
PIPER DIAGRAM PLOTS FOR THE BOREHOLES DRILLED

KEY

A + X: SANDSTONE AQUIFERS

B + Y: SHALE AQUIFERS

C + Z: BLIND VALLEY SAND AQUIFERS



PERCENT OF TOTAL EQUIVALENTS PER MILLION

(2) Anion Triangle - Cl type goundwater. The only exception to this is Bos 4 which shows a bicarbonate type groundwater.

(3) Composite diamond - groundwater is mainly characterized, firstly by concentrations in SO_4 and Cl, and secondly by concentrations in Na and K character. The BOS 4 borehole (sandstone aquifer) shows a strong Na + K character. The Piper diagram plots also distinguish between the different aquifers.

2. Comparisons between the aquifer types

With the exception of BOS 4 the characteristics of the groundwater samples obtained from the sandstone aquifers is well grouped and is shown on the Piper diagram by the area marked "A" in Figure 16. In all cases the results could be considered with greater certainty if more samples had been available for analysis. Only three boreholes penetrated shale aquifers. The grouping of these three (Area "B" in Figure 16) does however show an increase in Cl and SO_4 and a decrease in CO_3 + HCO_3 when compared to the sandstone groundwater. The blind valley sand aquifer groundwater (Plotted as area "C") contains the greatest me/l of SO_4 and Cl of all the aquifers sampled. The groundwater from the blind valley sand aquifers is, according to Back's (1966) classification, dominated by Cl + SO_4 anions.
The difference between the three aquifers is best shown in the anion triangle where circles X, Y and Z show an increase in Cl concentration from 45% - 70% in sandstones, to 68% - 82% in shales, to 88% - 93% in blind valley sand aquifers.

Some degree of overlap occurs between the three areas on the Piper diagram. The most noticable being: borehole KF 2, a blind valley sand borehole with the chemistry of a shale aquifer; borehole BOS 2, a shale borehole with the chemistry of a sandstone aquifer; and GV 2, a shale borehole with the chemistry of a sandstone aquifer.

Borehole KF2 was originally thought to be a blind valley sand aquifer supply, but aquifer test analyses and chemical analysis show that the influence of the pans (150m away) is minimal, the majority of the water being obtained from the shales.

Borehole BOS 2 has been drilled into shales, but appears within influence of the sandstone aquifer into which BOS 4 was drilled (The aquifer is about 60m north of BOS 3). Mixing of shale and sandstone groundwaters has resulted in a supply with a lower Cl content than expected for shale conditions.

Borehole GV2 is on the southerly margin of a northerly dipping sandstone horizon. The water extracted from GV2 is probably a mixture of waters derived mainly from the nearby permeable sandstones, yet influenced by water from the underlying shale. The unusually high Ca value of GV2 would not be expected from a sandstone aquifer in this study ··ea.

3. <u>Variations in water chemistry during extraction from the aquifer</u>

Water samples were collected during aquifer tests on BOS 4, GV 1, RMD 1, RMD 3 and RMD 4. The changes in major ion concentrations during extraction are given in Table 11.

The Piper diagram vector for BOS 4 during pumping shows a progressive change towards greater extraction of more Cl rich water - the quality is therefore deteriorating and the aquifer should be pumped with caution.

The chemical trends shown by the water samples from the other sandstone boreholes (GV 1, RMD 3 and RMD 4) appear at first to be similar to BOS 4 i.e. T.D.S. and Cl concentrations increase. Vectors on the Piper diagram (Figure 17) show that RMD 3 supports the trend at BOS 4 of a change towards extraction of more Cl rich water. RMD 4 and GV1 do not however support the trend on the Piper diagram. Even though their Cl concentration (in mg/l) increase, the most potent factor (in terms of me/l) influencing the direction of the vector is:

(1) For GV 1 - The big increase in T.A.L. which in terms of me/l is more important than a Cl ion increase. In BOS 4 and RMD 3 there was a decrease in T.A.L.
(2) For RMD 4 - The increase in Na ion concentration in RMD 4 was far greater than in BOS 4 and RMD 4. Similar to GV 1, RMD 4 also had an increase in T.A.L.

7.5.3 VARIATIONS IN WATER CHEMISTRY DURING DRILLING THROUGH THE AQUIFER

Variation in water chemistry with increasing depth through an aquifer were expected, especially in shale/pebble bed aquifers where different formations exist. Two samples were collected in borehole BOS 3 - at 51m depth (in the pebble bed), and the other at 59m depth (in the shale), so that variations in chemistry could be analysed.

TABLE 11 HYDROCHEMICAL ANALYSES FROM THE START AND END SAMPLES AQUIFER DURING AQUIFER TESTS ON BOREHOLES BOS 4, GV 1, RMD 1, RMD 3 AND RMD 4

TIME SINCE START OF PUMPING	BOREHOLE	T.D.S. (mg/l)	T.A.L. (mg/l)	Ca (mg/l)	Na (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
1/2 hour	BOS 4	1228.8	385.5	37.6	389.7	10.2	367.0	60.0	5.1
48 hours	BOS 4	1396.5	385.7	45.0	425.8	11.9	477.7	74.1	4.9
1/2 hour	GV 1	1075.2	166.2	63.3	245.1	20.9	358.0	74.3	1.4
9 hours	GV 1	1095.0	198.7	78.2	240.9	10.5	372.5	73.0	1.4
1/2 hour	RMD 3	1416.9	279.9	71.5	327.0	38.0	520.3	63.0	1.5
24 hours	RMD 3	1416.9	268.5	76.8	329.2	36.0	520.9	69.2	1.6
1/2 hour	RMD 4	1536.0	254.1	60.4	388.9	33.9	589.5	84.3	1.3
6 1/2 hours	RMD 4	1605.8	186.0	58.8	420.0	31.5	594.0	94.9	1.0
1/2 hour	RMD 1	7168.0	125.3	435.2	1646.9	268.0	3655.3	496.5	0.1
6 1/2 hours	RMD 1	6374.4	149.8	355.3	1534.6	213.7	3394.9	345.9	0.0

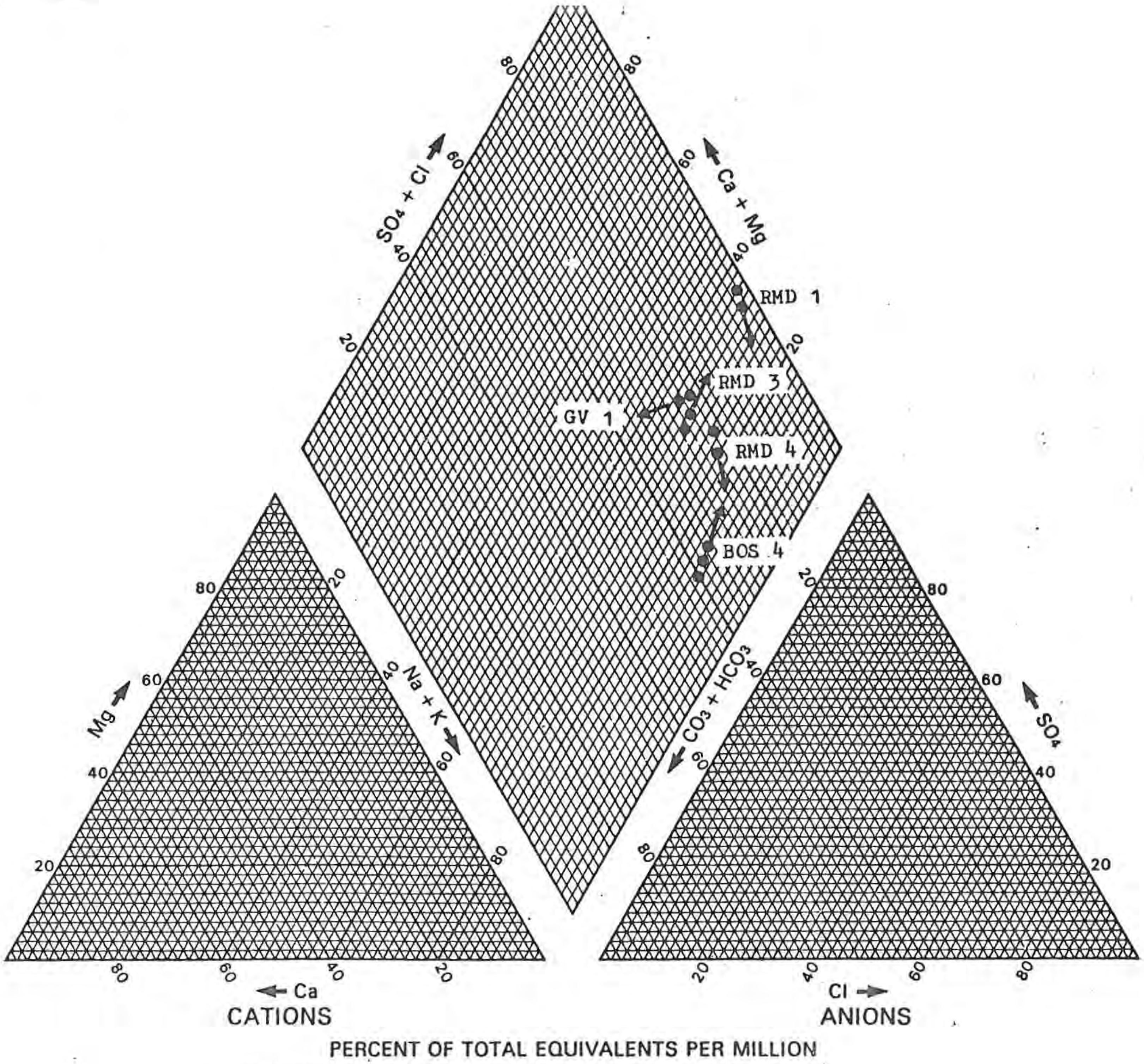


FIGURE 17 CHEMICAL CHANGES DURING AQUIFER TESTS

The analyses in Table 12 shows an increase in ion concentration for all elements except for T.A.L., NH_4 and P. The difference between the two could be explained by:

(1) The pebble bed's higher permeability thus resulting in greater dilution.

(2) Differences in rock chemistry between the shales and the pebble bed, resulting in different chemical characters being imparted to the groundwater.

(3) Better quality water closer to the surface - since recharge water from infiltration is usually of better quality than the water held in the shales.

7.5.4 SUITABILITY OF THE AQUIFERS AS SOURCES OF SUPPLY

Table 13 contains the specifications laid down for water for domestic use (S.A.B.S., 1971 : W.H.O., 1971) and the concentration found in the various aquifers of the different ions.

Both the shale and the blind valley sand aquifer contain water unsuitable as supplies for domestic use. The shale groundwater exceeds the recommended limits for concentrations of Ca, T.D.S. and T.A.L. while the Cl concentration is above the maximum allowable limit. In the blind valley sand aquifer maximum allowable limits are exceeded for concentrations of T.D.S., Ca, Cl and Mg. Throughout the study area neither the shale or the sand aquifers are used as supplies of domestic water - their only use being for stock watering. The sandstone aquifer inland of Cannon Rocks is however used for domestic supply to Cannon Rocks and Richmond, while the springs emerging at the sandstone/ Alexandria formation contact at Cape Padrone, supply the town of Alexandria. The groundwater extracted from the sandstones exceeds the recommended limits for T.D.S., T.A.L. and Cl concentrations, but is inside the maximum allowable limits. The dune aquifer supply at Bushman's River Mouth only exceeds the maximum allowable concentration for Cl. Total dissolved solids (T.D.S), T.A.L. and Ca exceed the recommended limit but are within maximum allowable limits while all other concentrations are within recommended limits.

In terms of supply for stock watering the maximum concentration of total dissolved solids should be 3000 mg/l (National Academy of Sciences and National Academy of Engineering, 1974) but Bower (1978) states that concentrations of up to 7000 mg/l may be used. The shale, sandstone and dune sand aquifers are within the 3000 mg/l concentration for T.D.S, while the blind valley sand aquifers are above the limit, but still below 7000 mg/l. In the study area the shale and blind valley sand aquifers are in fact only used as a supply for stock watering.

TABLE 12 VARIATION IN WATER CHEMISTRY DURING DRILLING IN BOREHOLE BOS 3

DEPTH	FORMATION	T.D.S.	T.A.L.	Ca	Cl	NO_3	Na	Mg	SO_4
51m	Pebble bed	2105	147.0	126.4	870.9	5.0	453.6	50.4	104.2
59m	Shale	2674	140.5	129.8	1112.4	18.7	592.0	70.5	119.6

TABLE 13 COMPARISON OF GROUNDWATER QUALITY BETWEEN THE DIFFERENT AQUIFERS AND RECOMMENDED LIMITS OF CHEMICAL CONCENTRATION

PROPERTY	RECOMMENDED LIMITED	MAXIMUM ALLOWABLE LIMITED	SANDSTONE AQUIFER	SHALE AQUIFER	BLIND VALLEY SAND AQUIFER	SHIFTING DUNE SAND AQUIFER
pH - min	6.0	5.5	7.9	7.8	7.6	8.1
- max	9.0	9.0				
T.D.S. (mg/l)	500	2 000	1264.6	1871.5	4762.8	1600
T.A.L. (mg/l) - min	20	not specified	236.0	232.8	123.5	235.9
- max	200	1 000				
NH_4 (mg/l)	10	not specified	0.009	0.017	0.006	0.026
Cl (mg/l)	250	600	441.1	726.1	2658.3	664.2
Mg (mg/l)	100	150	22.9	34.8	174.8	43.8
F (mg/l)	1.0	1.5	0.4	0.3	0.4	0.3
SO_4 (mg/l)	250	400	33.2	95.7	240.7	86.7
Ca (mg/l)	75	200	56.4	88.9	292.0	78.2

(W.H.O., 1971; S.A.B.S., 1971)

CHAPTER 8

HYPOTHESIS TESTING AND DISCUSSION

The purpose of this chapter is to examine each of the hypotheses separately in the light of the results obtained from the geophysics, drilling, aquifer testing and hydrochemical programmes.

AQUIFER GEOMETRY AND LITHOLOGY

Hypothesis 1: A single aquifer system occurs comprised of the weathered and fractured rocks at the top of the Cape Supergroup, the Alexandria formation and the overlying Quaternary sands.

The results show that more than one aquifer exists. No single aquifer was found which comprised all three formations mentioned in the hypothesis. The three aquifers that were found are;

Type 1: The weathered top of the Bokkeveld sandstone basement.
Type 2: The unconsolidated Quaternary sands in blind valley environments.
Type 3: The multiformation aquifer comprised of the weathered top of the Bokkeveld shale basement and the Alexandria pebble bed formation.
Type 4: The unconsolidated sands in the mobile dune belt.

Of the fourteen boreholes drilled, 4 were of Type 1, 5 of Type 2, and 4 of Type 3 (one borehole, GV 3 could not be completed and it was impossible to define the aquifer with certainity). No boreholes were drilled in the mobile dunes. The results from the drillings are shown in Tables 6 and 7.
The Hypothesis is rejected.

Hypothesis 2: The base of the aquifer is formed by the unweathered bedrock horizon of the seaward inclined slope of the pre Cretaceous erosion surface.

In all the boreholes drilled into the basement, no further water was struck once drilling proceeded deeper than the unweathered zone in the basement. Although the unweathered rock may have been saturated, it's low permeability excludes the zone from being included into the aquifer. The hypothesis is accepted.

HYDRAULIC PROPERTIES OF THE AQUIFERS

Hypothesis 3: Higher yielding supplies result from boreholes penetrating Bokkeveld sandstones, rather than Bokkeveld shales.

During the aquifer testing the lowest yield obtained from a sandstone borehole was 0.6 l/s, whereas the shale borehole tested only yielded 0.046 l/s (see Table 8). Data collected during the borehole survey shows a range for shale boreholes from 0.12 l/s to 3 l/s. Most of the yields obtained during the borehole survey were estimated during short term pump tests undertaken after drilling and are probably gross over estimates. Previous workers (Mountain, 1962; Meyer, 1971; Marais, 1962) have commented that yields of over 0.5 l/s are unusual for shales. High yields obtained from shales are probably associated with a thick Alexandria formation pebble bed.
The Hypothesis is accepted.

Hypothesis 4: The aquifer(s) shows differences in hydraulic properties in a horizontal direction.

Study of borehole logs (in the Appendix) shows that great variations occur between the different aquifers and within each aquifer type. Data from the boreholes drilled, shows that the shale aquifers are the thinnest (average thickness = 4m), followed by the sands (average thickness = 7m), while the sandstones are the thickest of all three (average thickness = 8m). Transmissivities vary greatly between the three aquifers. The average values for the respective aquifers are; (see Table 9)

Sandstones = $187m^2$/day
Shales = $3.5m^2$/day
Dune and blind valley sands = $6.2m^2$/day (underestimate - probably $50m^2$/day).

Within each aquifer variations in both thickness and transmissivity occur. In sands the aquifer depth depends on;

(1) thickness of sands;
(2) availability of recharge water (Blind valley aquifers may dry up during dry seasons).

The transmissivity variations in the sands are related to the degree of cementation. The variation in the thickness of the shale and sandstone aquifers probably depends on the degree of weathering and fracturing. The

thickness of the shale aquifer also depends on the thickness of any existing pebble bed, since any pebble bed occurring greatly improves the yield of boreholes drilled into the shale basement. Transmissivity variation in the sandstones are also probably related to the degree of weathering and fracturing, while in the shale/pebble bed aquifer the principle influence on transmissivity is probably the existence or not of the pebble bed formation. The existence of a pebble bed would probably result in a higher transmissivity than for a pure weathered shale.
The hypothesis is accepted.

HYDROCHEMISTRY OF GROUNDWATER

Hypothesis 5: Groundwater quality in the blind valley sand aquifers will be affected by the quality of the surface water in the area.

In both blind valley sand aquifers the T.D.S. of the groundwater is fairly high, varying from 2539 mg/l behind Bushmans River Mouth to 8129 mg/l inland of Diaz Cross. In both cases the T.D.S. of the rivers feeding the pans in the blind valleys, matches closely the T.D.S. in the groundwater. The T.D.S. of the respective surface supplies are: inland of Diaz Cross = 8100 mg/l
inland of Bushmans River Mouth = 2400 mg/l (Klipfontein River).

Concentration by evaporation in the pans probably also serves a role in the accumulation of certain ion concentrations in the groundwater. The groundwater seeping out along the coastline seaward of the blind valleys has a much lower T.D.S. content than the blind valley sand aquifer concentrations. This is probably a result of dilution of blind valley sand aquifer groundwater by the groundwater contained in the shifting dune beld. It is theorized that a considerable quantity of "fresh" groundwater exists in this shifting dune belt - the groundwater being recharged mostly by precipitation directly onto the dune belt. Recharge of the dune belt by groundwaters flowing seawards through the low transmissivity shale aquifer is of less importance.
The hypothesis is accepted.

Hypothesis 6: Bokkeveld sandstone aquifers will have a less mineralized groundwater than Bokkeveld shale aquifers.

The average T.D.S. contents from five sandstone and six shale aquifers penetrated during drilling was 1264 mg/l and 1871 mg/l respectively, while the range in T.D.S. within each aquifer was;

Sandstones: 1049 mg/l to 1585 mg/l
Shales: 1641 mg/l to 2105 mg/l.

The reasons for the lower mineralization in sandstone aquifers than in the shale aquifers is:

(1) Greater permeability of sandstones, thus allowing more flushing and greater dilution of marine water trapped in the sandstone. Marine water may be trapped in the Bokkeveld rocks during actual deposition in marine depositional basins or during later marine transgressional periods (i.e. when the Alexandria formation is deposited on top of the Bokkeveld rocks).
(2) Lower porosity of sandstone - thus less marine water was trapped in the aquifer.
(3) A less saline deltaic depositional environment for sandstones than for the shales, which were deposited in an off-shore environment.
(4) Greater mineralization of the shale rocks than of the sandstones - during weathering of the rocks more salts are taken into the groundwater in shales than in sandstones.

Based on the above data the hypothesis would be accepted.

CHAPTER 9

CONCLUSIONS

This section summarizes the results from Chapter 7.

9.1 GROUNDWATER DISTRIBUTION

There were four environments in which groundwater was found;

(1) In the weathered zone at the top of the Bokkeveld sandstone basement.
(2) In an aquifer system comprised of weathered sections of the basement Bokkeveld shale and the overlying pebble bed horizon.
(3) In unconsolidated and semi-consolidated sands overlying the Bokkeveld basement in blind valley environments.
(4) In sands of the mobile dune belt.

Groundwater is being held in storage in the interstices between the grains (most important in the sands and the pebble bed horizon), and in the fissures and weathering fractures (especially important in the sandstones, and to a lesser degree in the shales). The zones of weathering at the top of the Bokkeveld basement vary in thickness between 20m (Bos 4) to under 1m (KF 2 and KF3). In general sandstones are more deeply weathered than shales. In sandstones the borehole yield appears directly related to the thickness of weathered material.

9.2 AQUIFER YIELD

During the aquifer testing the only boreholes that could be pumped at over 1000 ml/s were BOS 4, GV 1, GV 2, RMD 3 and RMD 4 - all boreholes drilled into, or influenced by, sandstone. The two different sand aquifers, under saturated conditions, yield between 500 - 2000 ml/s, while all the boreholes drilled into shale during this study, yielded below 250 ml/s. In terms of supply the shale aquifer appears of low value while the sandstone and both sand aquifers can yield fairly substantial quantities of water. It must however be remembered that the blind valley sand aquifer is dependent on infiltration from the nearby pans which result from periods of high rainfall. Once the pans dry up, infiltration will stop and the storage in the sands would decrease as groundwater flows coastwards along the Bokkeveld basement.

9.3 GROUNDWATER QUALITY

The data in Chapter 7 shows that both the shale and blind valley sand aquifers are totally unsuitable as supplies for domestic use, because the salinity of the water is high, with a concentration exceeding the maximum allowable S.A.B.S. limit. The sandstone aquifer, although exceeding recommended limits for Cl, T.D.S. and T.A.L., is within maximum allowable limits, and is the most suitable of all the aquifers for domestic water supply. The dune sand supply is less mineralized than the shale and blind valley sands, but is still more saline than the sandstone supplies.

The quality of the water obtained from the Bokkeveld basement rocks appear directly related to the transmissivity and thus the borehole yield. It might be possible in the future to obtain some indication of yield by studying the water quality.

Any search for groundwater supplies in the Bushman's River/Cannon Rocks area should concentrate on conditions where the sands overlie Bokkeveld sandstones. The geological conditions found in this study area are duplicated along other areas of the Eastern Cape coast between Port Elizabeth and East London. The geohydrological results obtained during this study probably also apply to the remainder of the Port Elizabeth - East London coastal strip.

9.4 RECOMMENDATIONS

(1) This study has attempted to formulate an understanding of the coastal strip, up to 4 kms inland, but has not analysed the actual beach zone in detail. A study is necessary to evaluate the groundwater potential of the zone extending from the first vegetated dune to the shoreline. This zone is known to contain groundwater supplies but difficult working conditions have up until now prohibited any detailed work.

(2) The automatic water level recorders should be moved to monitor water level variations in the dune aquifer at Bushman's River Mouth and in the sandstone aquifer at Cannon Rocks.

(3) The dune sand should be carefully analysed (sieve analysis, etc) so that proper well construction can be undertaken in the dunes using gravel packs and screens.

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APPENDICES

APPENDIX A - BOREHOLE SURVEY

APPENDIX B - BOREHOLE LOGS

APPENDIX C - RESISTIVITY CURVES

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APPENDIX E - AQUIFER TEST CURVES

APPENDIX F - HYDROCHEMICAL DATA

APPENDIX A - BOREHOLE SURVEY

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE	TDS	ABSTRACTION QUANTITIES gp year	COLLAR ELEVATION (MAP)	GROUNDWATER LEVEL DATE	DEPTH BELOW COLLAR	HEIGHT ABOVE SEA-LEVEL	BOREHOLE DEPTH
BRM1	Bushmans River Mouth Municipality	Domestic	Electric Centrifuges	2400	2500 5/3/81 883 21/11/72	4050000	9.0m	5/3/81	3.0m	6.0m	4.0m
	WELL PUMPED 15 HOURS DAILY ON A 3 MONTHLY ALTERNATING BASIS WITH BRM 2. CHEMICAL ANALYSES FOR THIS WELL EXIST.										
BRM2	Bushmans River Mouth Municipality	Domestic	Electric Centrifuge	2200	2100 5/3/81	3240000	9.5m	5/3/81	3.69m	5.81m	5.25m
BRM3	Bushmans River Mouth Municipality	Unused	None		4400 5/3/81		9.0m	5/3/81	1.93m	7.07m	4.78m
KF1	Klipfontein C J Besenger	Unused	None	96 gph	2100 5/3/81		35.0m	22/5/5- 5/3/81	26.76m 20.91m	8.24m 14.09m	123.3m
	B/H LOG EXISTS - No S7164. B/H CAVED IN AND THE PIPES WERE EXTRACTED										
KF2	Klipfontein C J Besenger	Unused	None	200 gph			35.62m (Levelling not map)	-/8/79	21.42m	14.2m	27.0m
	B/H SILTED UP AND HAS SINCE BEEN BLOCKED UP COMPLETELY										
KF3	Klipfontein C J Besenger	Stock	Mono	1800 gph 5/3/81	3050 23/1/81 2950 5/3/81		23.11m (From levelling not map)	23/1/81	21.53m	1.57m	31.0m
DB1	Dagbreek S P Fourie	Unused	WP	266 gph 4/7/51 200 gph -/8/79	4500 5/3/81 1500 -/8/79		42.0m	4/7/57 5/3/81 -/8/79	19.69m 22.62m	22.31m 19.38m	67.07m 55.0m
	THE B/H LOG EXISTS (No 44121)										
DB2	Dagbreek S P Fourie	Stock	WP	84.5 gph 19/7/51	5400 5/3/81		32.3m	19/7/51 5/3/81	22.15m 34.26	10.15m. -1.96m	65.23m
	GEOL. LOG EXISTS (No 44290)										

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE	TDS	ABSTRACTION QUANTITIES gp year	COLLAR ELEVATION (FROM MAP)	GROUNDWATER LEVEL DATE	GROUNDWATER LEVEL DEPTH BELOW COLLAR	GROUNDWATER LEVEL HEIGHT ABOVE SEA-LEVEL	BOREHOLE DEPTH
NG1	Nooitgedacht M J Fourie	Stock	Windpump		6800 - 10/3/81		12.3m	10/3/81	7.39m	4.91m	36.9m
NG2	Nooitgedact M J Fourie	Unused	Windpump		2800 10/3/81		6.15m	10/3/81	3.0m	3.15m	3.0m
	WINDPUMP ACTUALLY PUMPS SURFACE WATER FROM THE VLEI INTO RESERVOIRS										
NG3	Nooitgedacht M J Fourie	Unused	Windpump		5200		6.15m	10/3/81	2.15m	4.0m	2.15m
	WATER PUMPED FROM MORE STAGNANT PART OF THE VLEI THAN AT NG2										
NG4	Nooitgedacht M J Fourie	Stock	Windpump	60 gph	1800 10/3/81		10.0m	10/3/81	18.36	-8.36m	52.30m
NG5	Nooitgedacht M J Fourie	Stock	Mono	1000 gph	8000 10/3/81		11.0m	10/3/81	1.54m	9.46m	24.6m
RM1	Richmond Municipality	Not used	Windpump	2600 gph -/8/67	1136 -/8/79 1000 -/7/70 1100 -/9/75		10.0m	11/3/81	7.18m	2.82m	18.5m
RM2	Richmond Municipality	Not used	None	1350 gph 28/11/67			11.0m	28/11/67 11/ 3/81	6.76 6.64	4.24m 4.36m	32.9m 30.13m
	THE TOP 12 - 12.5m CONSISTS OF SAND, WHILE THE UNDERLYING MATERIAL IS BOKKEVELD SHALE										
RM3	Richmond Municipality	Not used	None	433 gph 14/5/74			15.30m	2/5/74 11/3/81	6.77m 5.0m	8.63 10.40	62.7m
	THE B/H HAS FALLEN IN OR BEEN BLOCKED UP IN THE LAST 5 YEARS AND IS NOW ONLY 6m DEEP. THE BOKKEVELD SHALES OCCUR 30m BELOW THE SURFACE										
R1	Richmond E H Howarth	Not used	None				27.0m	11/3/81			7.84m
	B/H HAS BOTH DRIED UP AND FALLEN IN										
R2	Richmond E H Howarth	Stock	Windpump		2500 11/3/81		15.4m	11/3/81	12.39m	3.01	18.7m
R3	Richmond E H Howarth	Not used	None				14.0m	11/3/81			12.26

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE	TDS	ABSTRACTION QUANTITIES gp year	COLLAR ELEVATION (FROM MAP)	GROUNDWATER LEVEL DATE	DEPTH BELOW COLLAR	HEIGHT ABOVE SEA-LEVEL	BOREHOLE DEPTH
S1	Stillwater S Bakkes	Stock	Mono	3000 gph	3000 12/3/81	880 000	30.76m	12/3/81	44.6m (suspect)	-13.84	48.0m
S2	Stilwater S Bakkes	Stock	Windpump	350gph	5000 12/3/81		38.5m	12/3/81	27.22m	11.28,	47.54m
CR1	Cannon Rocks Township	General (not drinking)		14000gph 3/7/67 1000gph 29/1/71	2600 suspect 29/1/71 992 -/8/79		38.55m	3/7/69 29/1/71 -/8/79	30.07m 29.85m 32.7m	8.48m 8.7m 5.85m	36.3m 35.69m
	TWO SETS OF CHEMICAL ANALYSES EXIST - FOR 22/8/75 AND 15/7/75										
CR2	Cannon Rocks Township	General (not drinking)					35.92m	-/8/79			55.0m
	CHEMICAL ANALYSES EXIST FROM 24/8/75										
MP1	MIDDLEPLAAS J C Potgieter	Not used	None		2700 12/3/81		35.0m	-/8/79 12/3/81	32.42m 33.32m	2.58m 1.68m	44.68m
	YIELD NOT KNOWN BUT THOUGHT TO BE IN EXCESS OF 2000 gph										
MP2	Middleplaas J C Potgieter	Stock	Mono	3000gph 1960 2080gph 29/4/65	2200 12/3/81	365000	62.0m	29/4/65 29/1/71 -/8/79 12/3/81	42.15m 42.15m 41.02m 40.82m	19.85m 19.85m 20.98m 21.18m	46.15m 46.15m 44.70m
	THE B/H HAS ONLY BEEN DRILLED TO THE BOKKEVELD/SANDS CONTACT										
MP3	Middleplaas J C Potgieter	Not used	None				107.0m	12/3/81			82.0m
	B/H WAS 112.0m DEEP BUT HAS SINCE FALLEN IN AND IS NOW ONLY 82.0m DEEP AND ALSO DRY										
MP4	Middleplaas J C Potgieter	Stock	Mono	1200gph	2900 12/3/81	1 040 000	108.0m	12/3/81	98.5m	9.5m	110.0m
BM1	Balmoral J Gilfillan	Stock	Diesel	240gph	4700 17/3/81	730 000	134.0m	17/3/81	121.5m	12.5m	123.0m
	B/H YIELD DECREASES DURING DROUGHTS. DURING DRILLING WHITE POWDER (L'STN) WAS EXTRACTED BEFORE THE SHALE WAS STRUCK.										
V1	Vengrove W Scott	Stock	Mono		2900 17/3/81		84.6m	17/3/81	56.84m	27.77m	58.54m
	B/H IS VERY RELIABLE DURING DROUGHTS - YIELD NEVER CHANGES										

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE	TDS	ABSTRACTION QUANTITIES gp year	COLLAR ELEVATION (FROM MAP)	GROUNDWATER LEVEL			BOREHOLE DEPTH
								DATE	DEPTH BELOW COLLAR	HEIGHT ABOVE SEA-LEVEL	
TG1	THE GLADE G J Smith	Stock	Mono		2600 17/3/81	65 700	110.76m				91.30m
	NO SEASONAL OR LONG TERM FLUCTUATIONS IN YIELD OR QUALITY										
RF1	RUSTFONTEIN D Pullen	Unused	Windpump	122 gph			138.5m	17/3/81 29/1/71	86.17 86.15	52.33 52.35	89.06 129.2m
	LOG EXISTS (No 83525) BASE OF B/H. HAS FALLEN IN AND PIPES HAVE BEEN REMOVED										
RF2	RUSTFONTEIN D Pullen	Stock	Mono	350gph	2500 17/3/81		130.7m	17/3/81	79.32	51.38	96.45m
GD 1	GLEN DYE A J Neave	Stock	Submersible	850gph 8/11/62	2700 17/3/81		135.4m	17/3/81 8/11/62	91.9m 86.15	43.5m 49.25m	129.2m
	B/H LOG EXISTS (NUMBER 99027). THE B/H SINCE IT WAS DRILLED FOR STOCK, COULD ONLY BE TESTED BY THE GOVERNMENT DRILLER, UP TO 850gph PRIVATELY THE B/H HAS BEEN PUMPED AT 1800gph										
GD 2	GLEN DYE A J Neave	Unused	None	200gph			138.5m				84.0m
	B/H HAS FALLEN IN AND IS NOW DRY										
	CAPE PADRONE (SPRINGS) Alexandria Municipality	General	Submersible	6015gph October '80 8500gph 19/3/81	427 573 13/2/62 540 19/3/81	74 460 000	3.0m				
	SPRINGS HAS TWO PARTS TO ITS WATER SUPPLY (SEE MARAIS, 1962). ONE PART DELIVERS 6 000gph, THE OTHER GIVES 2 500 gph. THE TOTAL OF 8 500 gph IS IN FACT A MINIMUM CAUSED BY THE PAST DROUGHT. THE SPRINGS REACT TO RAINFALL 6 MONTHS LATER.										
TD 1	TIMBIDOLA Dr Heimsted	Stock	Mono		2300 18/3/81	584 000	169.2m	18/3/81	116.9m	52.33m	141.5m
	THE WATER WAS STRUCK JUST BEFORE A "PEBBLE BED" OVERLYING THE BOKKEVELD										

APPENDIX B - BOREHOLE LOGS

DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: BOS 1

LOCATION: MIDDLEPLAAS

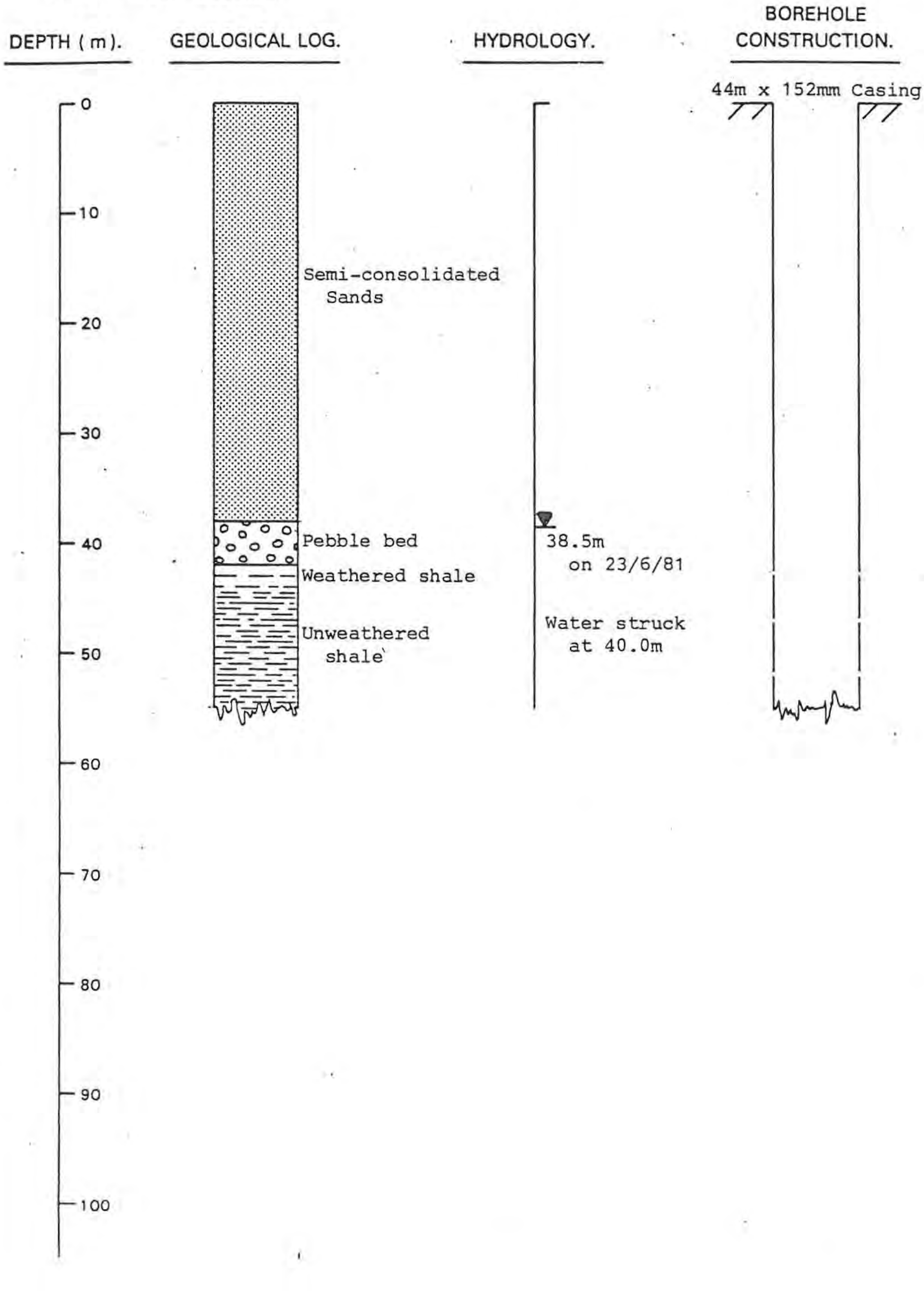
DRILLING STARTED: 26/5/81

DRILLING FINISHED: 23/6/91

WATER QUANTITY: 200mℓ/sec

WATER QUALITY: 230 mS/m

DRILLER: MR VELDSMAN



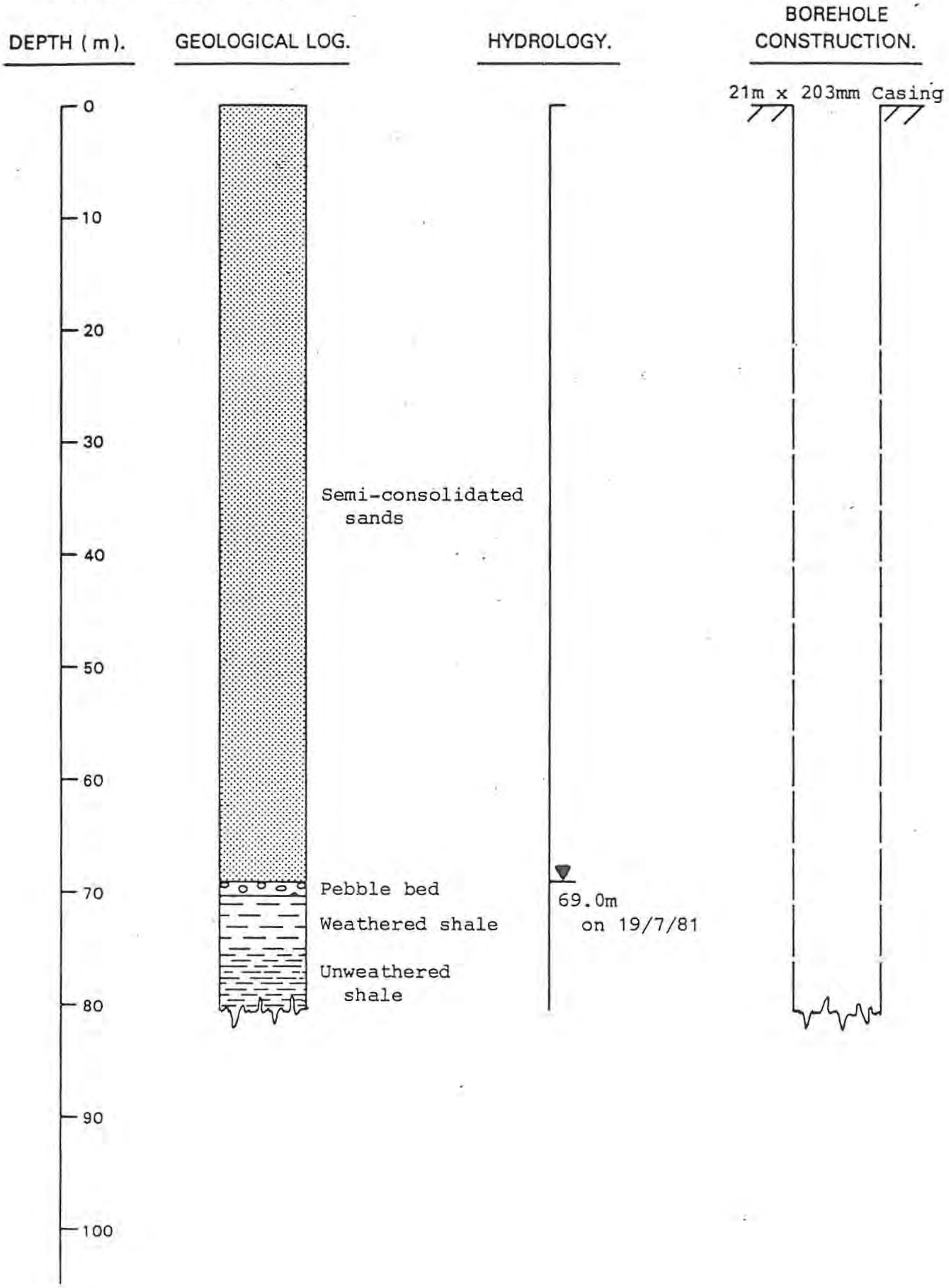
DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: BOS 2
LOCATION: MIDDLEPLAAS

DRILLING STARTED: 26/6/81
DRILLING FINISHED: 20/7/81

WATER QUANTITY: 250mℓ/sec
WATER QUALITY: 230 mS/m

DRILLER: MR VELDSMAN



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: BOS 3

LOCATION: MIDDLEPLAAS

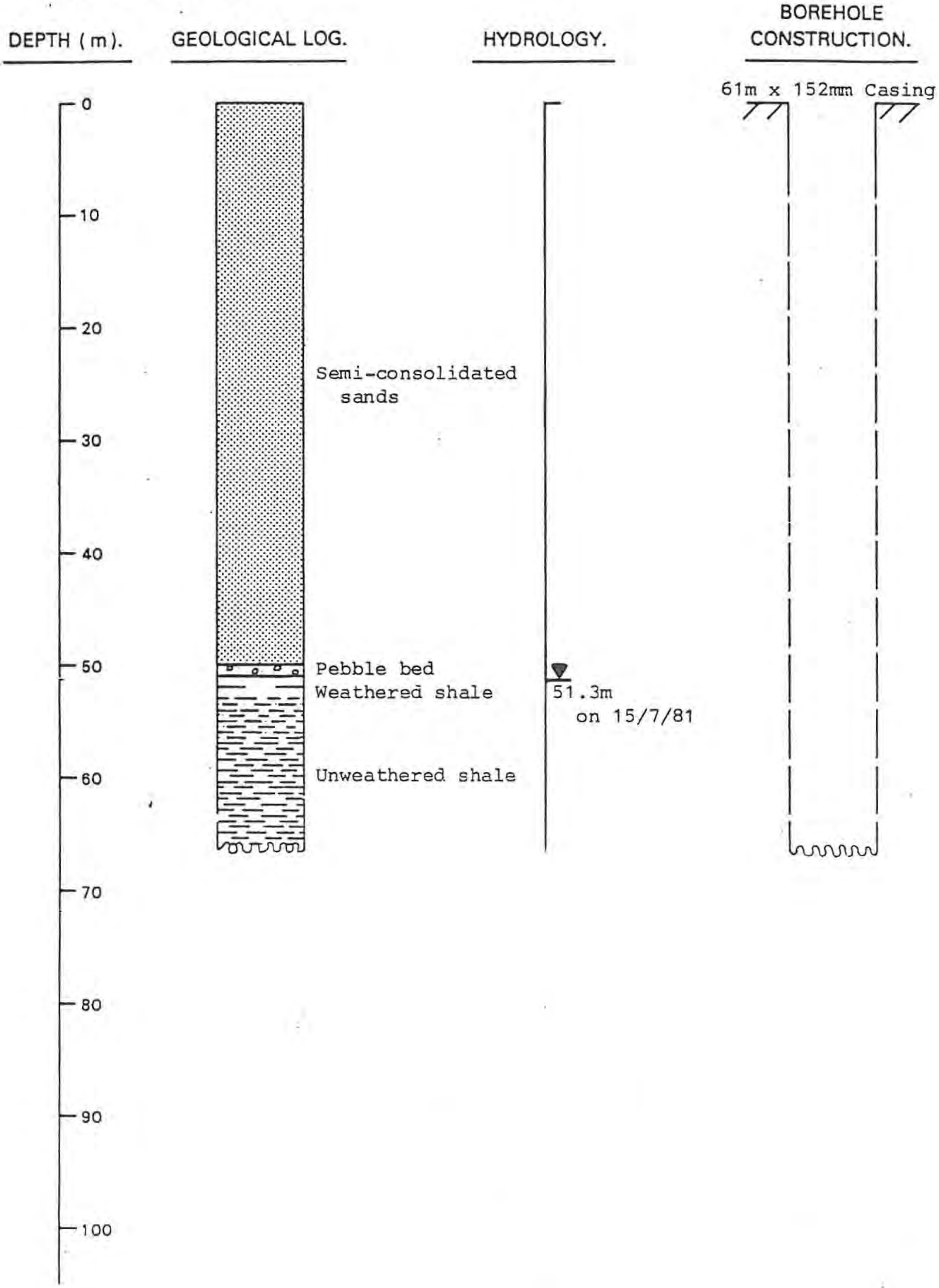
DRILLING STARTED: 6/7/81

DRILLING FINISHED: 16/7/81

WATER QUANTITY: 30-50mℓ/sec

WATER QUALITY: 280 mS/m

DRILLER: MR MATYS



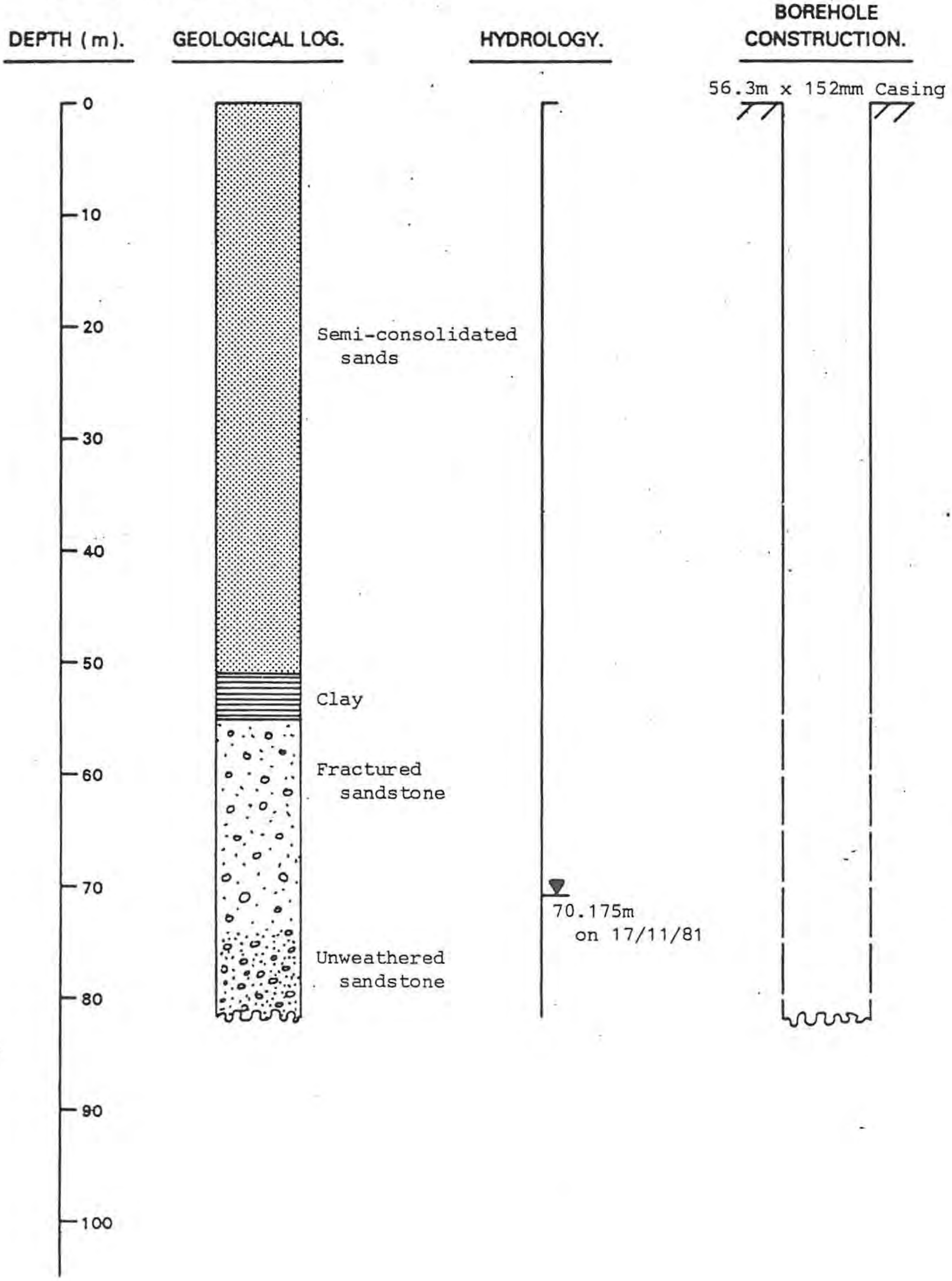
DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: BOS 4 **LOCATION:** MIDDLEPLAAS

DRILLING STARTED: 22/7/81 & 29/10/81 **DRILLING FINISHED:** 27/8/81 & 17/11/81

WATER QUANTITY: 6800 mℓ/sec **WATER QUALITY:** 187 mS/m

DRILLER: MR VELDSMAN and MR MATYS



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: GV 1

LOCATION: CAPE PADRONE

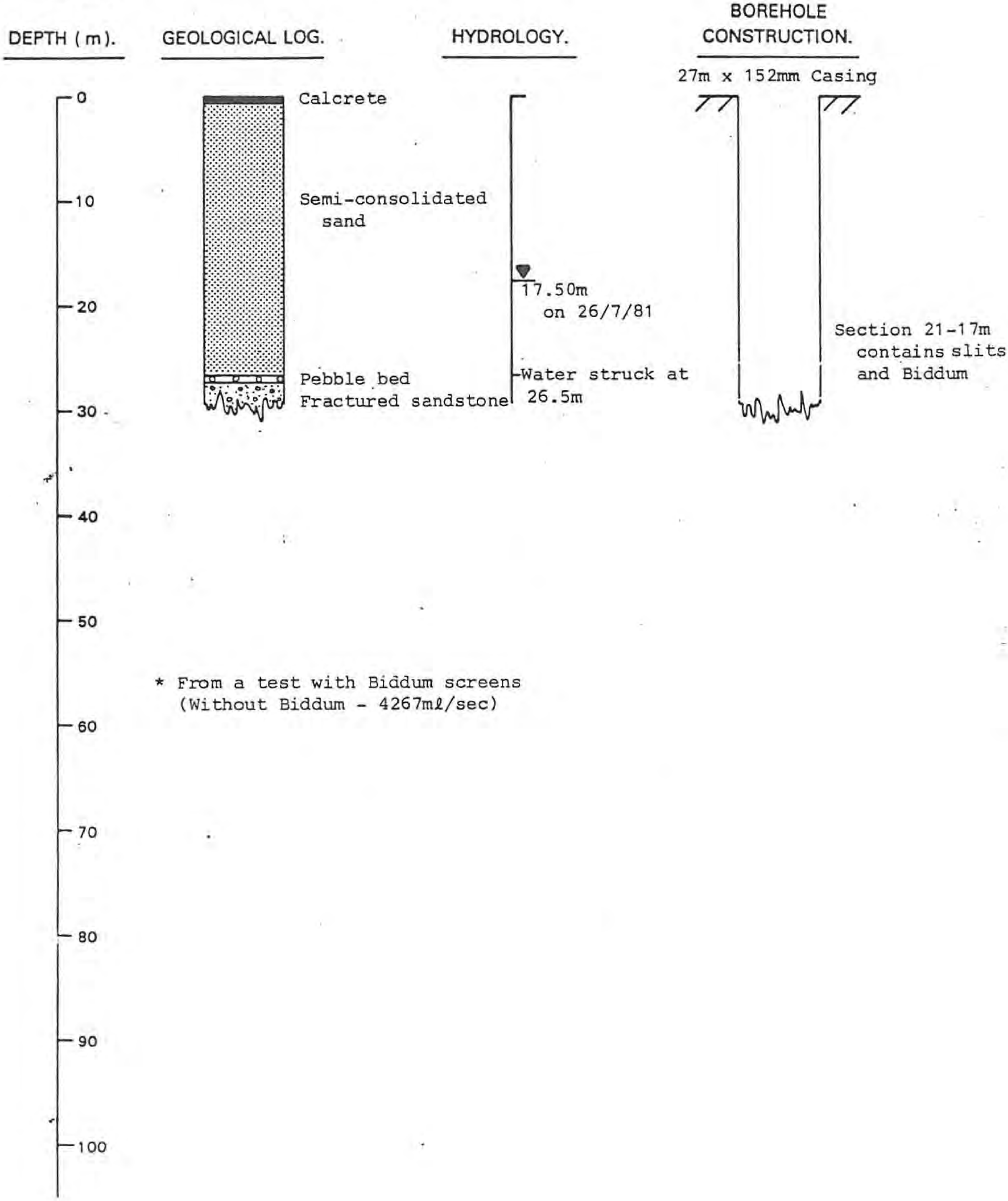
DRILLING STARTED: 20/7/81

DRILLING FINISHED: 28/7/81

WATER QUANTITY: 284mℓ/sec*

WATER QUALITY: 130 mS/m

DRILLER:



* From a test with Biddum screens
(Without Biddum - 4267mℓ/sec)

DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: GV 2

LOCATION: CAPE PADRONE

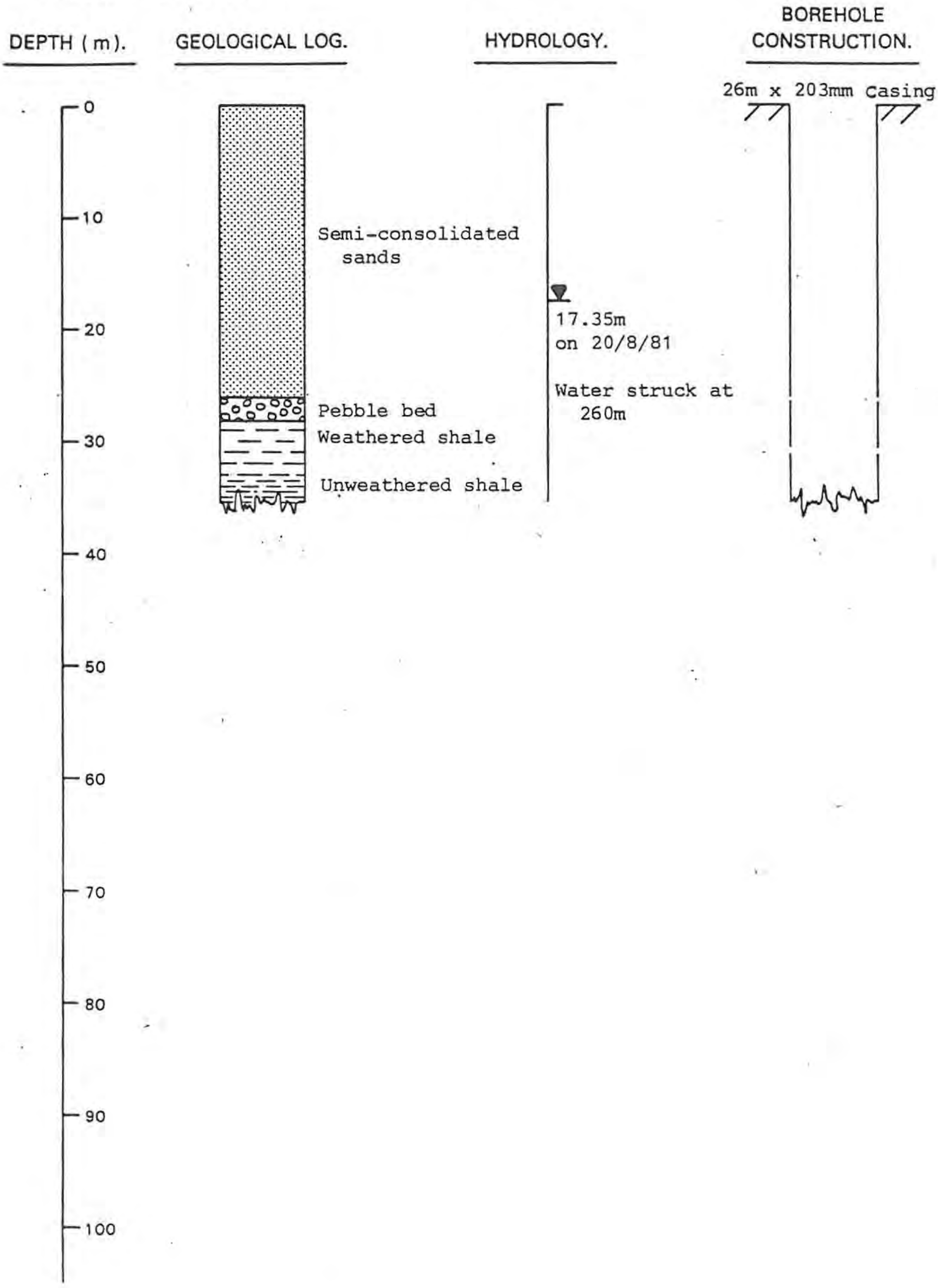
DRILLING STARTED: 5/8/81

DRILLING FINISHED: 20/8/81

WATER QUANTITY: 3400mℓ/sec

WATER QUALITY: 138 mS/m

DRILLER: MR MATYS



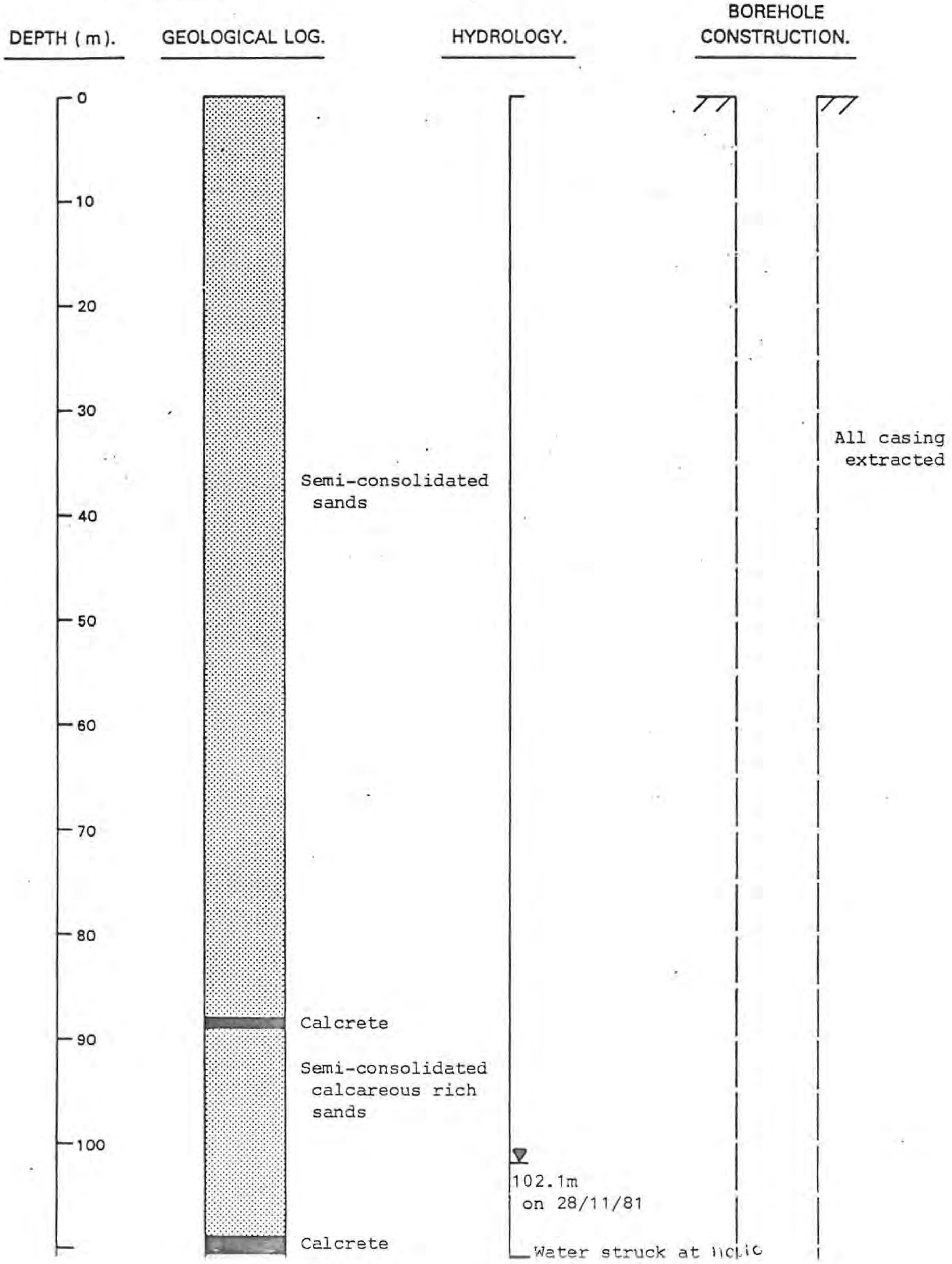
DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: GV 3 LOCATION: STELUICTION

DRILLING STARTED: 1/9/81 and 20/11/81 DRILLING FINISHED: 15/9/81 and 1/12/81

WATER QUANTITY: 800 mℓ/sec WATER QUALITY: NO SAMPLE

DRILLER: MR MATYS



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: KF 1

LOCATION: KLIPFONTEIN

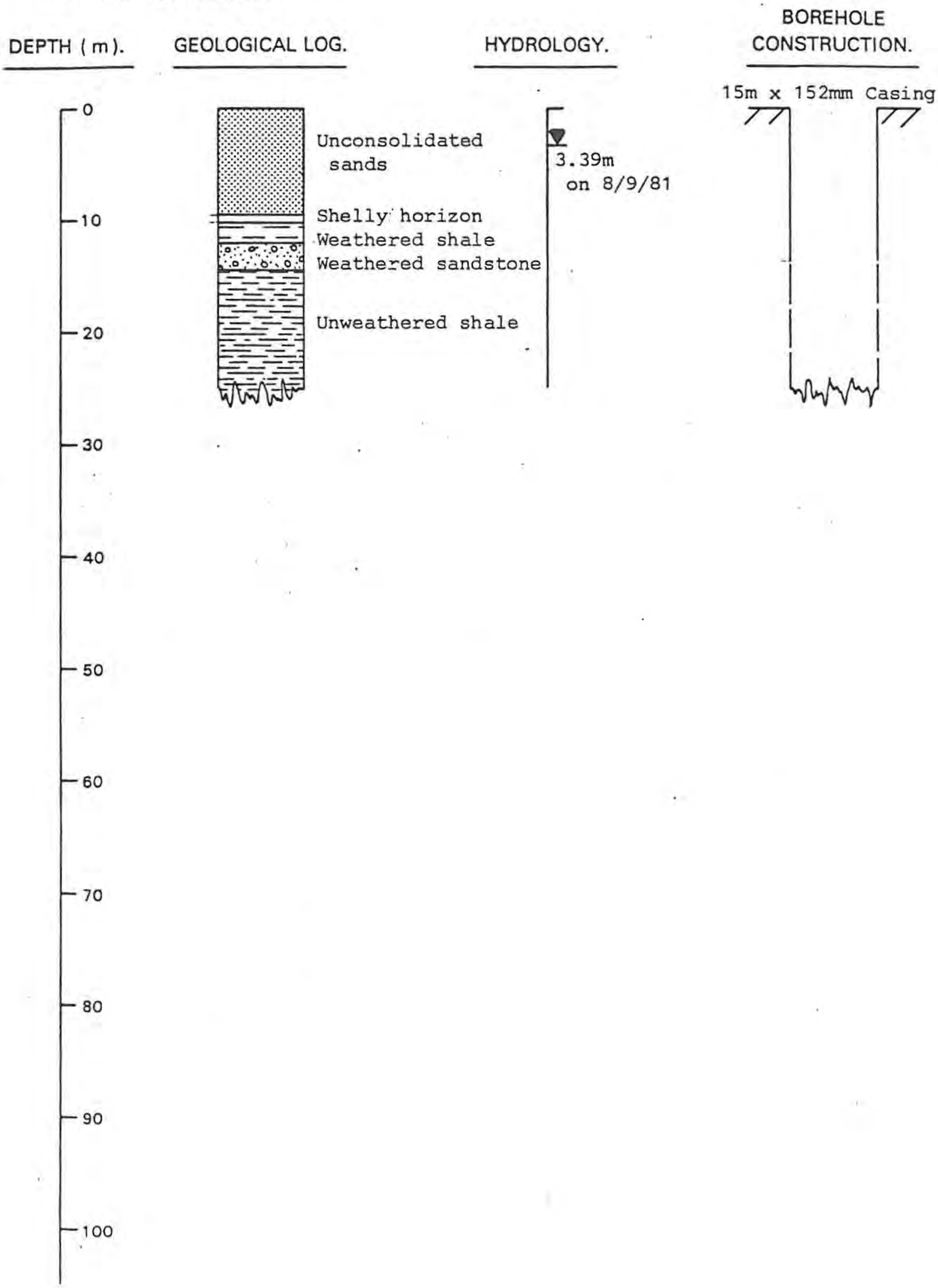
DRILLING STARTED: 28/8/81

DRILLING FINISHED: 8/9/81

WATER QUANTITY: 50mℓ/sec

WATER QUALITY: 305mS/m

DRILLER: MR VELDSMAN



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: KF 2

LOCATION: KLIPFONTEIN

DRILLING STARTED: 9/9/81

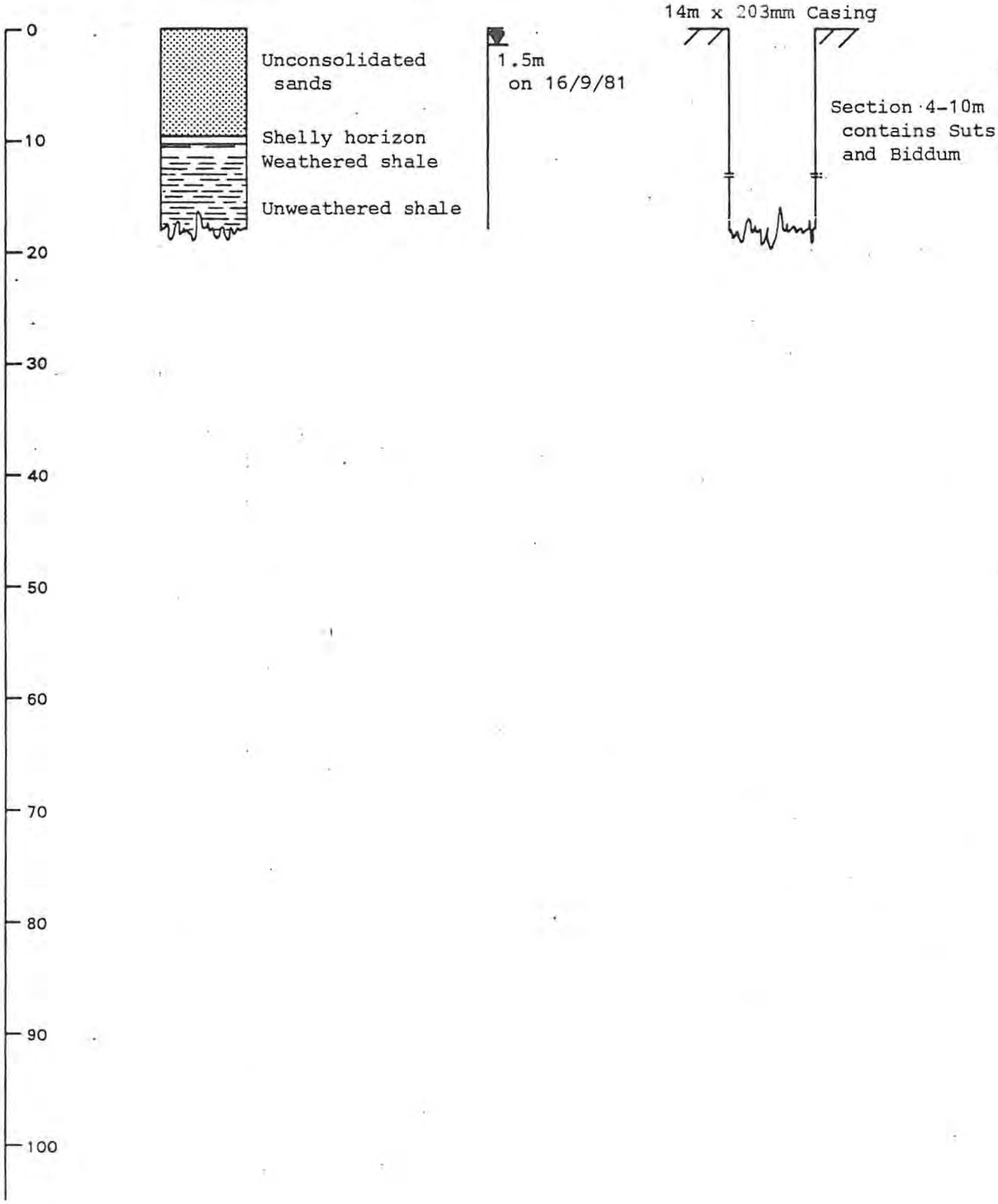
DRILLING FINISHED: 15/9/81

WATER QUANTITY: 1000mℓ/sec

WATER QUALITY: 250 mS/m

DRILLER: MR VELDSMAN

DEPTH (m). | GEOLOGICAL LOG. | HYDROLOGY. | BOREHOLE CONSTRUCTION.



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: KF 3

LOCATION: KLIPFONTEIN

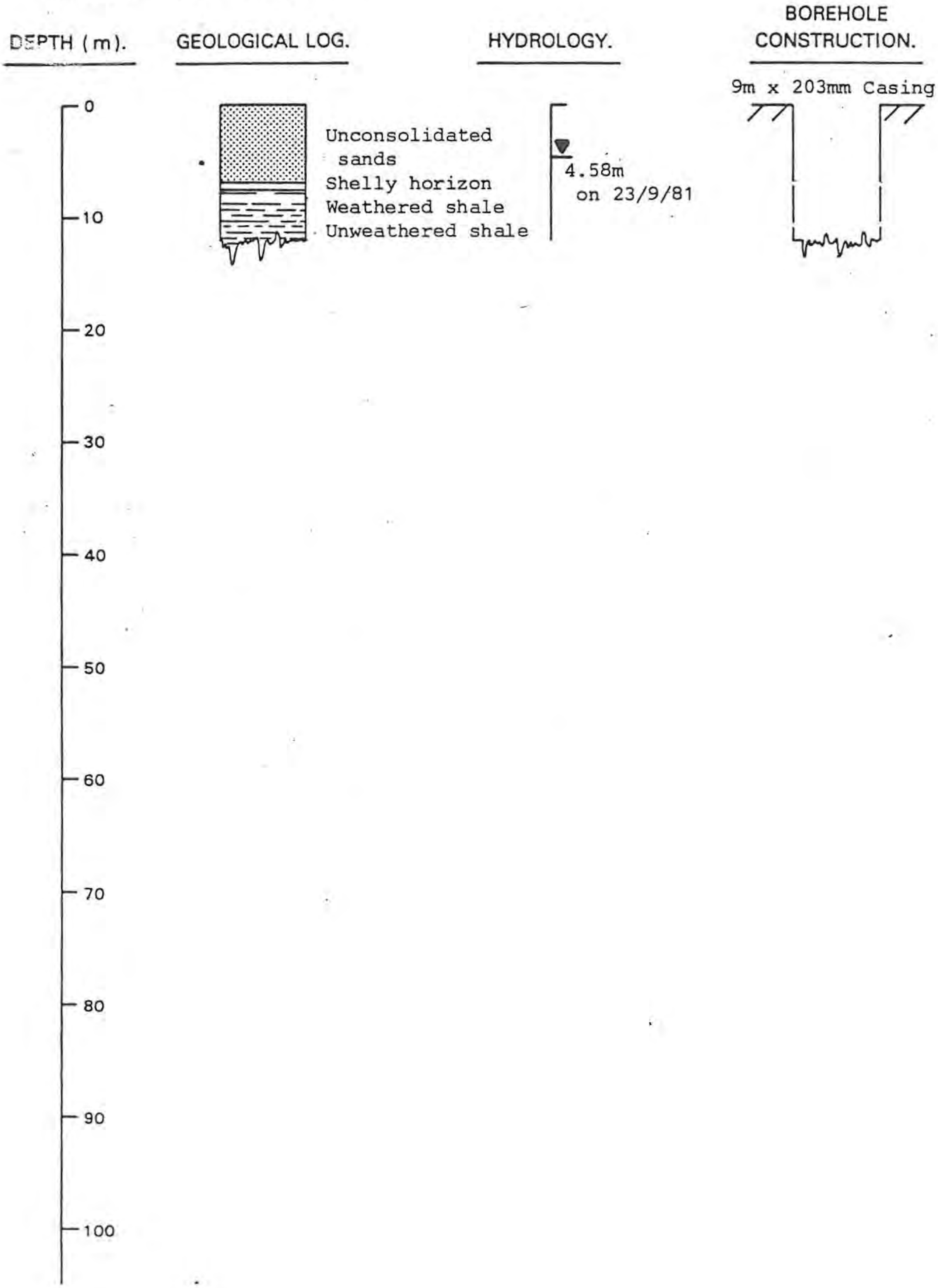
DRILLING STARTED: 16/9/81

DRILLING FINISHED: 17/9/81

WATER QUANTITY: 250mℓ/sec

WATER QUALITY: 380 mS/m

DRILLER: MR VELDSMAN



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: RMD 1

LOCATION: NOOITGEDACHT

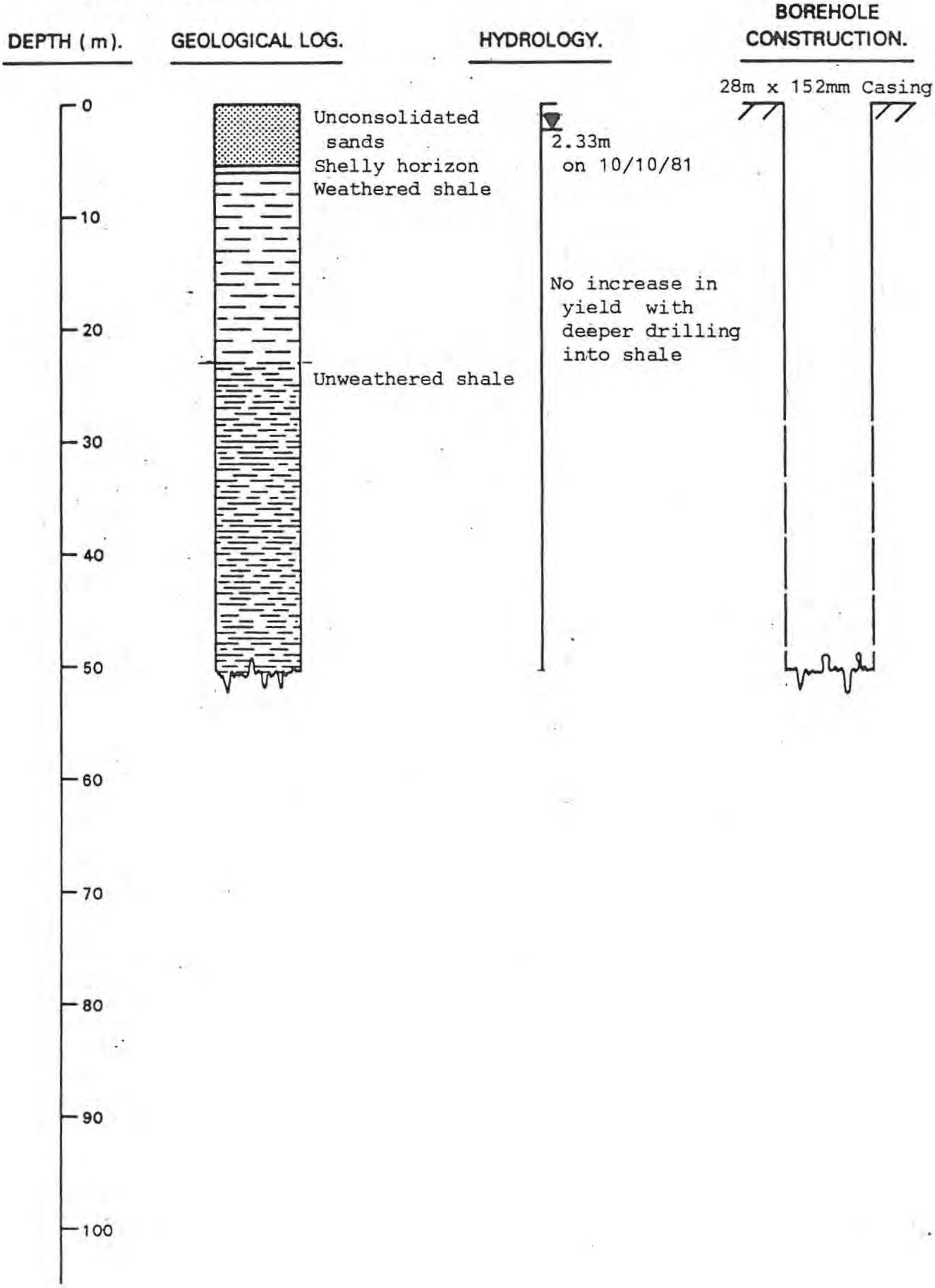
DRILLING STARTED: 16/9/81

DRILLING FINISHED: 7/10/81

WATER QUANTITY: 869mℓ/sec

WATER QUALITY: 830mS/m

DRILLER: MR VELDSMAN



DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: RMD 2

LOCATION: NOOITGEDACHT

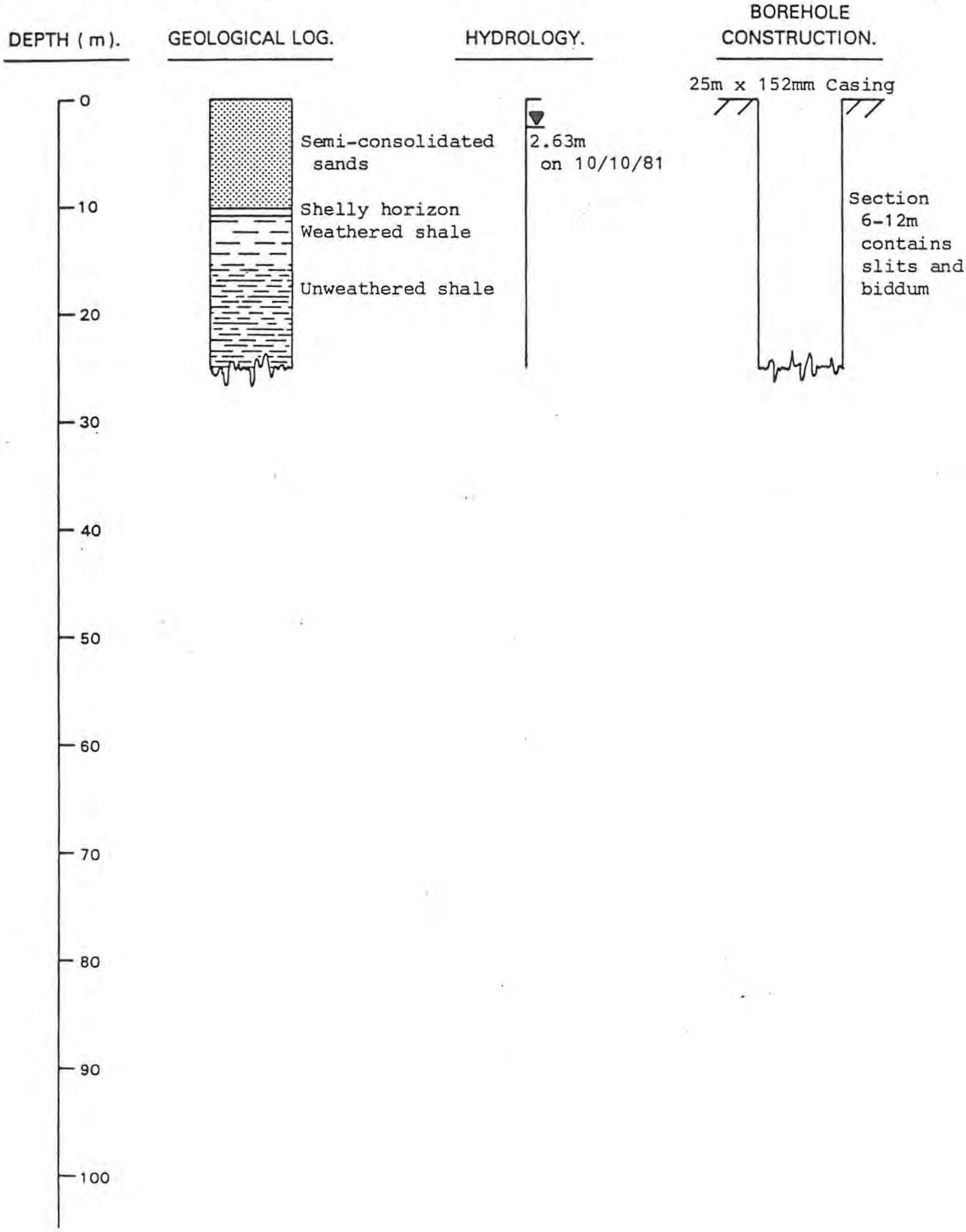
DRILLING STARTED: 8/10/81

DRILLING FINISHED: 6/10/81

WATER QUANTITY: 500mℓ/sec

WATER QUALITY: 650 mS/m

DRILLER: MR VELDSMAN



DIAGRAMATIC BOREHOLE LOG.

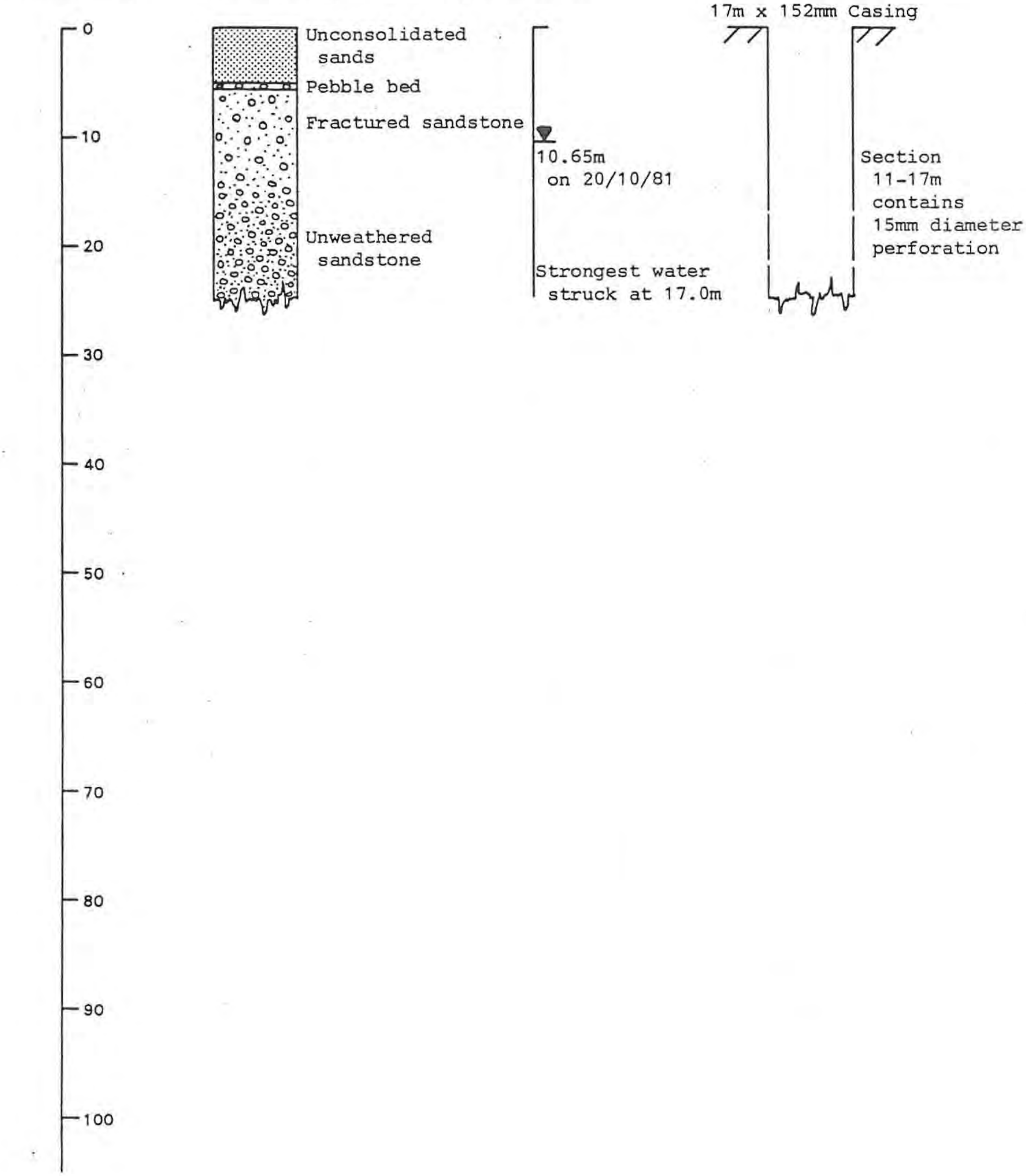
BOREHOLE No.: RMD 3 LOCATION: CANNON ROCKS

DRILLING STARTED: 6/10/81 DRILLING FINISHED: 21/10/81

WATER QUANTITY: 2562mℓ/sec WATER QUALITY: 210 mS/m

DRILLER: MR MATYS

DEPTH (m). GEOLOGICAL LOG. HYDROLOGY. BOREHOLE CONSTRUCTION.



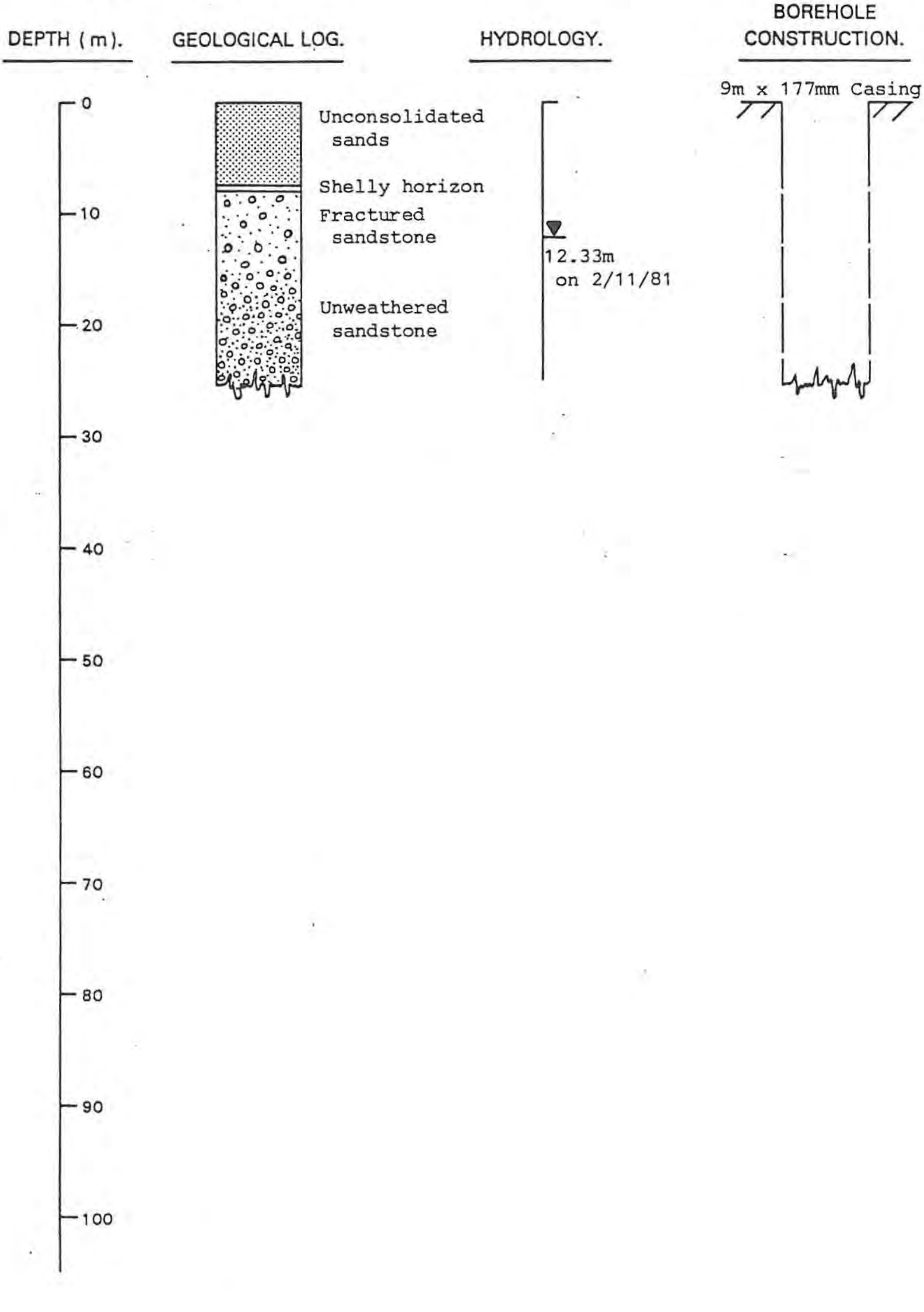
DIAGRAMATIC BOREHOLE LOG.

BOREHOLE No.: RMD 4 — LOCATION: CANNON ROCKS

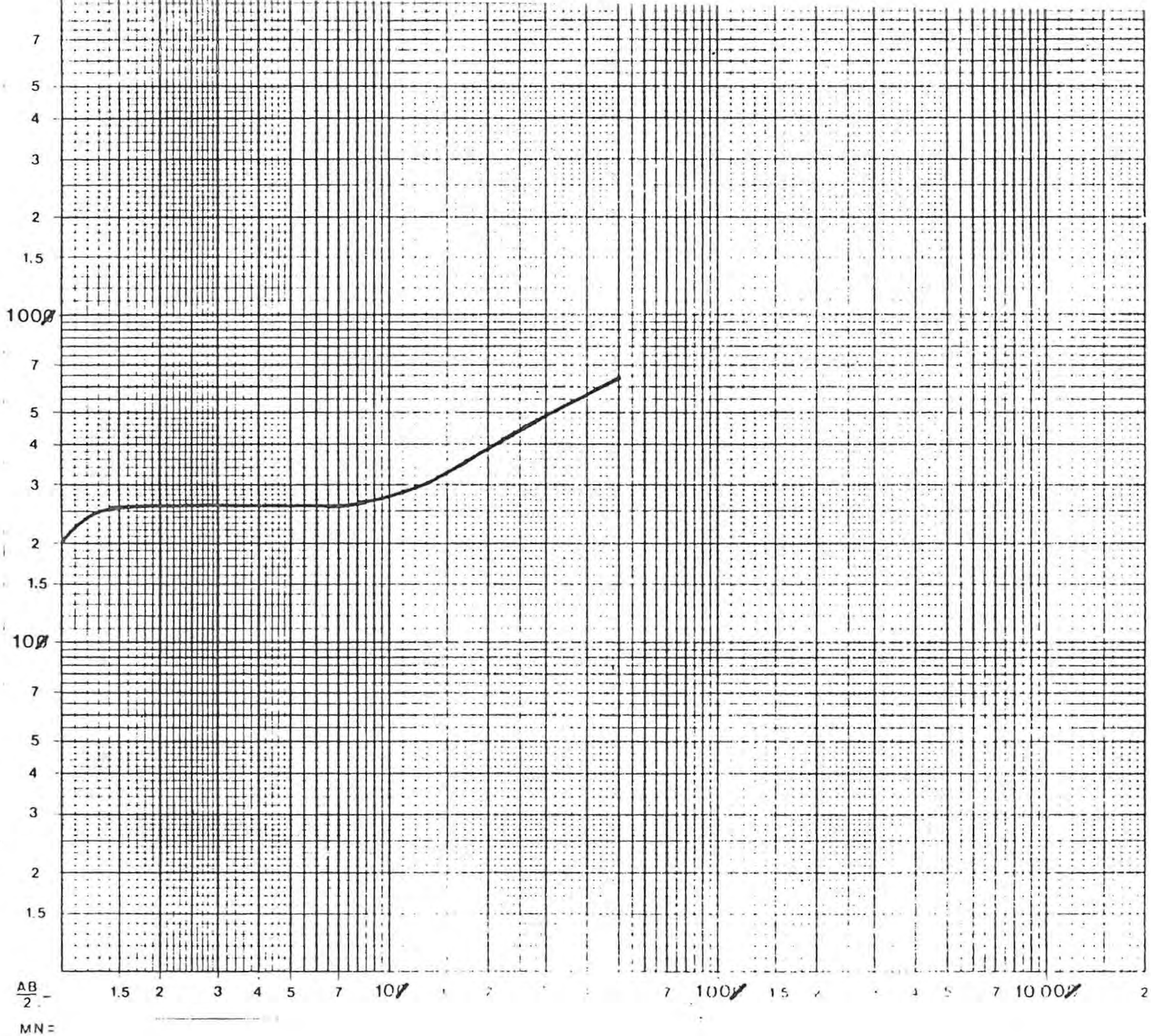
DRILLING STARTED: 22/10/81 — DRILLING FINISHED: 28/10/81

WATER QUANTITY: 1000mℓ/sec — WATER QUALITY: 195mS/m

DRILLER: MR MATYS

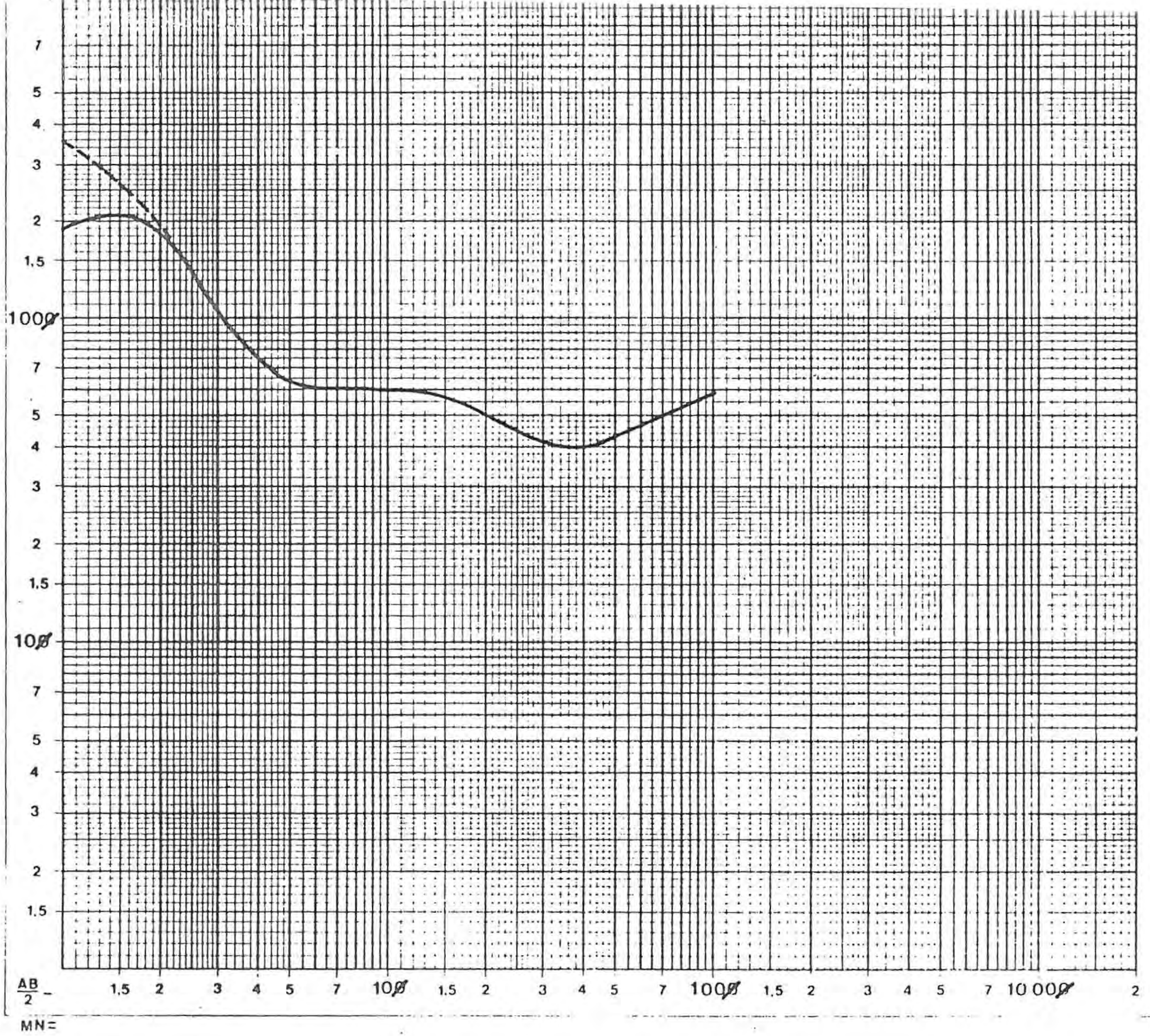


APPENDIX C - RESISTIVITY CURVES



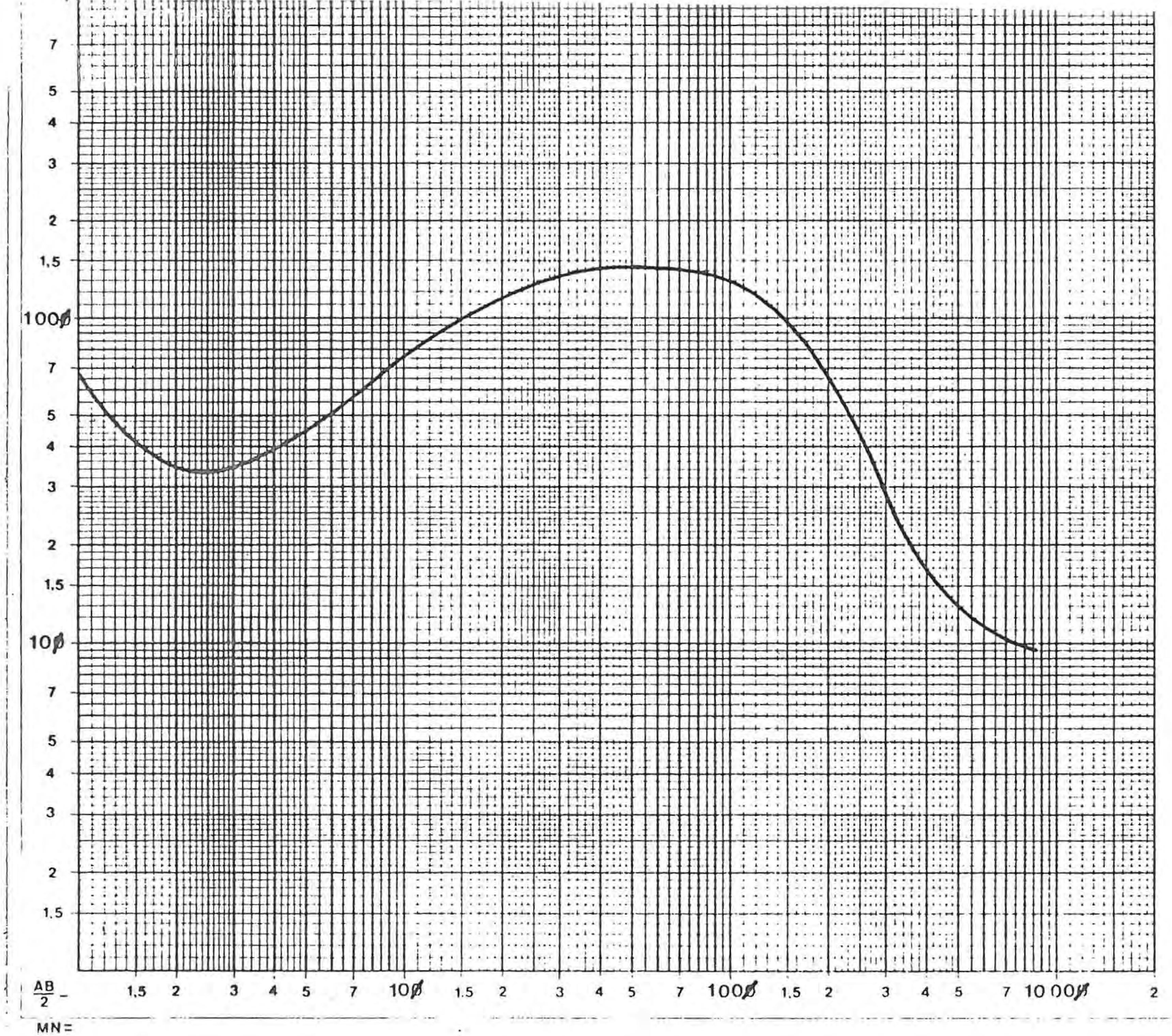
Opname - Survey
BUSHMANS RIVER MOUTH

E.S. No. 1/1



Opname - Survey BUSHMANS RIVER MOUTH

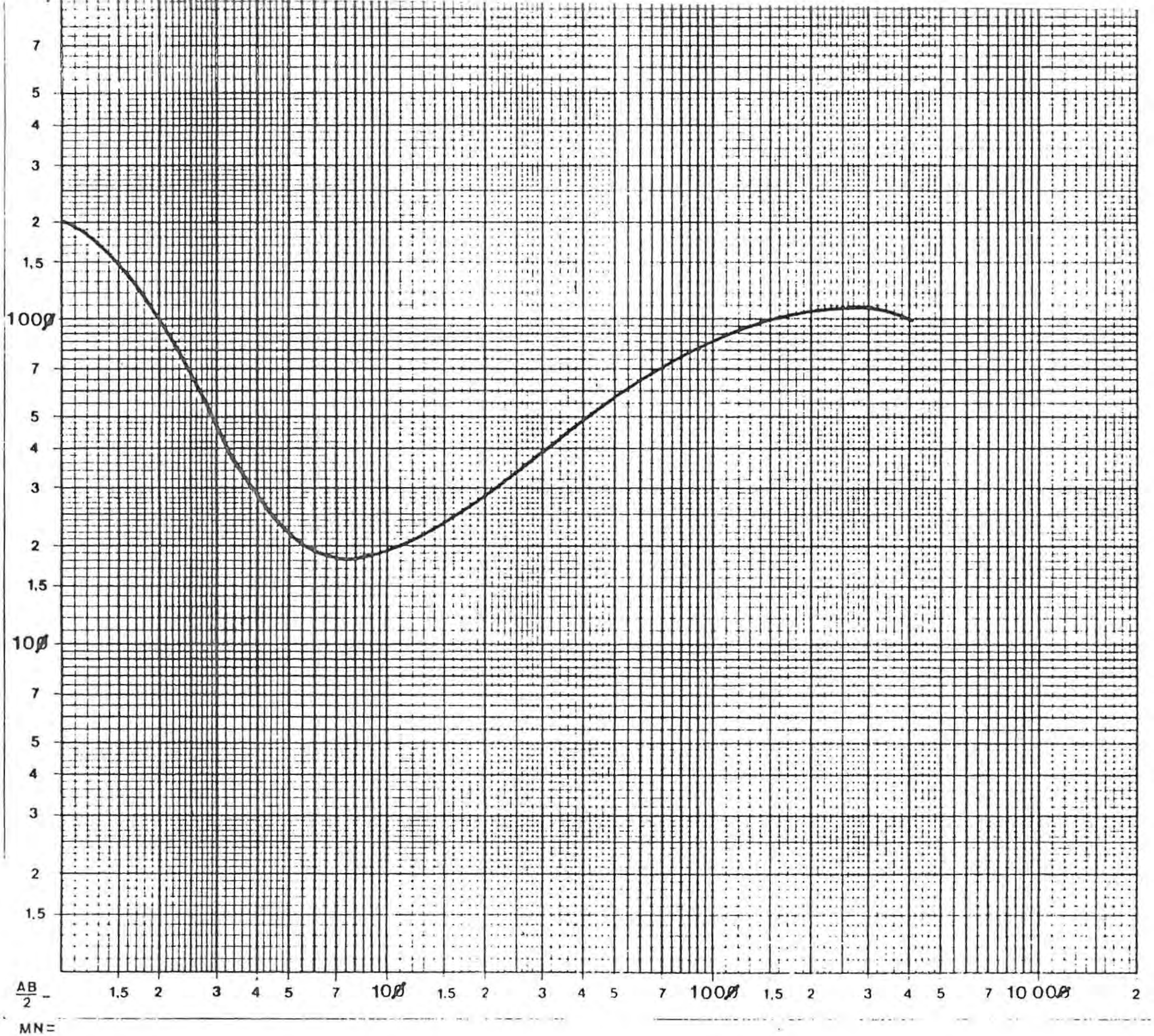
E.S. No. 1/2



Opname - Survey

BUSHMANS RIVER MOUTH

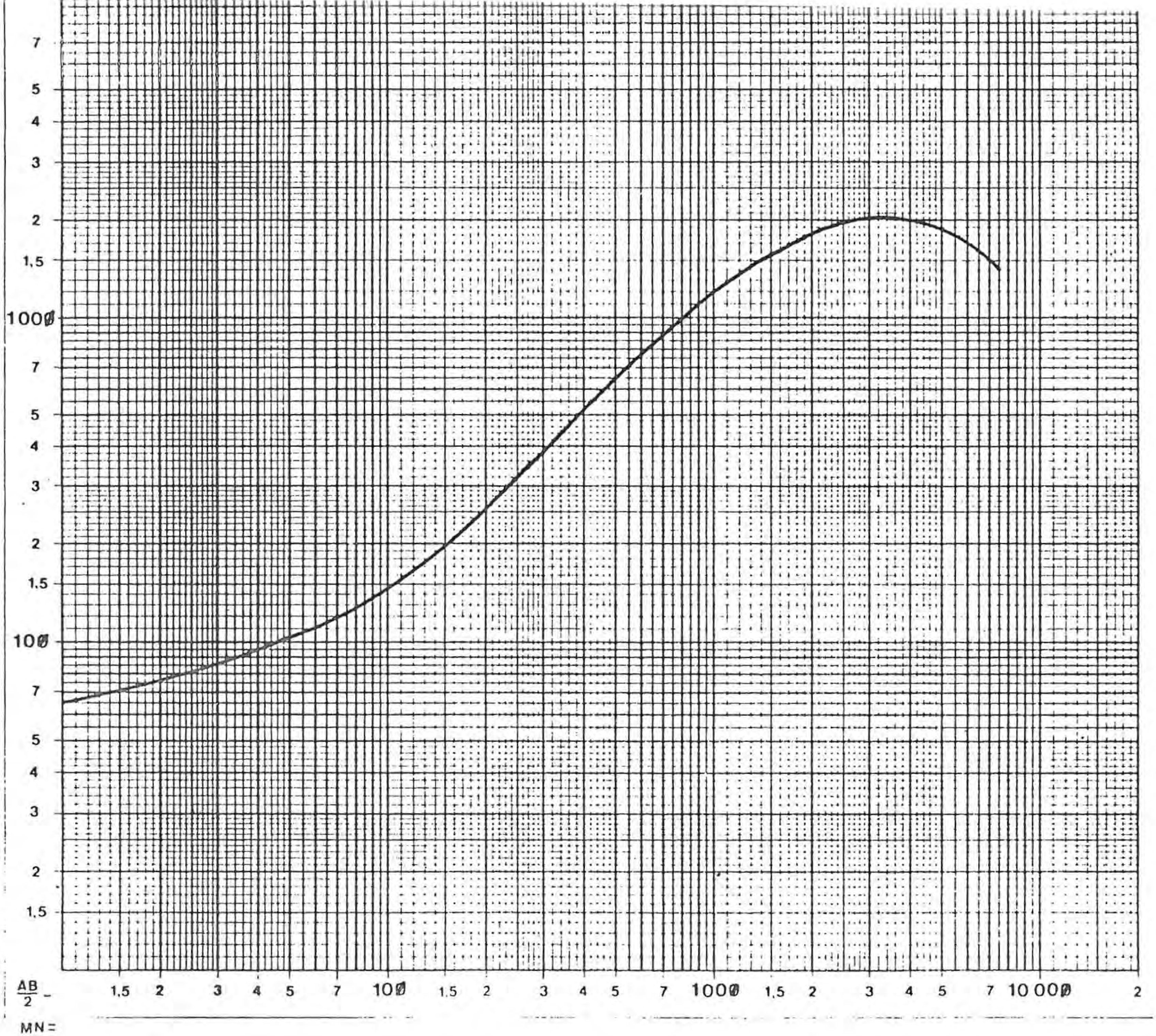
E.S. No. 1/3



Opname - Survey

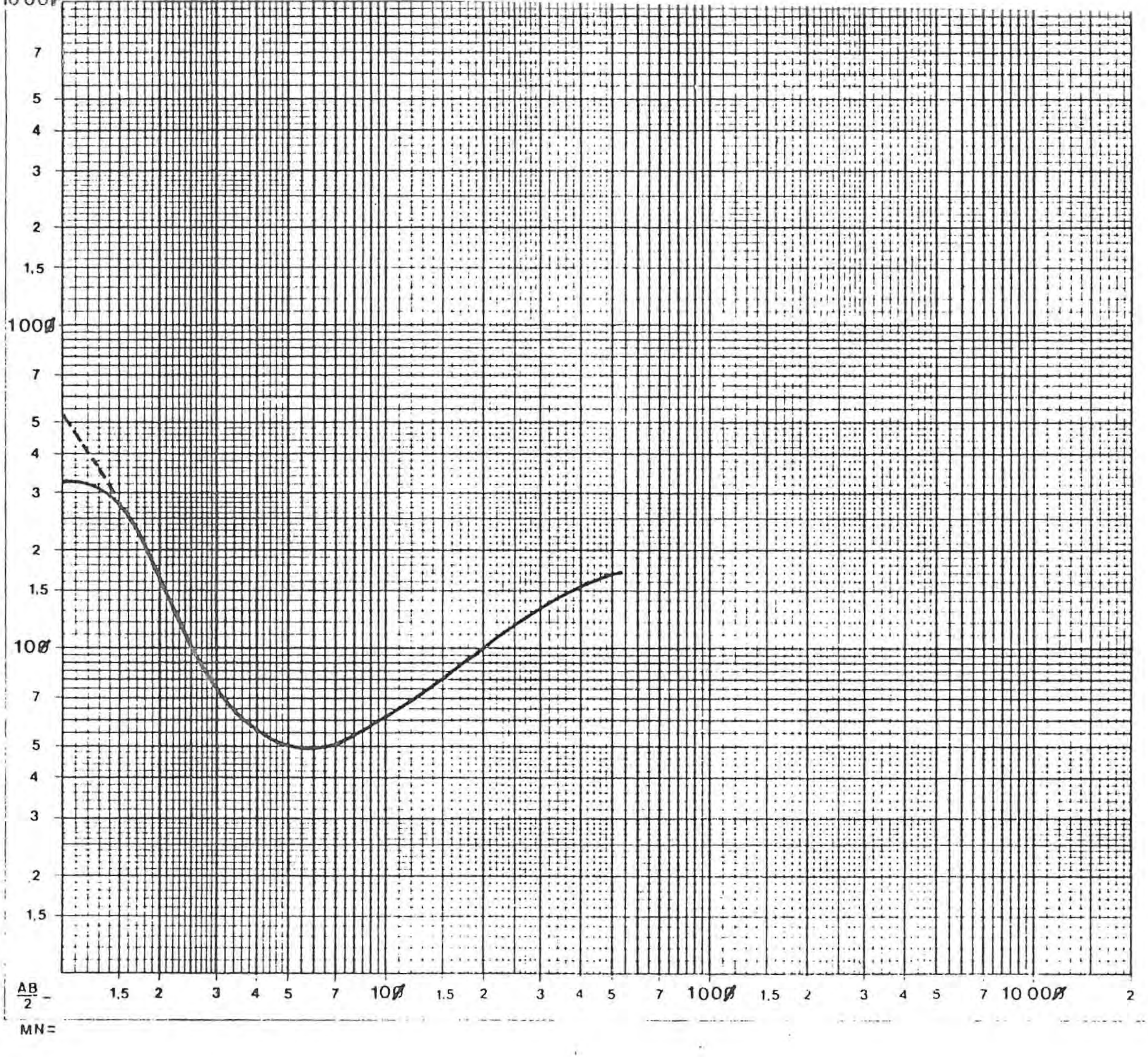
BUSHMANS RIVER MOUTH

E.S. No. 1/4



Opname - Survey DIAS CROSS

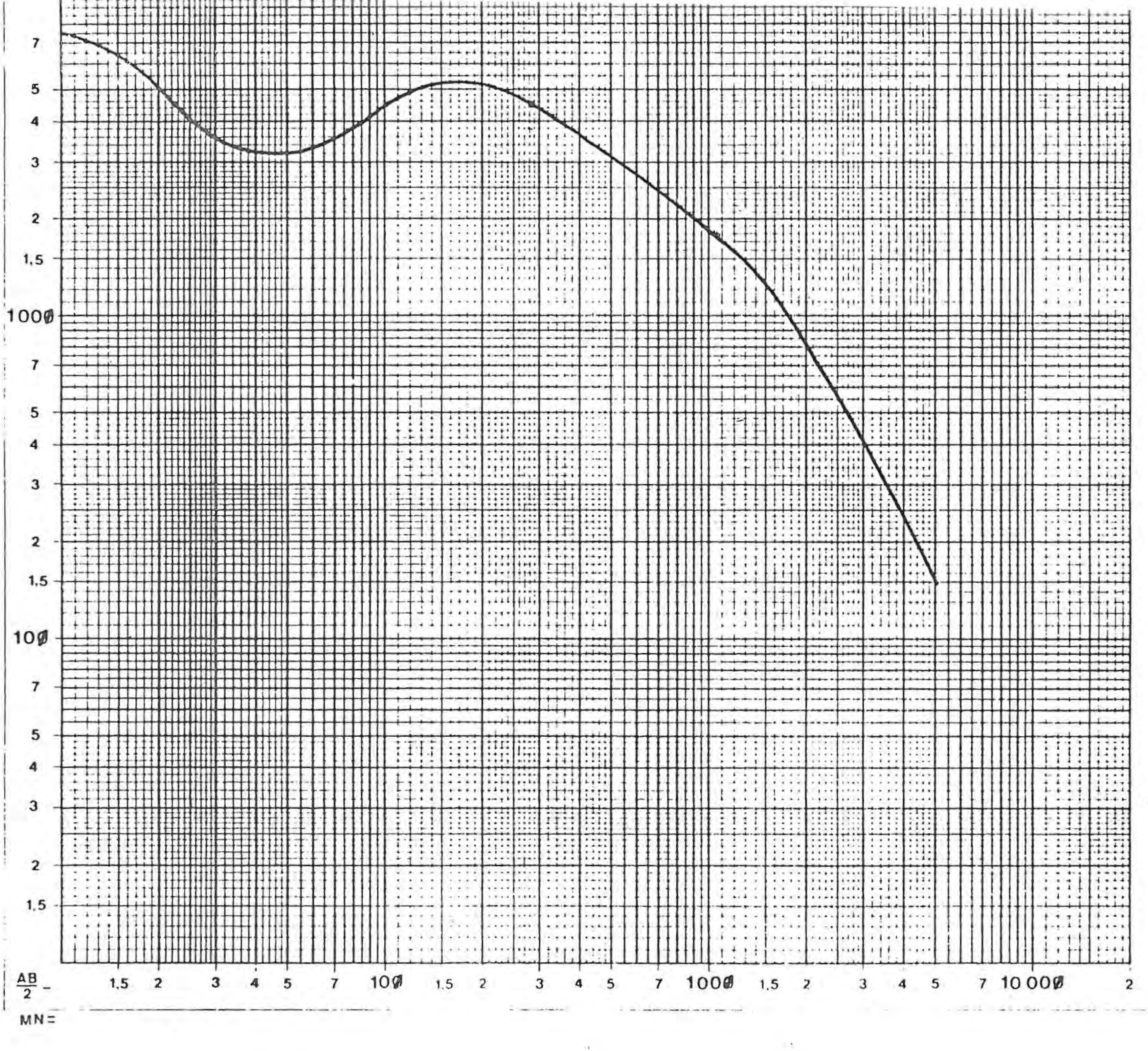
E.S. No. 2/1



Opname - Survey

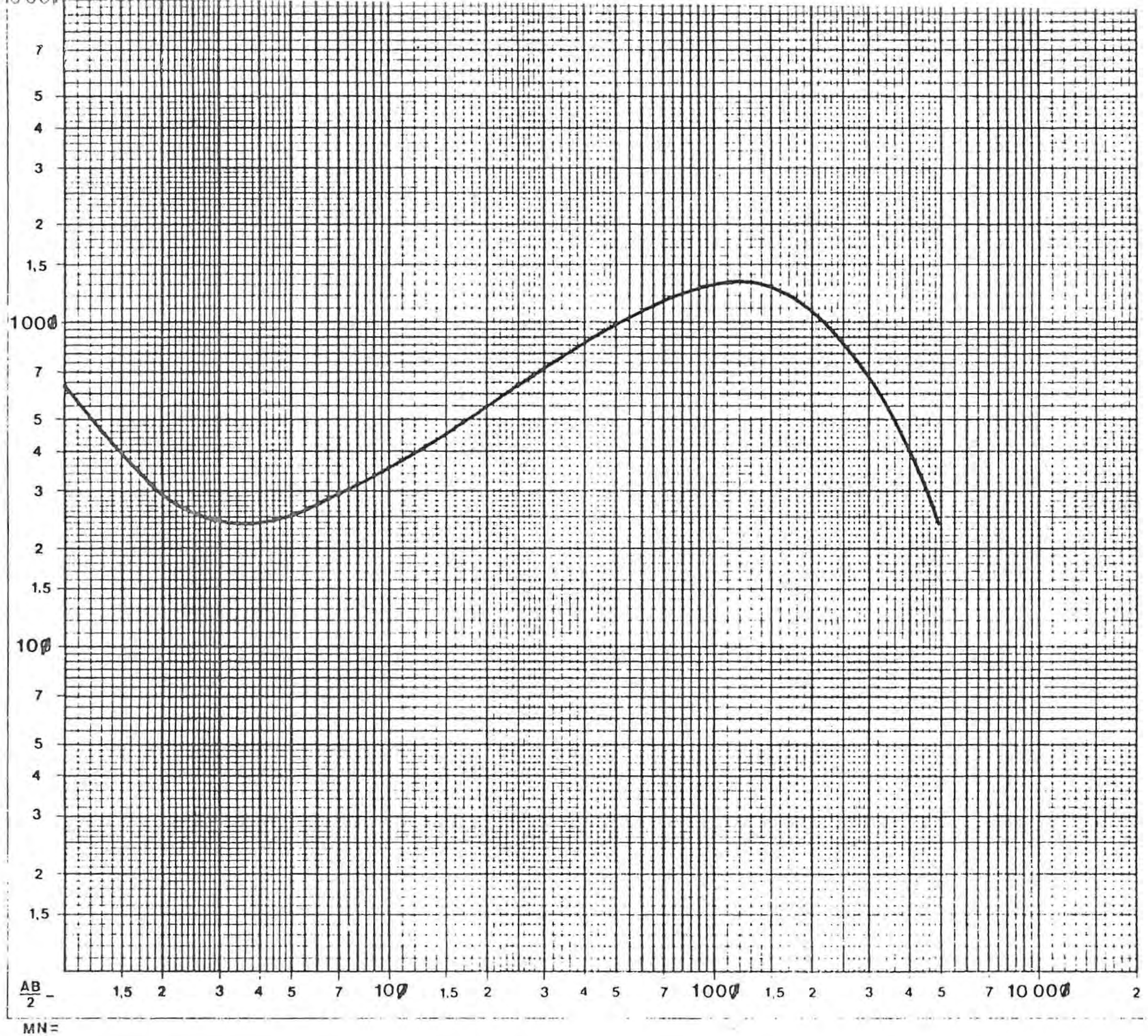
DIAS CROSS

E.S. No. 2/2



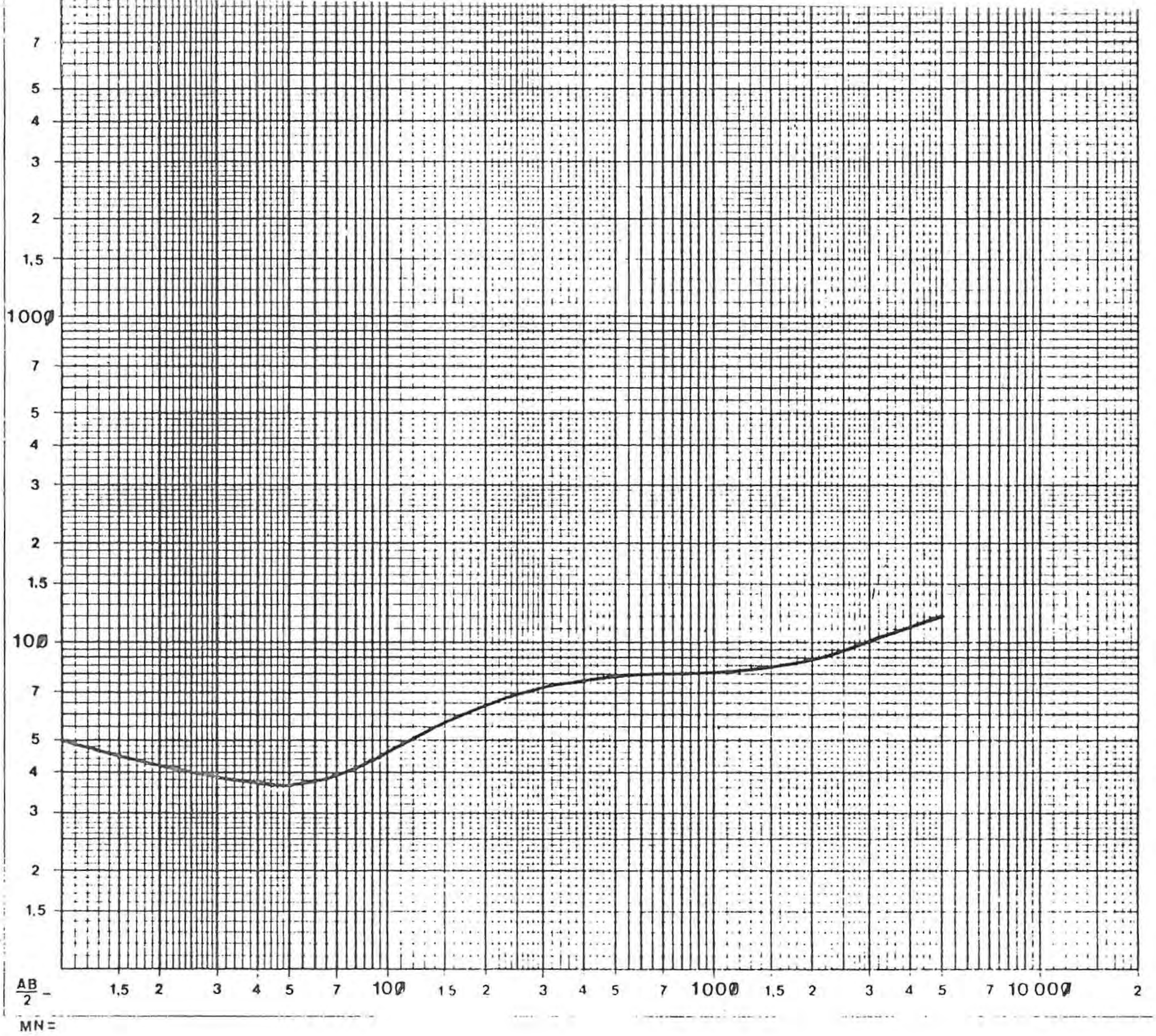
Opname - Survey DIAS CROSS

E.S. No. 2/3



Opname - Survey DIAS CROSS

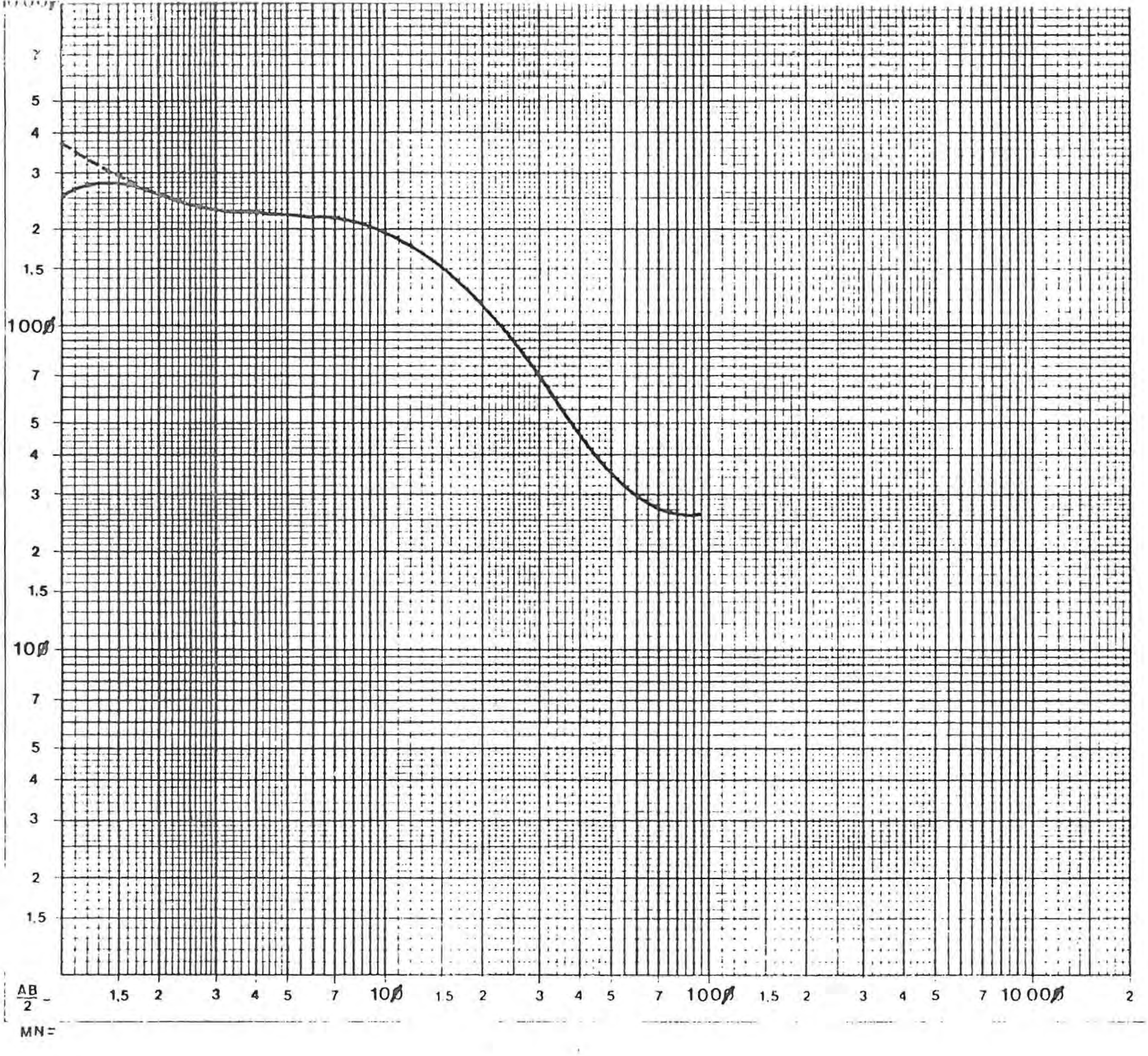
E.S. No. 2/4



Opname - Survey

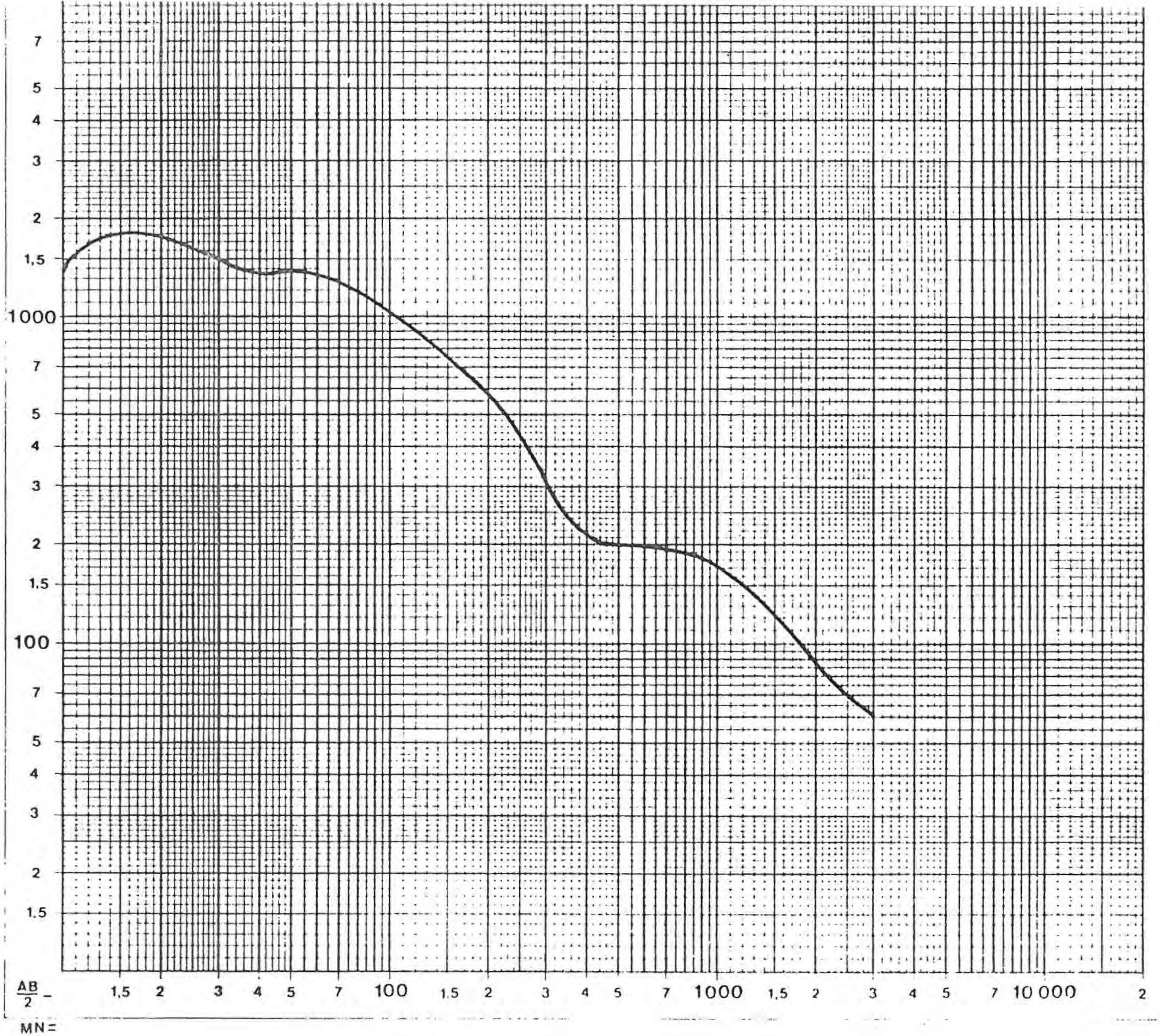
DIAS CROSS

E.S. No. 2/5



Opname - Survey RICHMOND

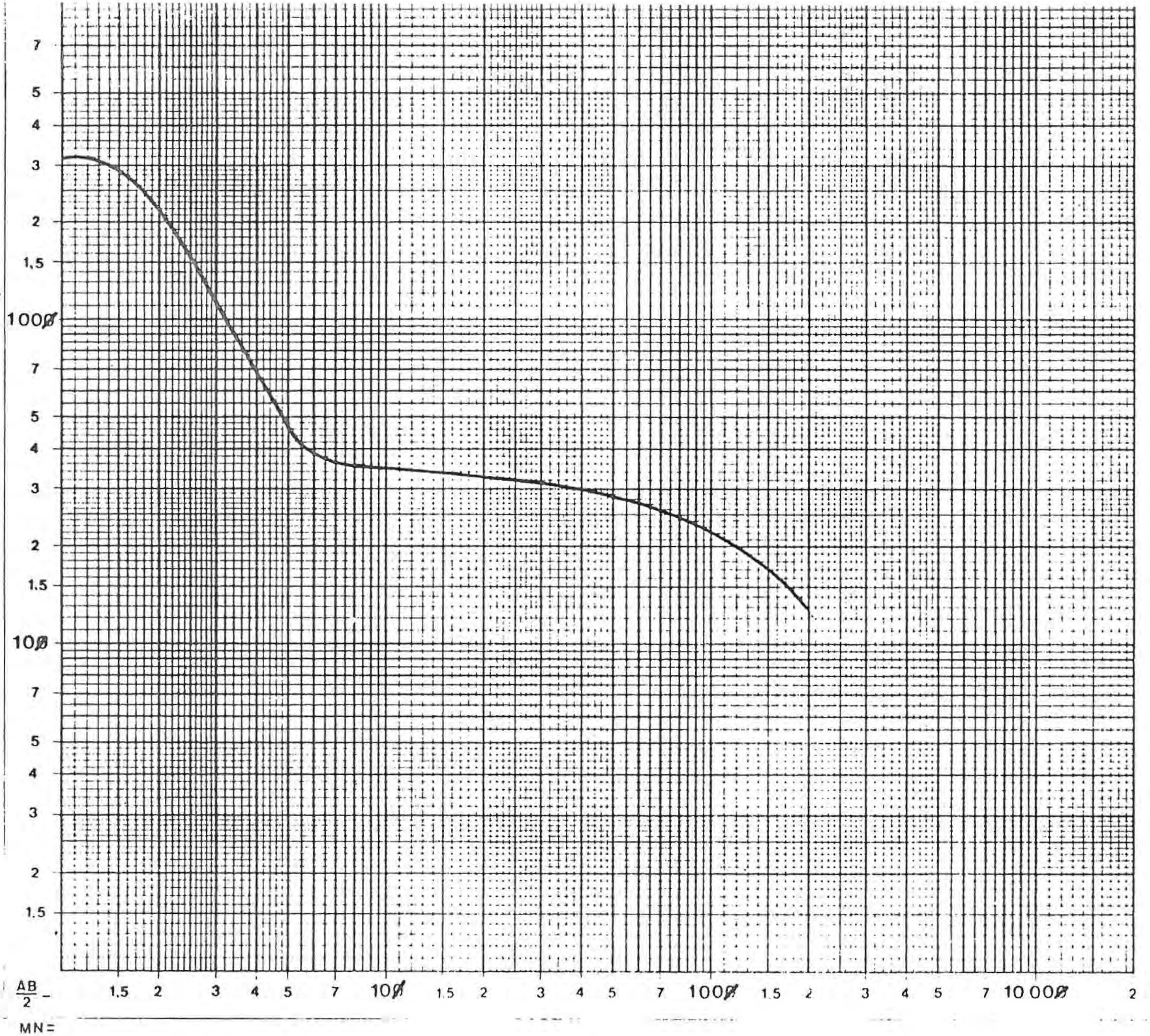
E.S. No. 3/1



Opname - Survey

RICHMOND

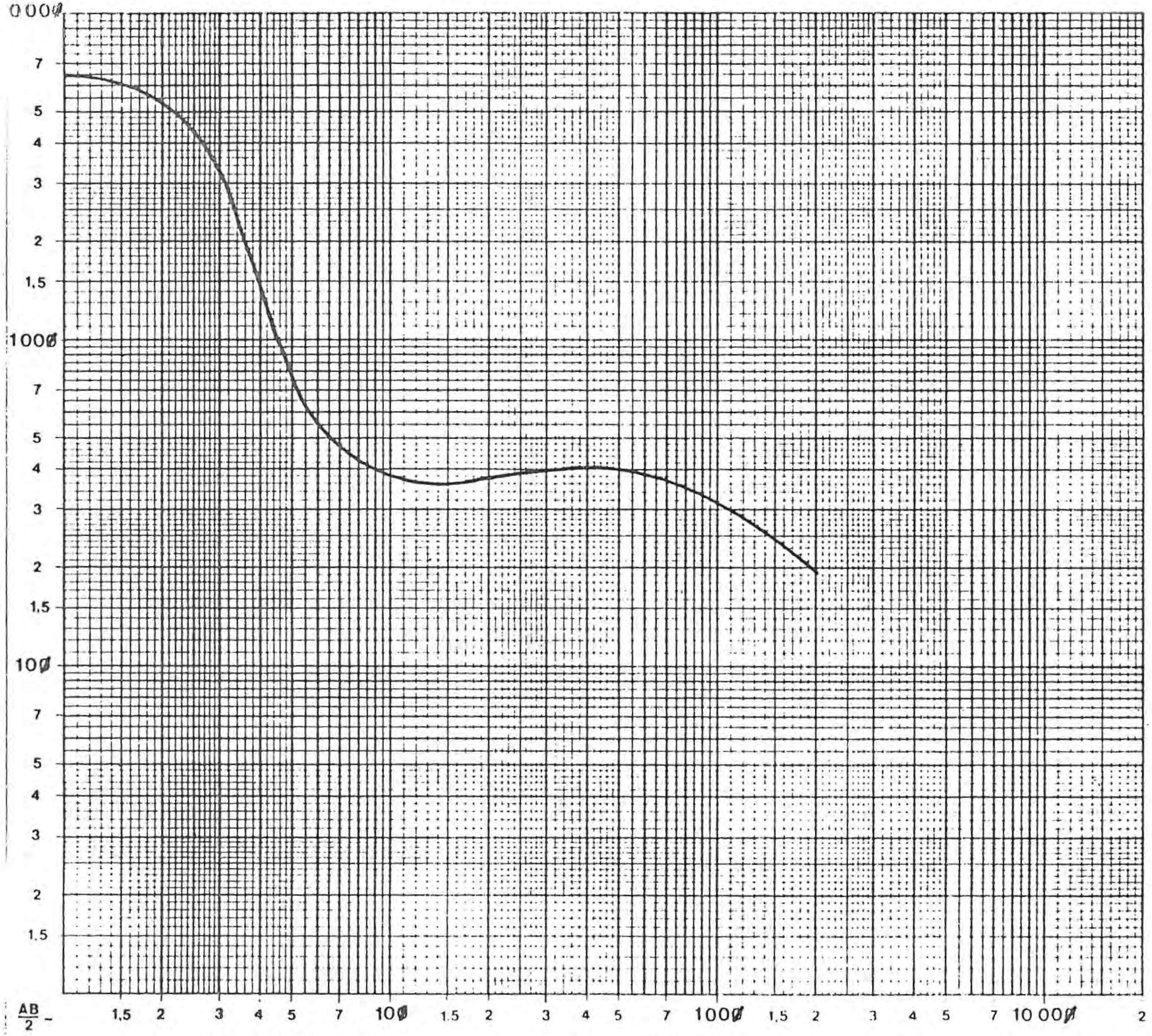
E.S. No. 3/2



Opname - Survey

RICHMOND

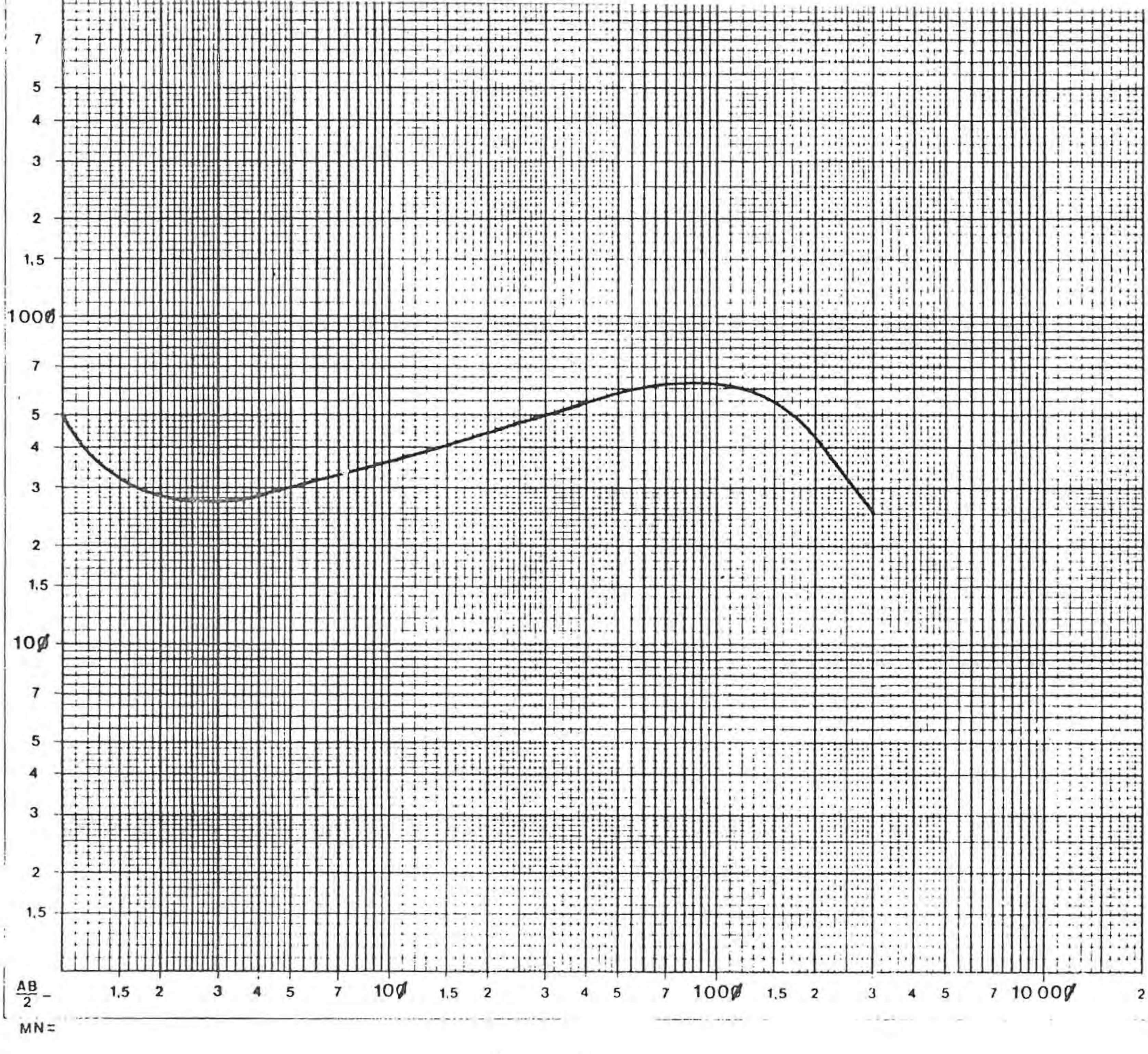
E.S. No. 3/3



Opname - Survey

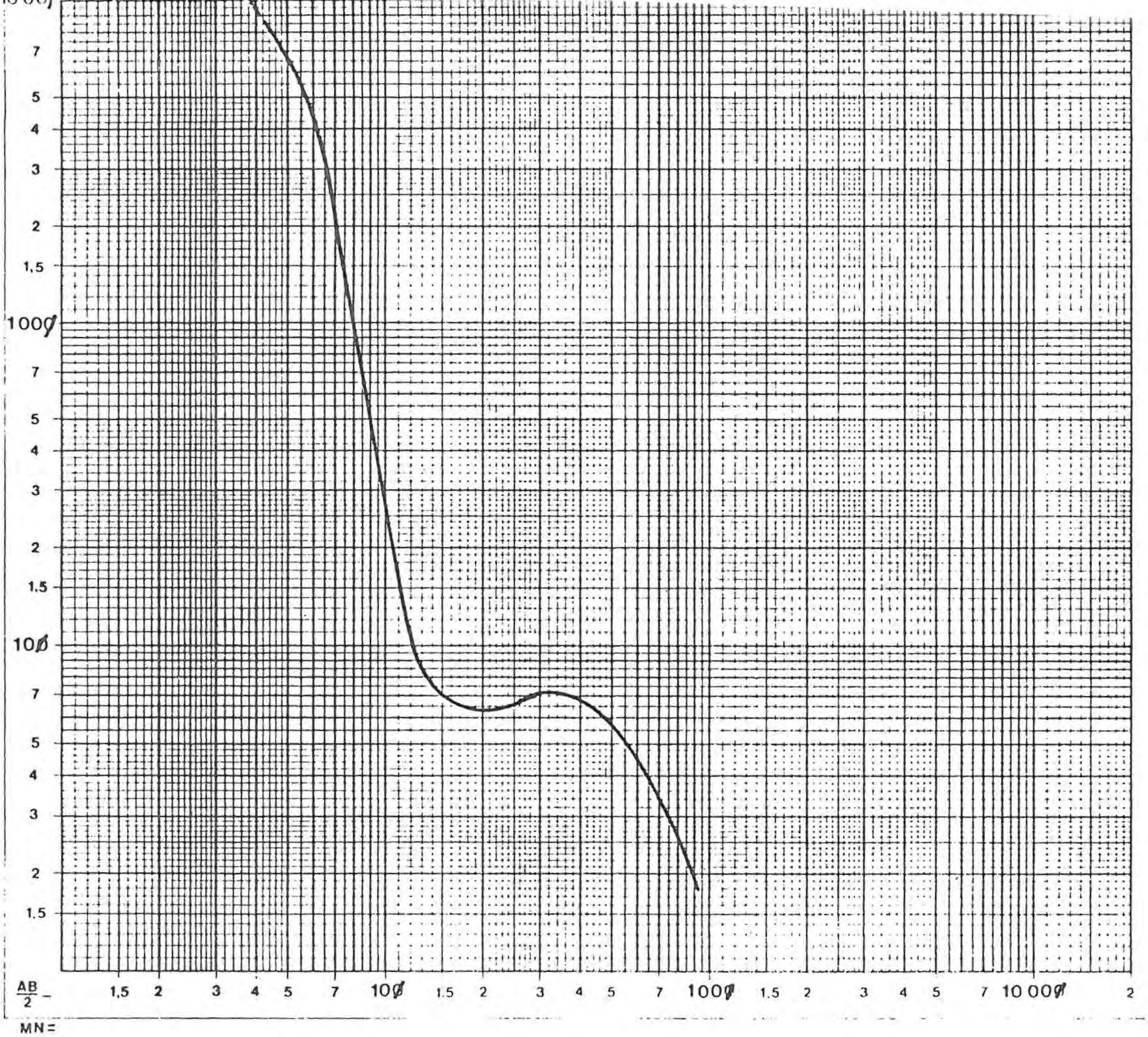
RICHMOND

E.S. No. 3/4



Opname - Survey
RICHMOND

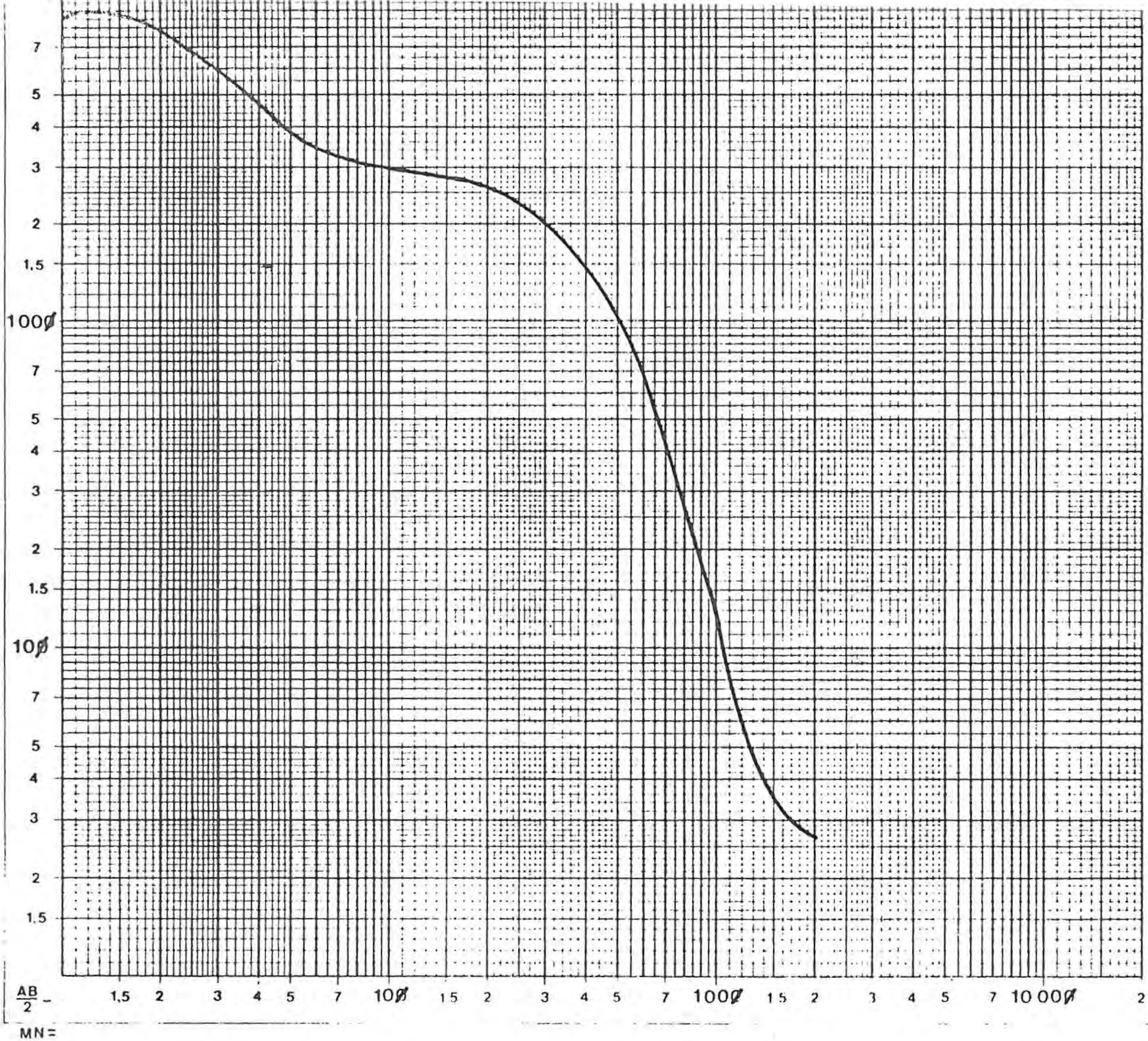
E.S. No. 3/5



Opname - Survey

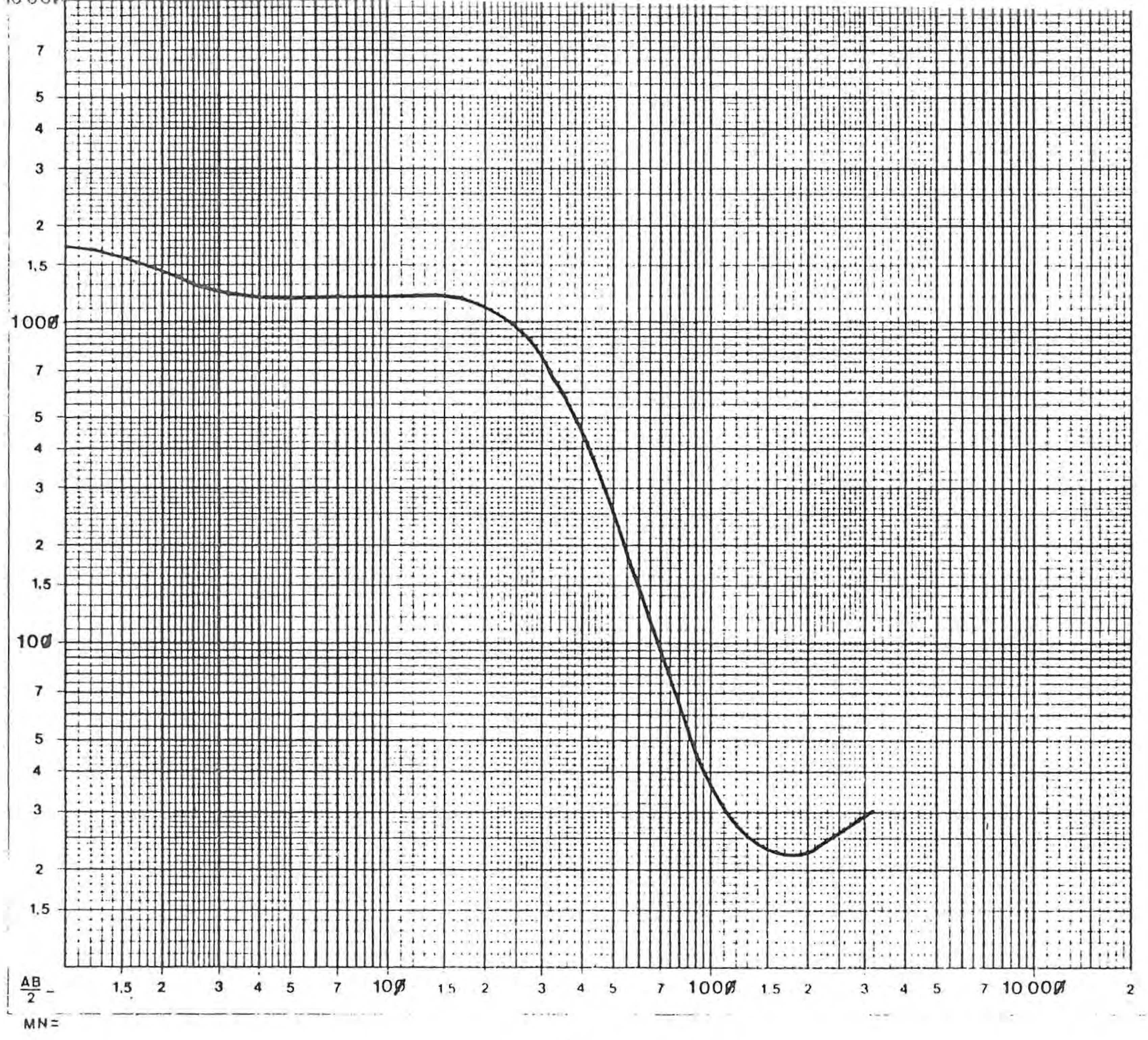
STILLEWATER

E.S. No. 4/1



Opname - Survey
STILLEWATER

E.S. No. 4/2

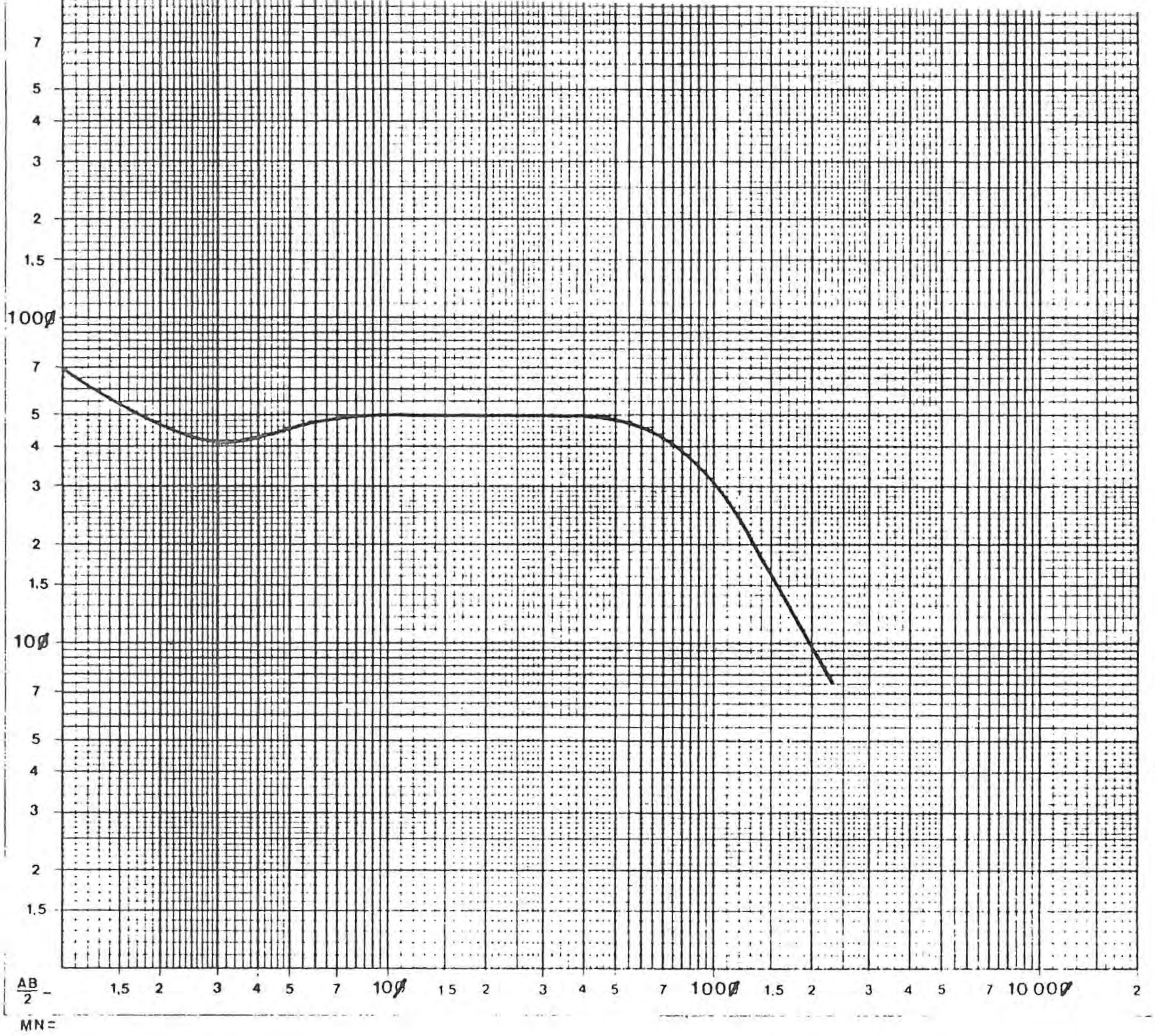


Opname - Survey STILLEWATER

E.S. No. 4/3

Opname - Survey STILLEWATER

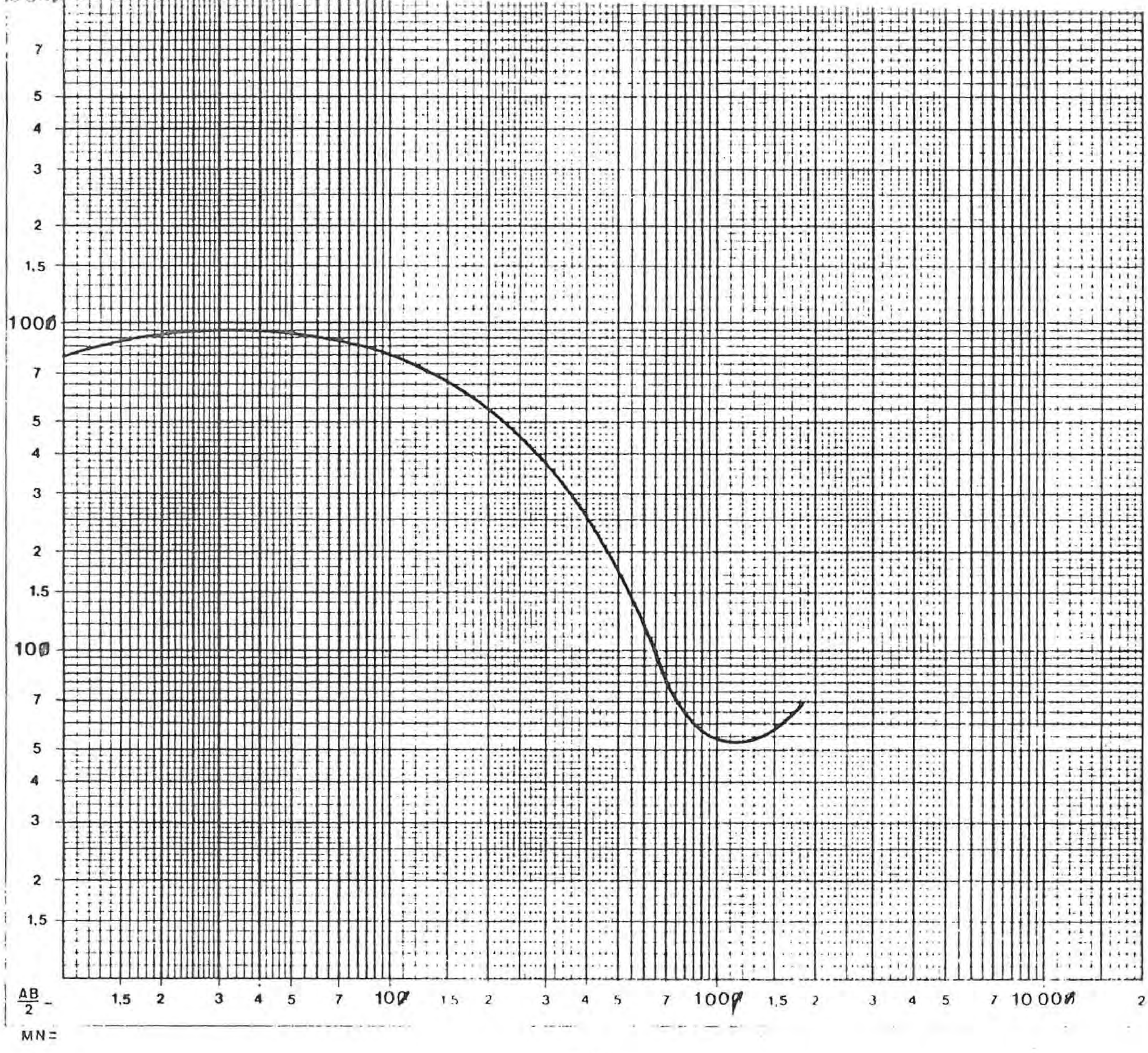
E.S. No. 4/4



Opname - Survey

STILLEWATER

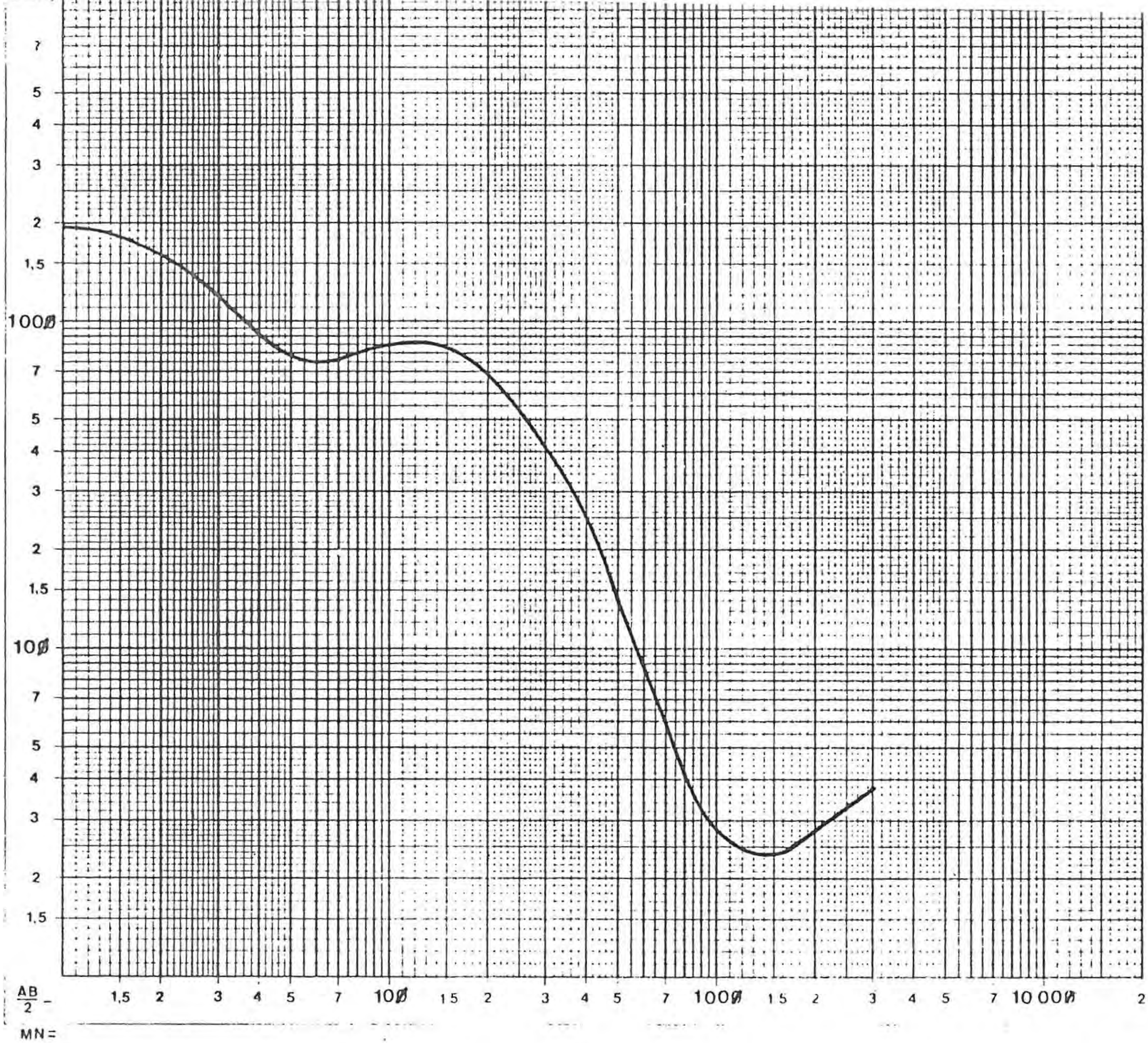
E.S. No. 4/5



Opname - Survey

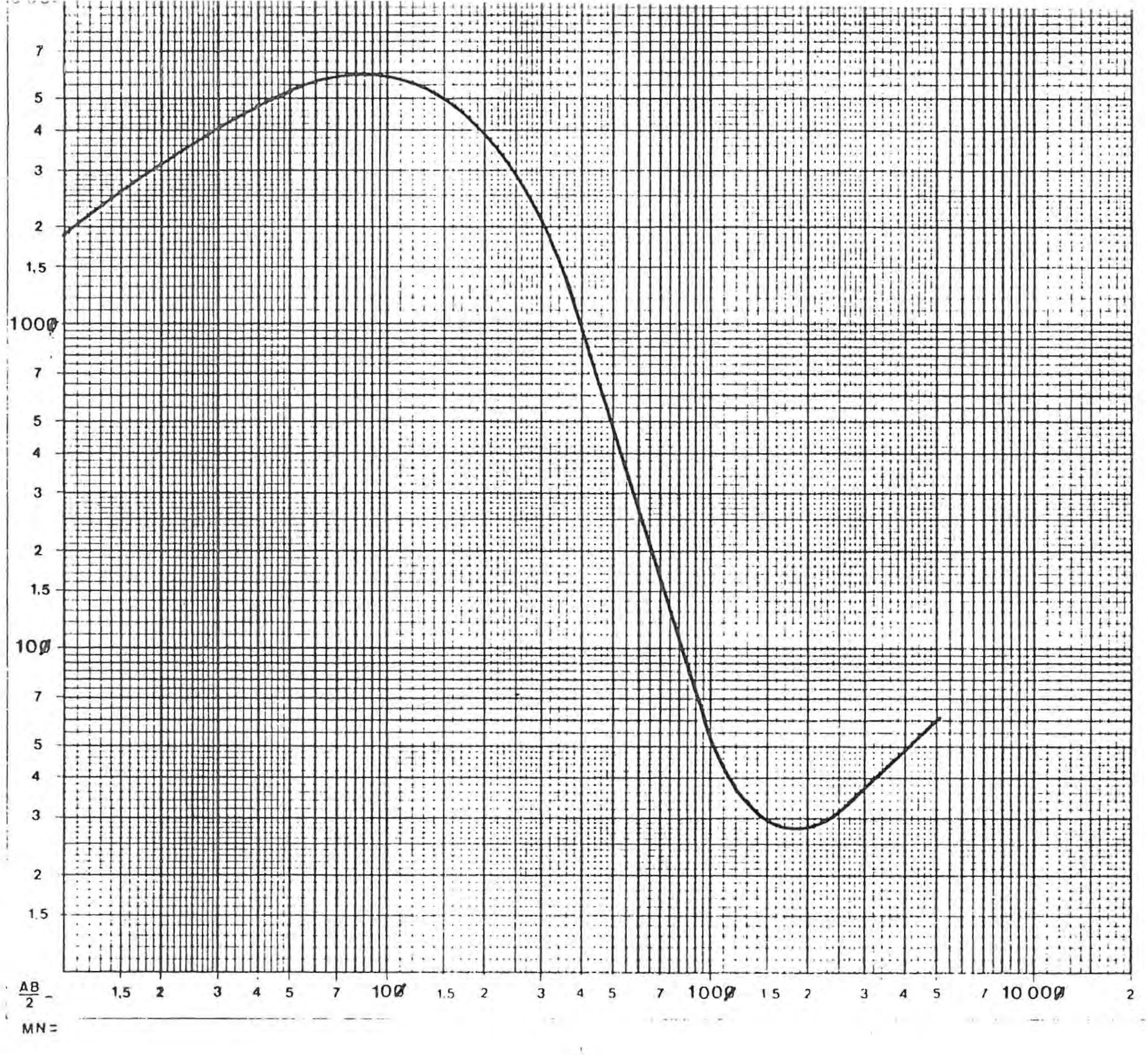
CANNON ROCKS (EAST)

E.S. No. 5/1



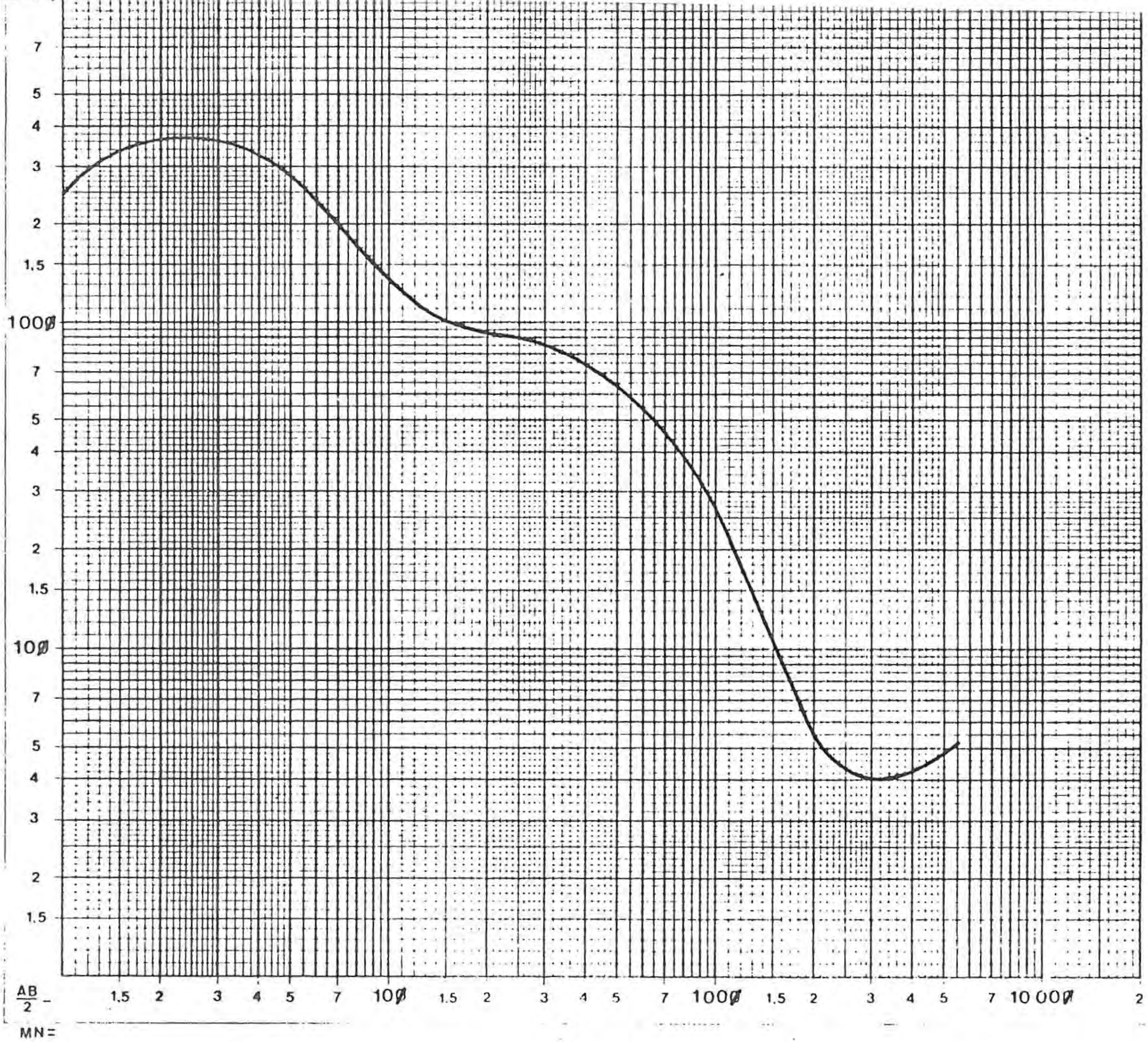
Opname - Survey
CANNON ROCKS (EAST)

E.S. No. 5/2



Opname - Survey
CANNON ROCKS (EAST)

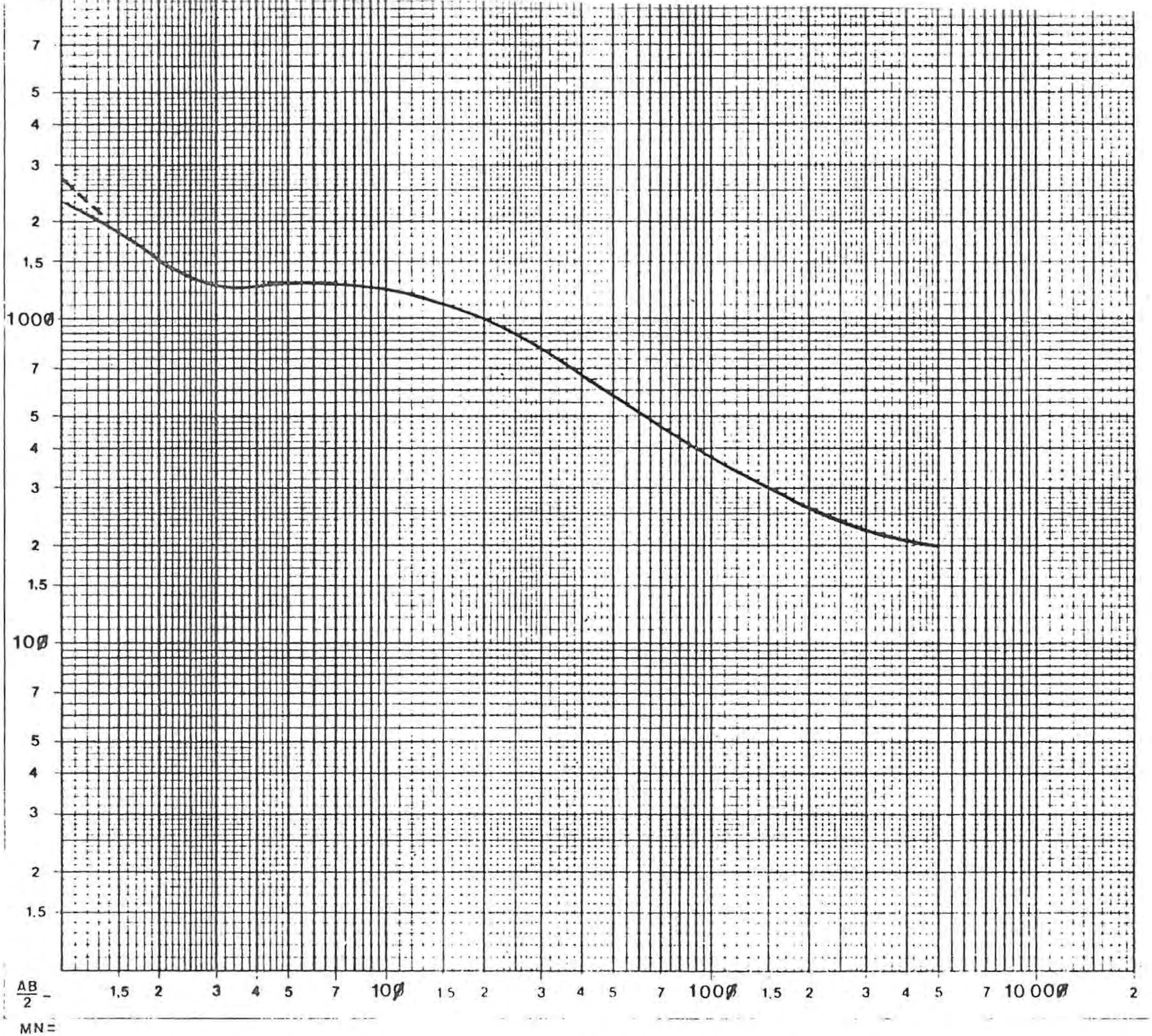
E.S. No. 5/3



Opname - Survey

CANNON ROCKS (EAST)

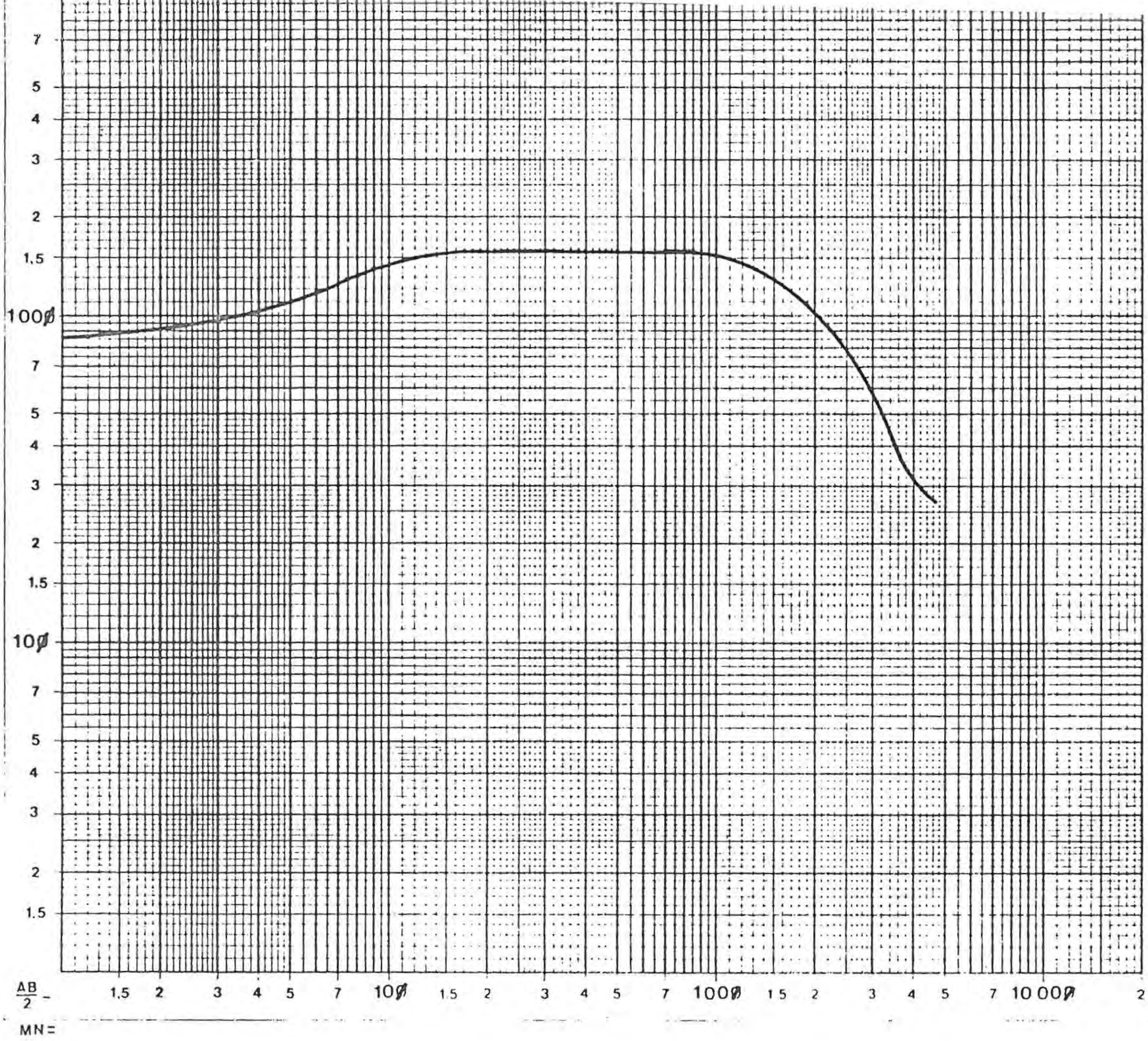
E.S. No. 5/4



Opname - Survey

CANNON ROCKS (CENTRE)

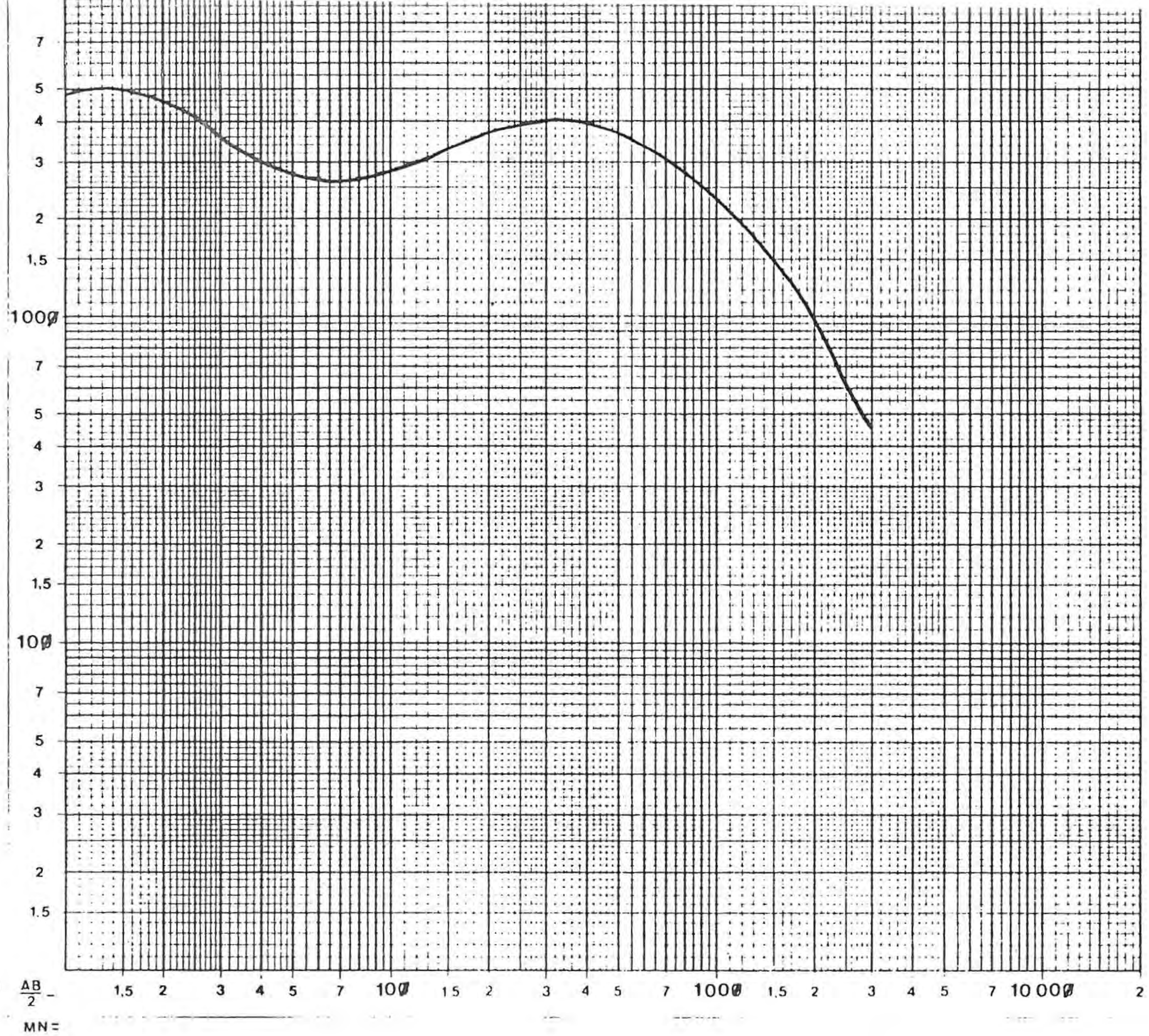
E.S. No. 6/1



Opname - Survey

CANNON ROCKS (CENTRE)

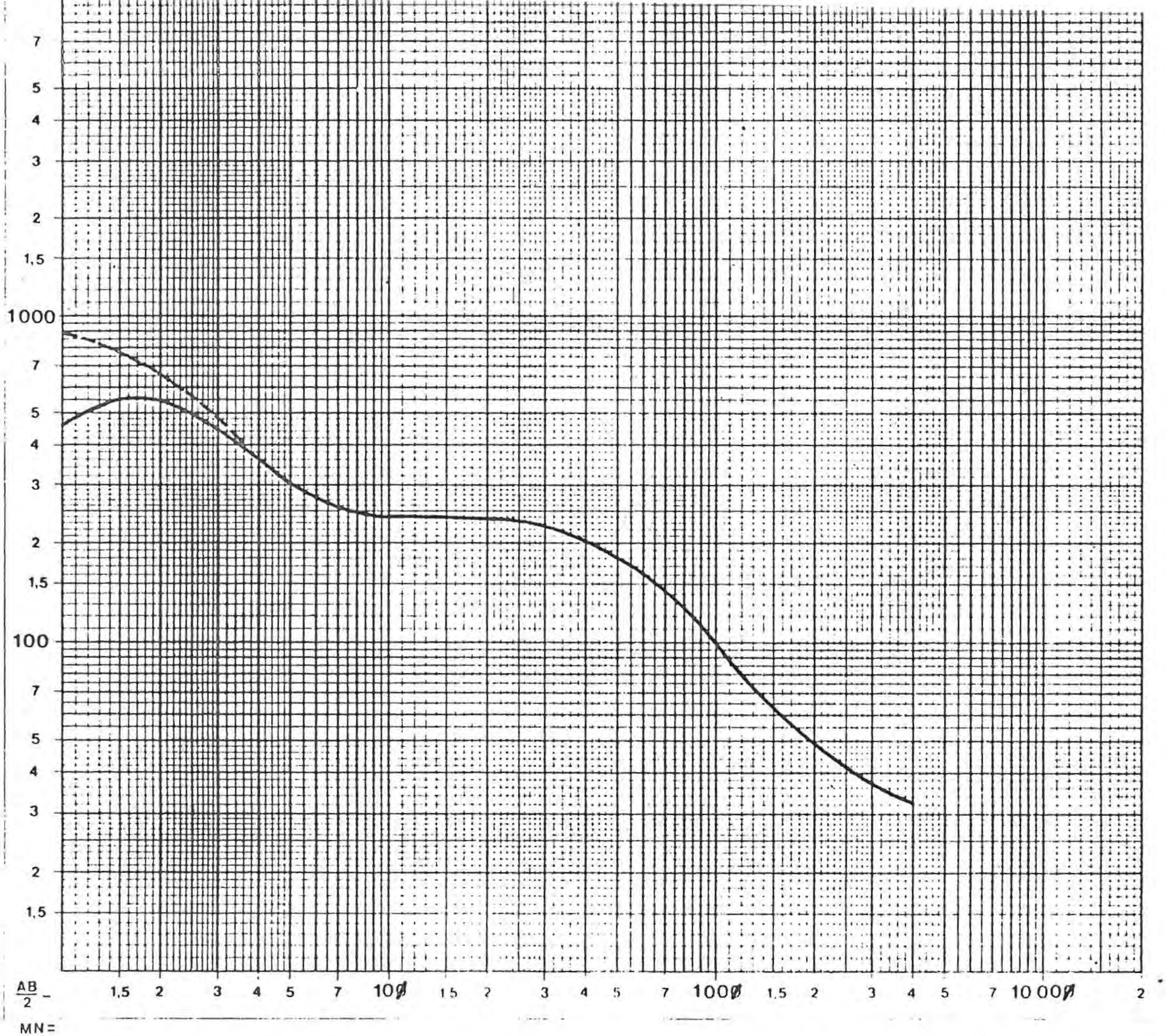
E.S. No. 6/2



Opname - Survey

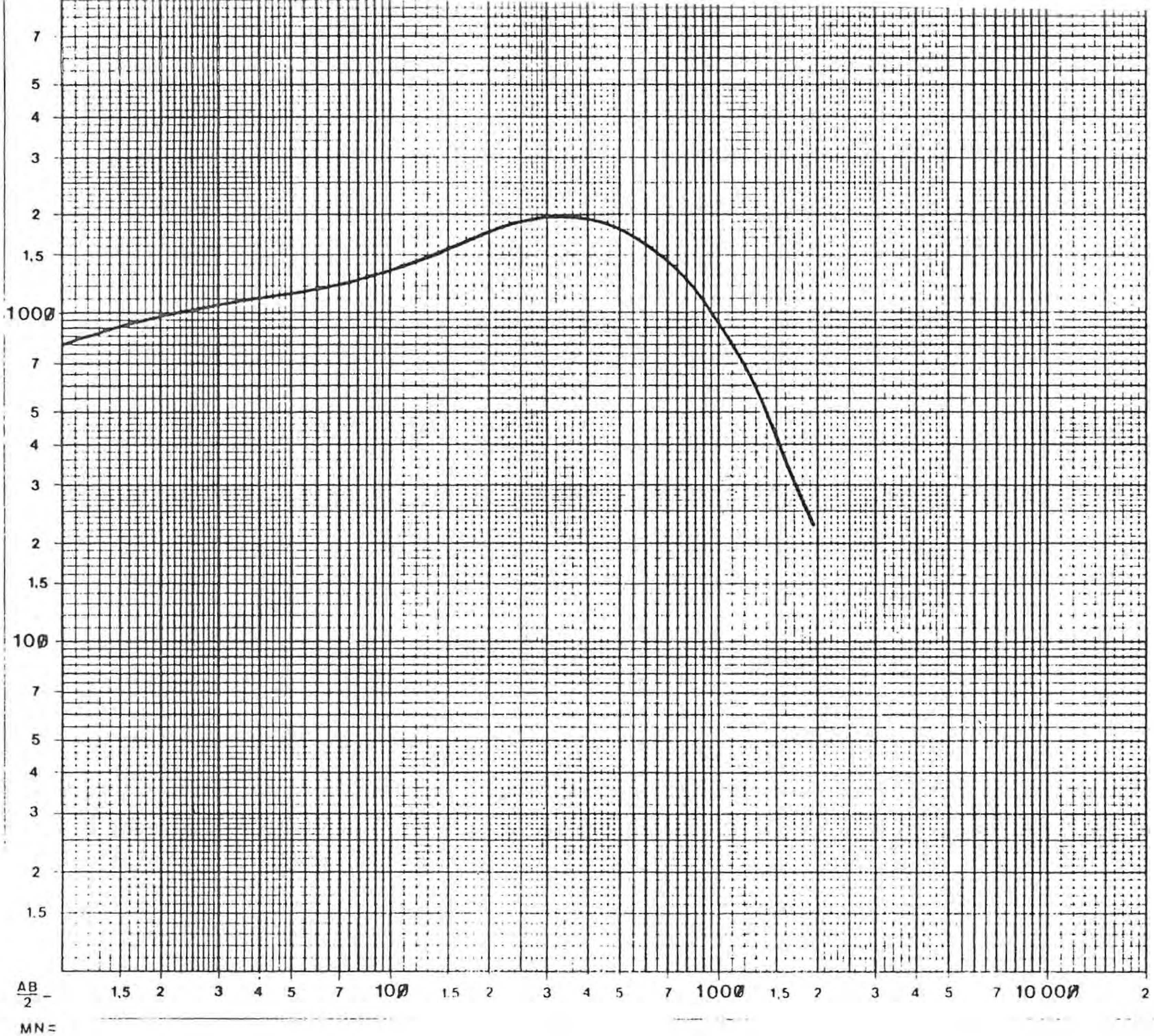
CANNON ROCKS (CENTRE)

E.S. No. 6/3



Opname - Survey
CANNON ROCKS (CENTRE)

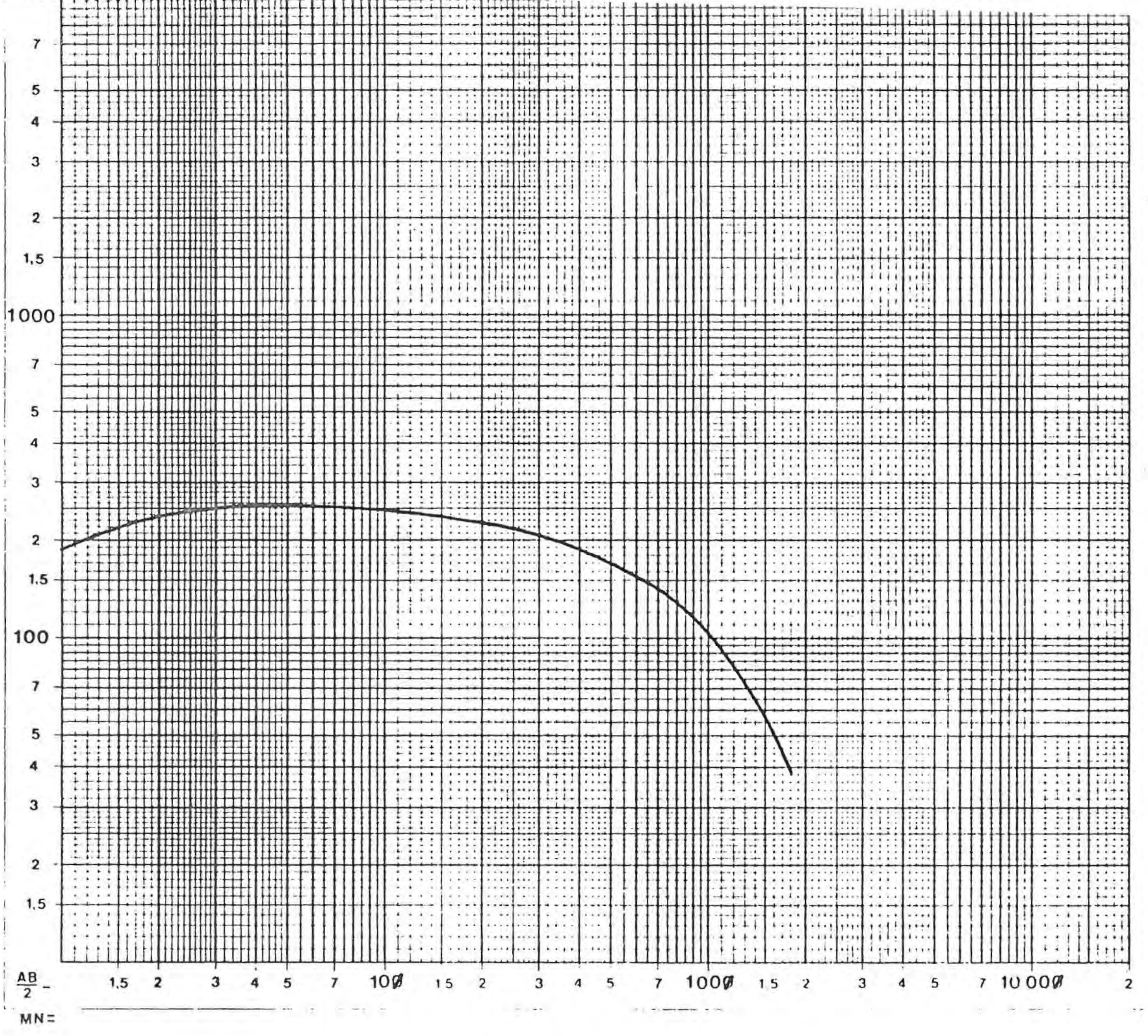
E.S. No. 6/4



Opname - Survey

CANNON ROCKS (CENTRE)

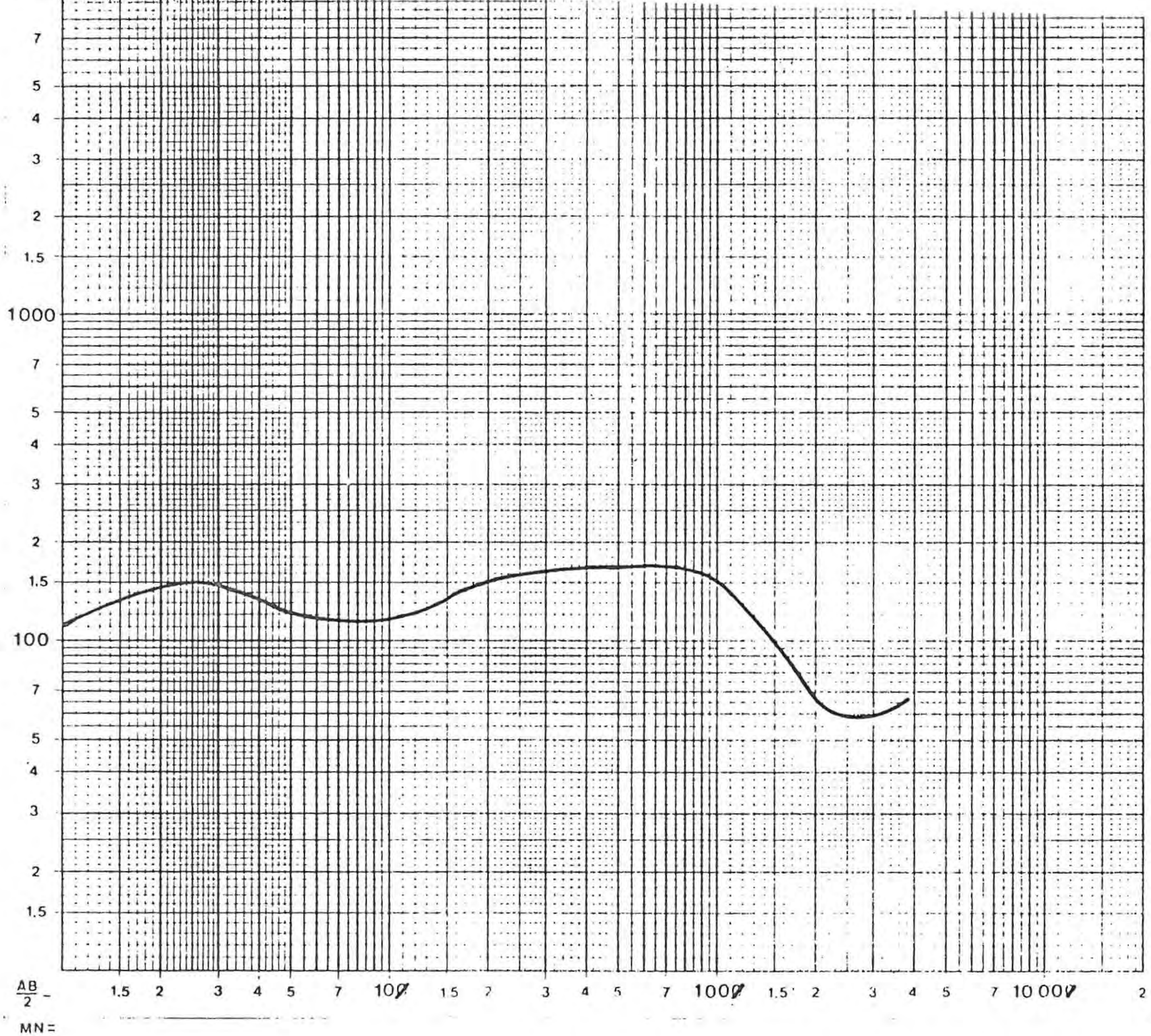
E.S. No. 16/5



Opname - Survey

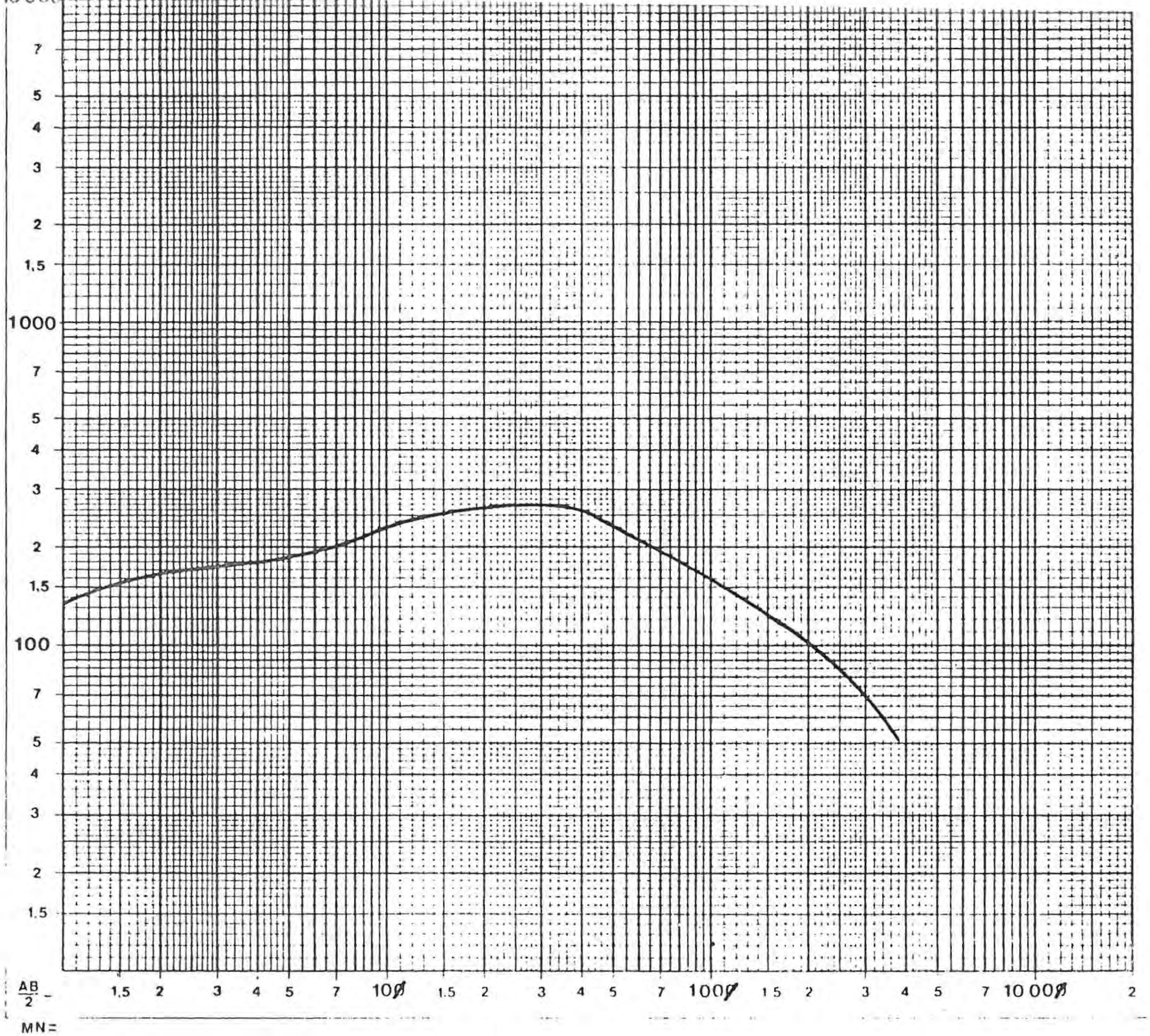
CANNON ROCKS (WEST)

E.S. No. 17/1



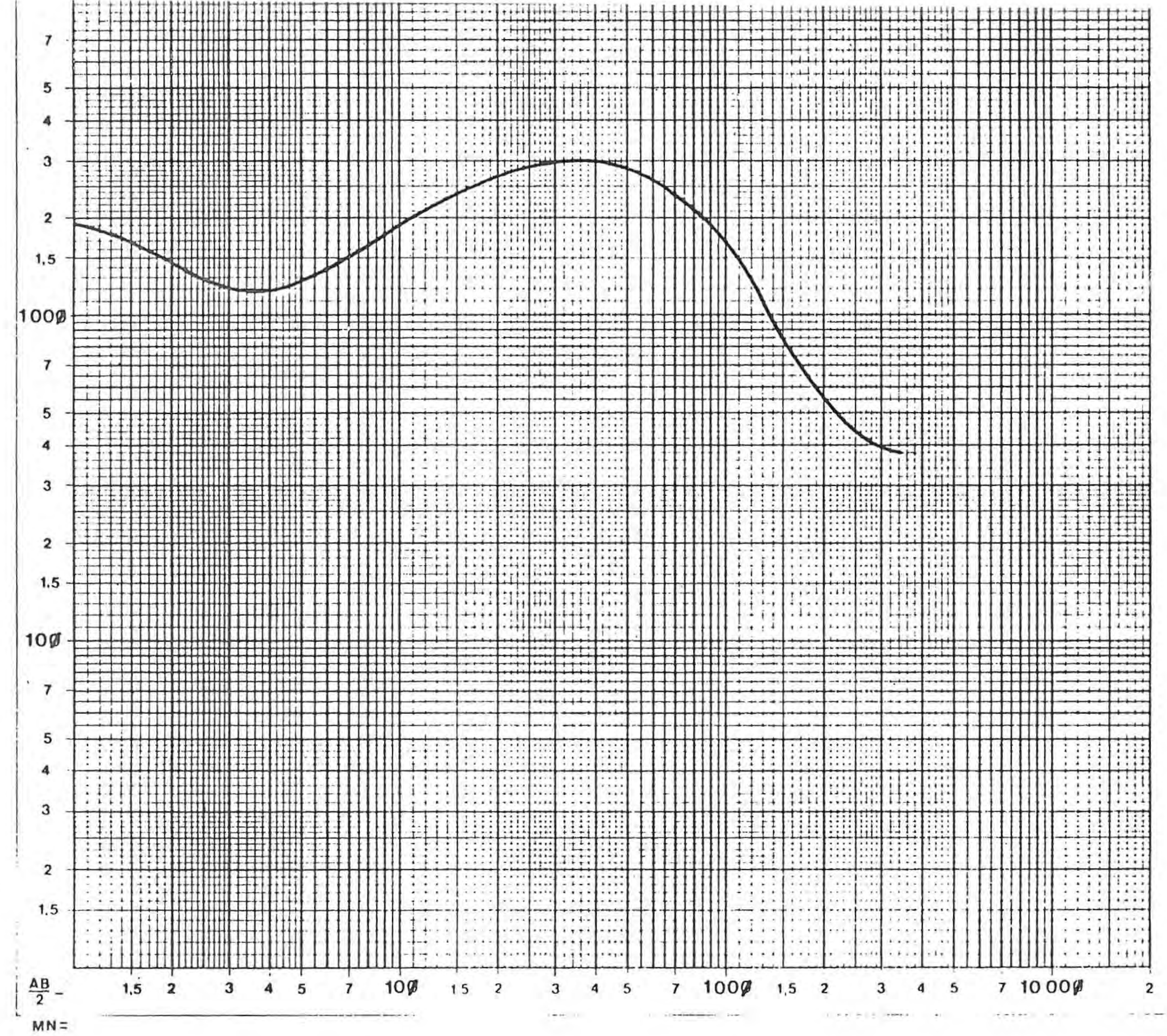
Opname - Survey
CANNON ROCKS (WEST)

E.S. No. 7/2



Opname - Survey
CANNON ROCKS (WEST)

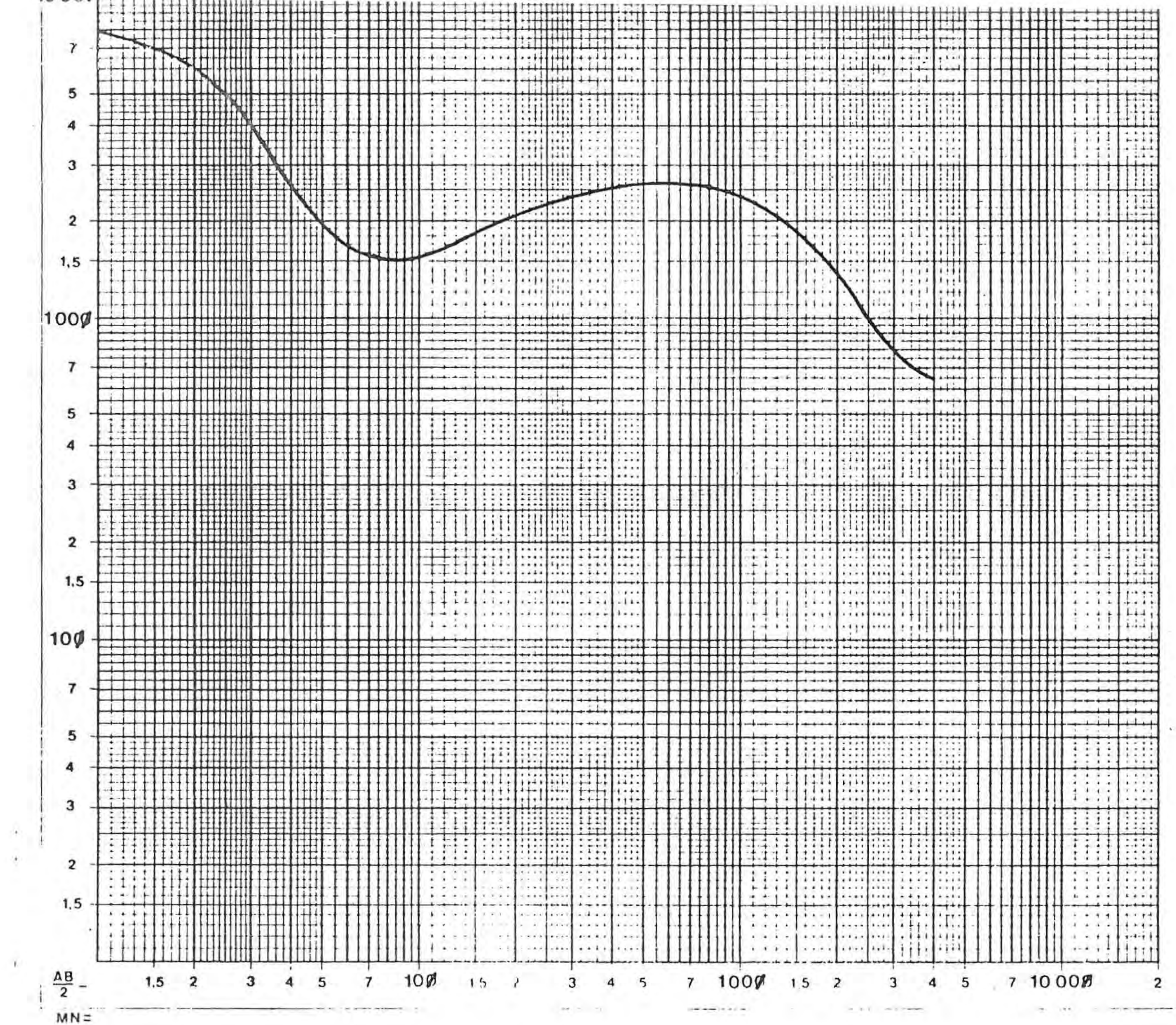
E.S. No. 7/3



Opname - Survey

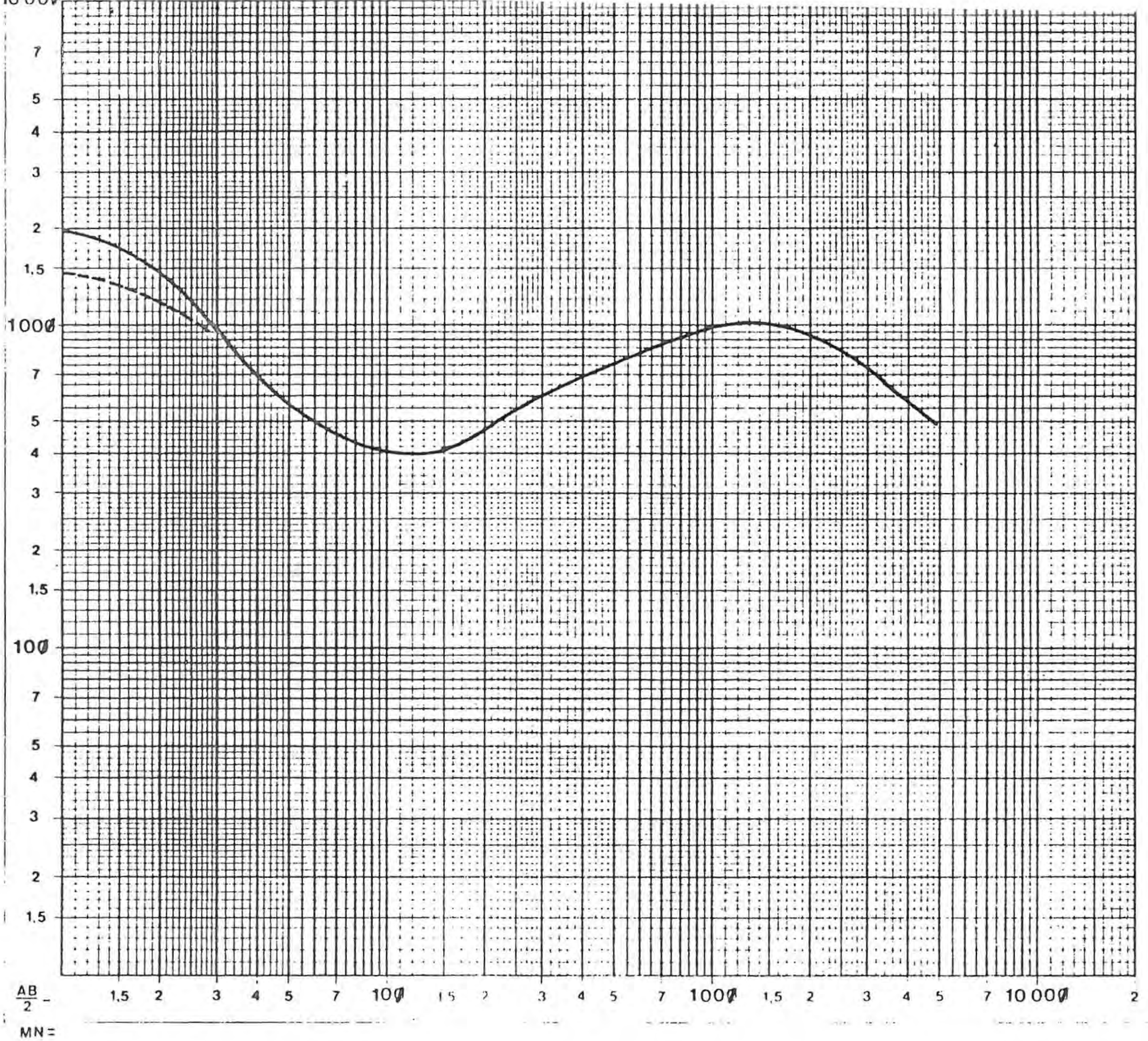
BOSCHFONTEIN

E.S. No. 8/1



Opname - Survey BOSCHFONTEIN

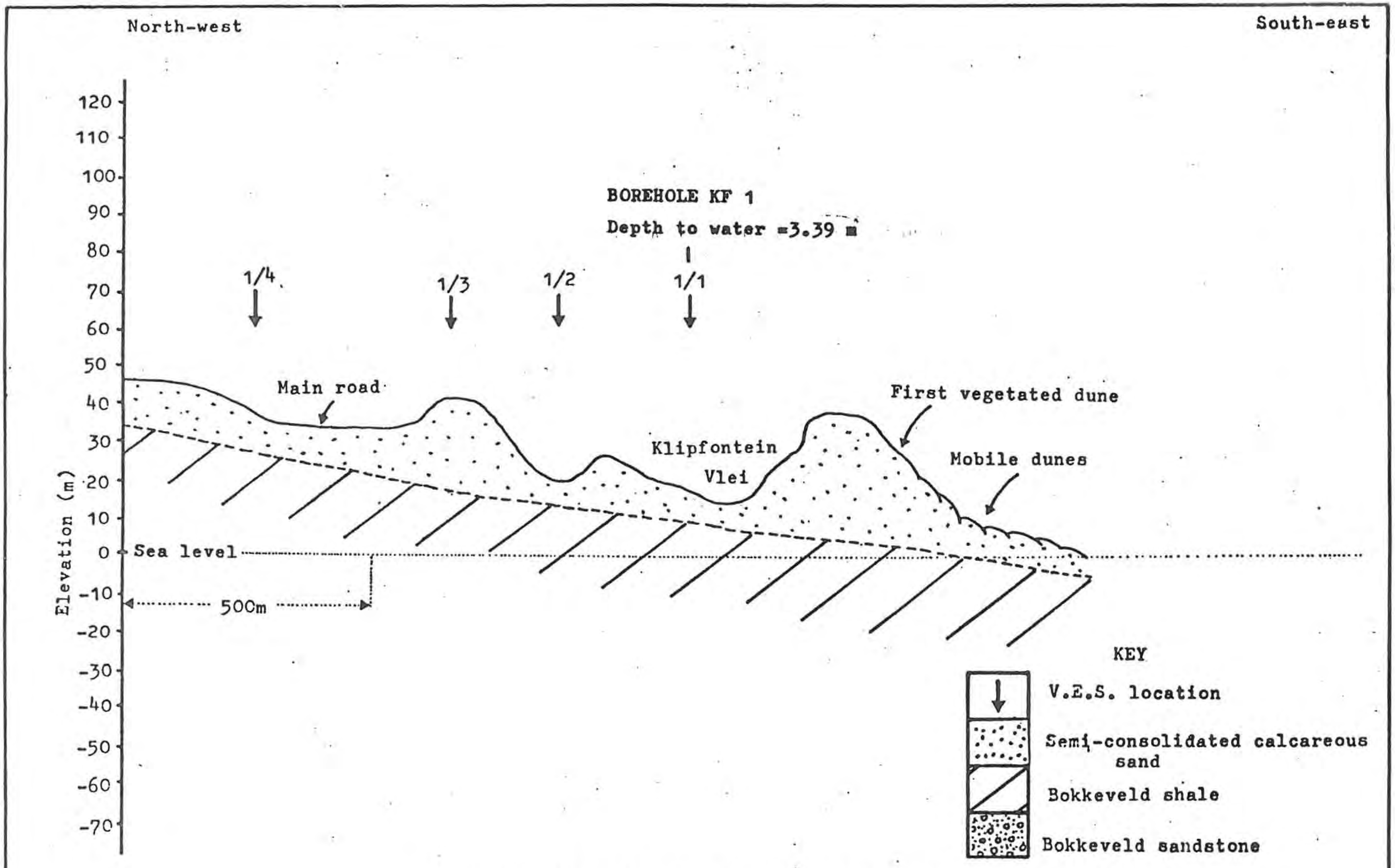
E.S. No. 8/2



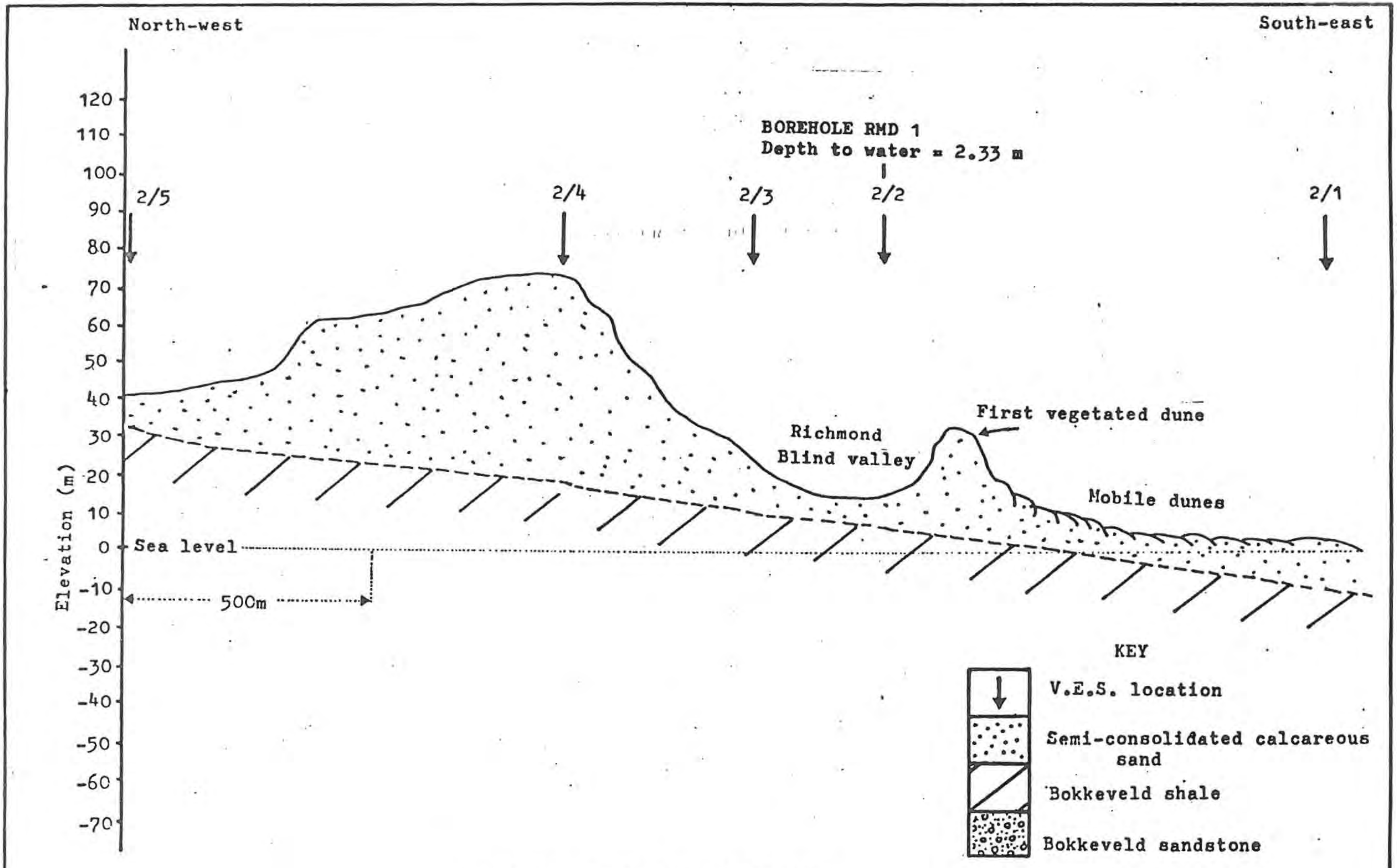
Opname - Survey
BOSCHFONTEIN

E.S. No. 8/3

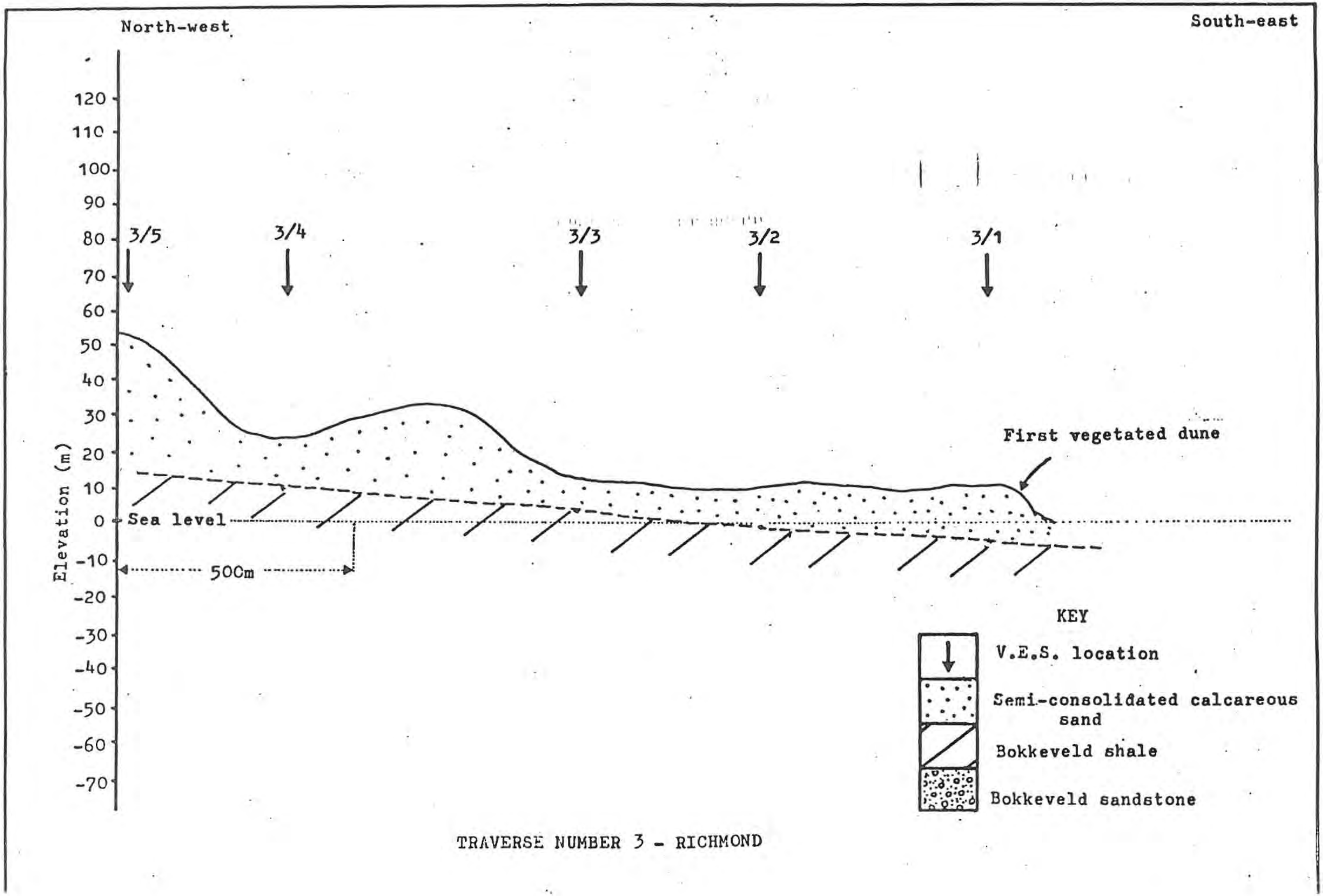
APPENDIX D - INTERPRETED RESISTIVITY SECTIONS



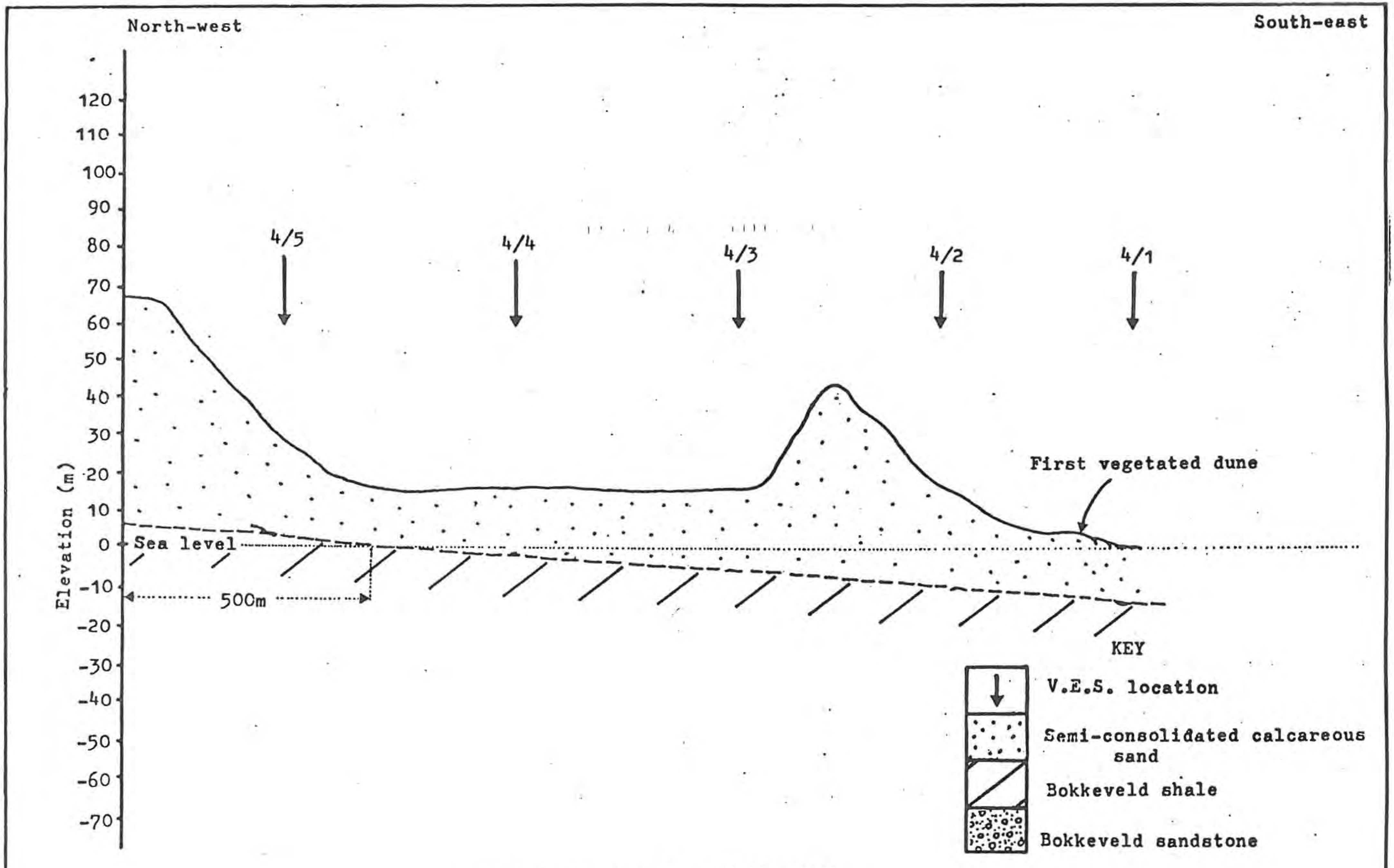
TRAVERSE NUMBER 1 - BUSHMANS RIVER MOUTH



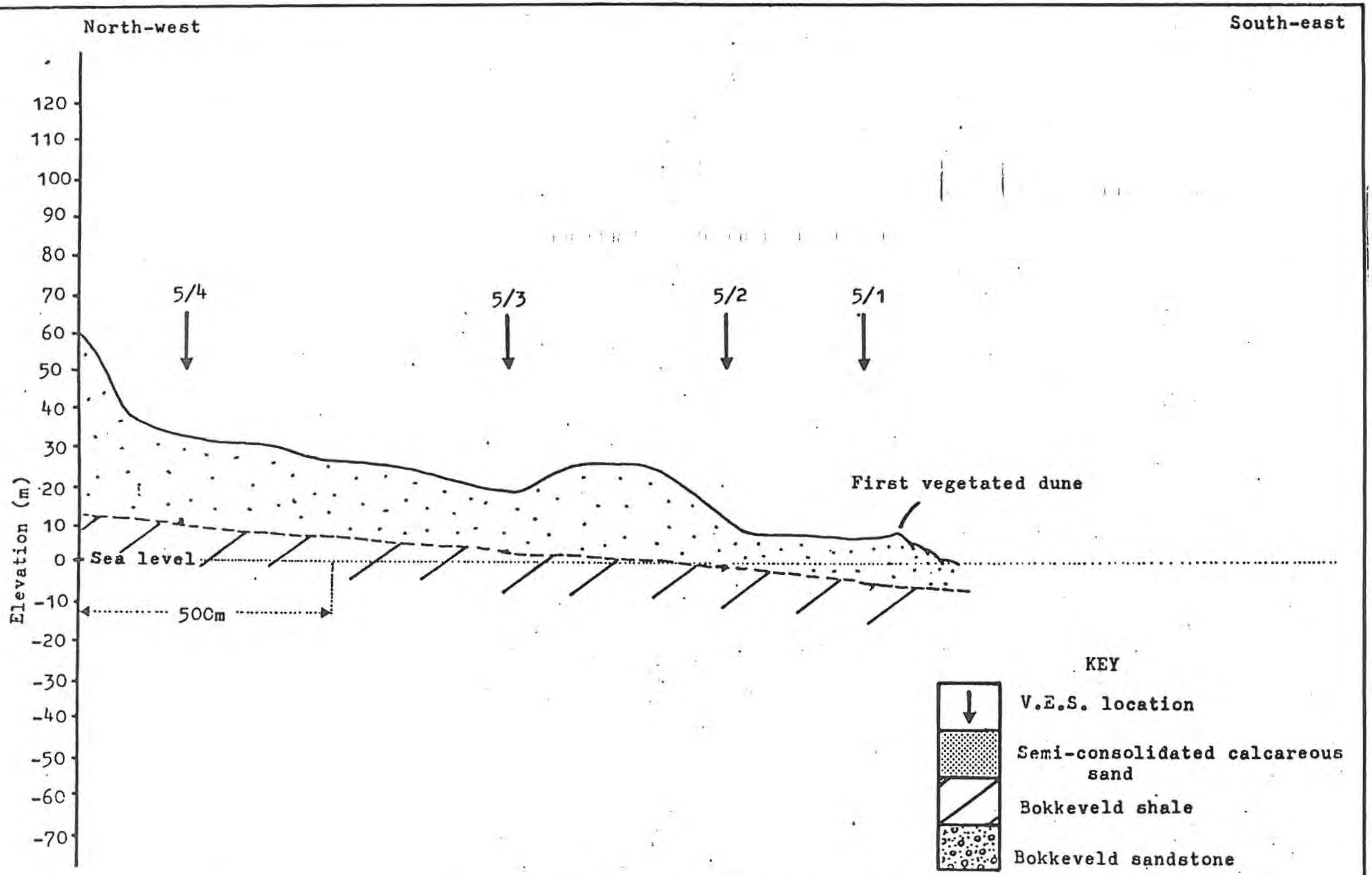
TRAVERSE NUMBER 2 - DIAZ CROSS



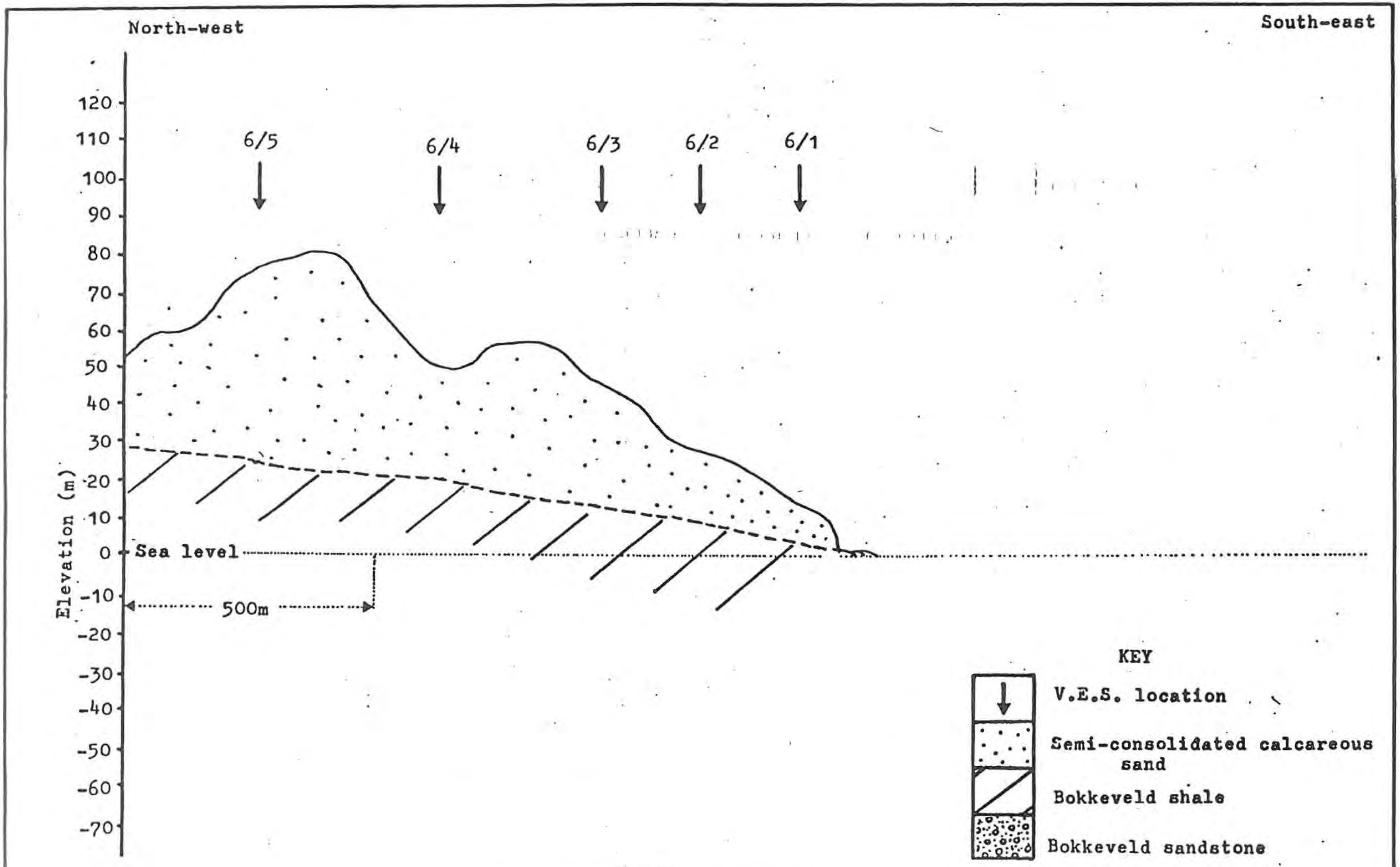
TRAVERSE NUMBER 3 - RICHMOND



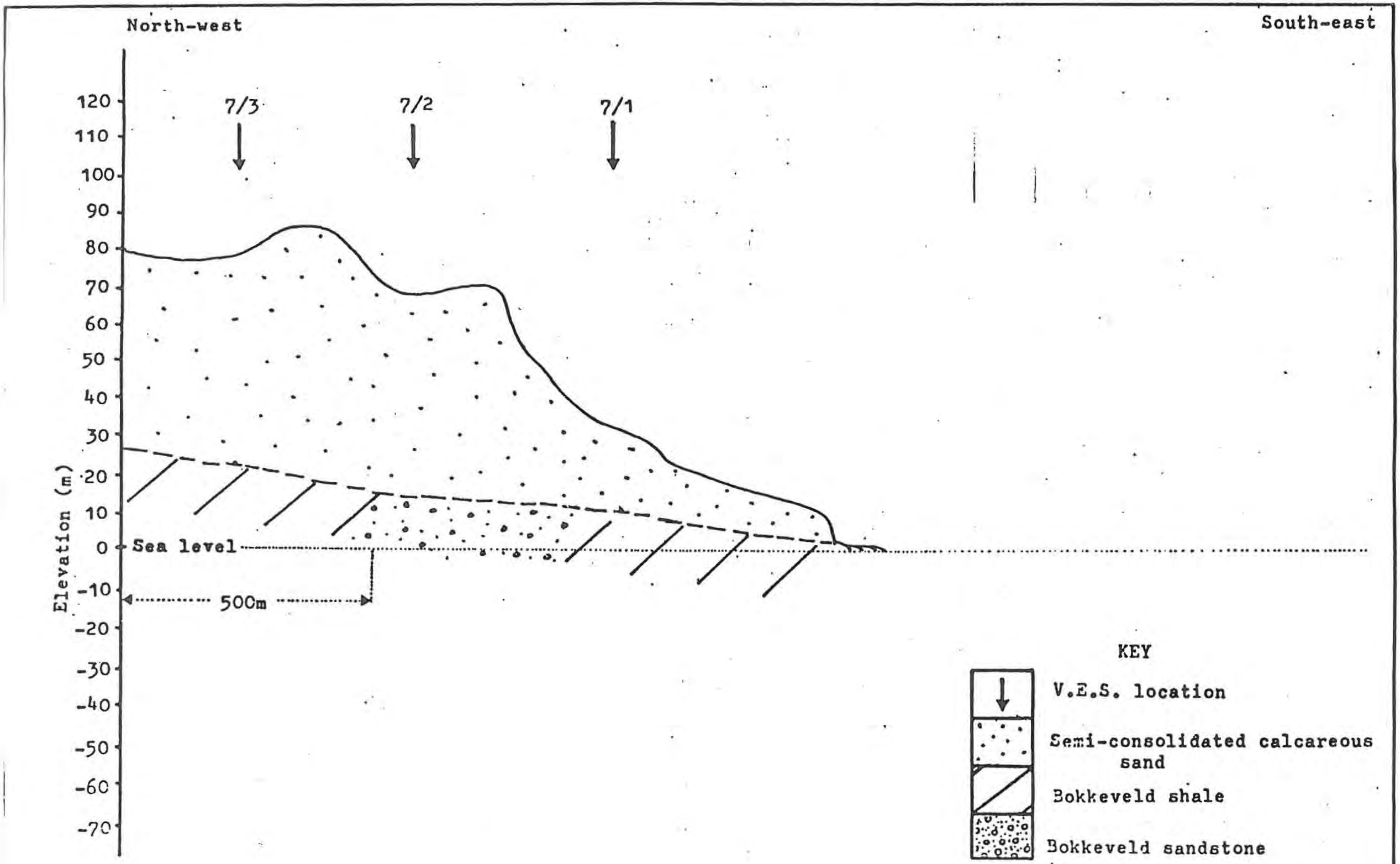
TRAVERSE NUMBER 4 - STILLEWATER



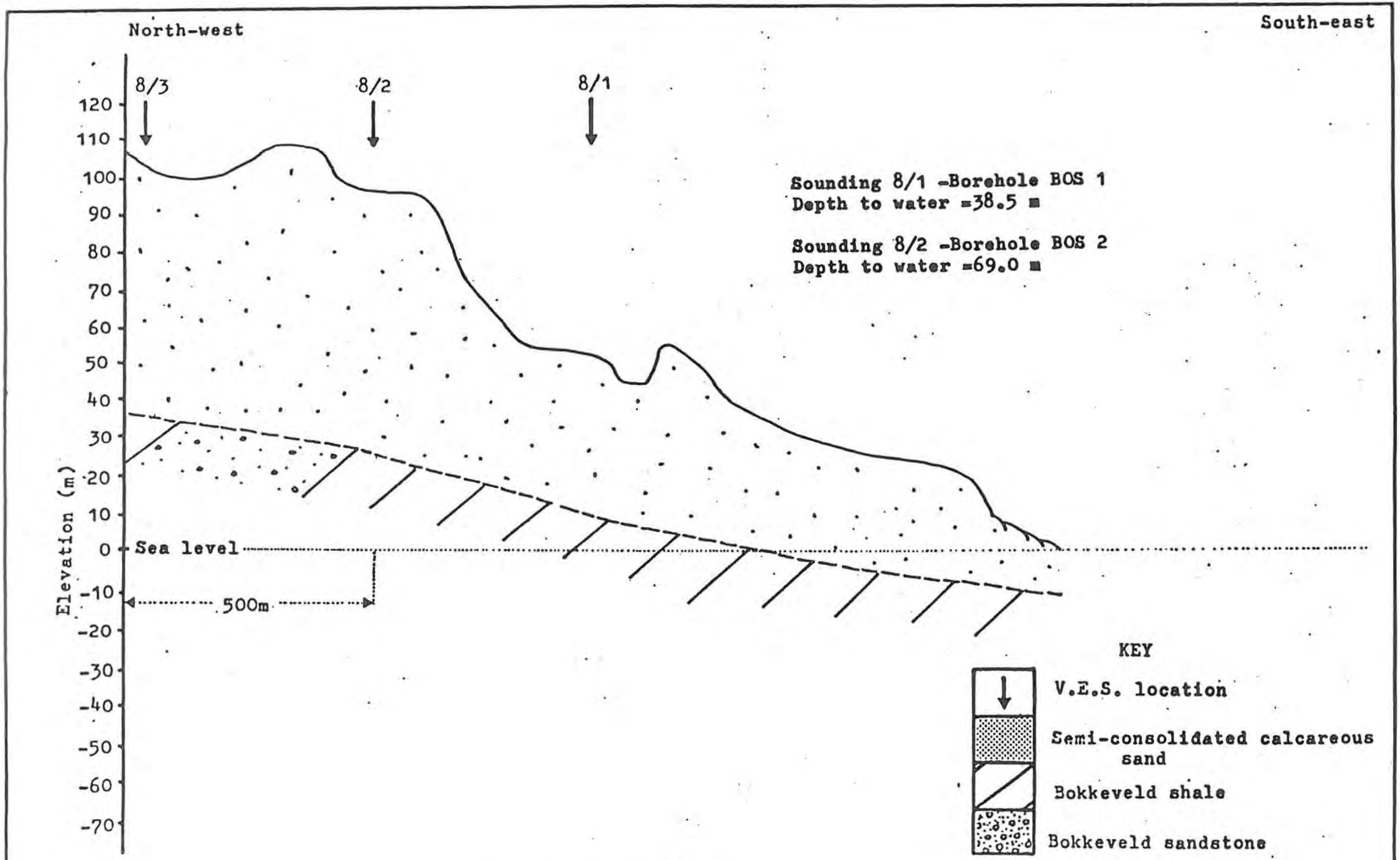
TRAVERSE NUMBER 5 - CANNON ROCKS (EAST)



TRAVERSE NUMBER 6 - CANNON ROCKS (CENTRE)

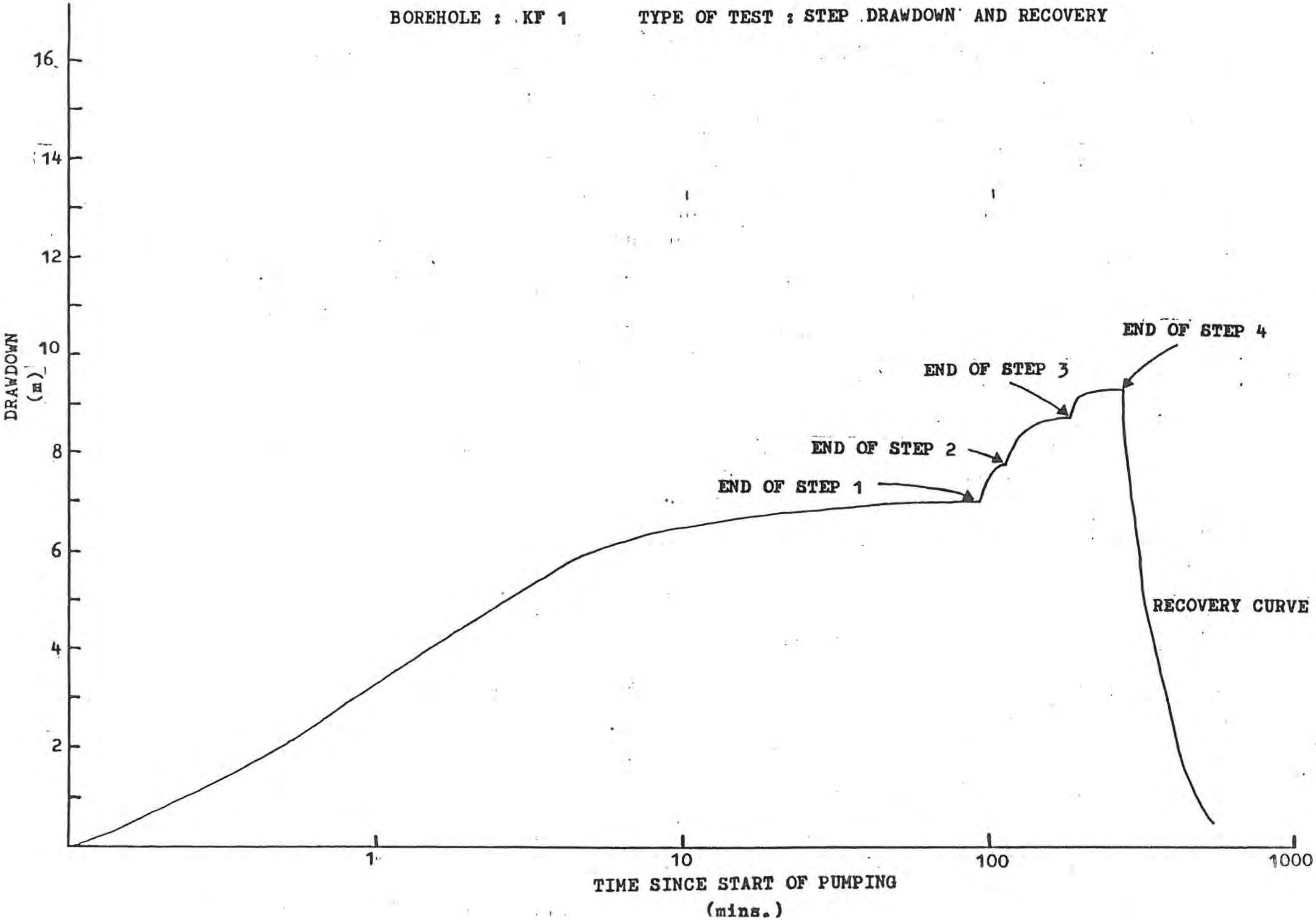


TRAVERSE NUMBER 7 - CANNON ROCKS (WEST)

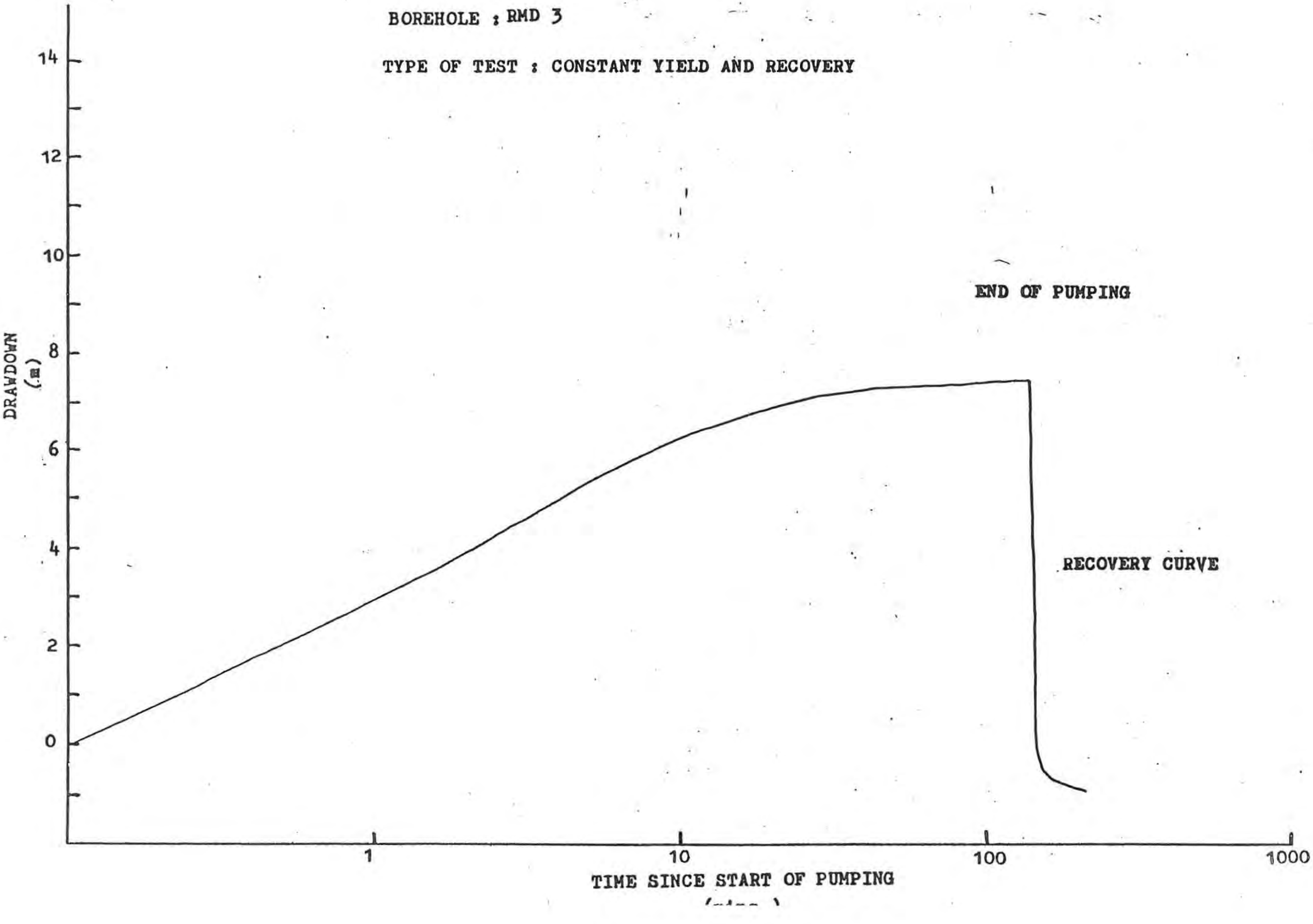


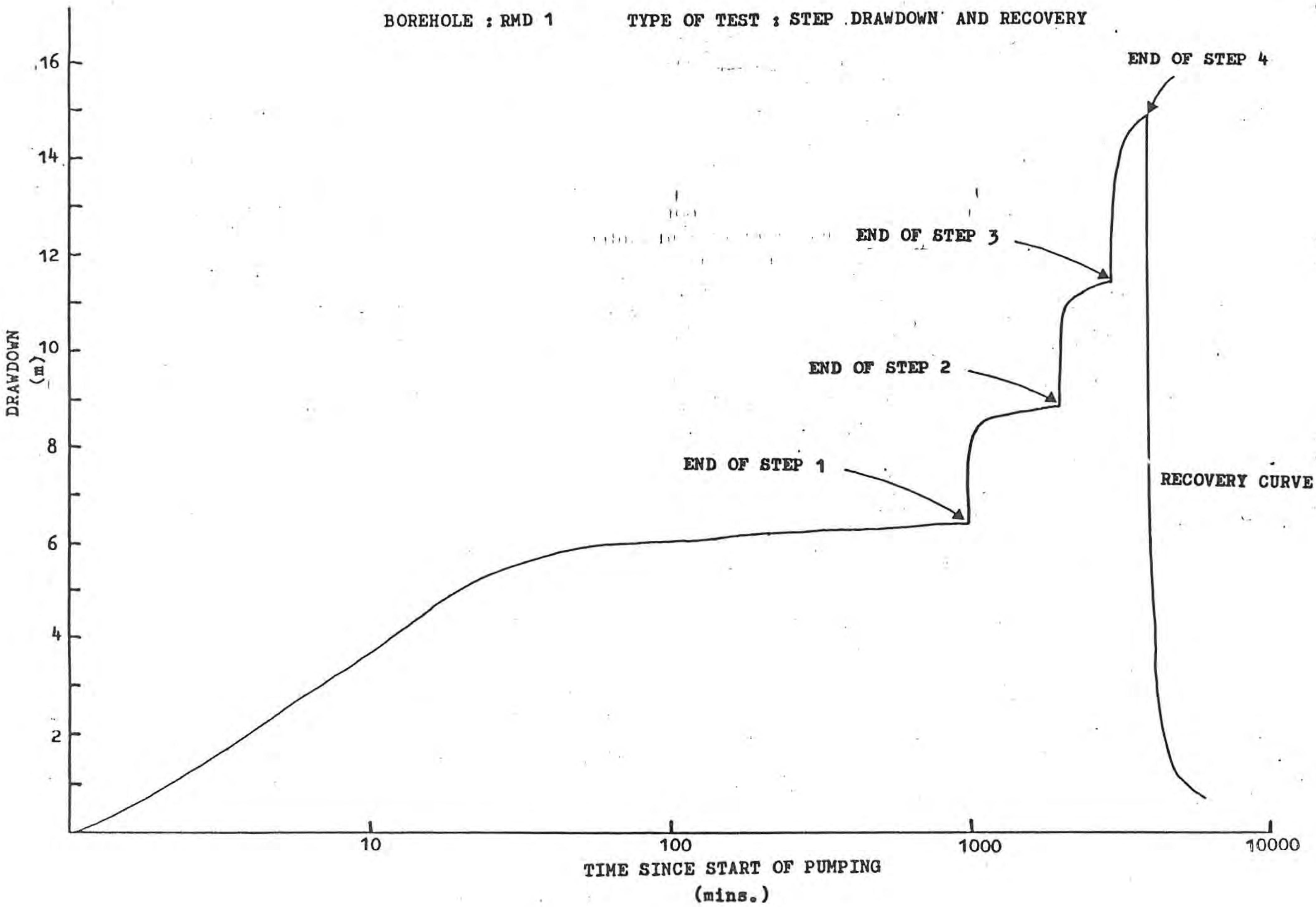
TRAVERSE NUMBER 8 - BOSCHFONTEIN

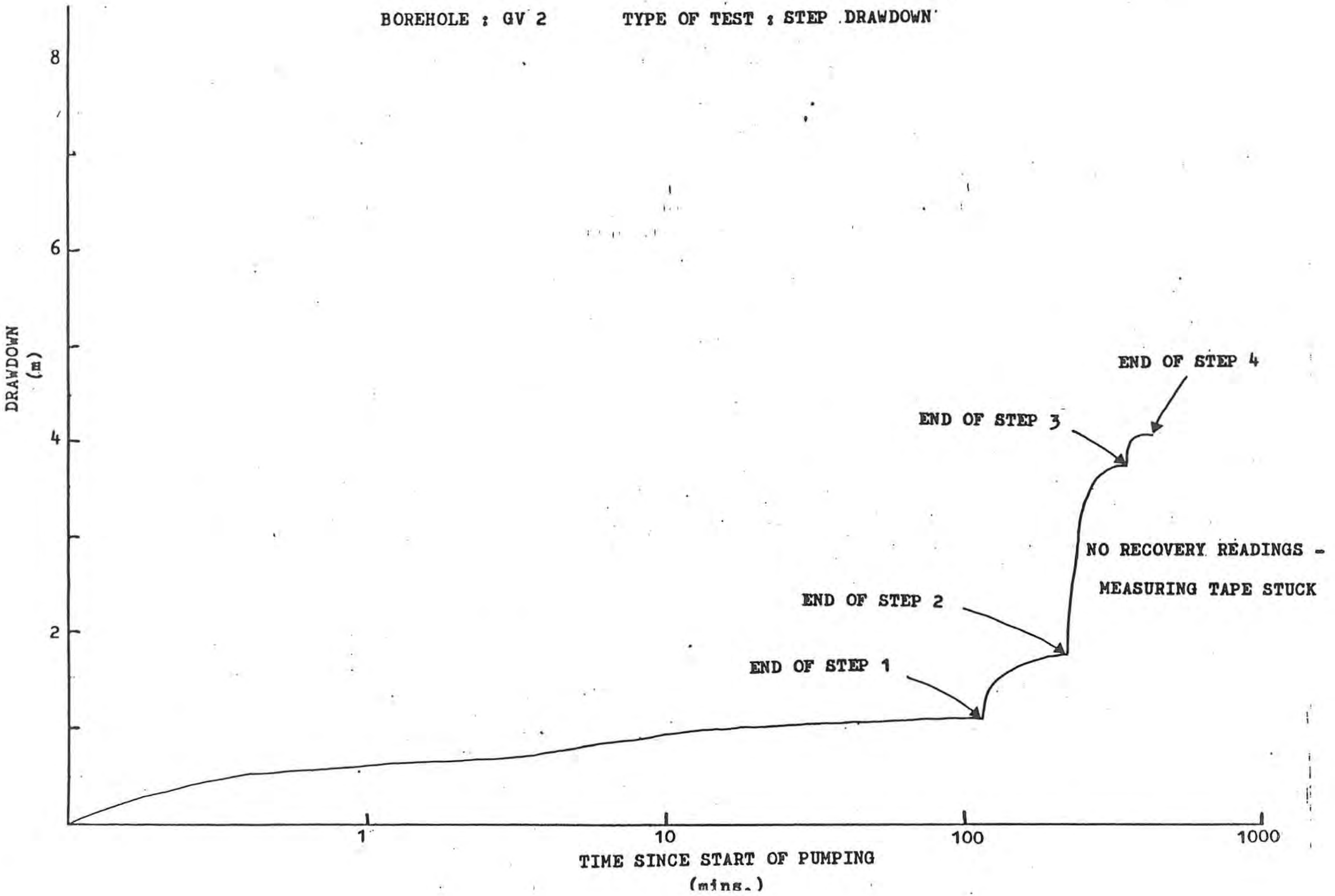
APPENDIX E - AQUIFER TEST CURVES

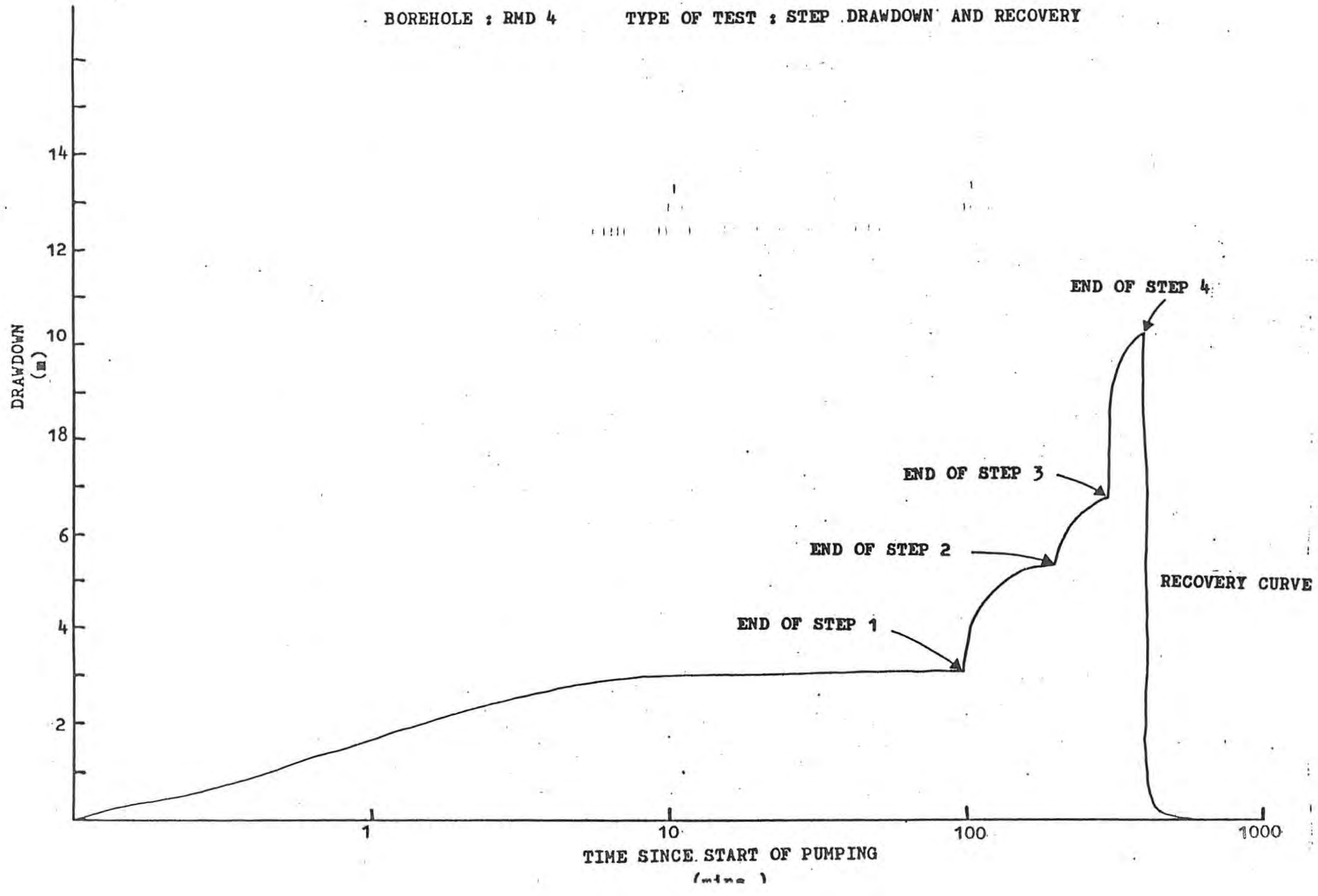


BOREHOLE : KF 1
TYPE OF TEST : STEP DRAWDOWN AND RECOVERY
DRAWDOWN (m)
16
14
12
10
8
6
4
2
END OF STEP 4
END OF STEP 3
END OF STEP 2
END OF STEP 1
RECOVERY CURVE
1
10
100
1000
TIME SINCE START OF PUMPING
(mins.)

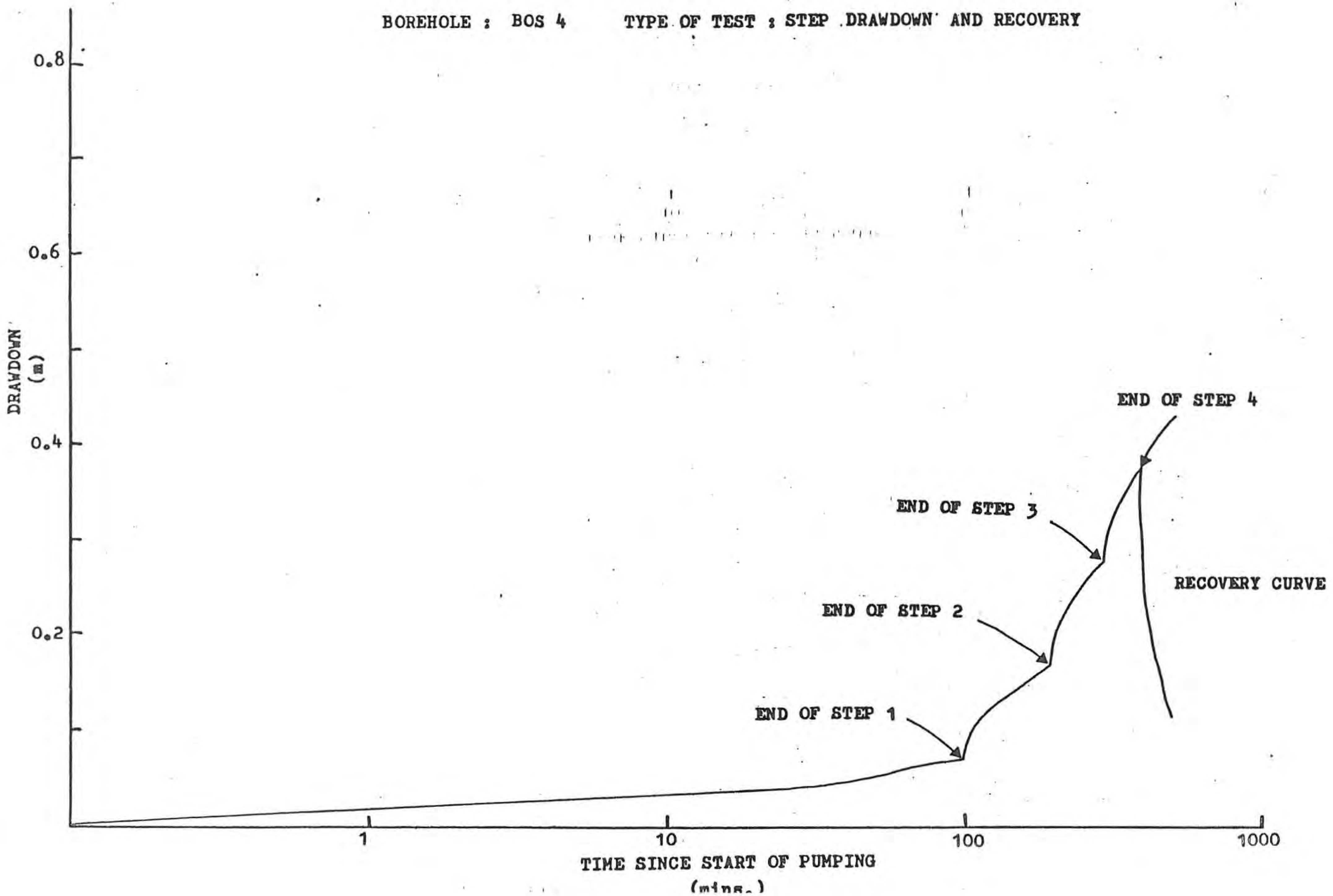

BOREHOLE : RMD 3
TYPE OF TEST : CONSTANT YIELD AND RECOVERY
END OF PUMPING
RECOVERY CURVE
DRAWDOWN (m)
14
12
10
8
6
4
2
0
1
10
100
1000
TIME SINCE START OF PUMPING


BOREHOLE : RMD 1
TYPE OF TEST : STEP DRAWDOWN AND RECOVERY
DRAWDOWN (m)
16
14
12
10
8
6
4
2
END OF STEP 4
END OF STEP 3
END OF STEP 2
END OF STEP 1
RECOVERY CURVE
10
100
1000
10000
TIME SINCE START OF PUMPING (mins.)


BOREHOLE : GV 2
TYPE OF TEST : STEP DRAWDOWN
8
6
4
2
DRAWDOWN (m)
END OF STEP 4
END OF STEP 3
NO RECOVERY READINGS - MEASURING TAPE STUCK
END OF STEP 2
END OF STEP 1
1
10
100
1000
TIME SINCE START OF PUMPING (mins.)



BOREHOLE : RMD 4
TYPE OF TEST : STEP DRAWDOWN AND RECOVERY
DRAWDOWN (m)
14
12
10
18
6
4
2
END OF STEP 4
END OF STEP 3
END OF STEP 2
END OF STEP 1
RECOVERY CURVE
1
10
100
1000
TIME SINCE START OF PUMPING
(mins.)


BOREHOLE : BOS 4 TYPE OF TEST : STEP DRAWDOWN AND RECOVERY
DRAWDOWN (m)
0.8
0.6
0.4
0.2
END OF STEP 4
END OF STEP 3
END OF STEP 2
END OF STEP 1
RECOVERY CURVE
1
10
100
1000
TIME SINCE START OF PUMPING (mins.)

APPENDIX F - HYDROCHEMICAL DATA

CHEMICAL ANALYSIS OF THE FIRST SAMPLE EXTRACTED FROM EACH BOREHOLE

BOREHOLE	pH	T.D.S. (ppm)	TAL (mg/l)	NH_4 (mg/l)	Ca (mg/l)	Cl (mg/l)	NO_3 (mg/l)	Na (mg/l)	Mg (mg/l)	F (mg/l)	SiO_2 (mg/l)	K (mg/l)	SO_4 (mg/l)	P (mg/l)
Bos 1	7.9	1867	235.6	0.009	98.3	721.7	0.1	472.7	37.3	0.3	5.1	3.8	119.9	0.002
Bos 2	8.0	1641	316.0	0.020	42.1	585.6	2.8	514.8	16.8	0.4	6.7	4.4	63.1	0.005
Bos 3	7.6	2105	147.0	0.022	126.4	870.9	5.0	453.6	50.4	0.2	4.4	6.7	104.2	0.003
Bos 4	8.2	1049	391.9	0.007	12.5	254.1	4.2	342.3	3.4	0.9	3.0	7.6	36.6	0.004
GV 1	7.7	1075	166.2	0.014	63.3	358.0	1.4	245.1	20.9	0.3	8.5	2.9	74.3	0.004
GV 2	7.8	1196	230.0	0.013	88.5	475.6	1.1	270.8	22.5	0.2	8.3	2.1	15.8	0.003
KF 1	7.9	2539	270.4	0.008	105.9	1078.4	0.1	641.2	55.4	0.3	4.9	12.5	95.8	0.008
KF 2	7.5	2048	78.1	0.000	94.4	1064.5	3.5	1005.0	36.2	0.7	1.0	12.5	197.6	0.005
RMD 1	7.5	8129	118.1	0.006	593.6	4590.4	0.0	1880.6	351.1	0.2	6.6	28.5	404.6	0.013
RMD 2	7.5	6272	27.5	0.009	374.0	3360.0	0.0	1453.3	256.4	0.1	1.4	25.1	265.4	0.012
RMD 3	7.9	1416	279.9	0.009	71.5	520.3	1.5	327.0	28.0	0.3	6.2	9.7	63.0	0.009
RMD 4	8.0	1585	261.2	0.005	46.2	598.8	0.8	426.3	29.7	0.3	5.8	13.2	92.7	0.011