R. Bradford

INSTITUTE of HYDROLOGY

MORUPULE POWER STATION

GROUNDWATER STUDIES

VOLUME 2

MORUPULE POWER STATION

GROUNDWATER STUDIES

This report is prepared for

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by

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Wallingford

Oxon

UK

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KEY TO FIGURES

Figure Number

	Site Location	Magnetic Traverse	Lithology and Drilling Details	Formation Logs	Conductivity and Temperature Logs	Step Test	Constant Rate Test
SYA			2	3	4	5	6
SYB	7		8	9	10	11	12
SYC	13		14	15	16	17	18
TS2	19	20	21	22	23	24	25
TS3	26		27	28	29	30	31
TS4	32	34	33	35	36	37	38
TS5	39	40	41	42	43	44	45
TS6	46	47	48	49	50	51	52
TS1	53	54	55	59	-		
EX7			56	60	(56)		
EX9			57	61	(57)		
EX10			58	62	(58)		

Notes:

1. *All figure numbers are prefixed A.3*
2. *Where there is a set of drawings referring to the same parameter at a particular site the same number has been used for the set*

A.1 INTRODUCTION

This volume presents the LANDSAT imagery interpretation, the data collected during the drilling investigation and the pump testing programme.

It has been divided into the following sections

A.2 LANDSAT imagery

A.3 Drilling investigations and pump testing

A.4 Chemistry and stable isotope data

Copies of the original field data are held in Botswana.

A.2 LANDSAT DATA ANALYSIS

A.2.1 Introduction

During the course of the field studies a research project concerned with an examination of the nature and quality of LANDSAT (ERTS) data presentation was carried out at the Institute of Hydrology. This work compared conventional photographic image output with various computer enhanced images taken from data obtained as computer compatible tapes. It was concerned with technique rather than with interpretation and concentrated upon producing various high quality spatially corrected images. As a secondary objective we attempted to determine whether features such as faults and dykes affecting the Cave Sandstone aquifer could be located beneath Kalahari Beds.

We find several characteristics of the area combine to obscure detail of the deeper geology on the plateau. Strong sand dune lineations combined with vegetation changes associated with fire burns dominate the detailed images. Also banding in the multi-spectral data parallels the linear features sought and thus further hinders recognition. However, several features of hydrogeological relevance are evident. Stock-watering boreholes can be identified from local over-grazing patterns and we have been interested to locate accurately the position of such boreholes. The location and extent of various pans and depressional hollows which might be associated with recharge processes can also be identified from LANDSAT. With this in mind we have prepared a colour composite LANDSAT image to serve as a location plan for this report.

Below we briefly outline the computer processing operations. These were funded by the Overseas Development Agency using facilities of the Space Department at the Royal Aircraft Establishment, Farnborough. Currently a report on this research into technique is being prepared at the Institute for Overseas Development Agency. Since it is not concerned with interpretation a description of the features on the plateau is given below.

A.2.2 LANDSAT classification and geometric correction

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Most evident is a vegetation effect which picks up the eastern limit of the Kalahari Plateau along the escarpment in a deep reddish-brown. This continuous line north-eastwards across the scene marks the edge of the Kalahari Beds and widens from 2 km in the south to about 7 km in the north. The vegetation appears to be most extensive in areas where the escarpment is highest perhaps suggesting enhanced moisture availability due to small scale orographic effects. No groundwater has been detected to explain this distribution.

Fire-burns provide the second most evident feature. The youngest (black/dark green) are identified on the overlay. Older burns show up in shades of green, lightening with age, the oldest appearing as irregular but sharply bounded areas of pale yellow. Similar in appearance but paler and less well defined are grazing areas around the stock watering boreholes. Boreholes are plotted on the overlay using the grid references given in the Groundwater Inventory of the GS10 Project Report No.3.

Vegetation also serves to indicate pan areas such as Serwe pan close to the watershed just within the escarpment. The reflectance characteristics of these grass pan areas are similar to those of some burns and the August 1975 imagery may not be the most suitable for identification of these features.

Within the escarpment the main dune-crest trend is indicated on the overlay as is the line-scan banding. Tracks are also shown, together with minor vegetation features which appear to indicate depression hollows. The possibility is raised elsewhere that these mark the location of potential groundwater recharge sites.

LANDSAT imagery provides much more detail of the geology and physiography outside the escarpment. The distribution of unconsolidated sands and fine grained deposits along the foot of the escarpment are clearly visible. Areas of basalt overlying the Cave Sandstone, particularly at Serowe and in the Paje area, appear again in pale green. Dykes at Serowe and Taukome Hill are evident but generally the detailed geology of the aquifer at outcrop is hidden.

A.2.4 Accuracy and borehole location

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A.2.4 Accuracy and borehole location

Accurate positioning of location in relatively featureless terrain such in the east. However systematic errors exist at traverses 2 and 4 with the surveyed traverses falling outside and to the west of the satellite fixes we suspect the primary survey beacon position to be in error for this region.

In many cases good agreement exists between the grid position of older boreholes in the area and the grazing patterns shown by LANDSAT in 1975. Some grazing patterns are clearly not coincident with borehole co-ordinates and indicate that errors of several kilometres may well exist within the data set.

In our interpretation of the geological structure of the area the position of a borehole relative for example to a geophysical anomaly has sometimes proved critical. We have tended to place less reliance upon those sites where grid position and grazing patterns are not coincident. This work is a first attempt to use combined satellite techniques. Clearly it has considerable promise for detailed field location at low cost and may be a most useful technique if large scale groundwater development takes place in the future.

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A.3 DRILLING INVESTIGATIONS SITES

A.3.1 Introduction

This section describes each site where drilling took place. There is a description of the site, drilling details, together with geophysical logs and the pumping test results.

Drilling

Drilling took place at 12 sites with a total of 27 boreholes drilled, the positions of the sites are shown in Plan 1. The borehole were constructed using an air hammer rig and to facilitate the return of cuttings foam or water was used at some of the sites. The unconsolidated sequence of the Kalahari Beds was cased out while the remainder of the hole was left open.

The time taken to drill 2 metre increments was used to produce the penetration rate log and the lithological logs are based on the examination of these drilling returns. Our presentation of the lithological log has been simplified to show only the significant strata, a complete set of samples are held by Geological Survey, Botswana.

At some sites detailed total magnetic field strength profiles obtained since the original geophysical survey are shown. After completion most of the boreholes were logged using self potential, single point resistance and gamma. While the detailed interpretation of the geophysical logs have not been included the following generalised responses of the main lithological units can be seen on the logs.

> The Kalahari Beds have not been electrically logged because either the water level is below these beds or they have been cased out. The gamma levels, while being variable, are generally higher than in the underlying basalts.
>
> The basalts of the Drakensberg Lava have a variable, but higher electrical resistance and a low gamma activity then the Cave Sandstone. The boundary between the basalt and the Cave Sandstone is always marked by an increase in gamma activity. Occasionally there are thin bands of higher activity within the baslat, such as TS5-OW2 at 85m, this is

unlikely to be due to weathering as there is an increase in resistance indicating a mineralogical change.

The Cave Sandstone is marked by a significant increase in gamma activity compared to the basalt, with the occasional clay bands producing large peaks, as at TS4/OW1 at 152m. Generally there is low resistance with little variation.

The Transition Beds are characterised by an increase in gamma activity and a decrease in electrical resistance due to the increased clay content. There are also some anomalies in self potential due to the formation water having a different conductivity from that in the borehole.

The only dolerite positively found is in SYA/OW1 between 127m and 134m and is marked by very low gamma activity, very high resistance and a self potential anomaly.

When unweathered can be very difficult to distinguish between basalt and dolerite. In cases of doubtful field classification geophysical logging has been used to determine the classification. Critical samples were returned to the Institute of Hydrology for microscopic and X-ray diffraction identification.

Fluid column logs, temperature and conductivity, were run at all sites except Test Site TS1 which was dry. On completion of drilling all the boreholes were allowed to establish equilibrium before being logged. At the sites where pumping tests were carried out at least one observation borehole was logged during pumping. In addition a saline injection test was carried out at specific yield site SYA.

Temperature logs normally show an increase in temperature with depth. A constant temperature, such as at specific yield site SYB, indicates a zone of vertical movement, while horizontal movements cause variations in the temperature gradient.

Temperature gradient variations can be caused by other factors. It is not only necessary to compare both static and pumped logs but also these should be compared with the conductivity logs. Jennings (1974) has demonstrated that changes in hydrochemistry can also occur with depth. As the hydrochemistry controls the conductivity it is necessary to interpret both temperature and conductivity logs together.

The interpretation of the fluid column logs allows an assessment of the relative rate of water movement to be made. As the Cave Sandstone is a single aquifer, demonstrated by the virtual absence of vertical flow in the boreholes, the rate of water movement is probably related to the permeability of the adjacent formation.

Pumping tests

Step drawdown and constant rate tests were carried out at 8 sites. The step drawdown tests were solved using the Jacob method to determine the aquifer and well losses. The constant rate test data were analysed using the Theis method for confined and the Boulton method for unconfined conditions to determine transmissivity and storage. At three sites there were single barrier boundary conditions and these data were solved using Stallman's image well method to obtain values for the aquifer parameters.

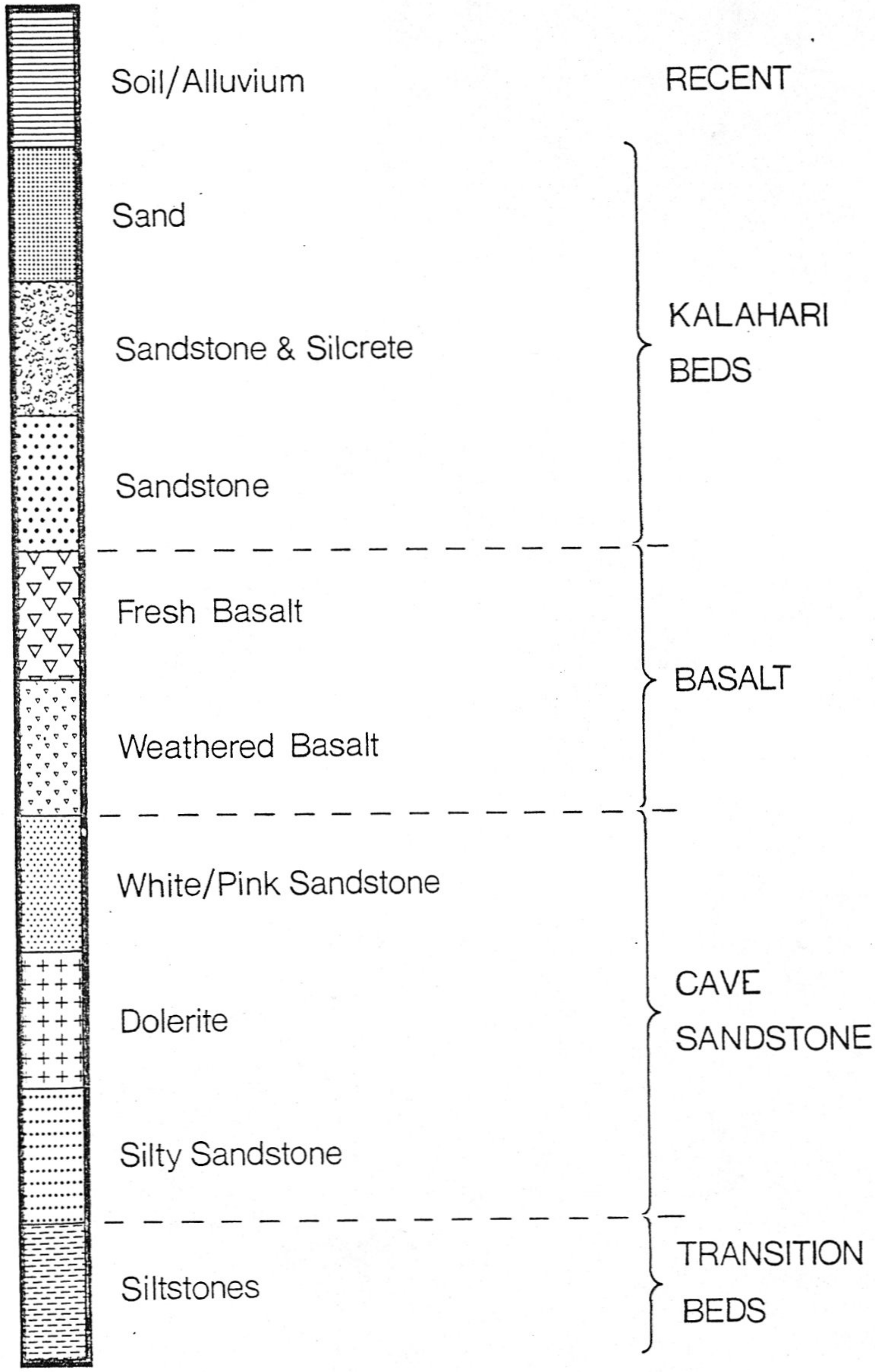
To compliment these analyses the data, where applicable, were analysed using Jacob and distance drawdown methods. The results are only given for comparative purposes as are the recovery transmissivities.

Before and during all pumping tests barometric pressure readings were taken. We found that barometric pressure fluctuations only materially affected the water levels at Specific Yield Site SYA, this is discussed further in A.3.2. The pace and timing of the field programme did not allow long term observations of water levels at individual sites prior to test pumping. Although there was rainfall during over field programme inspection of the water level data suggest that regional corrections would not make an appreciable difference to the various solutions adopted. Partial penetration corrections are not needed, test sites fully penetrate the aquifer.

Copies of the field data, together with listings of the data used in the computer generated graph plotting, are held in Botswana.

Jennings, C. M. H. Hydrogeology of Botswana, unpublished PhD Thesis, University of Natal 1974

KEY TO LITHOLOGY



A.3.2 Specific Yield Site SYA

Location

This, the most westerly of all project sites, is located adjacent to C5 (2226A/A58), an existing borehole drilled by the GS.10 project. It is positioned on geophysical line 5 and lies on the basalt plateau 55 kms to the west of the escarpment at Paje. A further two observation wells and a pump well were drilled alongside borehole C5 as shown in Figure A.3.1.

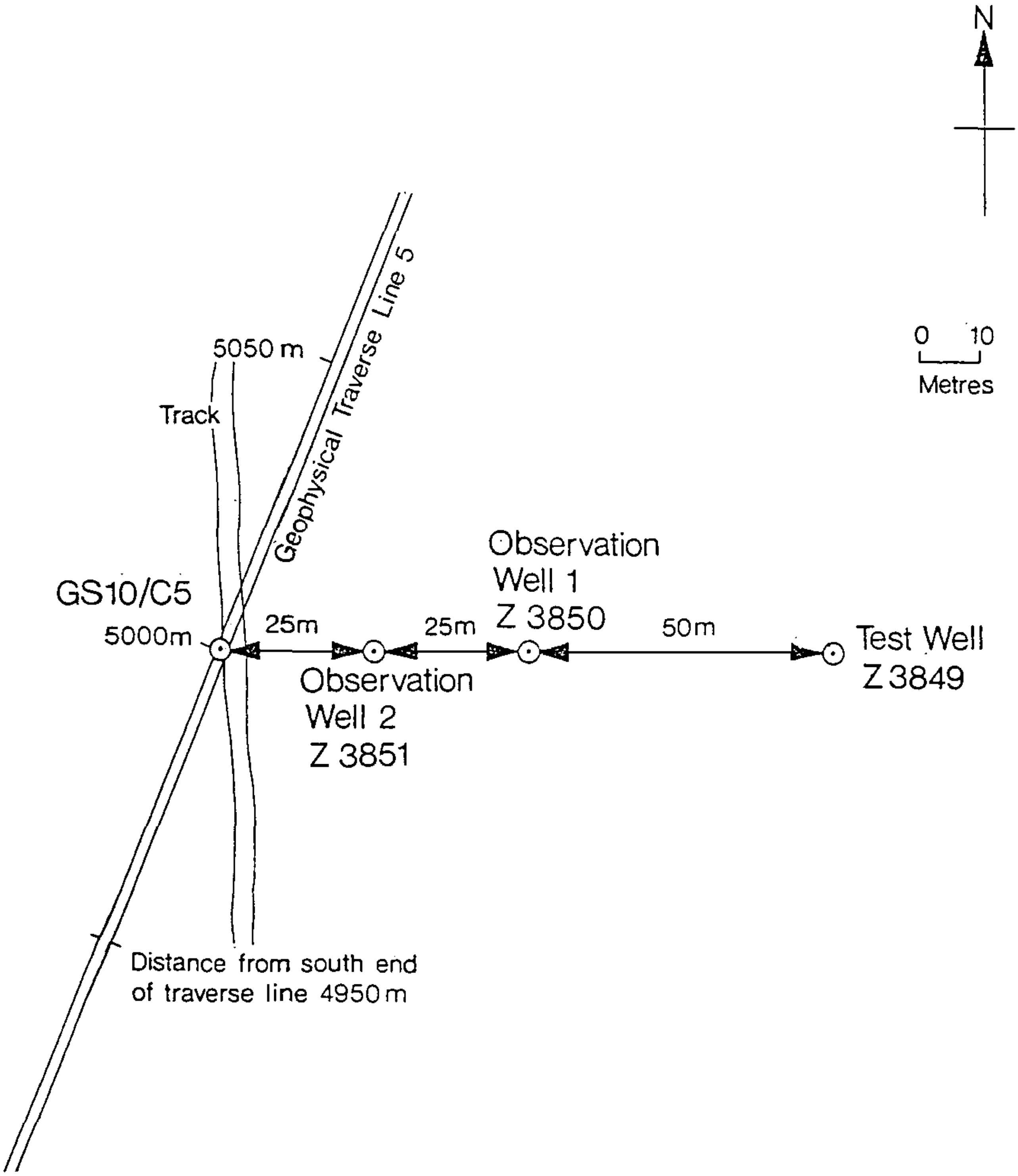
Unconfined conditions exist in all wells and the site was selected as one liable to provide a solution for unconfined storage by analysis of a long term pumping test.

Geology

The site lies on the extensive Drakensberg Basalt plateau which covers much of the study area. All four boreholes penetrate a thick cover of Kalahari Beds, pass through the Drakensberg Basalt and into the Cave Sandstone. Only C5, the deepest of the boreholes, enters the underlying Transition Beds, Figures A.3.2 and A.3.3.

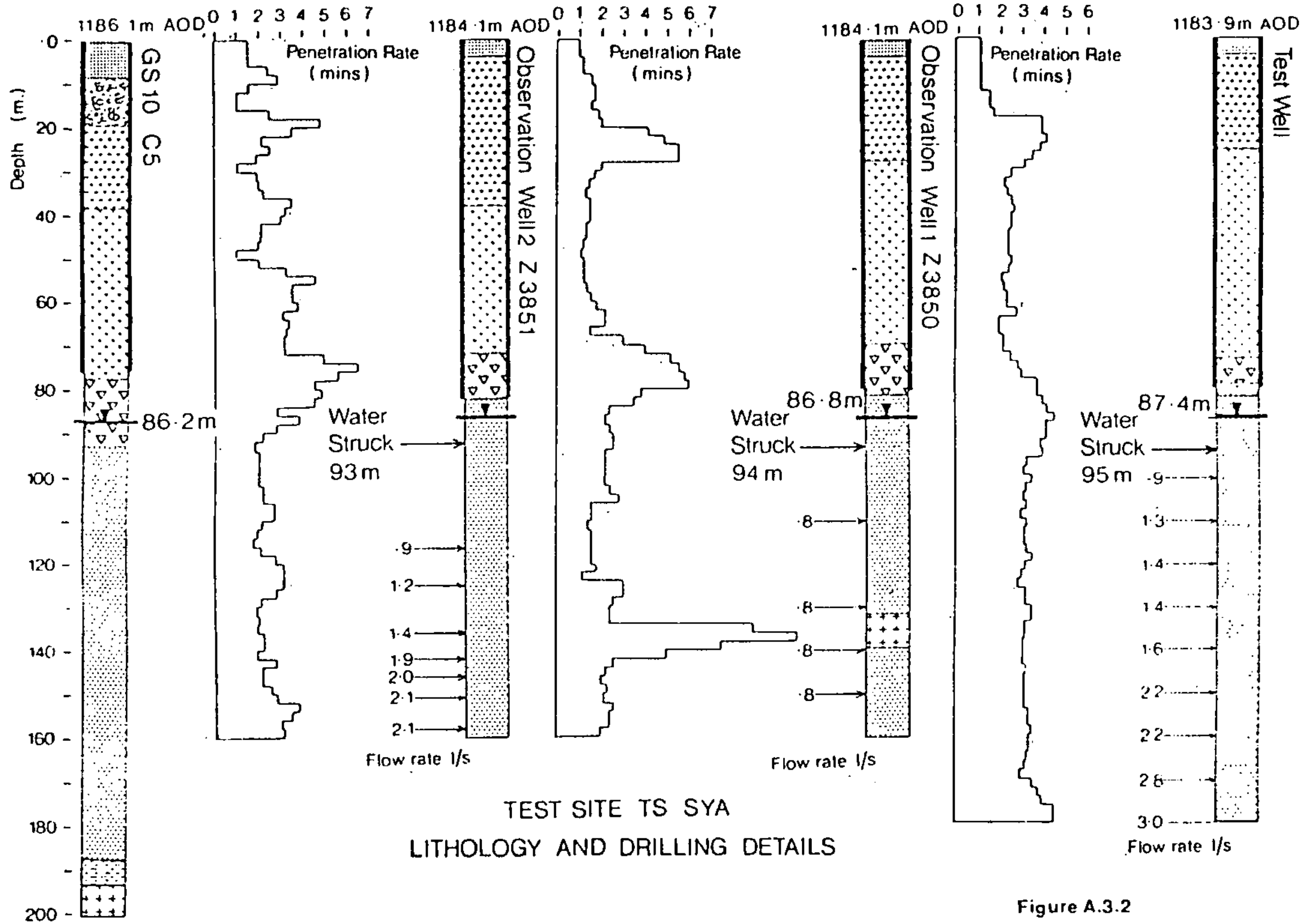
The Kalahari Beds comprise a 26-38 m thick sequence of calcrete, silcrete and sandstone with a 4-8 m thick layer of fine to medium grained yellow-orange sand at the surface. Rapid vertical and lateral changes of lithology characterise this formation and it is difficult to recognize a consistent sequence, even over a distance of one hundred metres. In general, it appears that calcretes and calcretised sandstones dominate in C5, whereas in the remaining three wells silcretes and siliceous sandstones are more important.

In the three project wells the Kalahari Beds gradually pass into the basalt. At this site, and others throughout the study area, the presence of calcretised and silicified sandstones at the base of the Kalari Beds passing down into extensively weathered basalt can make the precise boundary difficult to locate. It may be expected that slight differences in the thickness of the Kalari Beds at a site can be attributed to this lack of definition rather than a true difference in thickness.



Test Site SYA: Location

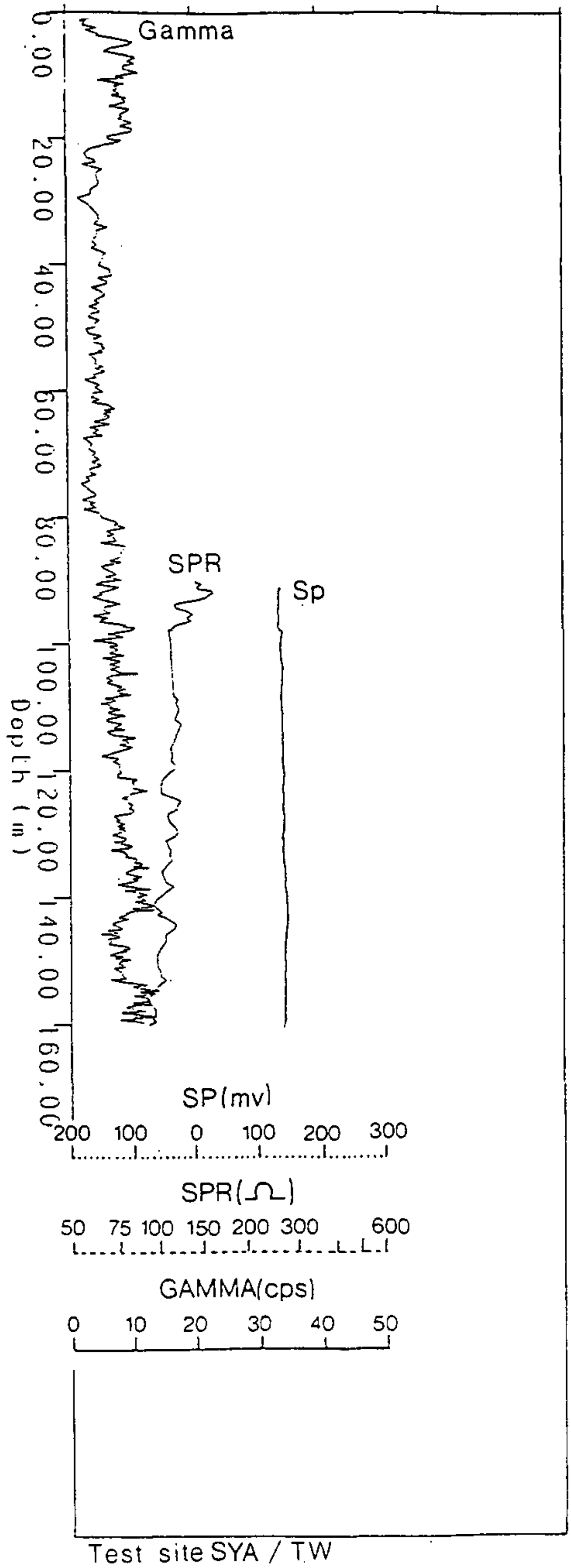
Figure **A.3.1**



TEST SITE TS SYA

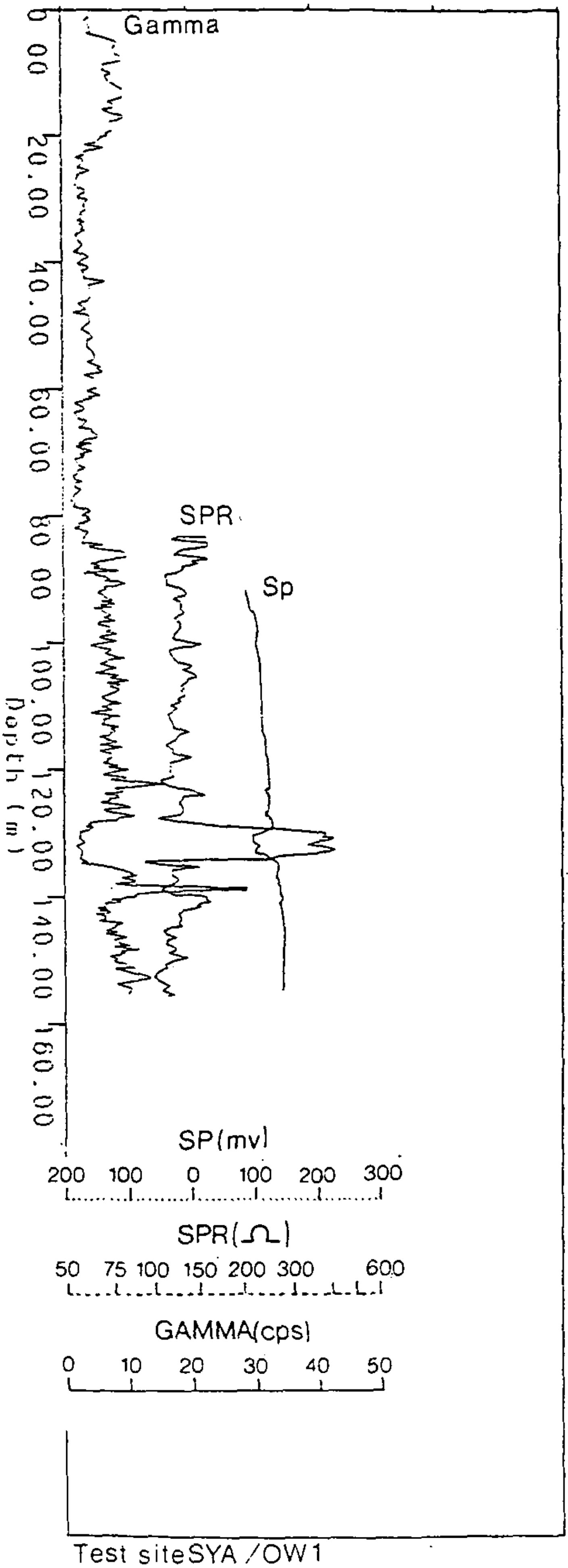
LITHOLOGY AND DRILLING DETAILS

Figure A.3.2



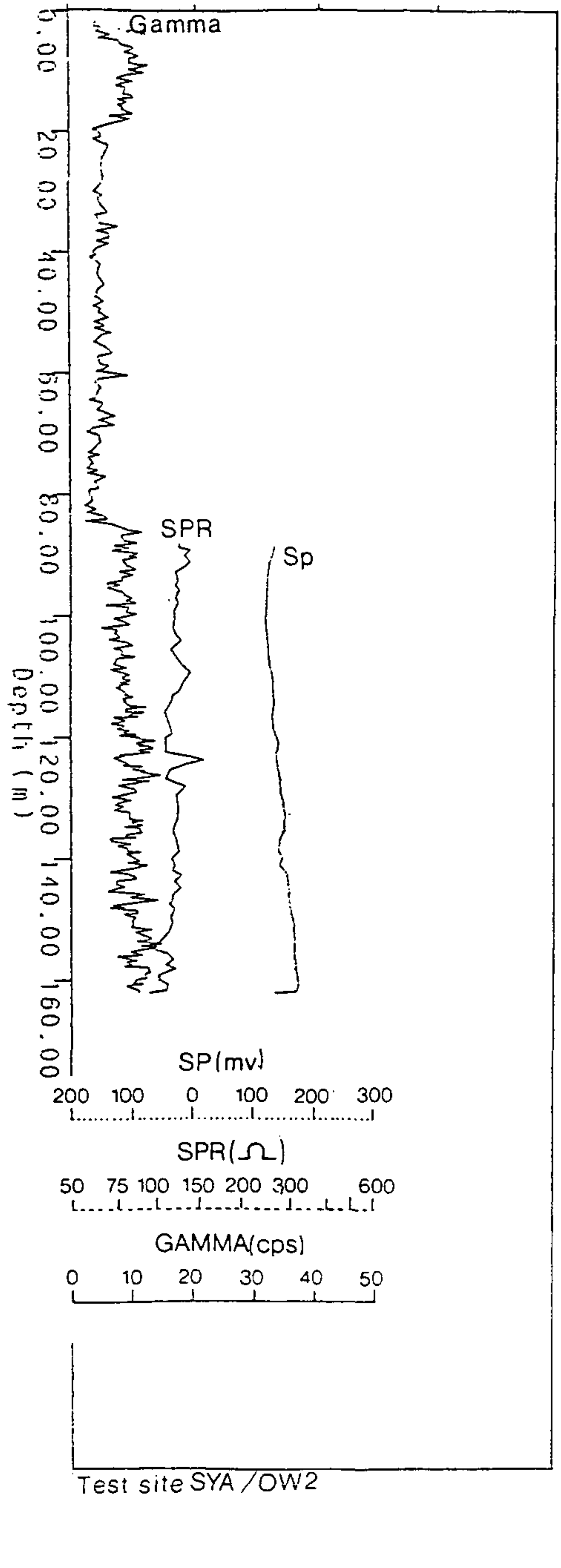
TEST SITE SYA FORMATION LOGS

Figure **A3.3**



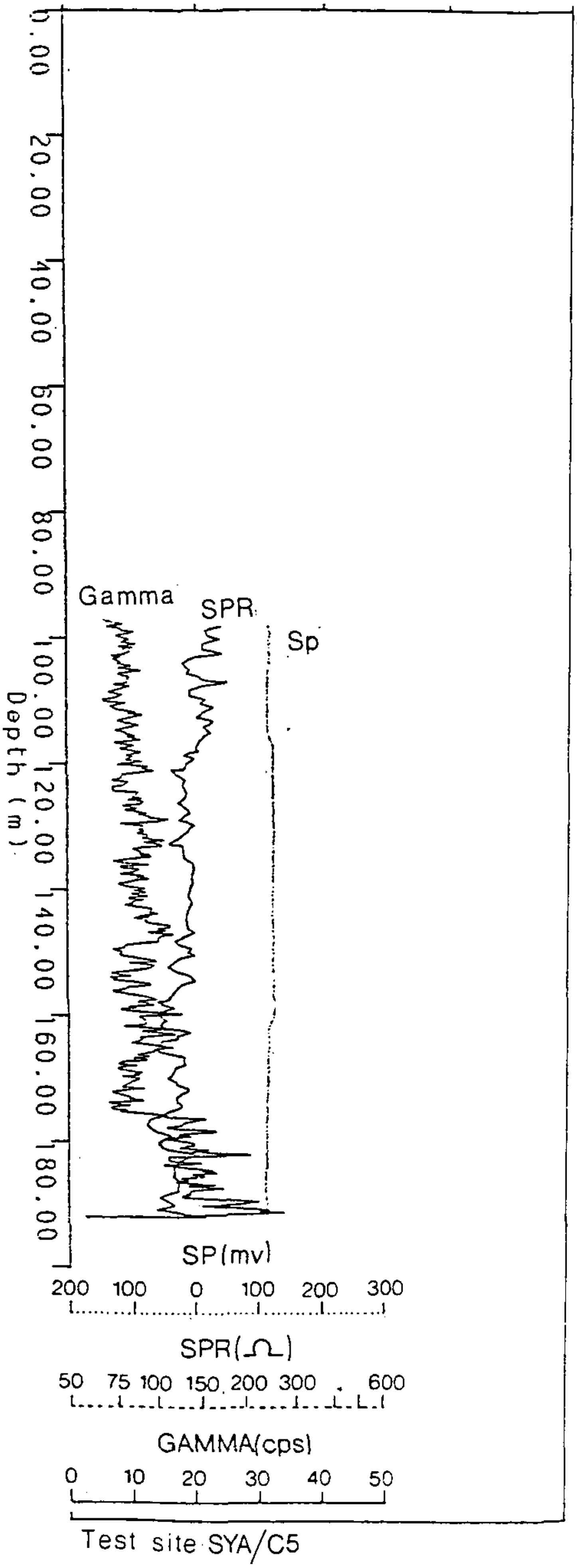
TEST SITE SYA FORMATION LOGS

Figure A.3.3



TEST SITE SYA FORMATION LOGS

Fi ure A.3.3



TEST SITE SYA FORMATION LOGS

Figure A.3.3

Underlying the Kalahari Beds is a 44-56 m thick sequence of Drakensberg Basalt. In each of the three project wells the base of the basalt is at a depth of 82 m. Whereas in C5 it is 10 m lower at 92 m; either faulting or pre-basalt topography is therefore indicated. Coarse, fine and amygdaloidal basalt types are present, with the most common secondary minerals being chorite, zeolite and calcite. A consistent feature throughout is the extensively weathered nature of most of the basalt with only the lowest 6 m being unweathered. The weathering has produced a red-brown colour which contrasts sharply with the dull grey-black appearance of the fresh basalt at the base; this contrast being emphasised by much longer drilling penetration rates over the unweathered part of the sequence.

Beneath the basalt is the Cave Sandstone which at this site is 95 m thick and comprises a monotonous succession of fine to very fine grained pink and white calcareous sandstone. Uniform penetration rates throughout the formation confirm the homogeneous nature of this lithology. However when C5 was drilled, the cored log showed one fissure in the formation. Similar observations in the three project wells were not possible because of the drilling method used.

The Transition Beds penetrated by C5 comprise a series of dark purple mudstones.

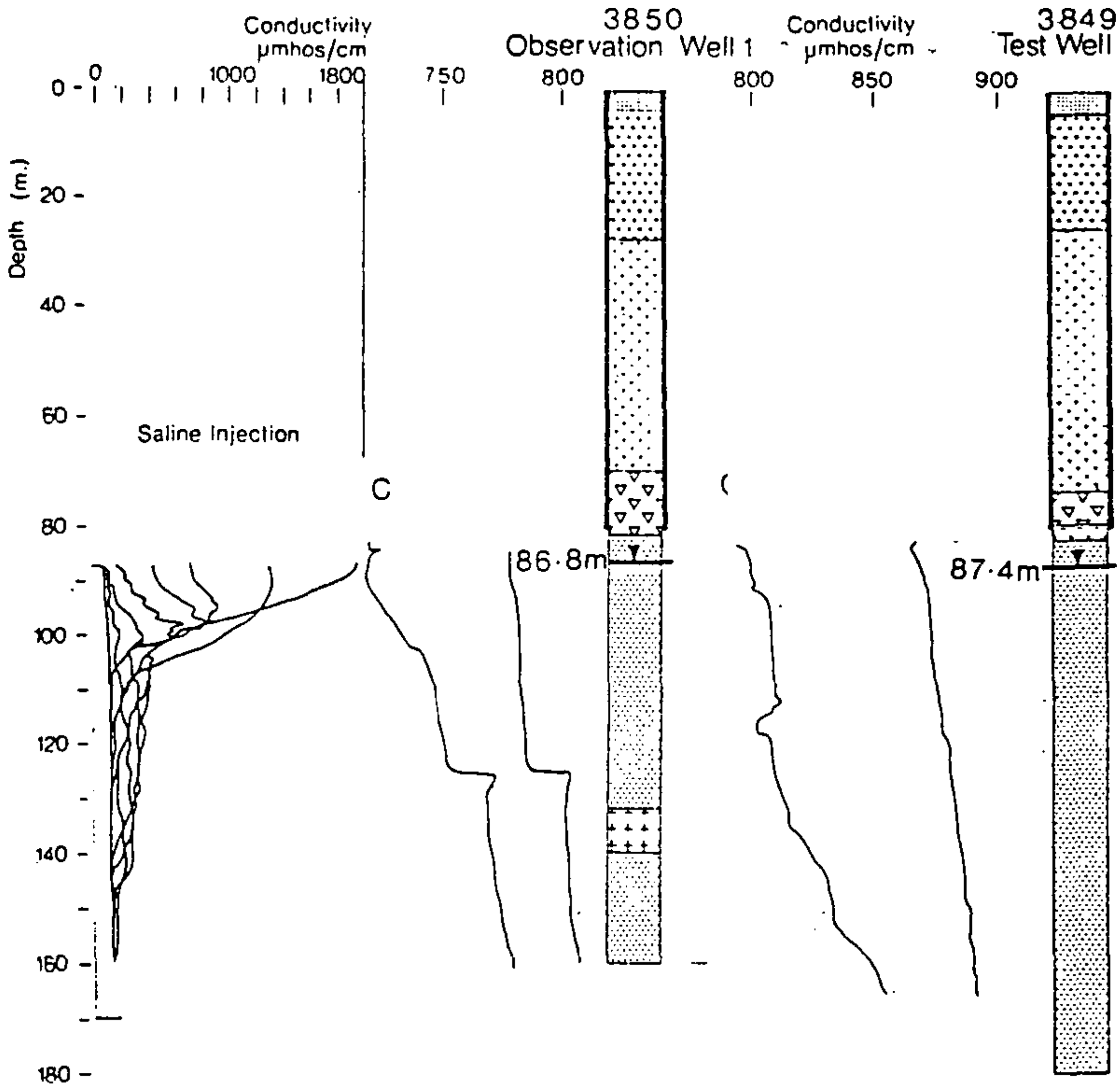
The site is traversed by two thin dolerite dykes; one is encountered in observation well I between a depth of 132-140 m and a second in C5 between 191-200 m. The second of these dykes may follow the line of a fault between C5 and observation well 2 that could account for the lower elevation of the base of the basalt in C5. Since both dykes are probably of the same age it is likely that they penetrate the Drakensberg Basalt.

Fluid column Logs

Temperature and conductivity logs were run in all the boreholes under static conditions, Figure A.3.4. During pumping logs were run in observation borehole 1, together with a saline injection test. This test confirmed the interpretation of the logs. They may be summarised as follows:

Observation Well 1

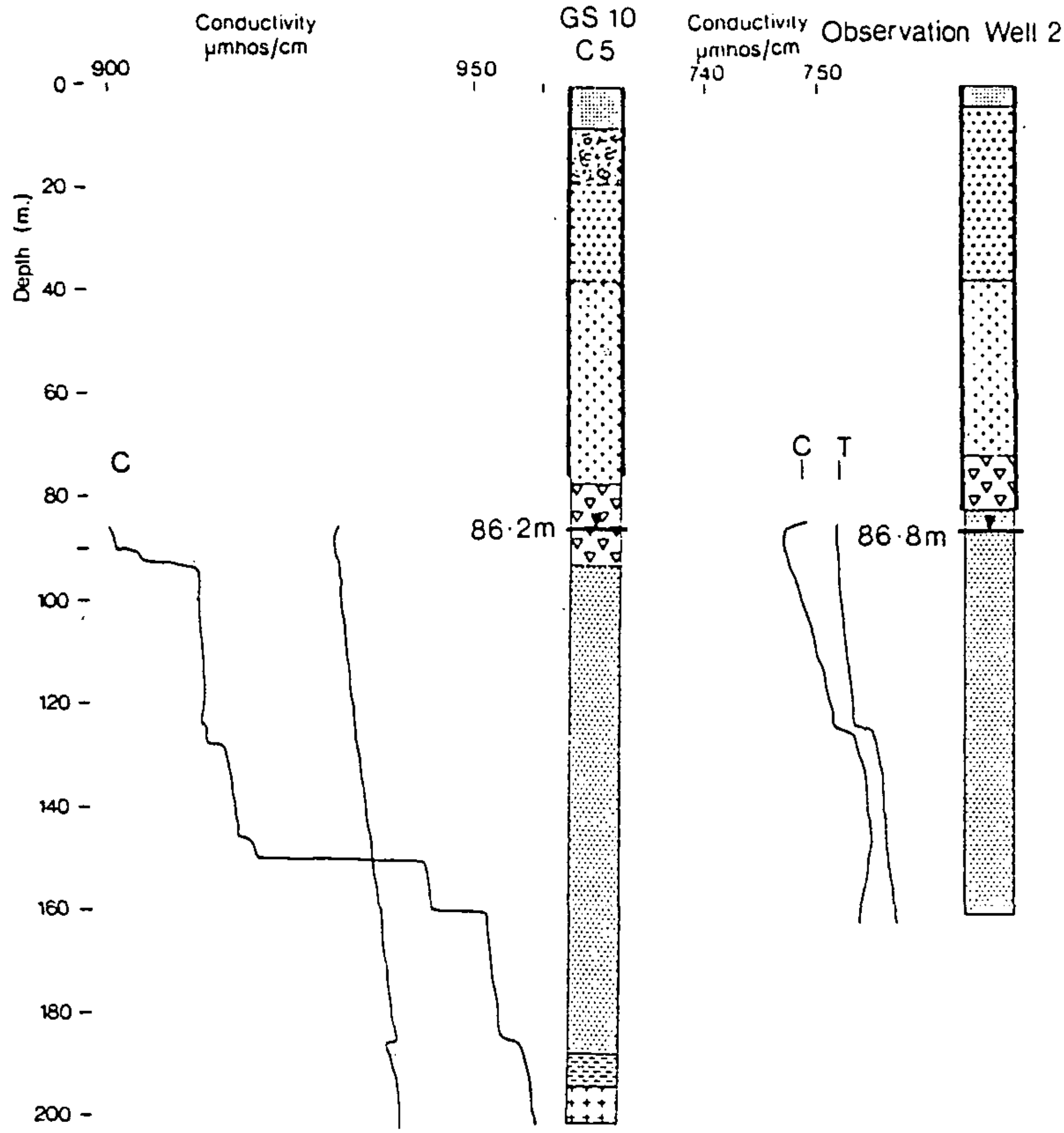
87-108 m horizontal flow. It is highest in thin layers about 1.5 m thick, with similar thickness zones of lower flow between them.



TEST SITE SYA

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.4a



TEST SITE TS SYA

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure
A.3.4b

108-134 m uniform horizontal flow

134-143 m no flow. This corresponds to the dolerite dyke.

below 143 m uniform horzontal flow.

Observation Well 2

82-103 m uniform horizontal flow

below 130 m decreased horizontal flow

There are indications of a different type or age of the water below 122 m

Observation Well 3 (C5)

The flow is fairly uniform and horizontal. The conductivity increases, in a stepped fashion, with depth. The reason for this is unknown.

Pump Well

82-92 m variable horizontal flow
92-111 m uniform horizontal flow
111-119 m decreased horizontal flow
119-132 m decreased horizontal flow
132-136 m increased horizontal flow
136-153 m decreased horizontal flow
below 153 m greatly reduced horizontal flow.

There is no evidence of vertical flow in any of these boreholes. Permeability probably increases with depth in these three boreholes to between 120 m and 130 m where it then begins to decrease. Observation borehole 3 is an exception where the flow appears to be fairly uniform. There is no evidence of fissure flow in these wells which supports the view that intergranular flow is dominant.

There are distinct steps in the logs of the boreholes between 120 m and 125 m which may suggest the presence of two types of water. The marked differences between the logs from observation well 3 and the others, suggests that the dyke at the bottom of this borehole may be affecting the movement of groundwater.

Pumping tests

A four stage variable discharge test was carried out at this site. Each stage last 180 minutes before the pump rate was increased, Figure A.3.5.

The test was solved, using the Jacob method, for the aquifer and well losses. It was only possible to use the first stage data to determine the transmissivity of the pumped well.

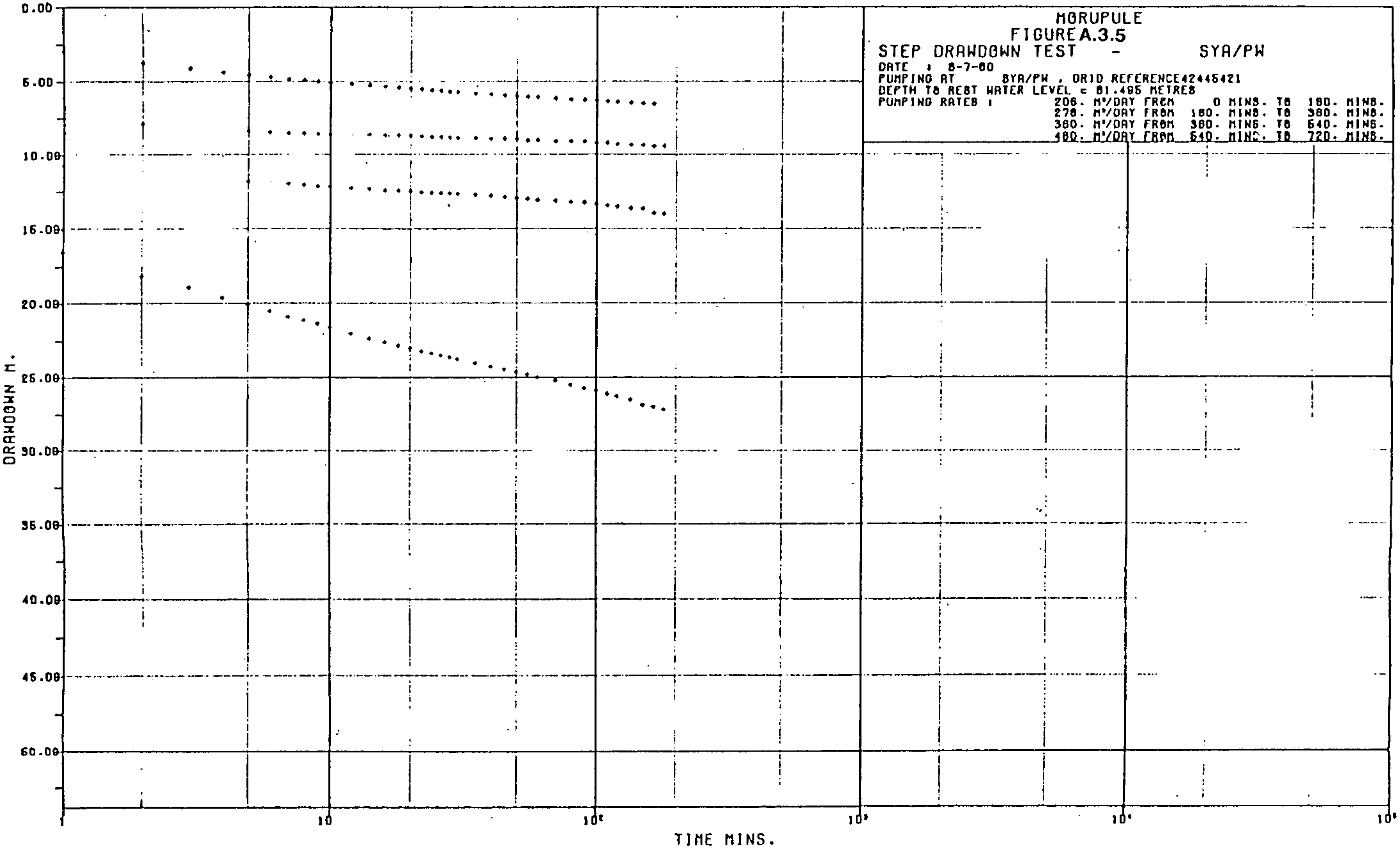
Table A.3.1 Specific Yield Site SYA Test Results

Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t = 100 min (m^2/d)	Efficiency %
206	6.3	32.70	77.6
278	8.9	31.24	71.9
360	12.9	27.91	66.4
480	24.7	19.43	59.7

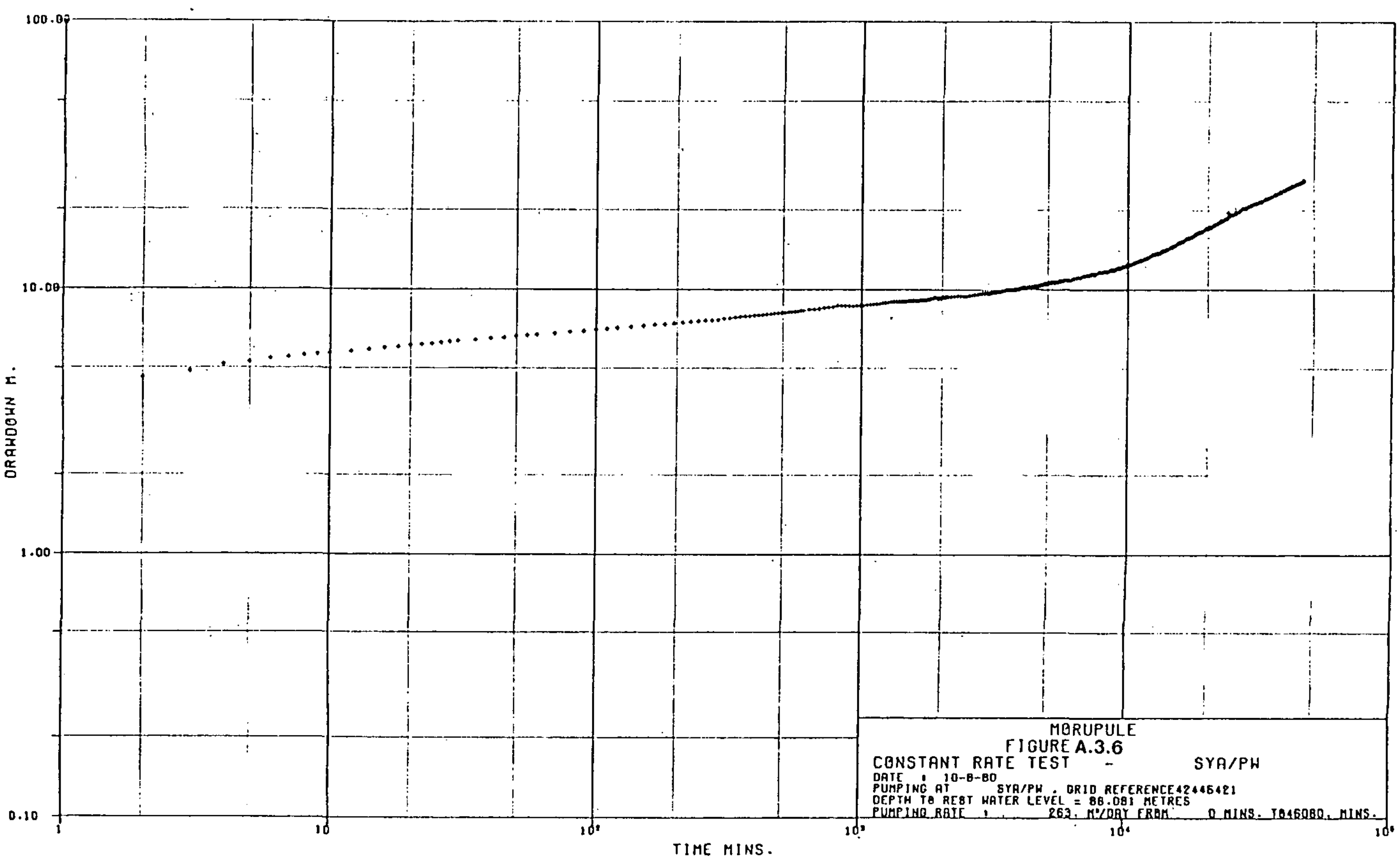
Aquifer constant	(B)	0.0237
Well constant	(C)	3.33×10^{-5}
Transmissivity		42 m^2/d

The pump well was pumped continuously for 768 hours (32 days) at a pump rate of 263 m^3/d; water levels were measured in all four wells. An earlier test had been carried out on borehole C5, by the GS10 project, in September, 1979 when the borehole was pumped at a rate of 81 m^3/d for 7 days. The constant rate test was carried out at this site to determine the specific yield and to examine delayed yield effects. It has proven to be the most difficult of the pumping test sites to interpret.

Water levels at this site respond with a 100 per cent efficiency to changes in barometric pressure and also show a diurnal response to earth tides. Whilst these responses do not significantly affect the drawdown data from the test well, Figure A.3.6, small variations in the drawdown at each observation well are masked by these responses. As a result, even after detailed correction, the drawdown from pumping cannot be distinguished until after several hours after the start of the test. By this time barrier boundary effects had begun to influence the development of the cone of depression.



MORUPULE
FIGURE A.3.5
STEP DRAWDOWN TEST - SYA/PW
DATE : 8-7-80
PUMPING AT SYA/PW , GRID REFERENCE 42445421
DEPTH TO REST WATER LEVEL = 81.495 METRES
PUMPING RATES :
206. M³/DAY FROM 0 MINS. TO 180. MINS.
278. M³/DAY FROM 180. MINS. TO 360. MINS.
360. M³/DAY FROM 360. MINS. TO 540. MINS.
480. M³/DAY FROM 540. MINS. TO 720. MINS.
DRAWDOWN M.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
TIME MINS.
1
10
10²
10³
10⁴
10⁵



100.00
10.00
1.00
0.10
DRAWDOWN M.
1
10
10²
10³
10⁴
10⁵
TIME MINS.
MORUPULE
FIGURE A.3.6
CONSTANT RATE TEST - SYA/PW
DATE : 10-8-80
PUMPING AT SYA/PW , GRID REFERENCE42446421
DEPTH TO REST WATER LEVEL = 86.081 METRES
PUMPING RATE : 263. M³/DAY FROM 0 MINS. TO46080. MINS.

The drawdown data from the pump well were plotted as a log-log graph. The form of this plot suggested the influence of gravity drainage. However, a match could only be obtained with a r/B value of 2.0, which is not consistent with gravity drainage through a fine-grained sandstone sequence.

Delayed yield effects were not apparent when the corrected drawdown data of each observation well were plotted as a log-log graph. The same data were also plotted as a log-linear graph. Each observation well showed increases in the rate of drawdown suggesting that two barrier boundaries were influencing the cone of depression. This interpretation is more compatible with the occurrence of dolerite dykes encountered at OW1 and OW3 (see Figure A.3.2).

Image well theory was applied to the results to locate the position of each barrier. The results of this analysis are as follows:

Observation Well	Barrier 1		Barrier 2	
	Time (mins)	Distance (m) to boundary	Time (mins)	Distance (m) to boundary
1	2400	86	18 500	216
2	2000	75	16 000	147
3	2000	79	14 000	200

Q 273 m^3/d

The respective distances to each barrier boundary were described by concentric circles on a scaled map of the site. The position of each barrier was then identified from the intersection of these circles.

The barrier boundaries are situated parallel to each other with a north-south trend at 85 and 150 m east of the test well. The separation between these boundaries of 65 m is very similar to the separation between OW1 and OW3 where dolerite dykes were encountered. It is likely that the interpretation of the early, pre-boundary data, which are strongly influenced by barometric pressure effects, has resulted in an apparent eastward displacement of the barrier boundaries.

The response to the various effects at this site influence the reliability of the Jacob method of solution using time-drawdown data.

Consequently, at each observation well after 1000, 5000 and 30000 minutes were plotted as a distance-drawdown graph.

Transmissivity and storage coefficients were computed, using data from OW1 and OW3 only as the data from OW2 showed a lag response or data inaccuracies:

Table A.3.2 Specific Yield SYA Constant Rate Test Results

	$T (m^2/d)$	S
Pre-barrier	260	2.8×10^{-2}
Post-barrier 1	170	2.7×10^{-2}
Post-barrier 2	70	2.7×10^{-2}

The very high initial transmissivity decreases to a value resembling regional values due to the influence of the barrier boundaries. The storage coefficient is consistent with the results from other sites and suggests that delayed yield effects occur in the early data but cannot be distinguished from the test results.

A.3.3 Specific Yield Site SYB

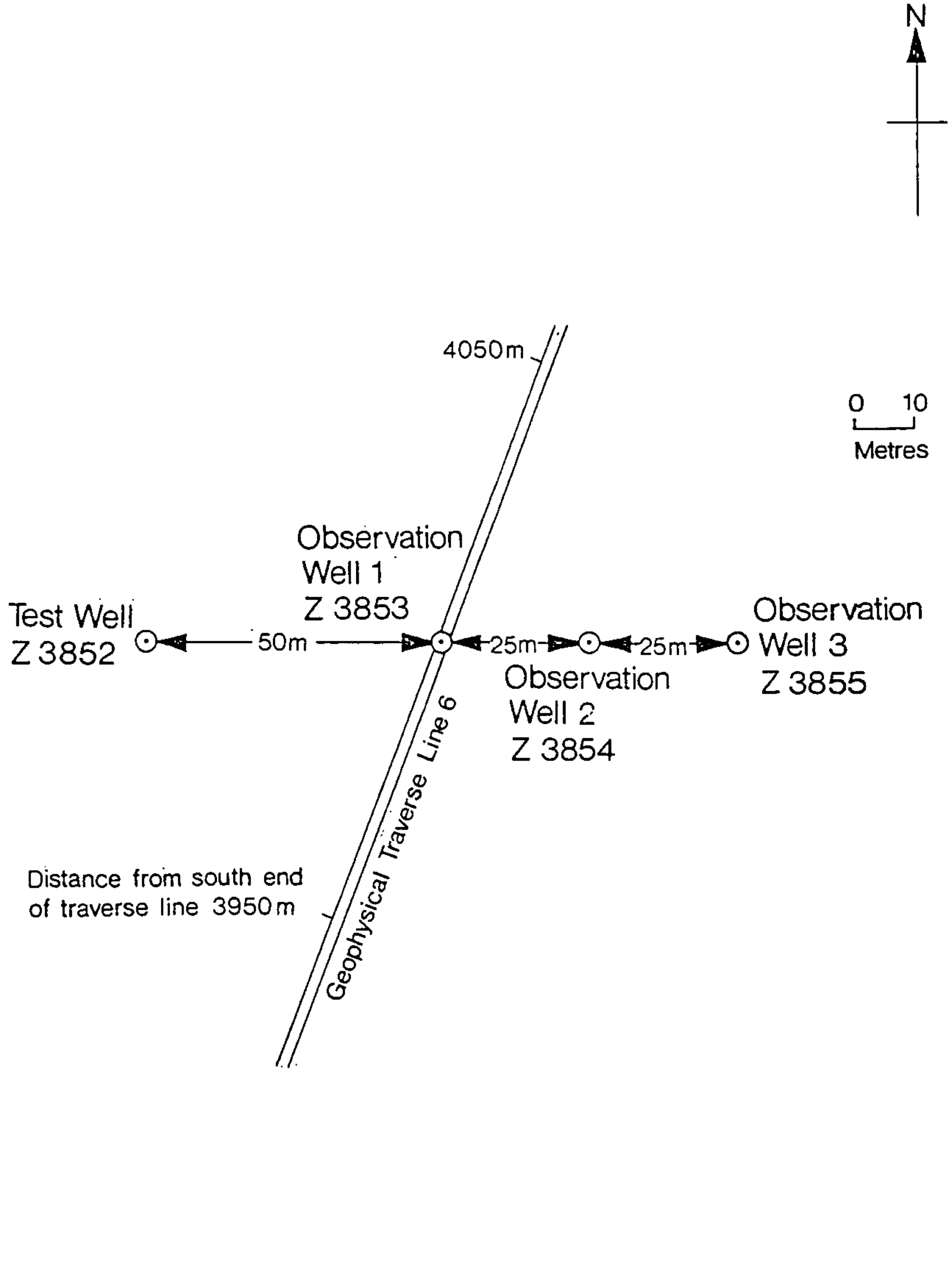
Location

The site is located on the basalt plateau on geophysical traverse 6, 4 kms from the southern end of the line and 15 kms from the west of the escarpment. At this site a pump well and three observation wells were drilled as shown in Figure A.3.7. This was originally chosen as a site to test for unconfined storage; however, when drilled the aquifer was found to be confined.

Geology

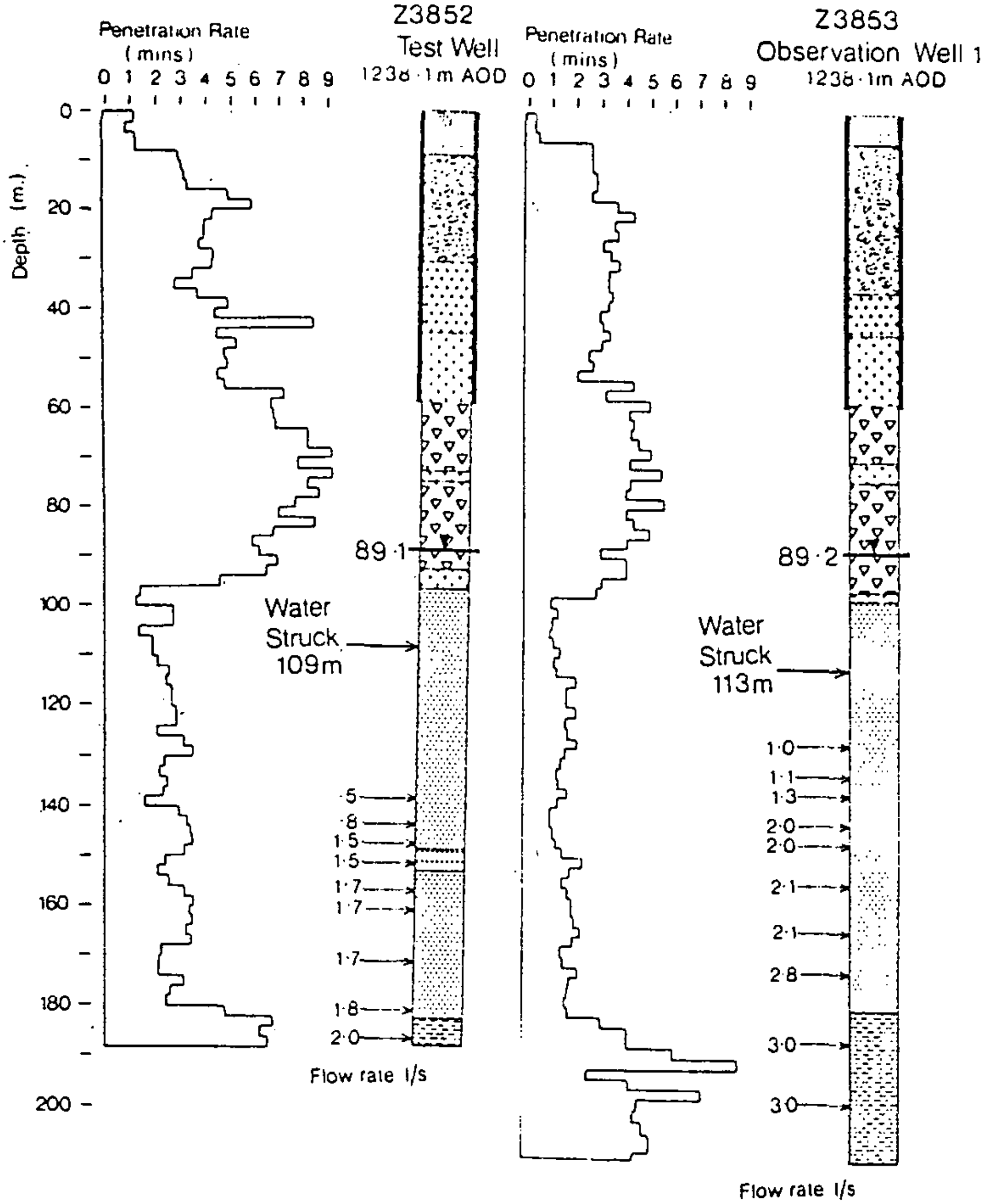
All four boreholes penetrate a thick sequence of Kalahari Beds, pass through the Drakensberg Basalt and Cave Sandstone before terminating in the Transition Beds, Figure A.3.8.

The Kalahari Beds here comprise a 44-46 m thick sequence of silcretes and siliceous sandstones with the top 5-8 m being a series of unconsolidated orange-yellow sands. For each borehole the succession is complex and correlation across the site is not possible; in general, however, it



Test Site SYB: Location

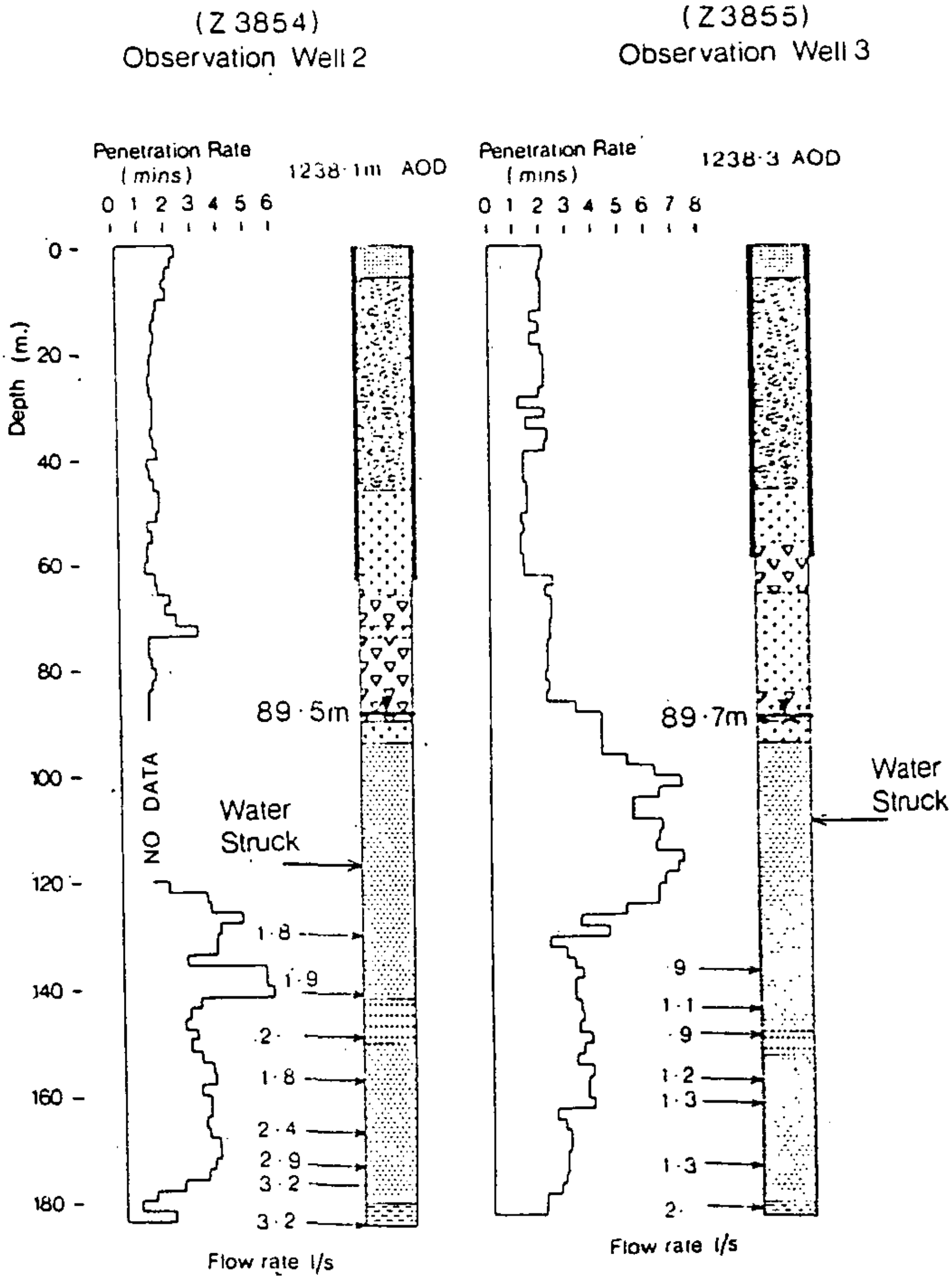
Figure A.3.7



TEST SITE TS B

LITHOLOGY AND DRILLING DETAILS

Figure A.3 8



TEST SITE TS B
LITHOLOGY AND DRILLING DETAILS

Figure
A.3.8

appears that in the upper two-thirds of the sequence silcretes dominate whilst in the lower third sandstones are more abundant.

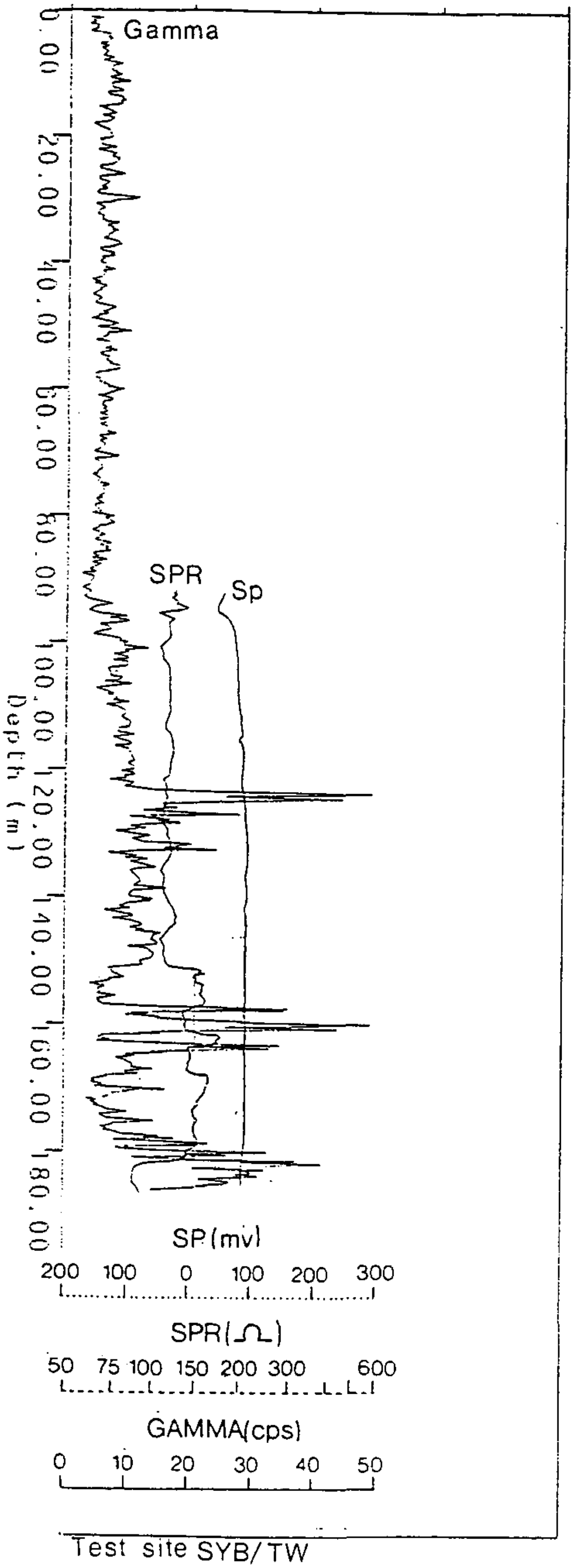
Below the Kalarhari Beds is a 48-54 m thickness of Drakensberg Basalt. The base lies at a depth of between 94-98 m and provides evidence that no faulting and little pre-basalt topographic relief exists at this site. The top 10-20 m and the lower 2-4 m of the succession are red-brown weathered basalts. The central part is fresh basalt except for a narrow 2-4 m weathered zone which widens to 18 m in observation well 3. Penetration rates show that although much of the basalt is weathered it still remains significantly harder than the Cave Sandstone or Kalahari Beds.

The Cave Sandstone at this site is between 82-86 m thick with the base between 180-182 m below ground level. The sample log shows a monotonous sequence of massive pink and white calcareous and siliceous sandstones with a 4-8 m thick silty horizon at around 150 m. In the pump well the gamma log, Figure A.3.9, shows the presence of thin mudstone horizons at depths of 123 m, 160 m and 182 m. There is also an indication that the clay content of the formation decreases below 150 m. The mudstone horizons are restricted to the vicinity of the test well although the decrease in clay content below 180 m is apparent throughout the site.

Below the Cave Sandstone the Transition Beds form a succession of green and red siltstone and sandy siltstones.

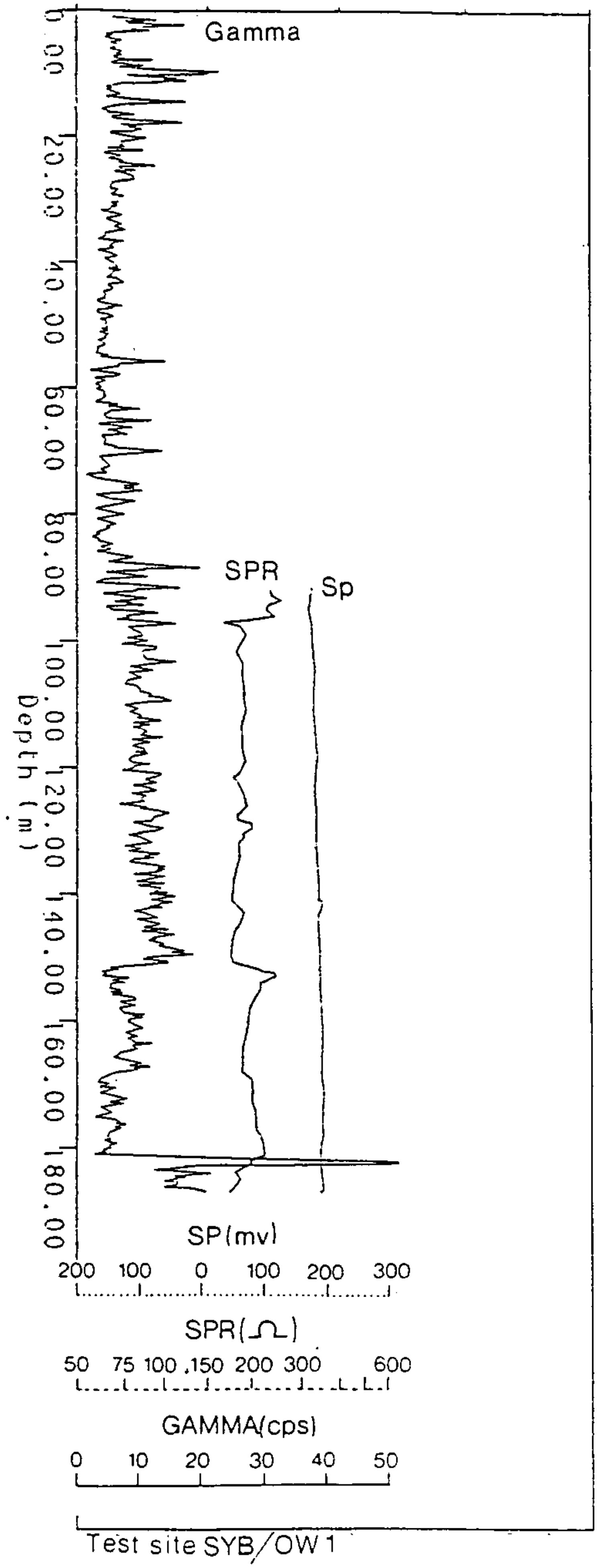
Fluid column logs

In observation wells 2 and 3 temperature and conductivity logs were run under static conditions, and in observation well 1 logs under both static and pumped conditions, Figure A.3.10.



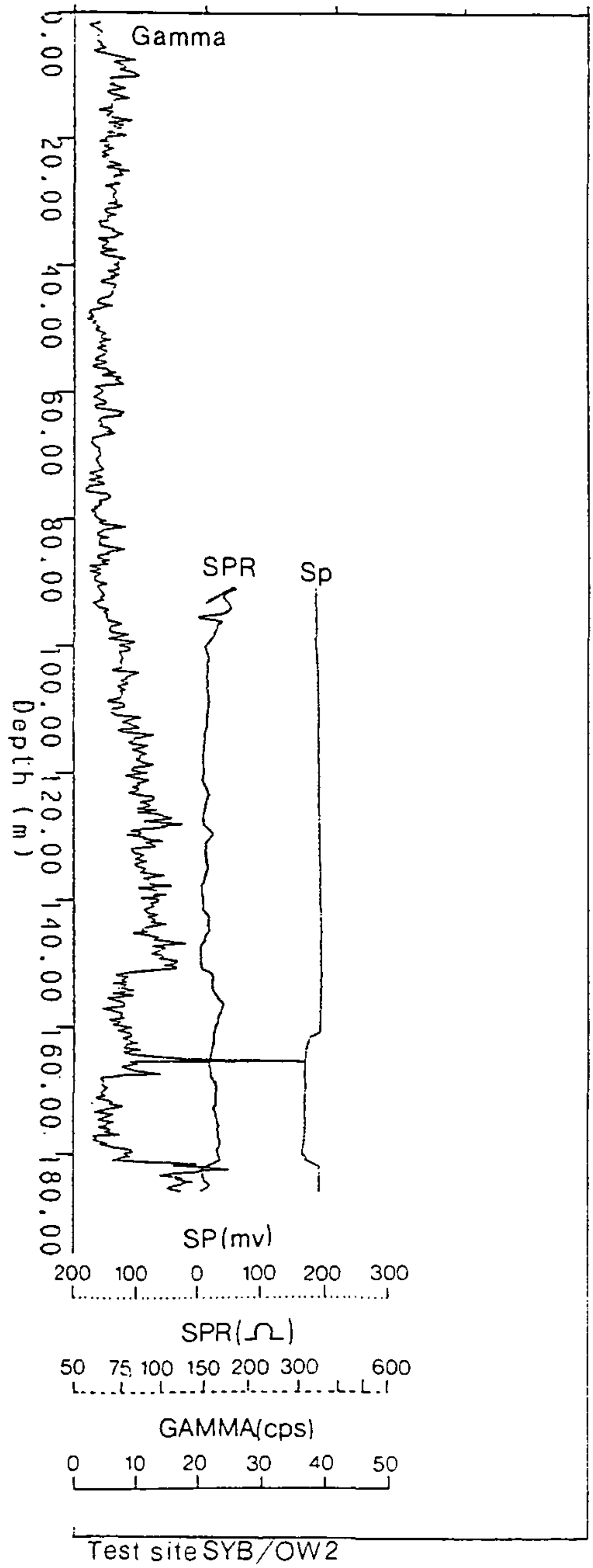
TEST SITE SYB FORMATION LOGS

Figure A.3.9



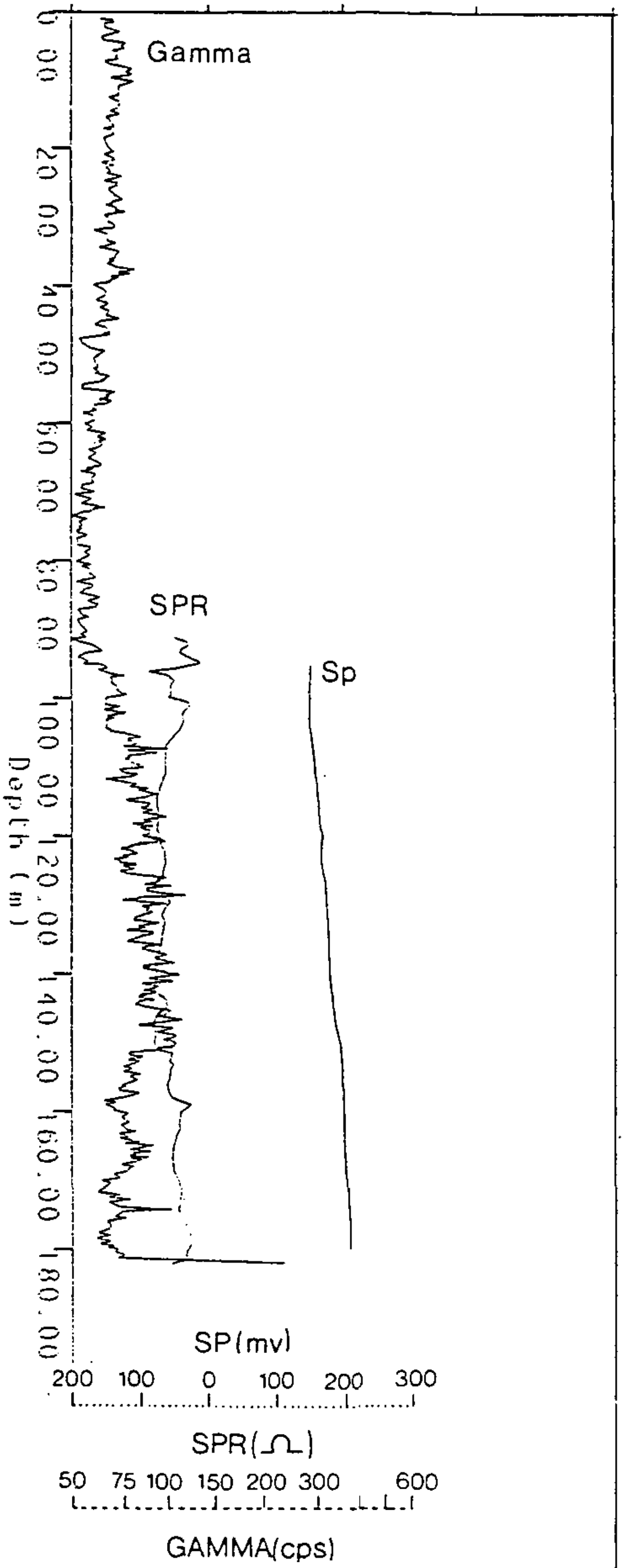
TEST SITE SYB FORMATION LOGS

Figure A.3.9



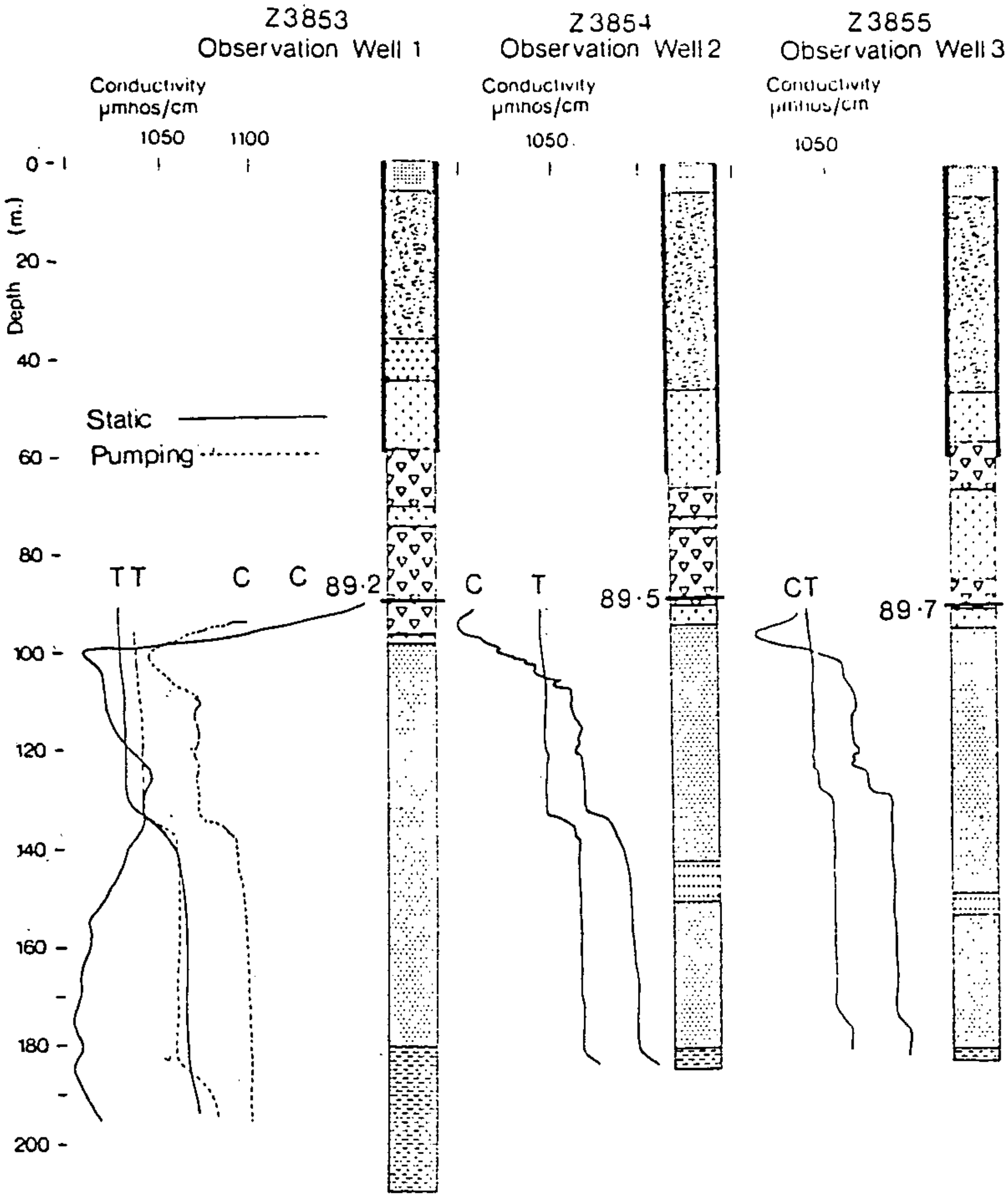
TEST SITE SYB FORMATION LOGS

Fi ure A.3.9



TEST SITE SYB FORMATION LOGS

Figure A.3.9



TEST SITE SYB

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.10

The static logs are summarised as follows:

Observation Well 1

90 - 98 m	Ion exchange occurring between the water in the borehole and clays in the basalt
98 - 110 m	horizontal flow
110 - 125 m	flow downwards
125 - 134 m	less flow downwards
134 - 138 m	greater horizontal flow
138 - 156 m	flow upwards
156 - 160 m	decrease in temperature shows a different type of water
160 - 164 m	upflow
164 - 171 m	little flow
171 - 182 m	down flow
182 +	rapid rise in temperature indicates a third type of water, horizontal flow

Observation Well 2

90 - 106 m	horizontal flow
106 - 136 m	downflow
136 - 141 m	strong horizontal flow
141 - 182 m	lower horizontal flow
182 +	different type of water, horizontal flow

Observation Well 2

90 - 106 m	horizontal flow
106 - 120 m	down flow
120 - 126 m	stronger horizontal flow
126 - 129.5 m	lower horizontal flow
129.5 - 131 m	stronger horizontal flow
131 - 174 m	upflow
174 +	different type of water, horizontal flow

The logs taken during pumping indicate several horizons of water movement summarised as:

- 110 m to 134 m water flowing down the hole
- 134 m to 138 m flow across the hoel
- 156 m to 138 m upflow of water
- 164 m to 160 m upflow of water
- 171 m to 182 m water flowing down the hole

a decrease of temperature between 156 m and 163 m and an increase below 182 m indicate different water types

Pumping test

A 4 stage variable discharge test was carried at this site. Each stage lasted for 180 mintues before the pump rate was increased, Figure A.3.11.

The test was solved, using the Jacob method, for well and aquifer losses. It was also possible to use the first stage data to determine the aquifer characteristics of storage and transmissivity in the observation boreholes and transmissivity in the pump well, using the Theis, Jacob and distance drawdown methods.

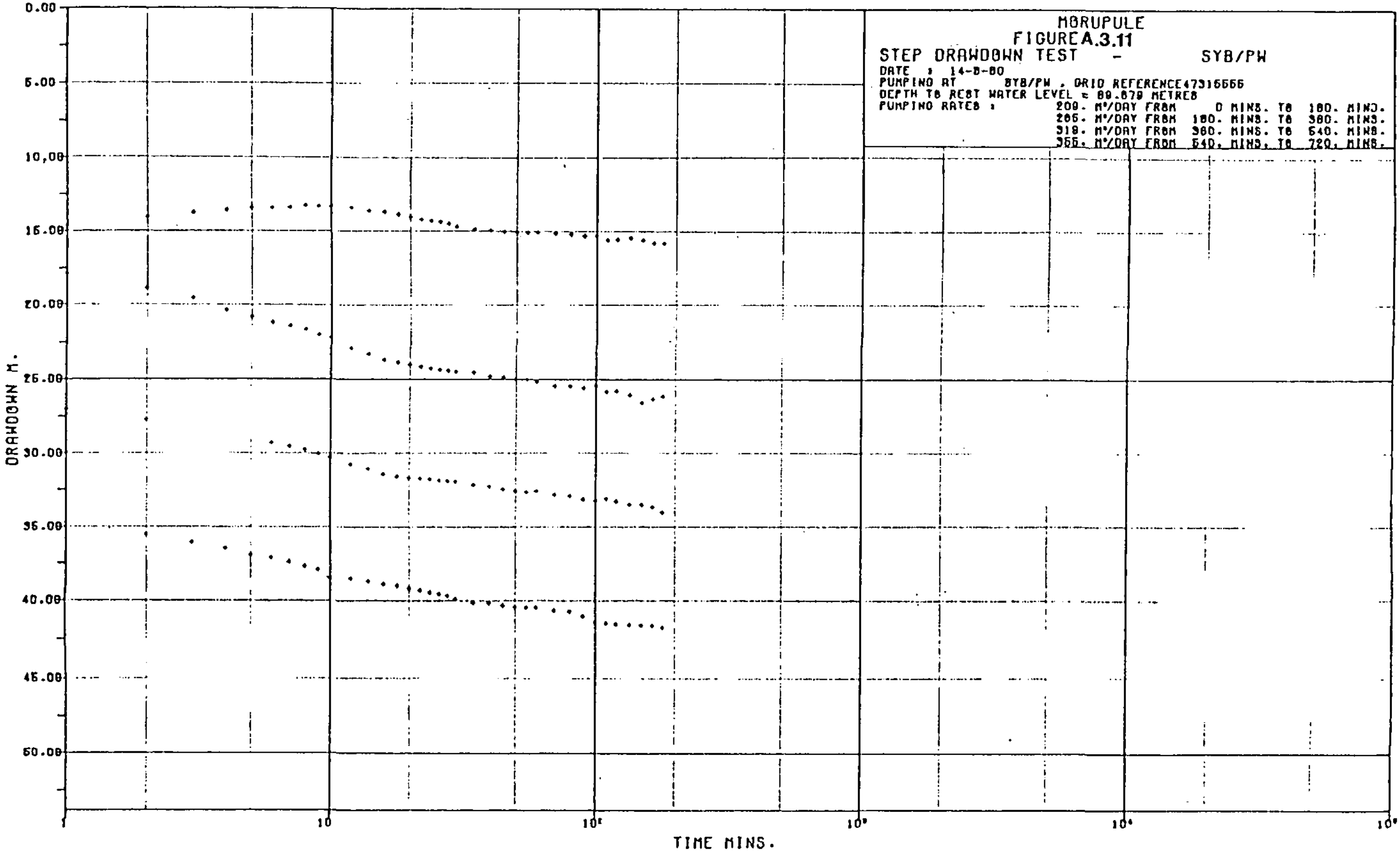
Table A.3.3 Specific Yield Site SYB Test Results

Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t = 100 min (m^2/d)	Efficiency (%)
209	15.3	13.66	4.7
285	25.1	11.35	3.5
319	31.8	10.03	3.1
355	39.0	9.10	2.8

Aquifer constant (B) 0.0031

Well constant (C) 3.01×10^{-4}

(Jacob Solutions for Stage 1 Theis Solutions for Stage 1)


MORUPULE
FIGURE A.3.11
STEP DRAWDOWN TEST - SYB/PW
DATE : 14-8-80
PUMPING AT SYB/PW , GRID REFERENCE(47316555
DEPTH TO REST WATER LEVEL = 89.679 METRES
PUMPING RATES : 209. M³/DAY FROM 0 MINS. TO 180. MINS.
265. M³/DAY FROM 180. MINS. TO 360. MINS.
319. M³/DAY FROM 360. MINS. TO 540. MINS.
355. M³/DAY FROM 540. MINS. TO 720. MINS.
DRAWDOWN M.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
1
10
10²
10³
10⁴
10⁵
TIME MINS.

	Transmissivity (m^2/d)	Storage	Transmissivity (m^2/d)	Storage
PW	21			
OW1	47	1.76×10^{-4}	38	0.94×10^{-4}
OW2	54	1.87×10^{-4}	43	5.40×10^{-4}
Distance-Drawdown	38	2.5×10^{-4}		

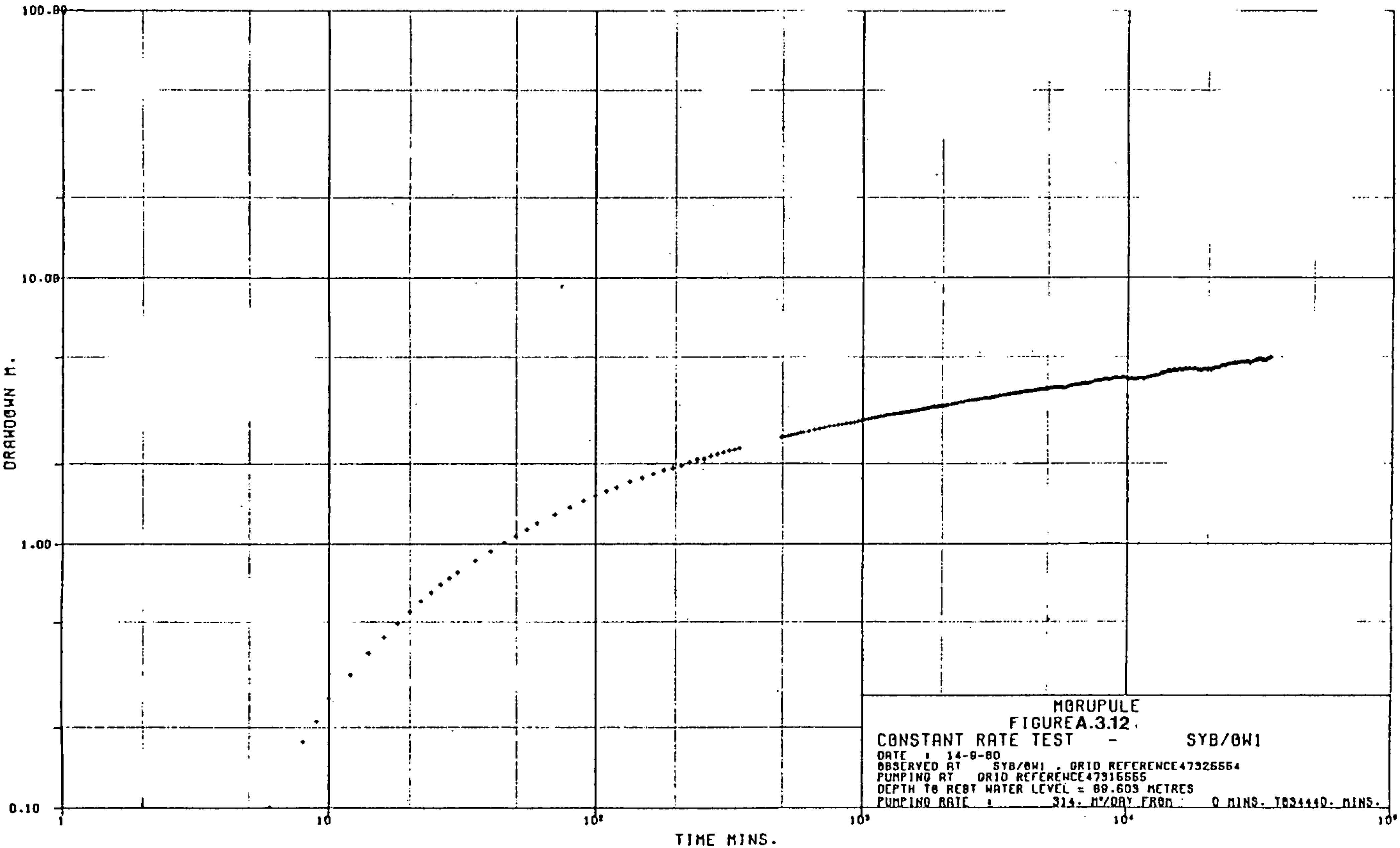
As the data for solving the aquifer and well loss constants are not linear, the best straight line was fitted to the data points. The aquifer constant is much lower at this site than the other sites tested during the investigation. The well efficiencies are very low at less than 5%. This low efficiency can be explained by most of the water coming from a narrow horizon of relatively high permeability. This is equivalent to a low open area and coupled with the resultant vertical flow can cause low efficiencies.

To establish the effects of longer periods of pumping and to determine if there are variations in the aquifer parameters a constant rate test was performed. The test lasted for 574 hours (23.9 days) at a pump rate of 314 m^3/d.

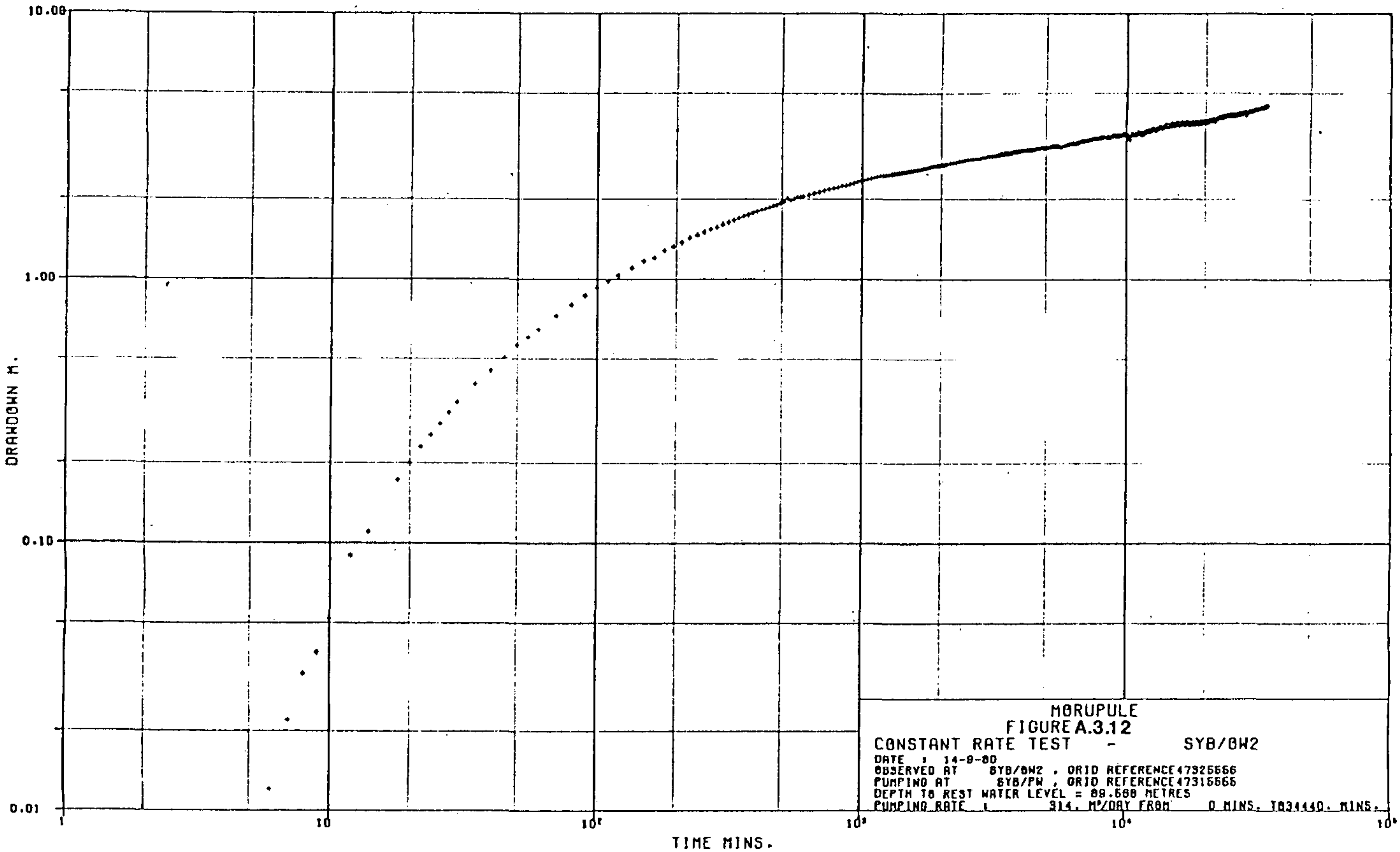
The log-log graphs of the observation well data follow the Theis non-leaky confined curve, Figure A.3.12. The data were also solved using the Jacob method for pumping and recovery conditions.

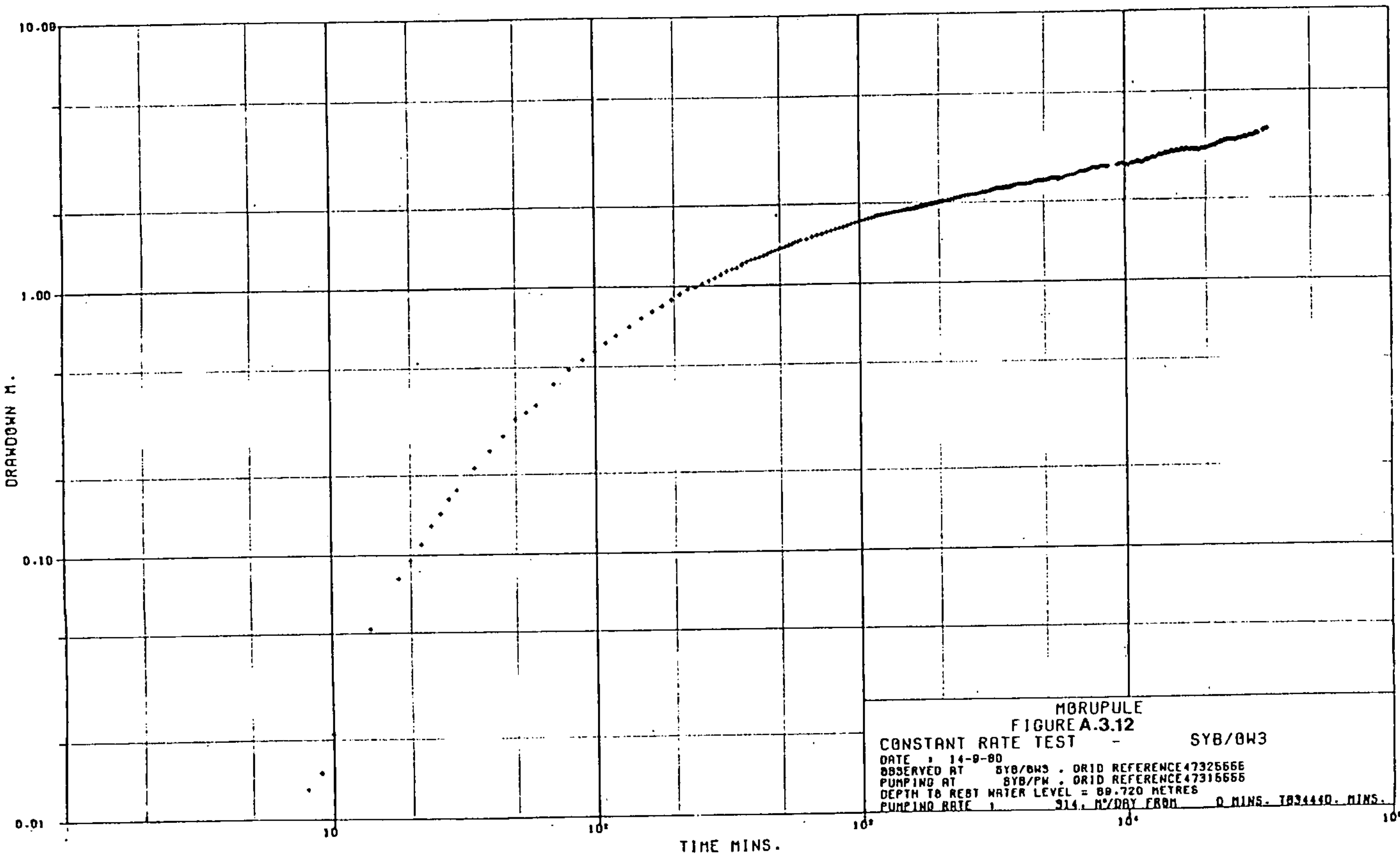
Table A.3.4 Specific Yield SYB Constant Rate Results

	Theis Transmissivity (m^2/d)	Storage	Jacob Transmissivity (m^2/d)	Storage	Jacob Recovery Transmissivity $m^2/$
Pump well					32
OW1	35	2.8×10^{-4}	41	2.2×10^{-4}	43
OW2	38	2.9×10^{-4}	40	2.5×10^{-4}	44
OW3	48	2.8×10^{-4}	50	2.6×10^{-4}	50
Distance-Drawdown			28	8.4×10^{-4}	



MORUPULE
FIGURE A.3.12.
CONSTANT RATE TEST - SYB/OW1
DATE : 14-9-80
OBSERVED AT SYB/OW1 . GRID REFERENCE47326564
PUMPING AT GRID REFERENCE47316565
DEPTH TO REST WATER LEVEL = 89.609 METRES
PUMPING RATE : 314. M³/DAY FROM 0 MINS. TO34440. MINS.
DRAWDOWN M.
100.00
10.00
1.00
0.10
TIME MINS.
1
10
10²
10³
10⁴
10⁵


10.00
1.00
0.10
0.01
DRAWDOWN M.
1
10
10²
10³
10⁴
10⁵
TIME MINS.
MORUPULE
FIGURE A.3.12
CONSTANT RATE TEST - SYB/OW2
DATE : 14-9-80
OBSERVED AT SYB/OW2 , GRID REFERENCE 47925666
PUMPING AT SYB/PW , GRID REFERENCE 47316665
DEPTH TO REST WATER LEVEL = 89.660 METRES
PUMPING RATE : 314. M³/DAY FROM 0 MINS. TO34440. MINS.


10.00
1.00
0.10
0.01
DRAWDOWN M.
10
10^2
10^3
10^4
10^5
TIME MINS.
MORUPULE
FIGURE A.3.12
CONSTANT RATE TEST - SYB/OW3
DATE : 14-9-80
OBSERVED AT SYB/OW3 . GRID REFERENCE47325556
PUMPING AT SYB/PW . GRID REFERENCE47315555
DEPTH TO REST WATER LEVEL = 89.720 METRES
PUMPING RATE : 914. M³/DAY FROM 0 MINS. TO34440. MINS.

It is also possible to fit the data to leaky confined curves, but they show very little leakage. This decreases as the distance from the pumped well increases.

A.3.4 Specific Yield Site SYC

Location

Site SYC is located at the foot of the escarpment and lies in the Pitsi river valley, 2.5 kms, North West of Mabeleapodi. In addition to the pump well two observation wells were drilled at distances of 50 m and 75 m as shown in Figure A.3.13. This site was originally drilled as exploration Site 8.

Unconfined conditions exist in all three wells and the site was selected to provide an estimate of unconfined storage by analysis of a long term pumping test.

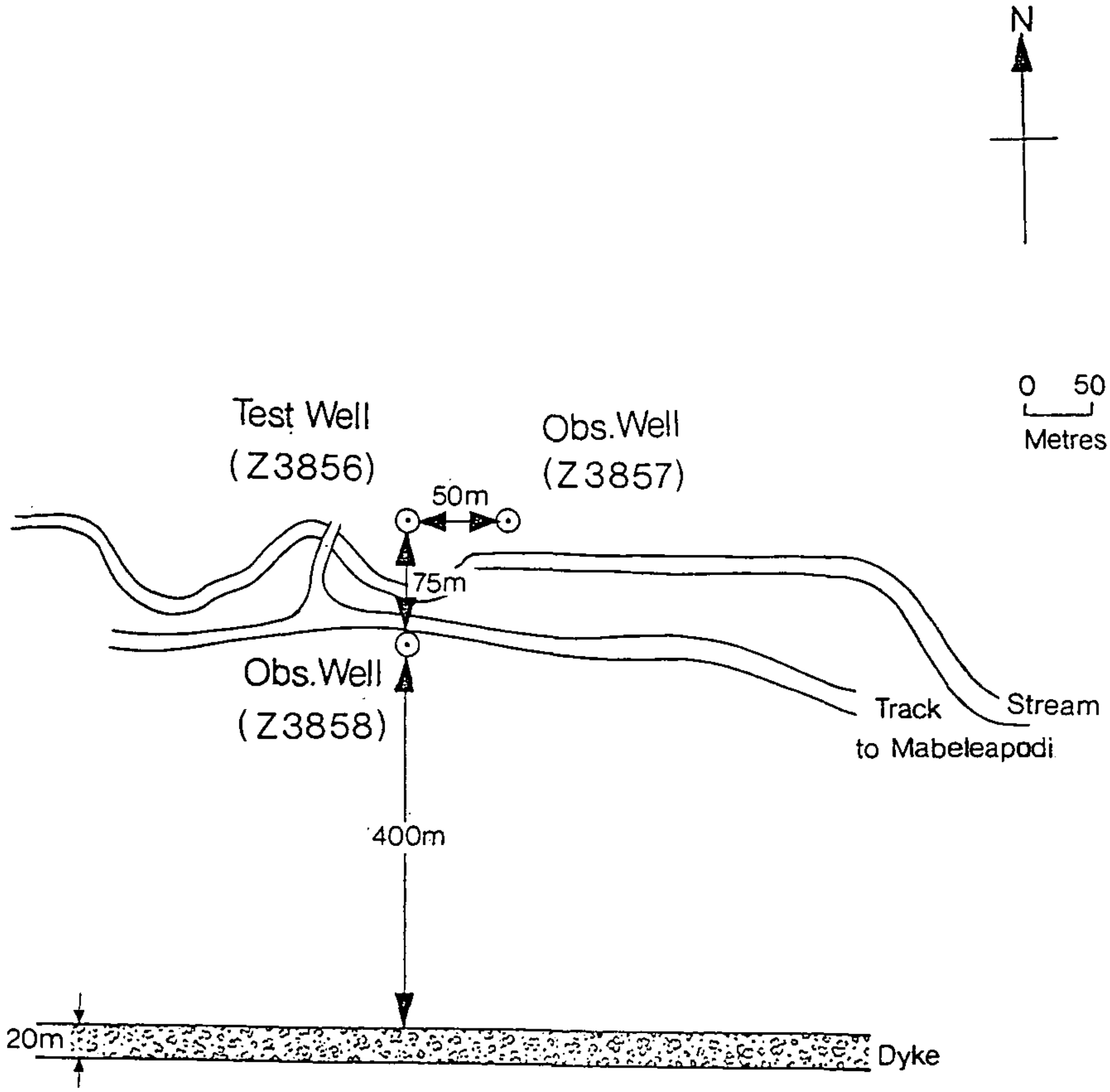
Geology

The site is on the outcrop of the Cave Sandstone. All three boreholes fully penetrate the formation to finish in the underlying Transition Beds. The Cave Sandstone has a thickness of 82 m and exhibits rapid vertical and lateral variations in lithology. Vertical variations are shown in the logs of the pump well and observation well 2, Figures A.3.14, A.3.14. The upper 30 m of soft fine-grained white calcareous sandstone passes down into a succession dominated by pink and white silty sandstones. Lateral variation is demonstrated by the almost complete absence of these silty sandstones in the log of observation well 1 where soft white and pink calcareous sandstones dominate throughout the sequence.

Underlying the Cave Sandstone are green and red siltstones of the Transition Beds which were not fully penetrated. They are, however, shown to have a thickness of at least 26 m and to be considerably more resistant to drilling than the overlying sandstones.

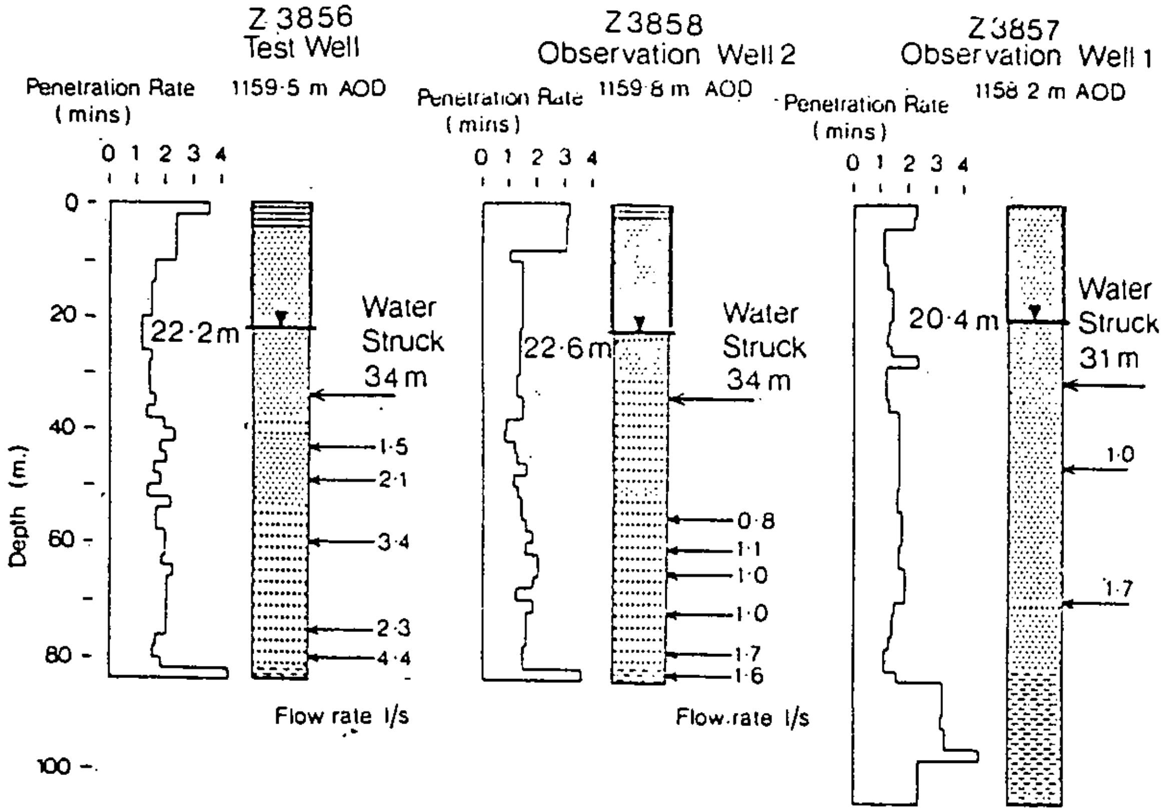
Fluid column logs

Temperature and conductivity logs were run in observation wells 1 and 2 under both static and pumped conditions. No logs were run in the pump well, Figure A.3.16.



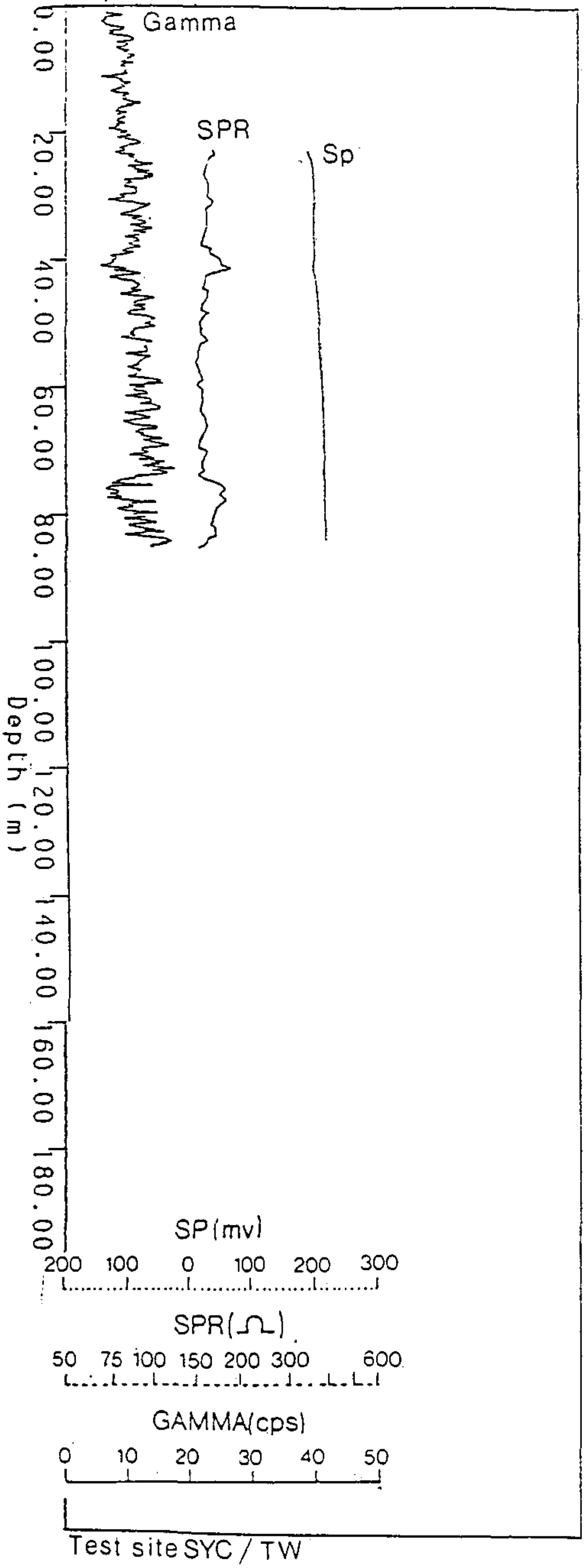
Test Site SYC: Location

Figure **A.3.13**

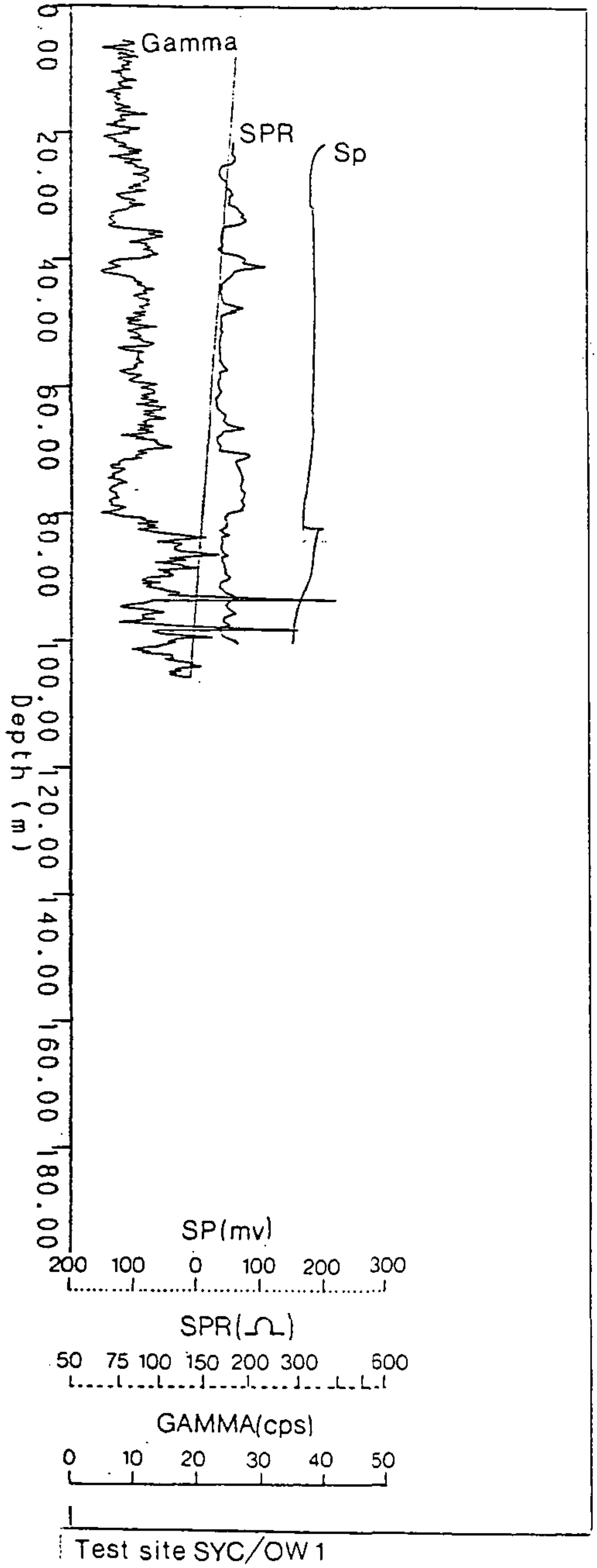


TEST SITE TS SYC LITHOLOGY AND DRILLING DETAILS

Figure A.3.14

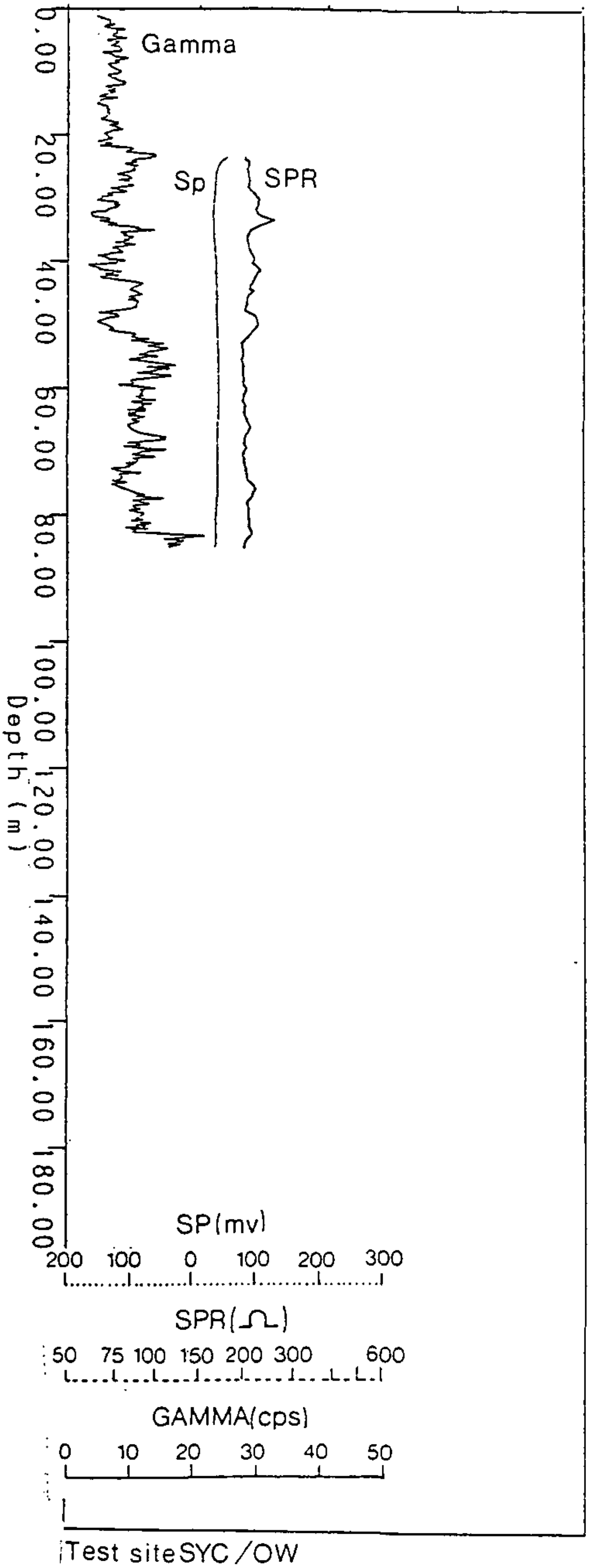


TEST SITE SYC FORMATION LOGS



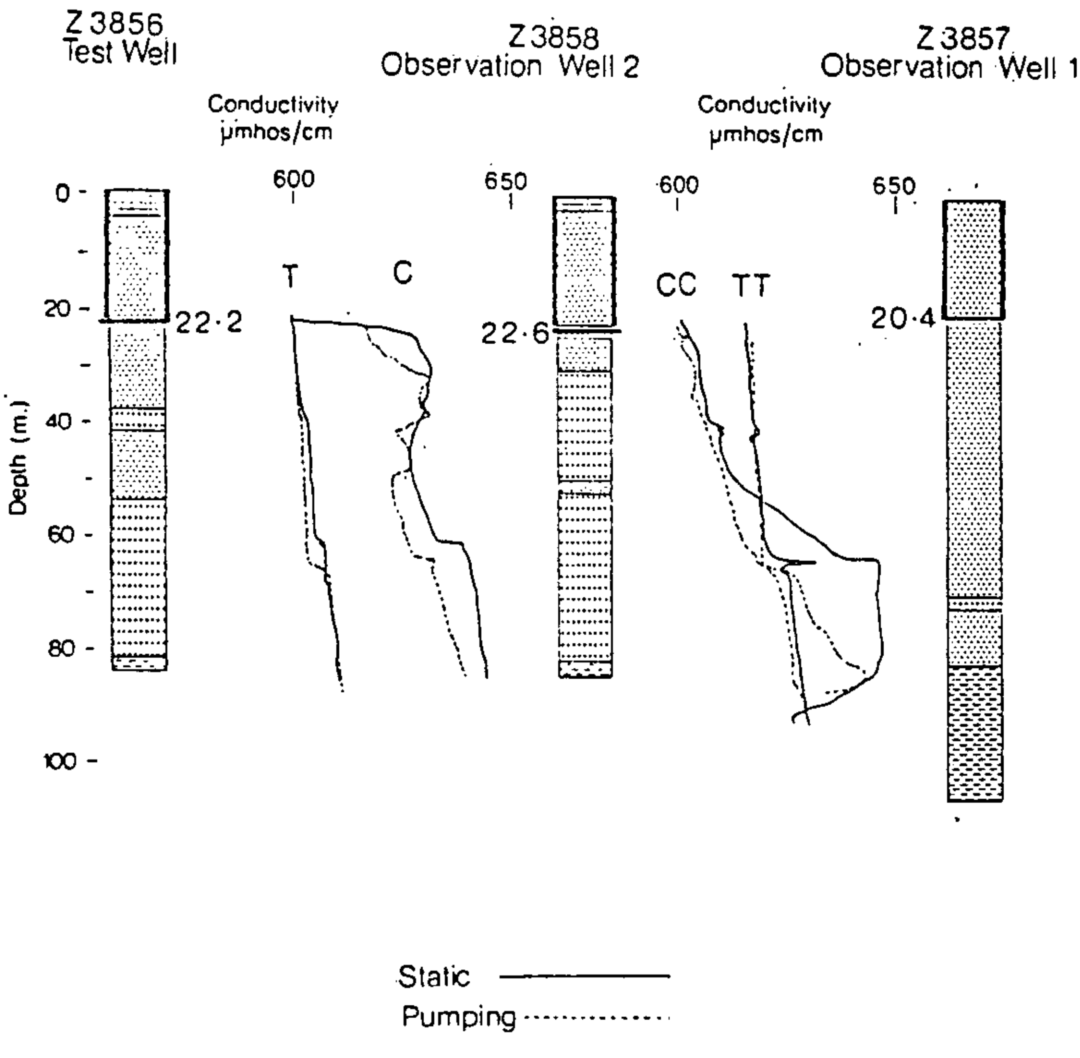
TEST SITE SYC FORMATION LOGS

Figure A.3.15



TEST SITE SYC FORMATION LOGS

Figure A.3.15



TEST SITE TS SYC

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure
A.3.16

Observation Well 1

20-41 m	horizontal flow
41 m	possible fissure
41-48 m	horizontal flow
48-64,5 m	increased horizontal flow
64,5 m	possible fissure
64,5-82 m	decreased horizontal flow
Below 82 m	increased horizontal flow

There is no critical flow

Observation Well 2

23-32	horizontal flow
32-39	decreased horizontal flow
39-46	decreased horizontal flow
46-48	increased horizontal flow
48-61	uniform, lower horizontal flow
Below 61 m	a different type of water, lower horizontal flow

There is no vertical flow.

Three points of interest may be highlighted.

(a) Distinct zones of higher permeability may be distinguished in both boreholes although the magnitude of permeability variations throughout the aquifer may not be great.

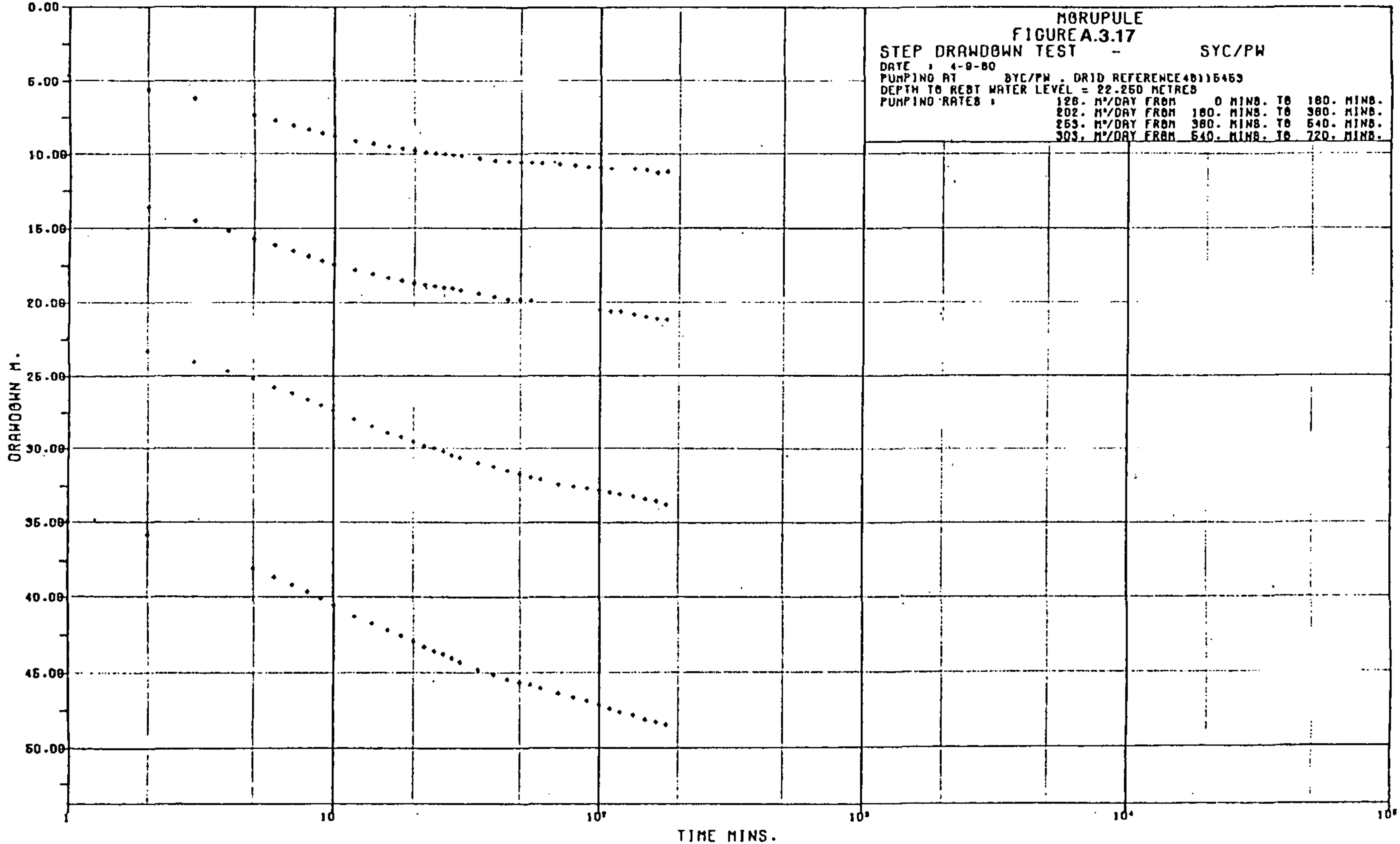
(b) Evidence from observation well 1 indicates that fissure flow may be taking place from at least two horizons.

(c) Below a depth of 61 m in observation well 2 and possibly in observation well 1 the presence of a different type or age of water is suggested by both temperature and conductivity logs.

Pumping tests

A four stage step drawdown test was carried out. Each pump rate lasted for 180 minutes before being increased, Figure A.3.17.

The test was solved, using the Jacob method, for the well and aquifer constants. It was also possible to use the first stage data to determine


MORUPULE
FIGURE A.3.17
STEP DRAWDOWN TEST - SYC/PW
DATE : 4-9-80
PUMPING AT SYC/PW , GRID REFERENCE 48115463
DEPTH TO REST WATER LEVEL = 22.250 METRES
PUMPING RATES : 126. M³/DAY FROM 0 MINS. TO 180. MINS.
202. M³/DAY FROM 180. MINS. TO 360. MINS.
253. M³/DAY FROM 360. MINS. TO 540. MINS.
303. M³/DAY FROM 540. MINS. TO 720. MINS.
DRAWDOWN M.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
1
10
10²
10³
10⁴
10⁵
TIME MINS.

transmissivity for the pump and observation wells, and storage for the observation wells, using the Jacob method.

Table A.3.5 Specific Yield SYC Step Test Results

Discharge m^3/d	Drawdown m	Specific Capacity at t = 100 min (m^2/d)	Efficiency
126	10.9	11.56	48.2
202	20.1	10.05	36.7
253	31.5	8.03	31.6
303	44.7	6.78	27.9

Aquifer constant (B) 0.0410

Well constant (C) 3.5×10^{-4}

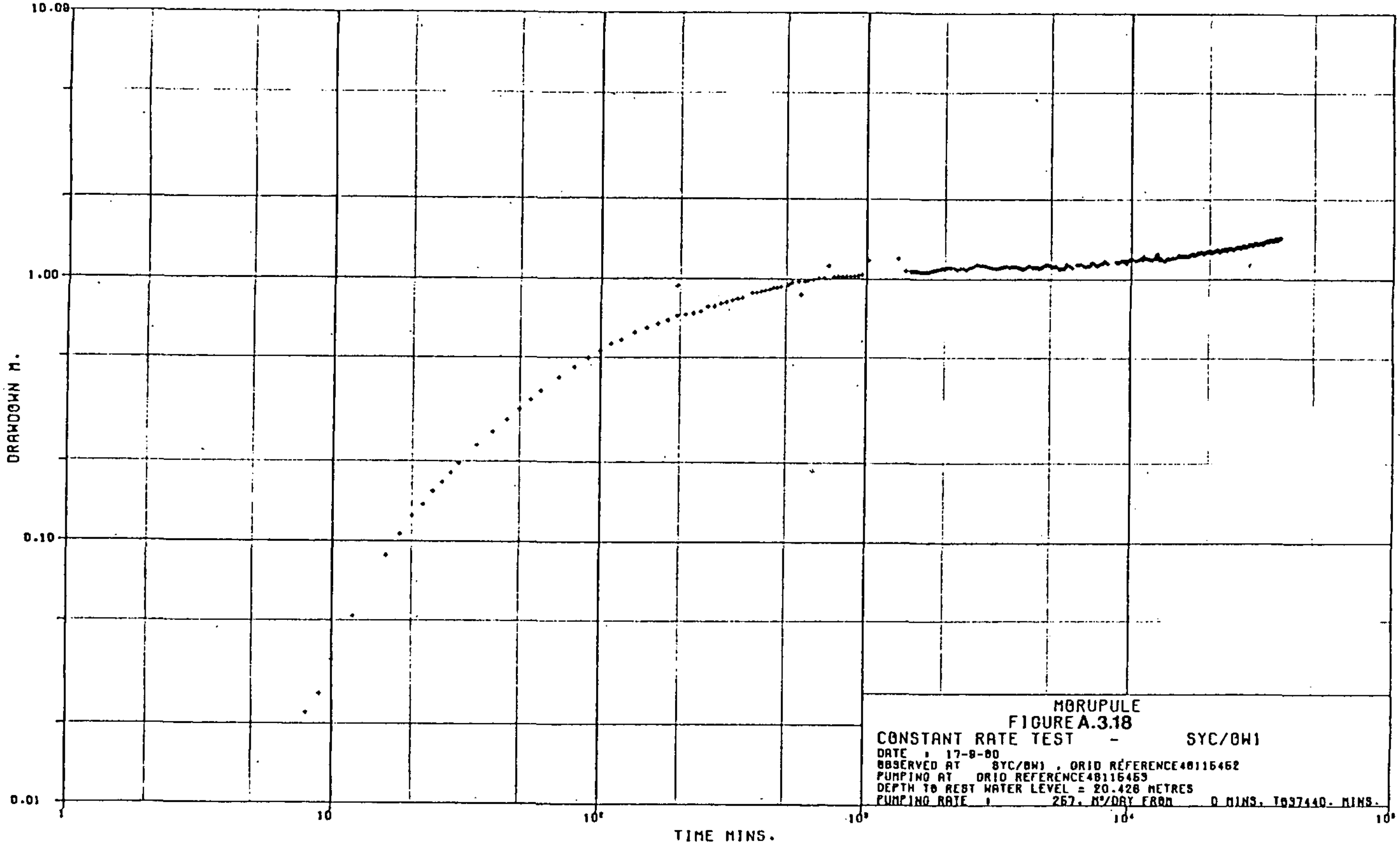
Jacob Solutions

	Transmissivity m^2/d	Storage
Pump Well	15	
OW1	97	2.7×10^{-4}
OW2	42	2.7×10^{-4}

The data for solving the aquifer and well losses is not linear. The best straight line has been fitted to the data points.

In order to establish the longer term pumping conditions a constant rate was carried out. The test lasted for 624 hours (26 days) at a pump rate of 257 m^3/d.

The log-log graph, figure A.3.18, follows theTheis non-leaky confined curves and then follows a Boulton water table curve. The Boulton method was used to solve for transmissivity and specific yield. As the later data are unconfined the Jacob method can only be applied to the early data.


10.00
1.00
0.10
0.01
DRAWDOWN M.
1
10
10^2
10^3
10^4
10^5
TIME MINS.
MORUPULE
FIGURE A.3.18
CONSTANT RATE TEST - SYC/OW1
DATE : 17-8-80
OBSERVED AT SYC/OW1 , GRID REFERENCE48116452
PUMPING AT GRID REFERENCE48116453
DEPTH TO REST WATER LEVEL = 20.428 METRES
PUMPING RATE : 257. M³/DAY FROM 0 MINS. TO37440. MINS.

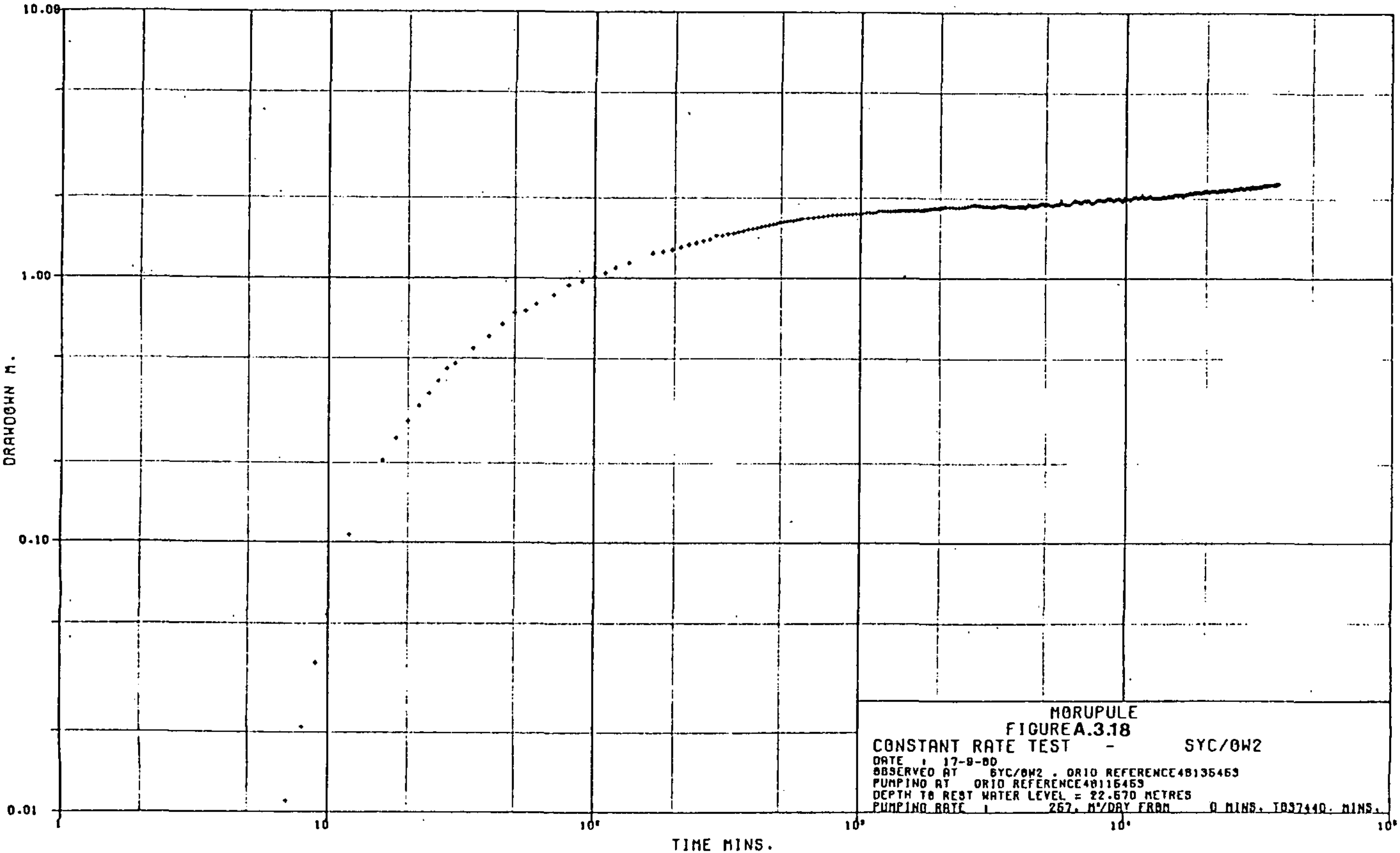

10.00
1.00
0.10
0.01
DRAWDOWN M.
1
10
10²
10³
10⁴
10⁵
TIME MINS.
MORUPULE
FIGURE A.3.18
CONSTANT RATE TEST - SYC/OW2
DATE : 17-9-80
OBSERVED AT SYC/OW2 . GRID REFERENCE48135463
PUMPING AT GRID REFERENCE48115463
DEPTH TO REST WATER LEVEL = 22.570 METRES
PUMPING RATE : 257. M³/DAY FROM 0 MINS. TO37440. MINS.

Table A.3.6 Specific Yield SYC Constant Rate Results

	Early Data		Late Data		Jacob Early Data	
	Transmissivity (m^2/d)	Storage	Transmissivity (m^2/d)	Storage	Transmissivity (m^2/d)	Storag
Pump Well					70	
OW1	43	$3.8x10^{-4}$	43	$3.4x10^{-2}$	78	$3.0x10^{-4}$
OW2	31	$3.8x10^{-4}$	30	$3.8x10^{-2}$	51	$2.8x10^{-4}$

This test gives values of the aquifer parameters for both confined and unconfined conditions.

A.3.5 Test Site TS2

Location

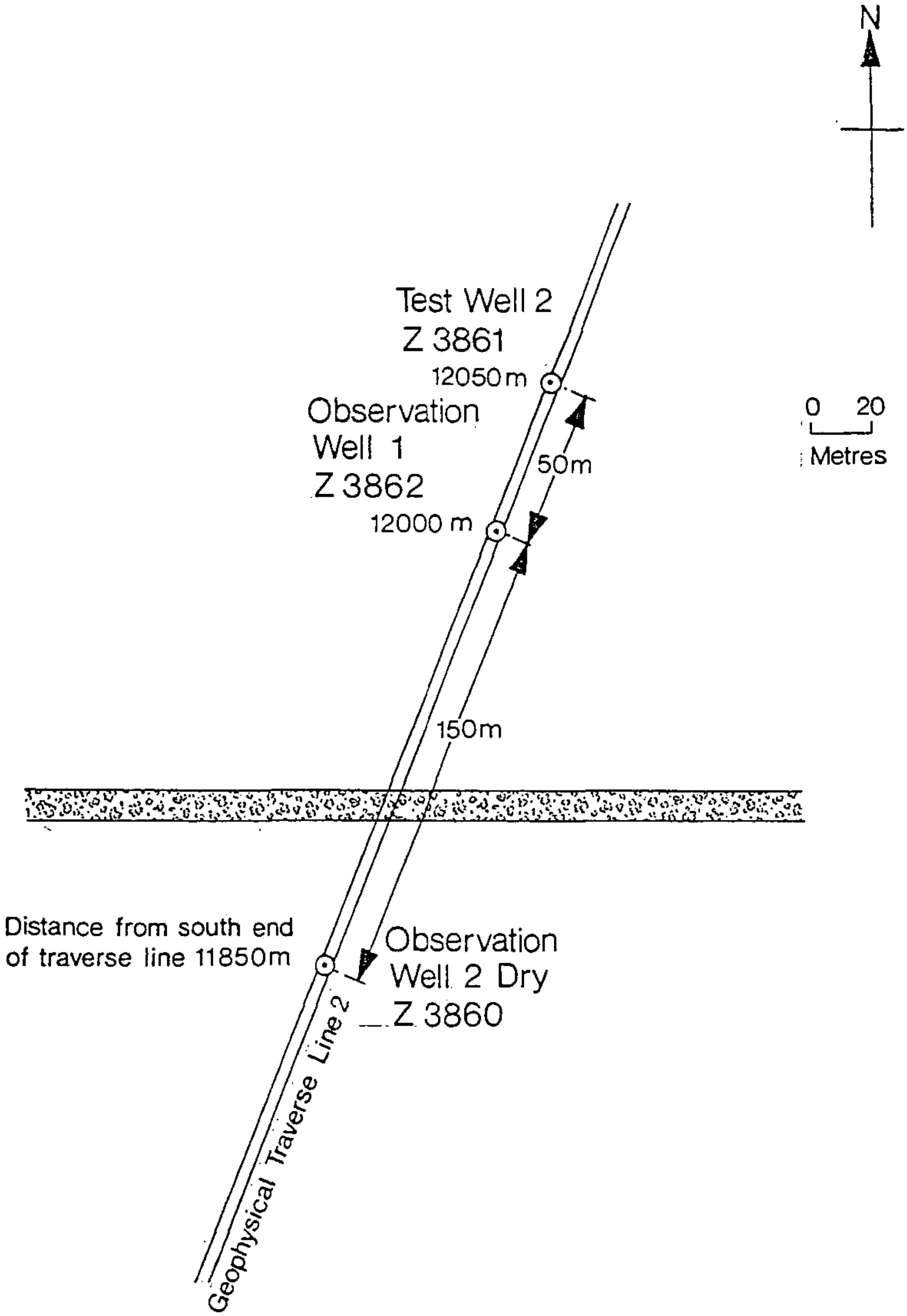
Site TS2 is 24 kms to the west of the escarpment and lies on the basalt plateau. It is positioned on and is 12 kms from the south end of geophysical traverse line 2. Three wells, one pump well and two observation wells, located at distances of 50 m and 200 m from the pump well, were drilled at the site, Figure A.3.19. The most southerly and distant of the observation wells was dry and abandoned at a depth of 160 m. The two remaining wells have confined groundwater conditions.

These wells were drilled to test the hydraulic effects, upon pumping, of a fault and dolerite dyke thought to exist in the area.

Geology

Observation well 1, the deepest of the three wells, penetrates a very thick sequence of Kalahari Beds before passing through the Drakensberg Basalt, Cave Sandstone and terminating in the Transition Beds. The pump well penetrates the lower half of the Cave Sandstone whereas the abandoned observation well 2 terminates in basalt.

At this location the blanket of Kalahari beds is very thick and ranges between 66 m - 72 m. There is a 10 m - 12 m cover of unconsolidated yellow-orange sand. The rest of the succession comprises of a variable sequence



Test Site 2: Location

Figure **A.3.19**

of pink and white siliceous and calcareous sandstones with subordinate silcretes.

In all three wells the Kalahari Beds pass down into a succession of weathered red-brown and fresh grey-black basalt. The thickness of the basalt in each well is controlled by a large fault which passes between observation wells 1 and 2. This is associated with a dolerite dyke located by a magnetic traverse, Figure A.3.20. The lithological and geophysical logs are shown in Figures A.3.21 and A.3.22.

On the northern, upthrown, side of the fault the thickness of the basalt in the test well and observation well 1 is 64 m with the base at a depth of 130 m. On the downthrown side the basalt in observation well 2 has a minimum thickness of 88 m, the base was not penetrated by 160m. This gives the fault a minimum downthrow of 30 m to the south.

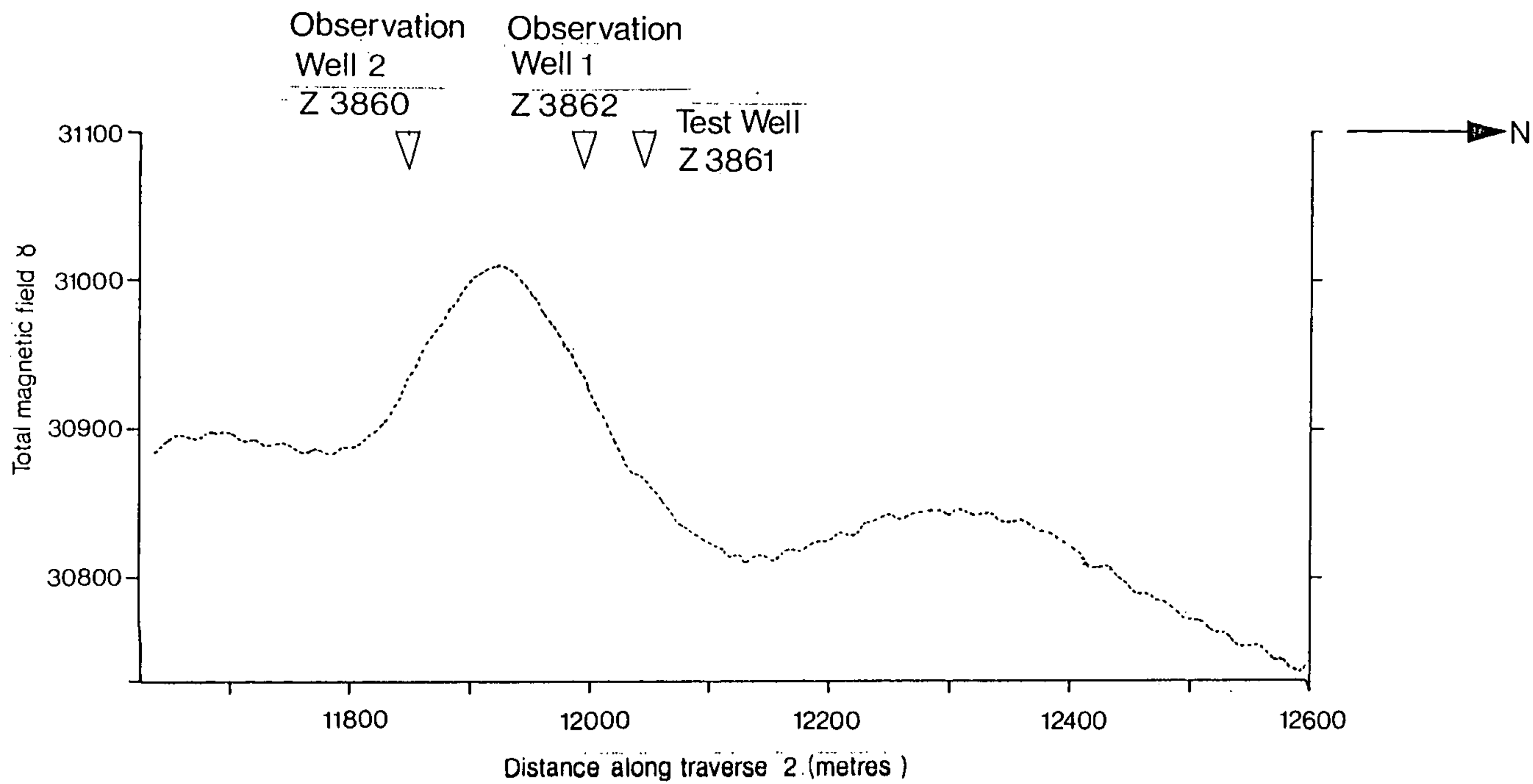
On the northern side of the fault groundwater conditions are confined with water levels standing only 2 m - 3 m below the base of the Kalahari Beds. To the south groundwater conditions are unknown since observation well 2 is dry.

Beneath the basalt is the Cave Sandstone which at this site is fully penetrated only by observation well 1. Here the sandstone is 54 m thick with the upper 20 m comprising a monotonous sequence of pink and white calcareous and siliceous sandstones. The lower 30 m are a series of pink and white silty sandstones. A similar succession is present in the pump well.

The underlying Transition Beds are penetrated for a thickness of 15 m by observation well 1. Pink and green silty sandstones and siltstones dominate with subordinate pink and white silty sandstones.

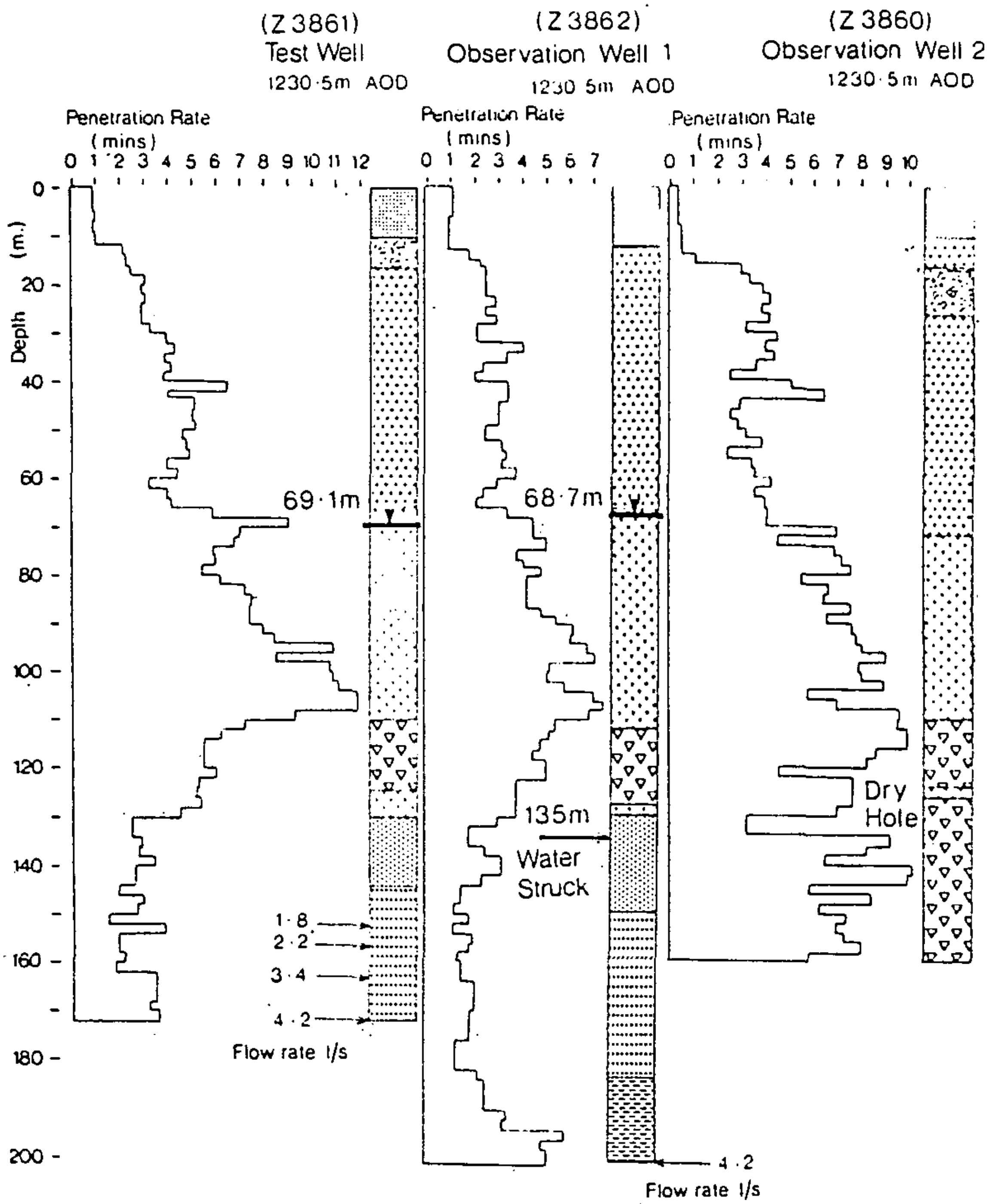
Fluid column logs

Temperature and conductivity logs were run under both static and pumped conditions in observation well 1 but only under static conditions in the pump well, Figure A.3.23.



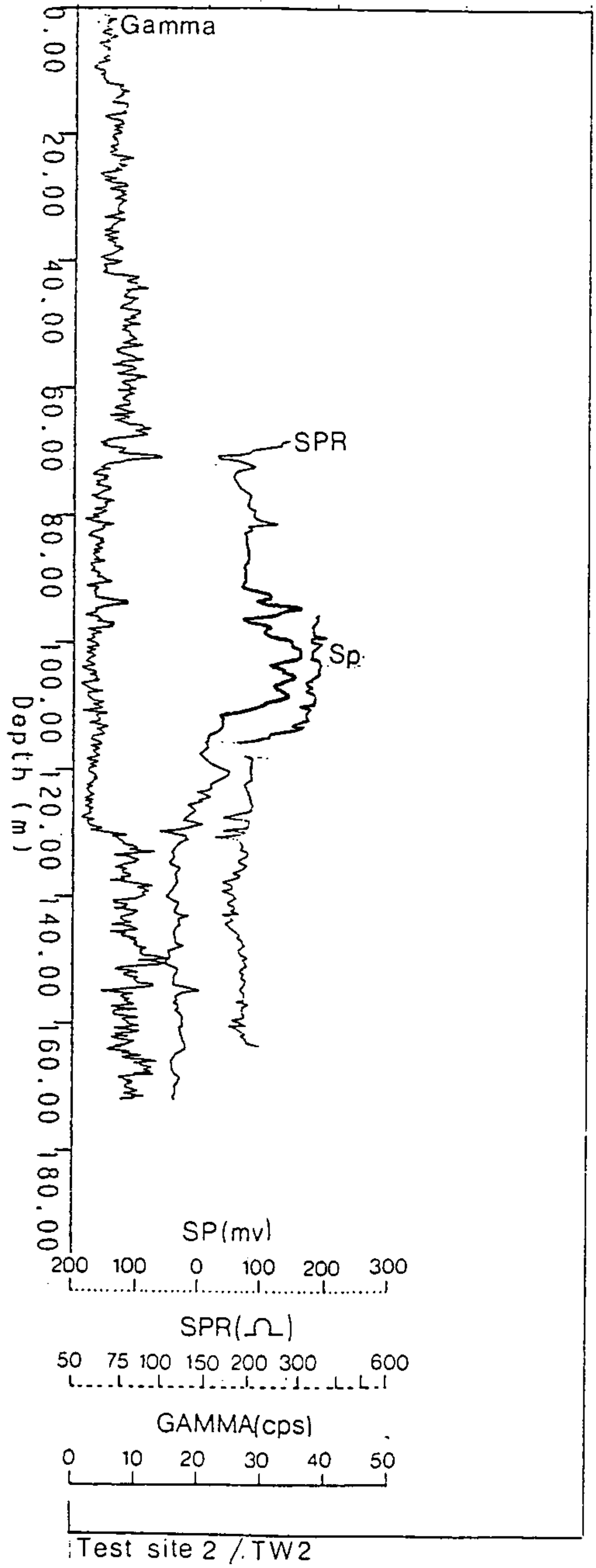
Magnetic Anomalies at Site 2

Figure **A.3.20**



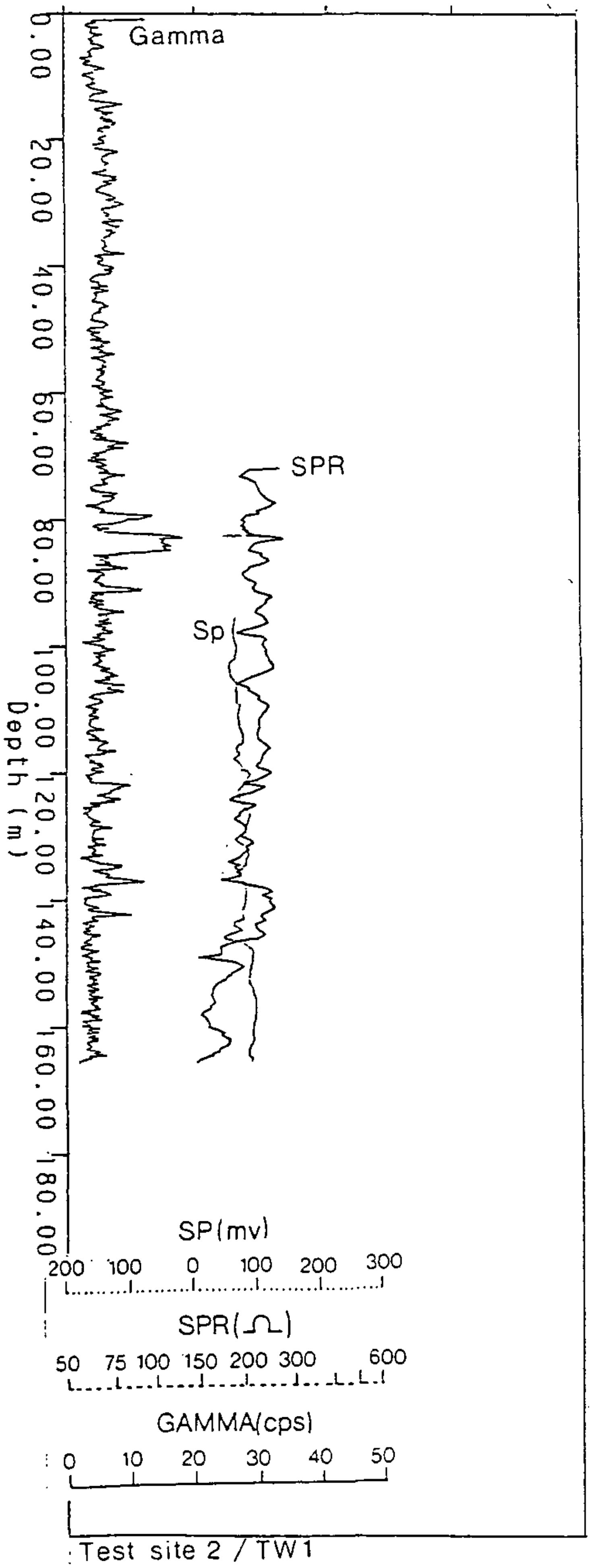
TEST SITE TS 2
LITHOLOGY AND DRILLING DETAILS

Figure A.3.21



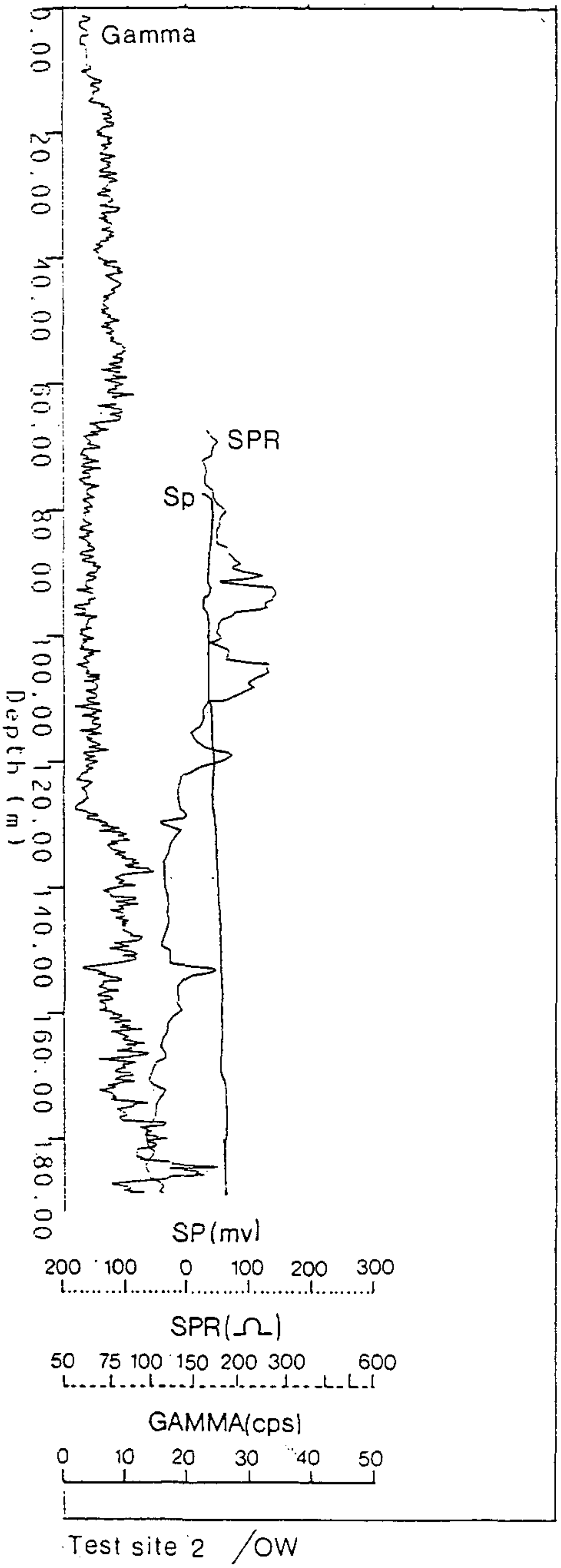
TEST SITE TS 2 FORMATION LOGS

Figure A.3.22



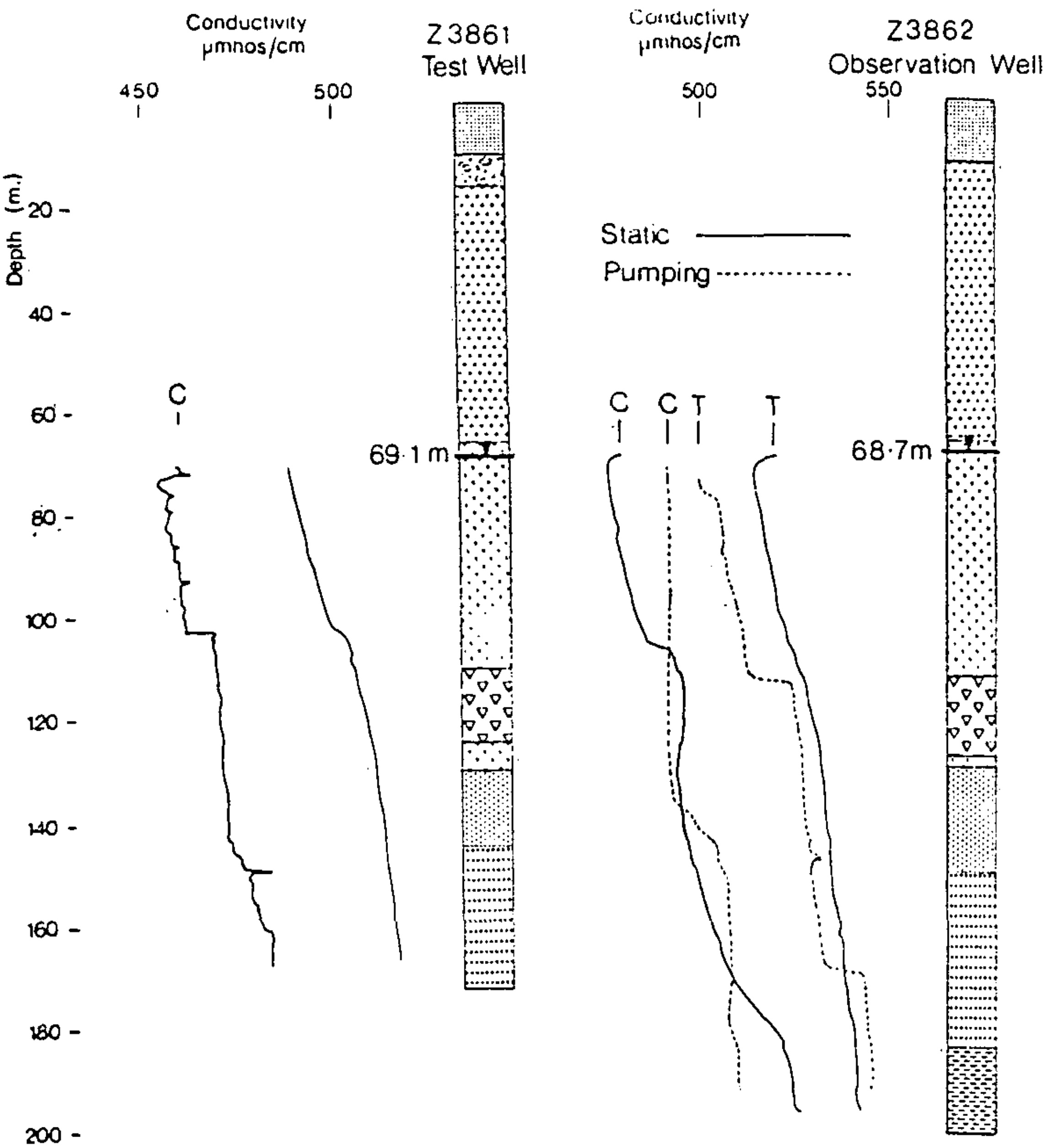
TEST SITE TS 2 FORMATION LOGS

Figure **A.3.22**



TEST SITE TS2 FORMATION LOGS

Figure **A.3.22**



TEST SITE TS 2

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.23

Observation Well 1

68-78 m	low horizontal flow
78-112 m	no flow, ion exchange taking place between the water in the borehole and clays in the basalts
112-136 m	no flow, different conductivity due to a different ion exchange process taking place
136-143 m	horizontal flow
143-146 m	increased horizontal flow
146 m	probable fissure
146-150 m	lower horizontal flow
150-167.5 m	increased horizontal flow
167.5-179 m	horizontal flow but a different type of water
179 + m	decreased horizontal flow.

There is no vertical flow.

Pump Well

68-78 m	low horizontal flow
78-142 m	no flow, ion exchange taking place between the water in the borehole and clays in the basalts
142-148 m	variable horizontal flow
148-160 m	horizontal flow
160 + m	increased horizontal flow

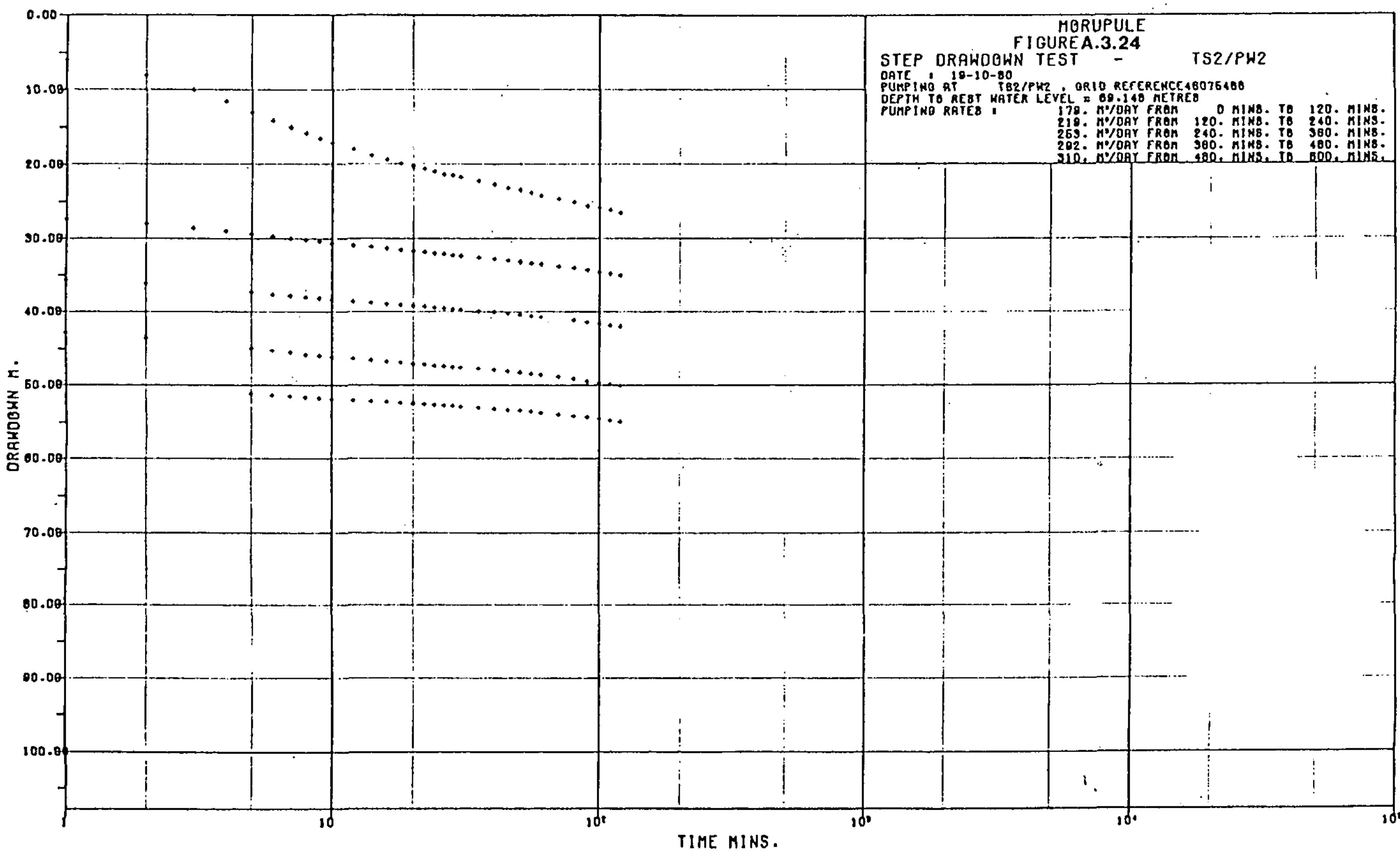
There is no vertical flow.

It appears that both fissure and intergranular flow take place at this site, the latter probably predominates. It also appears that contact of the Cave Sandstone water type with basalt produces rapid chemical changes. Different ages of groundwater could exist within the Cave Sandstone and Transition Bed formations.

Pumping tests

A five stage variable rate test was carried, with each stage lasting 120 minutes before the pump rate was increased, Figure A.3.24.

The test was solved, using Jacob's method, for the well and aquifer losses. It was possible to use the first stage data to determine the aquifer characteristics of transmissivity and storage for the observation borehole


MORUPULE
FIGURE A.3.24
STEP DRAWDOWN TEST - TS2/PW2
DATE : 19-10-80
PUMPING AT TS2/PW2 , GRID REFERENCE46076486
DEPTH TO REST WATER LEVEL = 69.148 METRES
PUMPING RATES : 179. M³/DAY FROM 0 MINS. TO 120. MINS.
219. M³/DAY FROM 120. MINS. TO 240. MINS.
263. M³/DAY FROM 240. MINS. TO 360. MINS.
292. M³/DAY FROM 360. MINS. TO 480. MINS.
310. M³/DAY FROM 480. MINS. TO 600. MINS.
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DRAWDOWN M.
1
10
10²
10³
10⁴
10⁵
TIME MINS.

and transmissivity for the pumped well using the Jacob method.

Table A.3.7 Test Site TS2 Test Results

Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t=100 min (m^2/d)	Efficiency %
179	25.8	6.94	89.6
219	32.0	6.83	87.6
253	38.1	6.65	85.9
292	44.9	6.50	84.1
310	48.8	6.36	83.3

Aquifer constant (B) 0.1294
Well constant (C) 8.37×10^{-5}

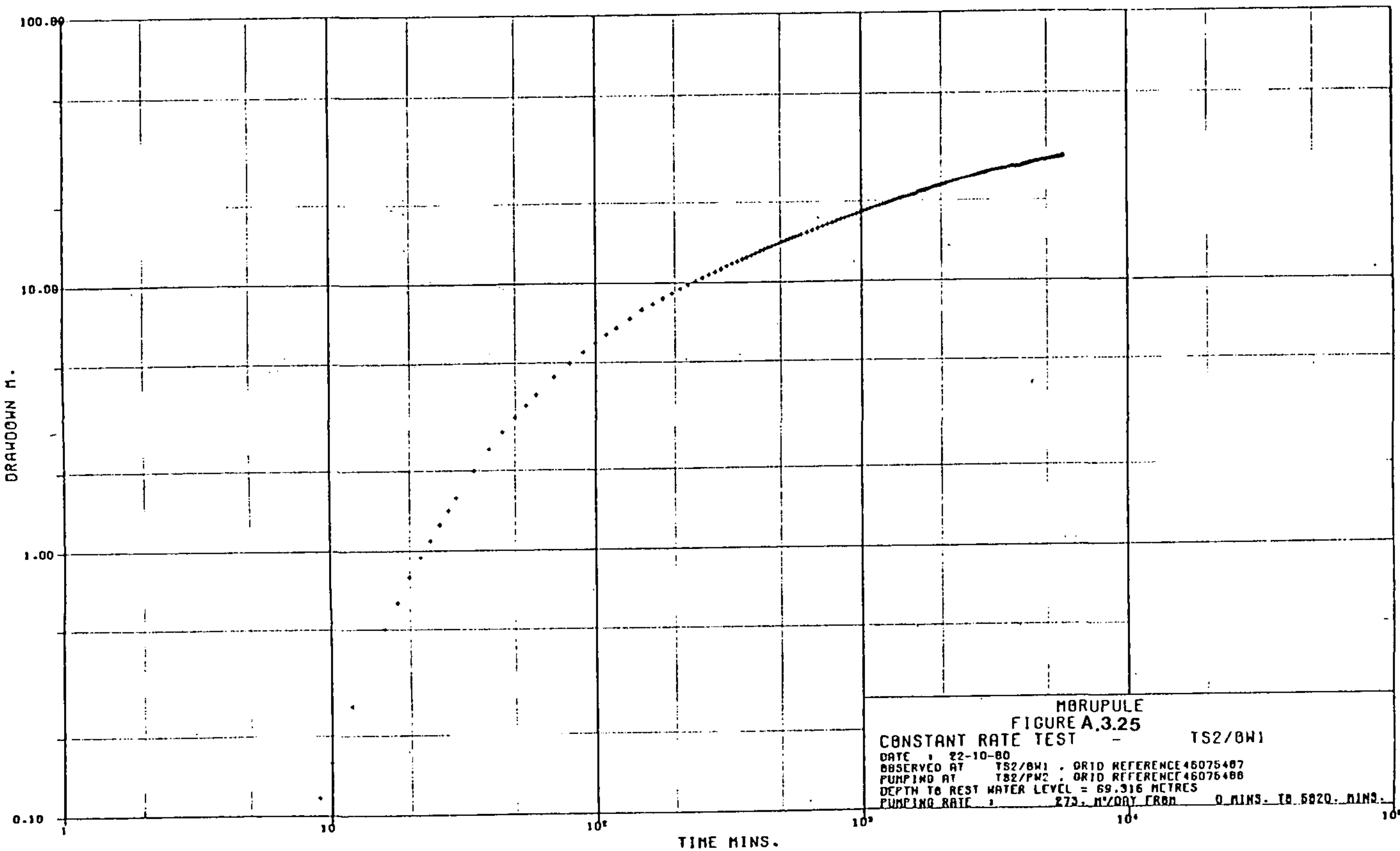
Jacob Solutions for Stage 1

	Transmissivity (m^2/d)	Storage
Pump well	4	
OW	-	0.7×10^{-4}

As the data for solving the well and aquifer constants were not linear, the best fit straight line was used.

A constant rate test was also carried out to determine the aquifer characteristics for a longer period of pumping at a higher discharge. The test lasted for 97 hours (4 days) at a pump rate of 277 m^3/d.

The log log graph, Figure A.3.25, indicates a barrier boundary. Consequently we have used the Stallman image well method to solve for the aquifer characteristics of transmissivity and storage.



MORUPULE
FIGURE A.3.25
CONSTANT RATE TEST - TS2/OW1
DATE : 22-10-80
OBSERVED AT TS2/OW1 . GRID REFERENCE46075487
PUMPING AT TS2/PW2 . GRID REFERENCE46075486
DEPTH TO REST WATER LEVEL = 69.316 METRES
PUMPING RATE : 273. M³/DAY FROM 0 MINS. TO 5820. MINS.
DRAWDOWN M.
TIME MINS.
100.00
10.00
1.00
0.10
1
10
10²
10³
10⁴
10⁵

Table A.3.8 Test Site TS2 Test Results

	Stallman Image Well Transmissivity (m^2/d)	Stallman Image Well Storage	Jacob Transmissivity (m^2/d)	Jacob Storage	Recovery Transmissivity (m^2/d)
PW					4
OW		2.1×10^{-4}		1.0×10^{-4}	4

The results provided by the Jacob method are for comparison purposes only as the method does not strictly apply when barrier boundary conditions operate.

A.3.6 Test Site TS3

Location

Site TS3 is 32 km to the west of the escarpment and lies on the basalt plateau. It is positioned on and is 14.7 km from the south end of geophysical traverse line 4. A pump well and an observation well, 75m to the north, were drilled at this site, Figure A.3.26. Confined conditions exist in both wells.

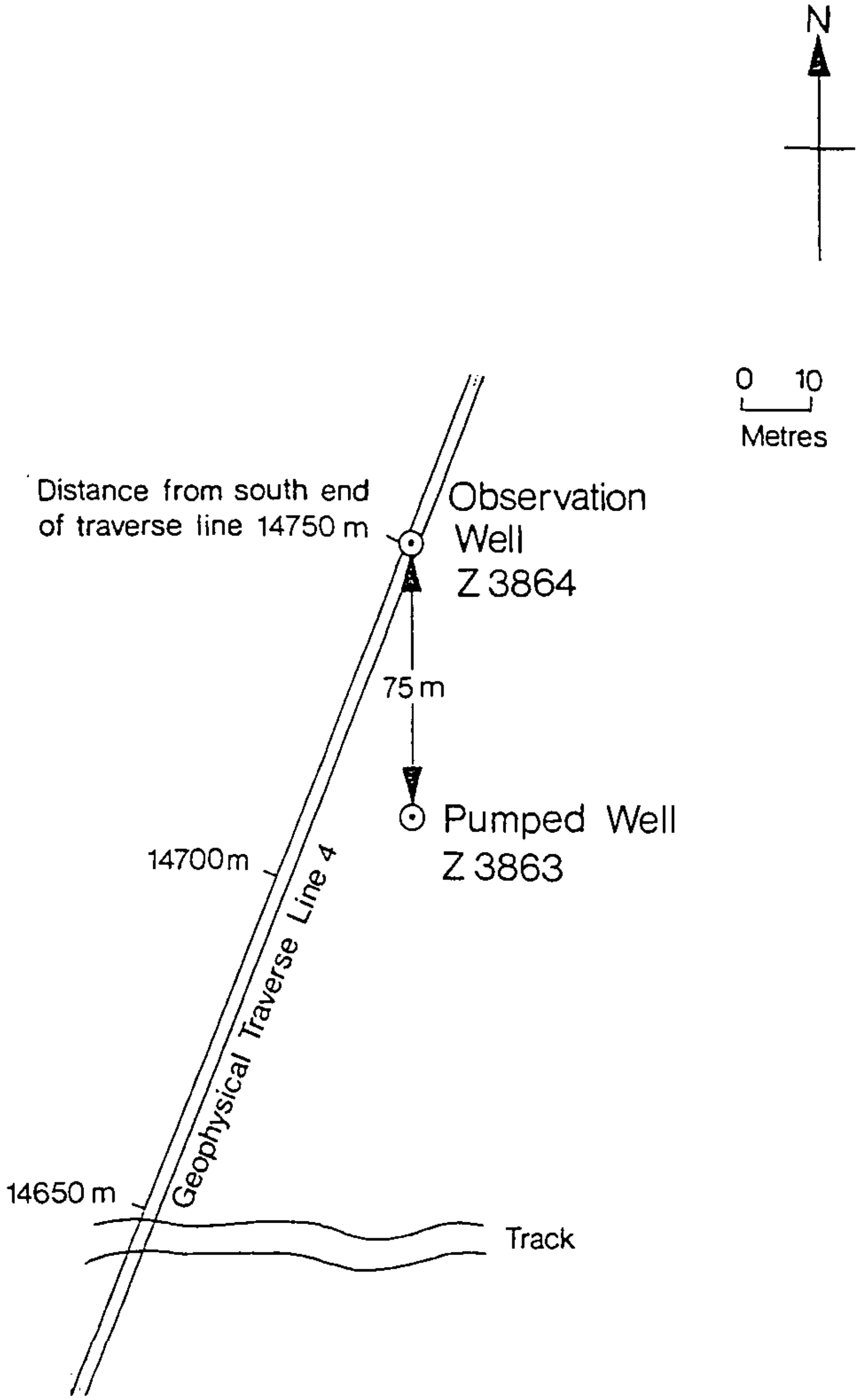
The site was located, using geophysics, on a large dyke-free fault to test the fault's hydraulic properties. Unfortunately the sensitivity of the geophysical technique proved insufficient to define accurately such a narrow feature, though drilling may have encountered a small secondary fault. Consequently the site has been used to determine aquifer properties under confined conditions.

Geology

The site lies on the extensive Drakensberg Basalt plateau. Both wells penetrate the blanket of Kalahari Beds, the Drakensberg Basalt, the Cave Sandstone and terminate in the Transition Beds, Figures A.3.27 and A.3.28.

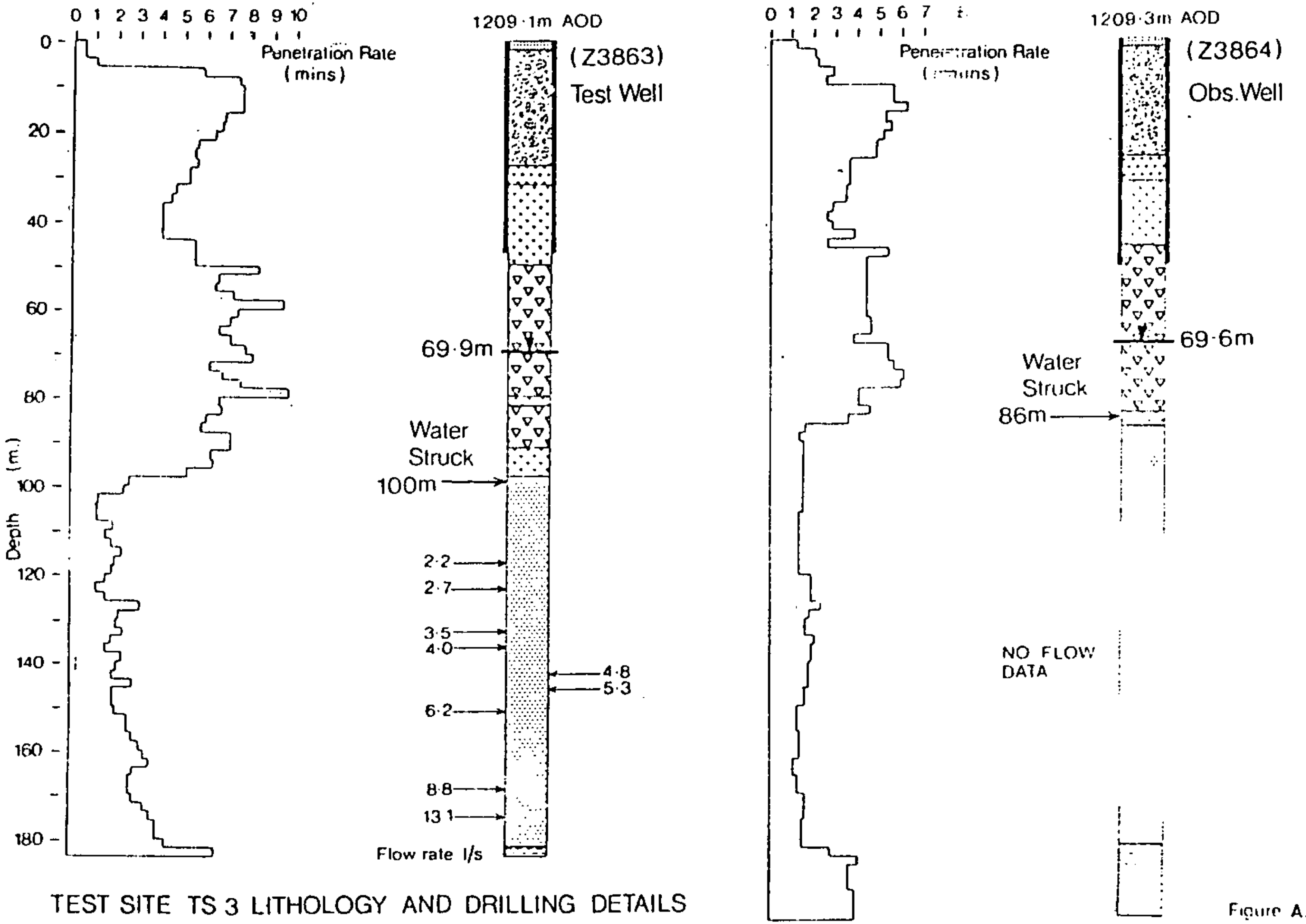
At this site the Kalahari Beds are 32m thick. There is a thin 2m cover of very fine grained unconsolidated pale orange sand. This passes into a 24-26m thick complex sequence of brown, green and pink silcretes with subordinate siliceous sandstone. At the base of the succession in both boreholes is a 4-6m thick series of white and pale green calcareous and siliceous sandstones. These pass gradually into the underlying Drakensberg Basalt.

At this site the basalt is 55-66m thick and the base lies between 87-98m. The weathered basalt is red-brown in colour which contrasts sharply with the grey-black appearance of unweathered basalt. Much of the formation at this site is fresh except for a 14-18m thick weathered zone at the top and a narrower 3-6m zone at the base. Both fine and coarse grained basalt types, as well as amygdaloidal varieties are present. The most common secondary minerals are chlorite, calcite, zoelite and quartz.



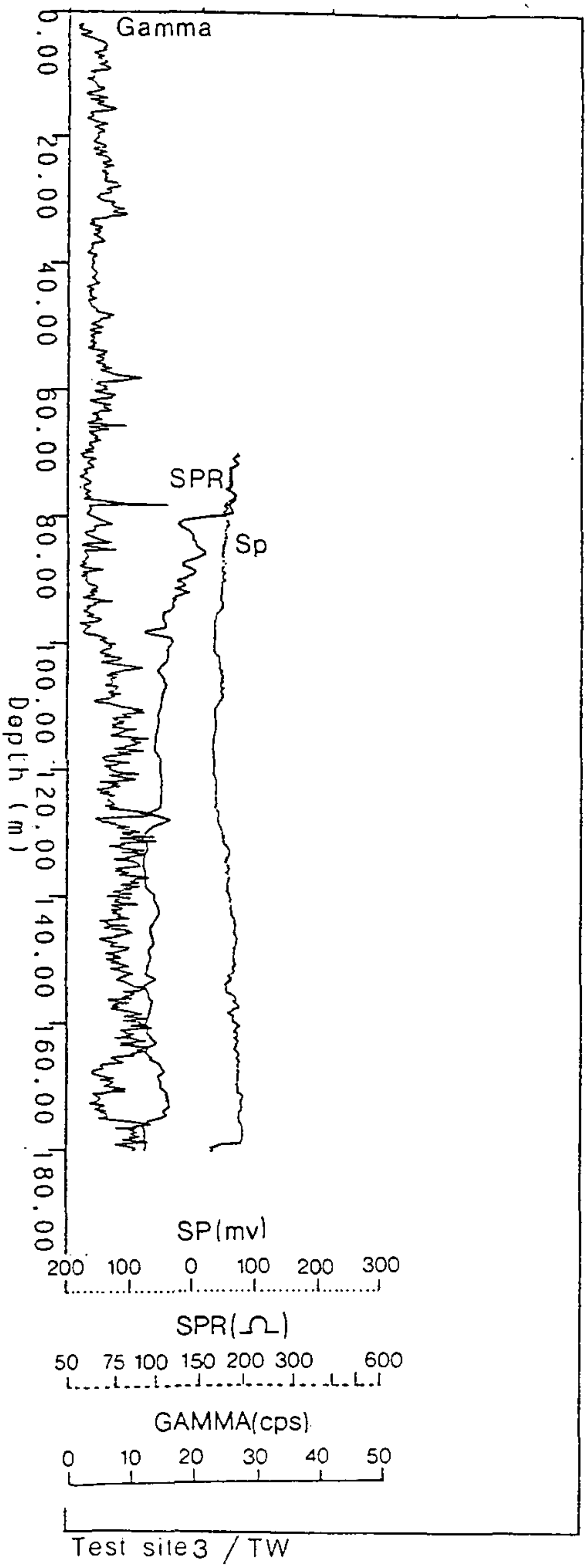
Test Site 3: Location

Figure **A.3.26**



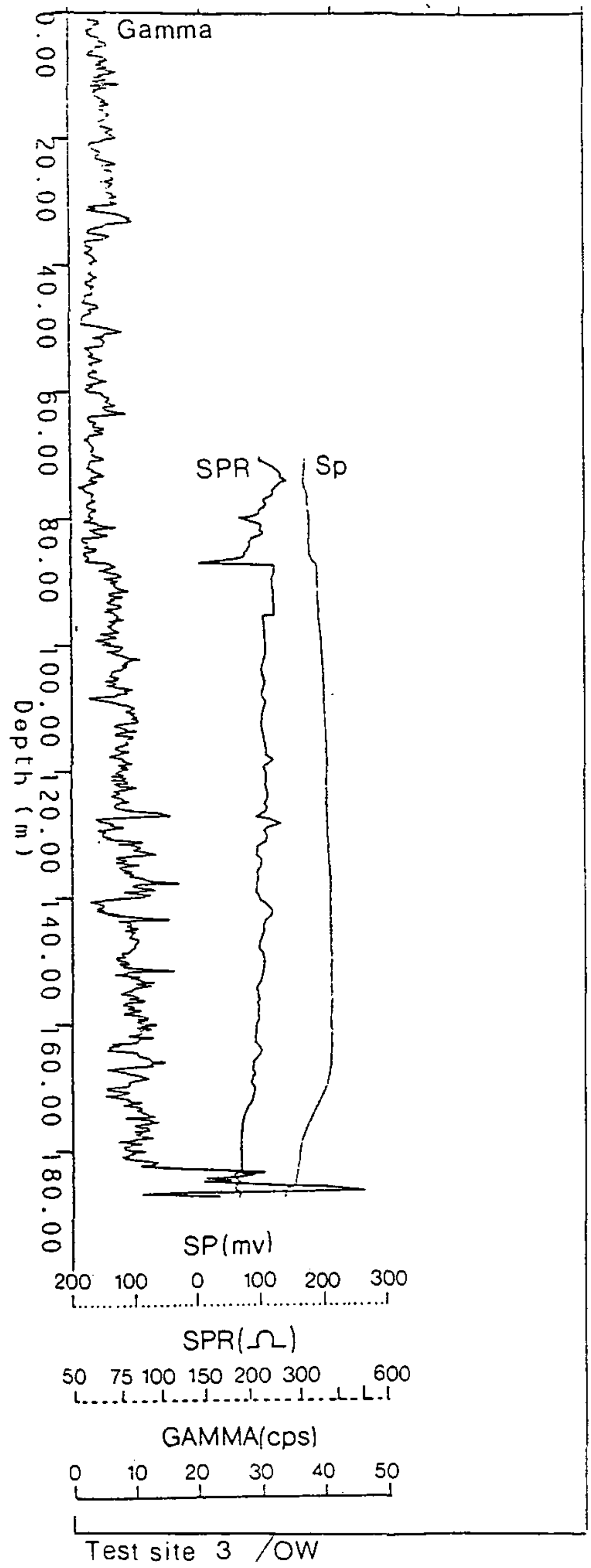
TEST SITE TS 3 LITHOLOGY AND DRILLING DETAILS

Figure A.3.27



TEST SITE TS3 FORMATION LOGS

Figure **A.3.28**



TEST SITE TS 3 FORMATION LOGS

Figure A.3.28

The underlying Cave Sandstone is between 85m and 35m thick. The top of the formation is 11m lower in the test well but the base is the same elevation in both wells. This may be explained by one of the following

a 1 in 7 slope on the pre-basalt topography

a small fault passing through the test well with an 11m downthrow to the south

Unfortunately there is insufficient evidence to determine which is correct.

The lithology of the Cave Sandstone is very uniform, comprising a monotonous succession of very fine grained white and pink calcareous sandstones.

The Transition Beds below are a succession of red and green siltstones with subordinate silty sandstones, which are penetrated to a thickness of 16m.

Fluid Column Log

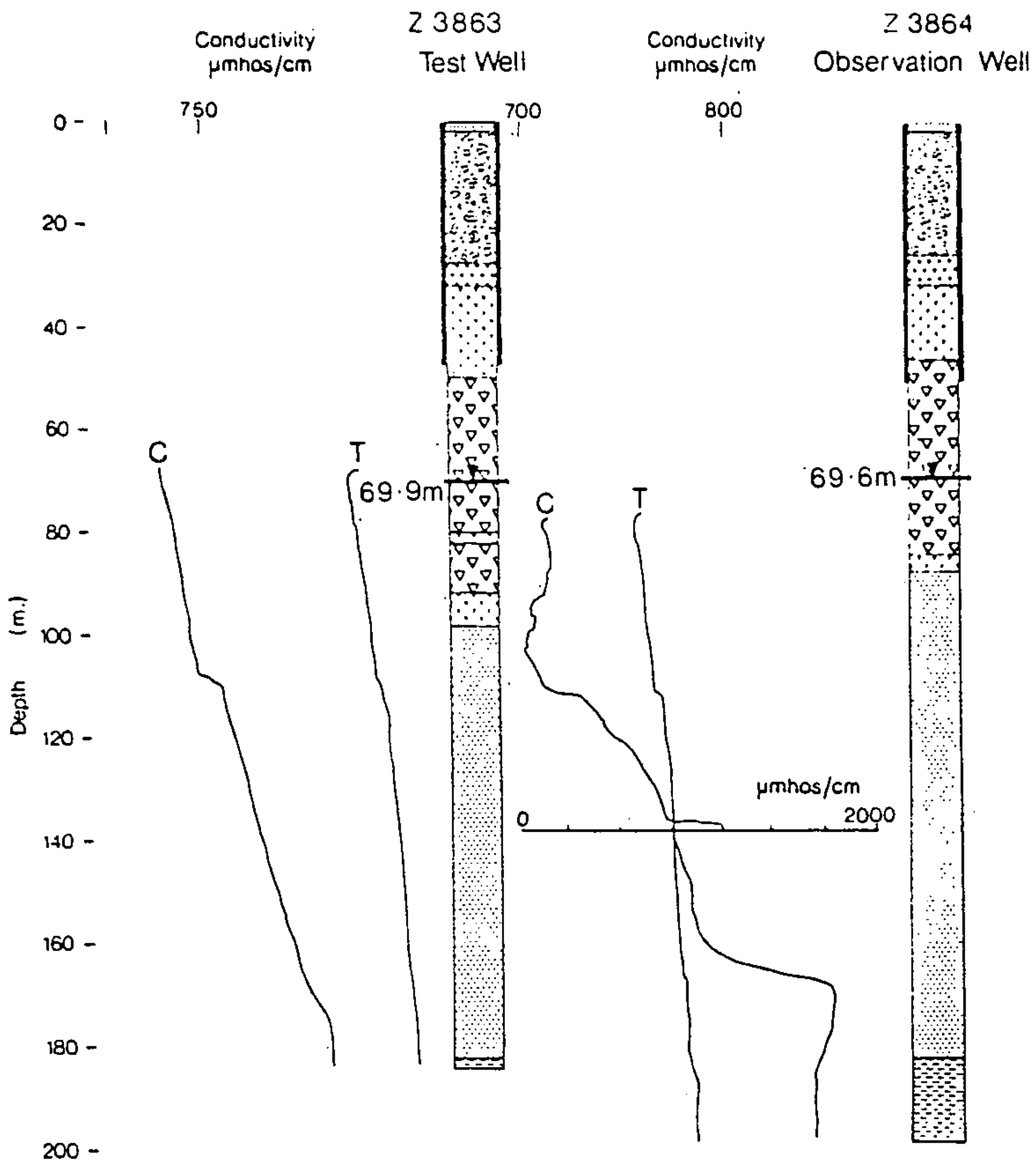
Temperature and conductivity logs were run in both wells under static conditions only, Figure A.3.29. The standing water levels in both wells was 69m.

Observation Well

The temperature log suggests that horizontal flow throughout the Cave Sandstone is fairly uniform. The conductivity log, however, is much more variable. From 128m to 160m there are a series of 5 steps in the conductivity log, each showing increasing conductivity with depth. The steps are at 128m, 139m, 139.5m, 146.5m, 150m, and 160m. There is no vertical flow between the steps and it is probable that the quality changes are related to differing lithologies. The highest conductivities occur in the interval 160m to 168m where upflow is taking place. Below 168m the conductivity decreases down to 180m.

Pump Well

The permeability throughout is uniform. The conductivity log shows a gradual increase from the base of the basalt at 99.2m to 176m below



TEST SITE TS 3
CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.29

which it remains constant.

In conclusion it may be noted that this is the only site where uniform permeability conditions throughout the Cave Sandstone have been noted. All other sites have preferred zones of integranular, with occasional fissure flow. At this site uniform intergranular flow seems to exist throughout.

Pumping tests

A four stage variable discharge test was carried out at this site. Each stage was pumped for 720 minutes before the pump rate was altered, Figure A.3.30.

Jacob's method was used to solve the test for aquifer and well losses. The first stage data for the observation borehole gave ambiguous solutions for the aquifer parameters; so it was only possible to determine transmissivity for the pump well by the Jacob method.

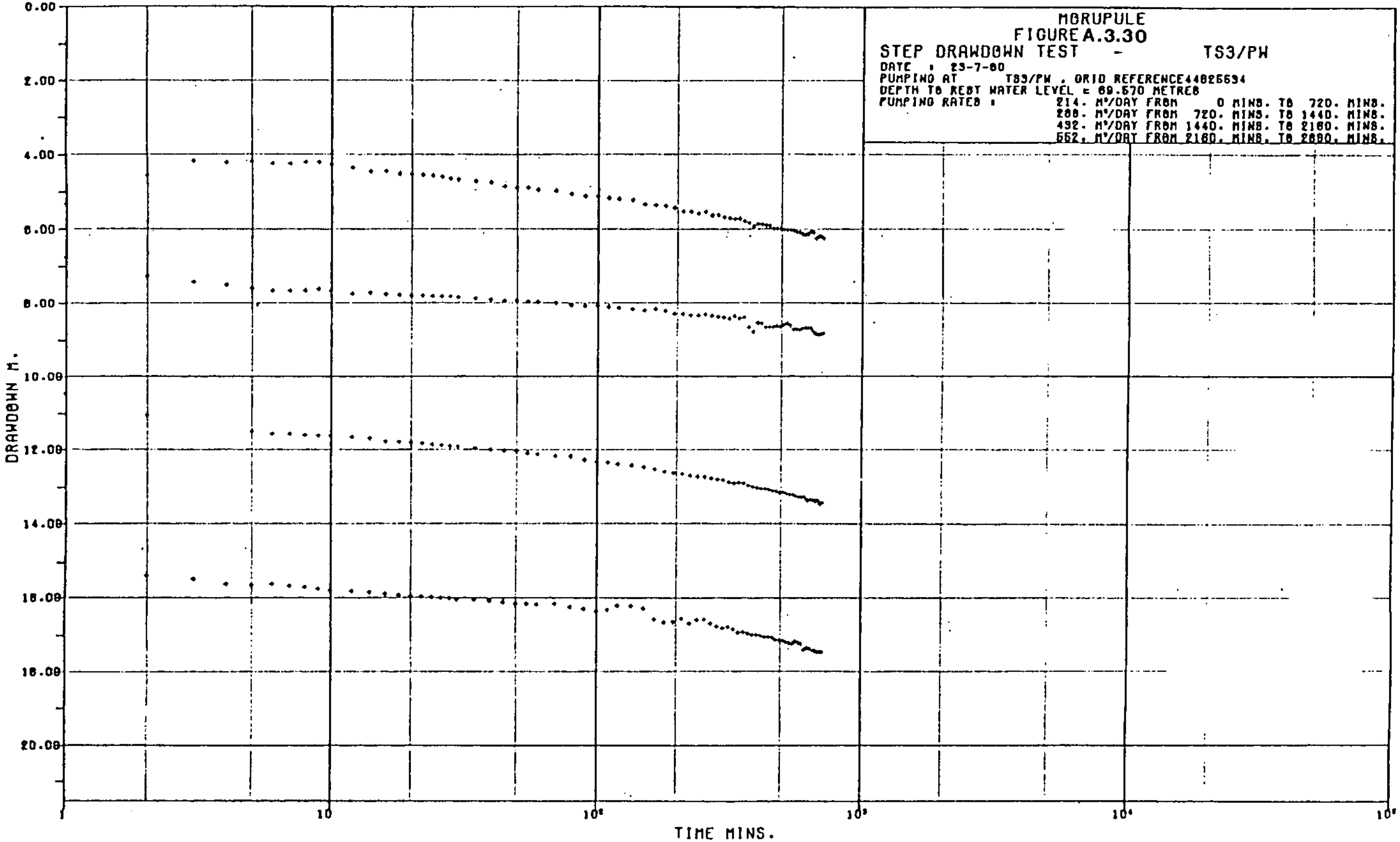
Table A.3.9 Test Site TS3 Step Drawdown Results

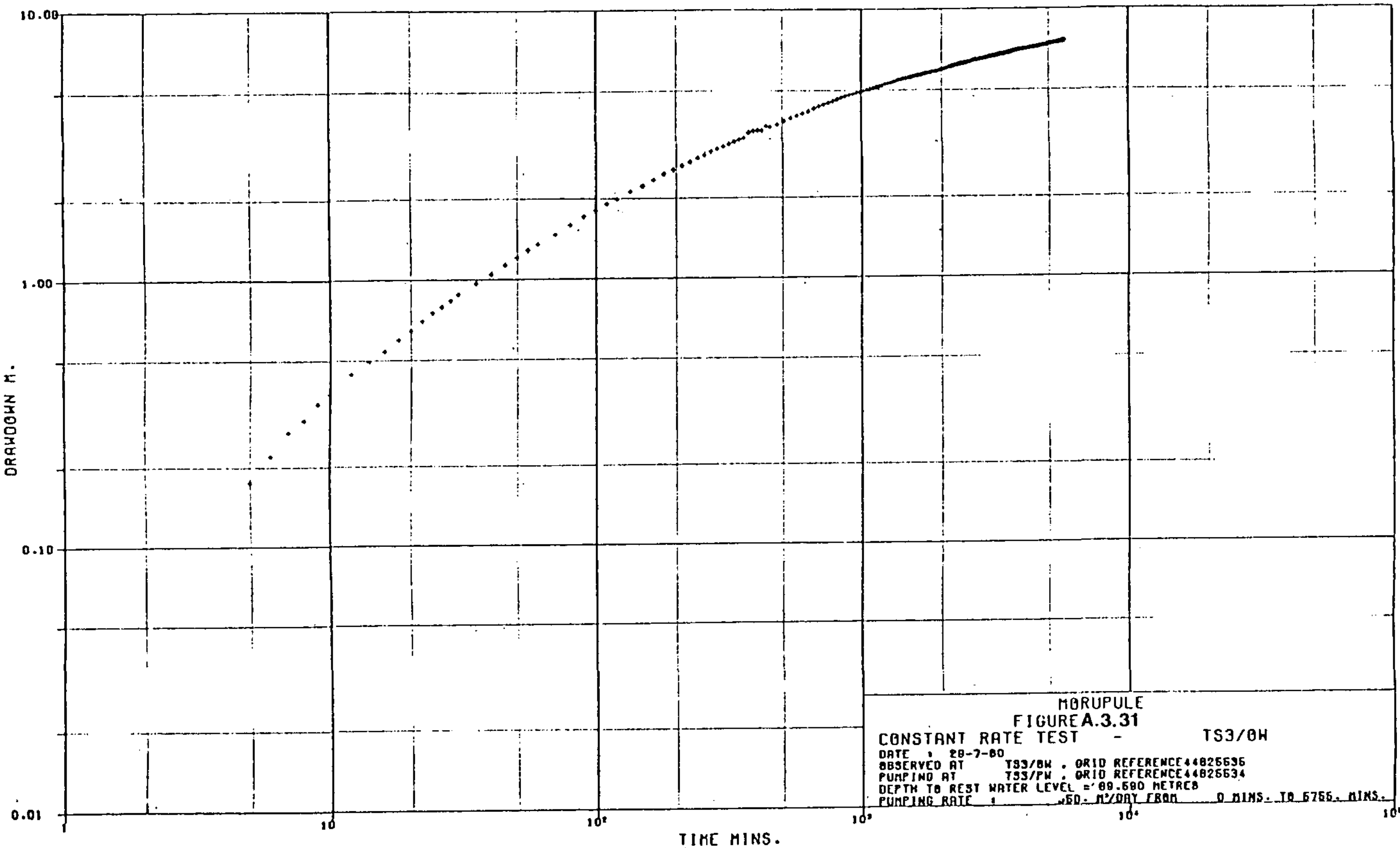
Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t=100 min (m^2/d)	Efficiency %
214	5.21	41.07	94.9
288	7.80	36.92	93.2
432	11.93	36.21	90.2
552	15.67	35.23	87.8

Aquifer constant (B) 0.0250
Well constant (C) 6.30×10^{-6}
Pump Well Transmissivity 36 m^2/d

A 96 hour (4 day) constant rate test was also carried out. The pump rate used was 550 m^3/d, Figure A.3.31.

It was possible to fit a Boulton delayed yield curve to the later data. However, as the piezometric head lies within the basalt and there is no evidence to support water table conditions, we have discounted delayed yield. The graph follows the non-leaky confined type curve for the first 20 to 30 minutes of the test and the data after 100 minutes. It is also possible to get a Stallman curve match for the later data, however the Jacob


MORUPULE
FIGURE A.3.30
STEP DRAWDOWN TEST - TS3/PW
DATE : 23-7-80
PUMPING AT TS3/PW , GRID REFERENCE44826634
DEPTH TO REST WATER LEVEL = 69.570 METRES
PUMPING RATES : 214. M³/DAY FROM 0 MINS. TO 720. MINS.
288. M³/DAY FROM 720. MINS. TO 1440. MINS.
432. M³/DAY FROM 1440. MINS. TO 2160. MINS.
552. M³/DAY FROM 2160. MINS. TO 2880. MINS.
DRAWDOWN M.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TIME MINS.
1
10
10²
10³
10⁴
10⁵


MORUPULE
FIGURE A.3.31
CONSTANT RATE TEST - TS3/OW
DATE : 28-7-80
OBSERVED AT TS3/OW . GRID REFERENCE44826636
PUMPING AT TS3/PW . GRID REFERENCE44826634
DEPTH TO REST WATER LEVEL =' 89.690 METRES
PUMPING RATE : 60. M³/DAY FROM 0 MINS. TO 6755. MINS.
DRAWDOWN M.
10.00
1.00
0.10
0.01
TIME MINS.
1
10
10²
10³
10⁴
10⁵

method does not suggest a barrier boundary.

Table A.3.10 Test Site TS3 Constant Rate Test Results

	Transmissivity (m^2/d)	Storage	
PW	24		Jacob (recovery)
OW	100	1.6×10^{-4}	Theis (early data)
	28	3.3×10^{-4}	Theis (late data)
	28	3.4×10^{-4}	Jacob
	61	6.0×10^{-4}	Stallman (late data)
	25		Jacob (recovery)

We have decided to use the more conservative Theis solution rather than the higher Stallman results.

A.3.7 Test site TS4

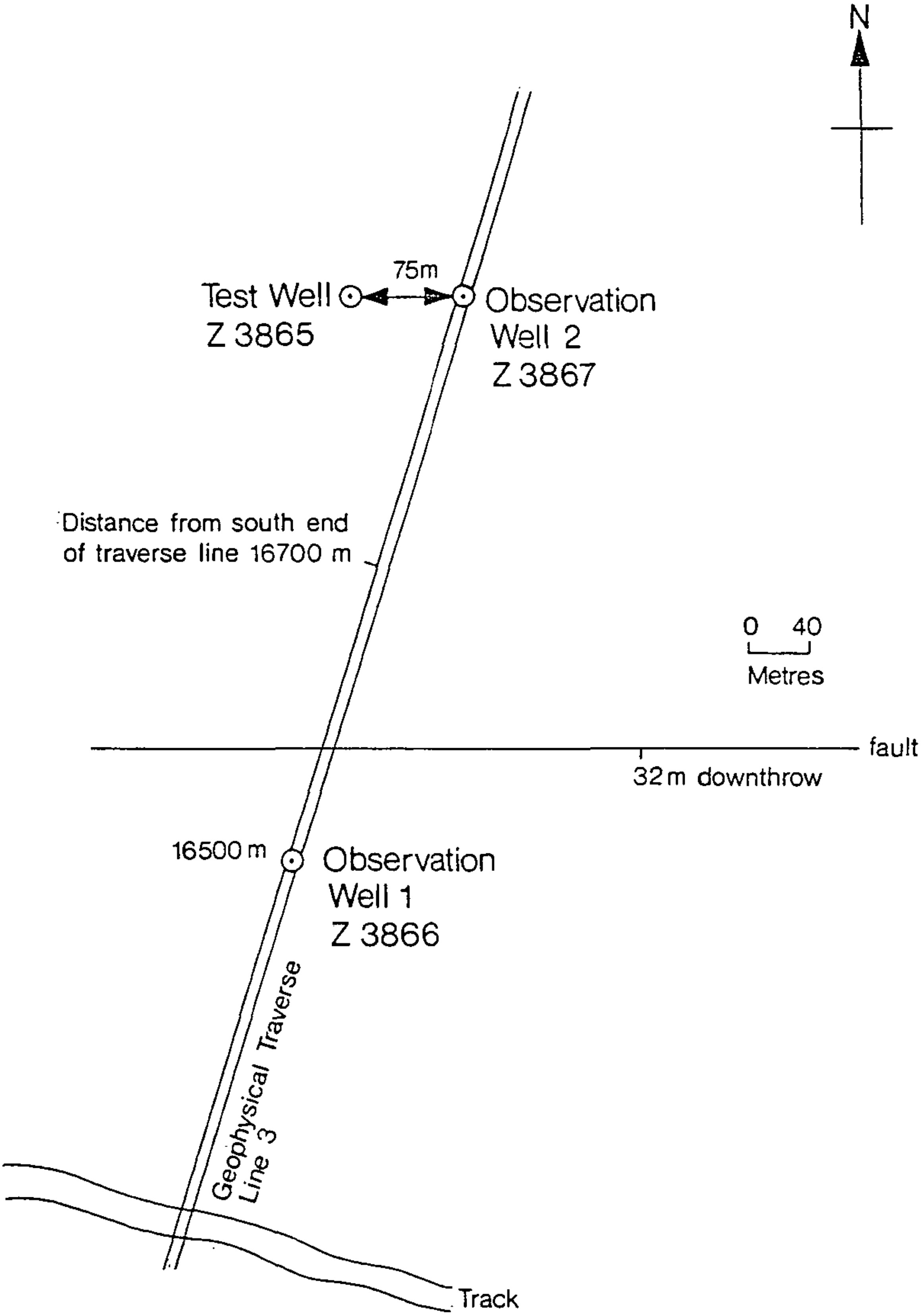
Location

Site TS4 lies 4 km to the west of the escarpment on the basalt plateau. It is positioned on and is 16.9 km from the south end of geophysical traverse line 3. Three wells, one pump well and two observation wells located at distances of 75m and 375m were drilled at the site; Figure A.3.32. These were drilled to evaluate the hydraulic significance of a dyke intruded fault which was thought to run through the area. The unexpected presence of unconfined conditions in the pump well and the nearer observation well also provided an opportunity to derive a value for unconfined storage.

Geology

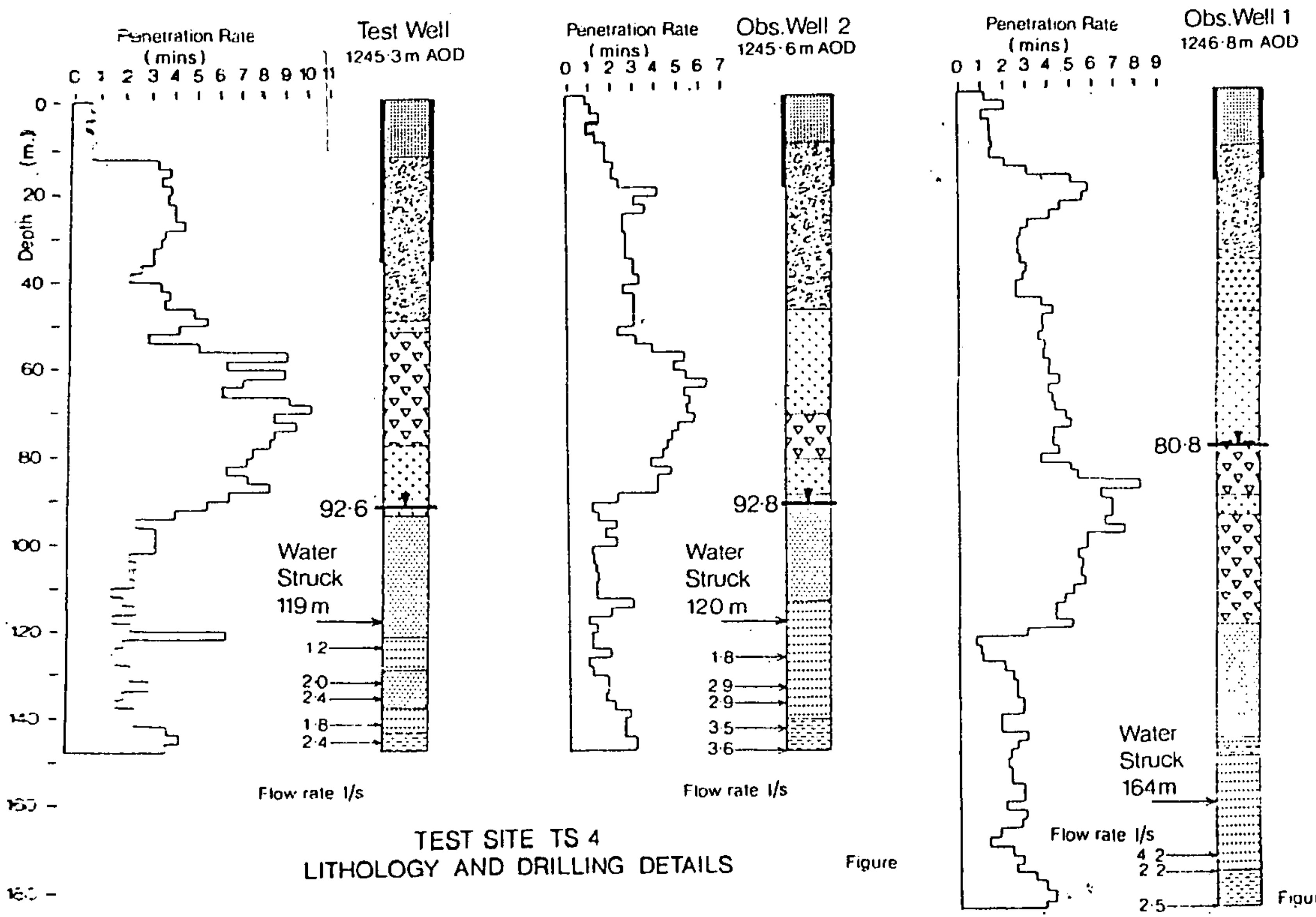
The site lies on the Drakensburg Basalt plateau. All three boreholes penetrate a very thick cover of Kalahari Beds, pass through the Drakensberg Basalt and into the Cave Sandstone before terminating in the Transition Beds. Figure A.3.33.

At this locality the Kalahari Beds are between 48m to 50m thick. The top 10m - 12m of the succession are unconsolidated yellow-orange sands



Test Site 4: Location

Figure **A.3.32**



TEST SITE TS 4
LITHOLOGY AND DRILLING DETAILS

Figure

Figure A.3.33

which pass down into a variable sequence of siliceous sandstones and silcretes. In general silcretes dominate the upper half of the formation while sandstone become more important with depth.

In all three wells the Kalahari Beds pass down into a succession of weathered red-brown and fresh grey-black basalt. The thickness of the basalt is controlled by a large fault which passes between observation will 1 and the two remaining wells. On the northern, upthrown, side of the fault the thickness of the basalt in the pump and observation wells is 44m and the base lies between 90 - 94m. In contrast on the downthrown side the basalt, in observation well 1, is 72m thick with the base at a depth of 122m. A total downthrow of 32m, to the south, therefore exists. The presence of the fault, probably associated with a dyke, is confirmed by a detailed magnetic traverse conducted along the line of geophysical traverse 3. Figure A.3.34. This dyke intruded fault is very significant as the groundwater elevations on either side of it differ by 12m.

Beneath the basalt is the Cave Sandstone which at this site is between 50-56m thick. The top 25m - 36m of the formation is a succession of pink and white calcareous and siliceous sandstones, whilst below white and pink silty sandstones dominate. Within this silty sandstone sequence the gamma log reveals one very thin siltstone horizon at 150 m, Figure A.3.35.

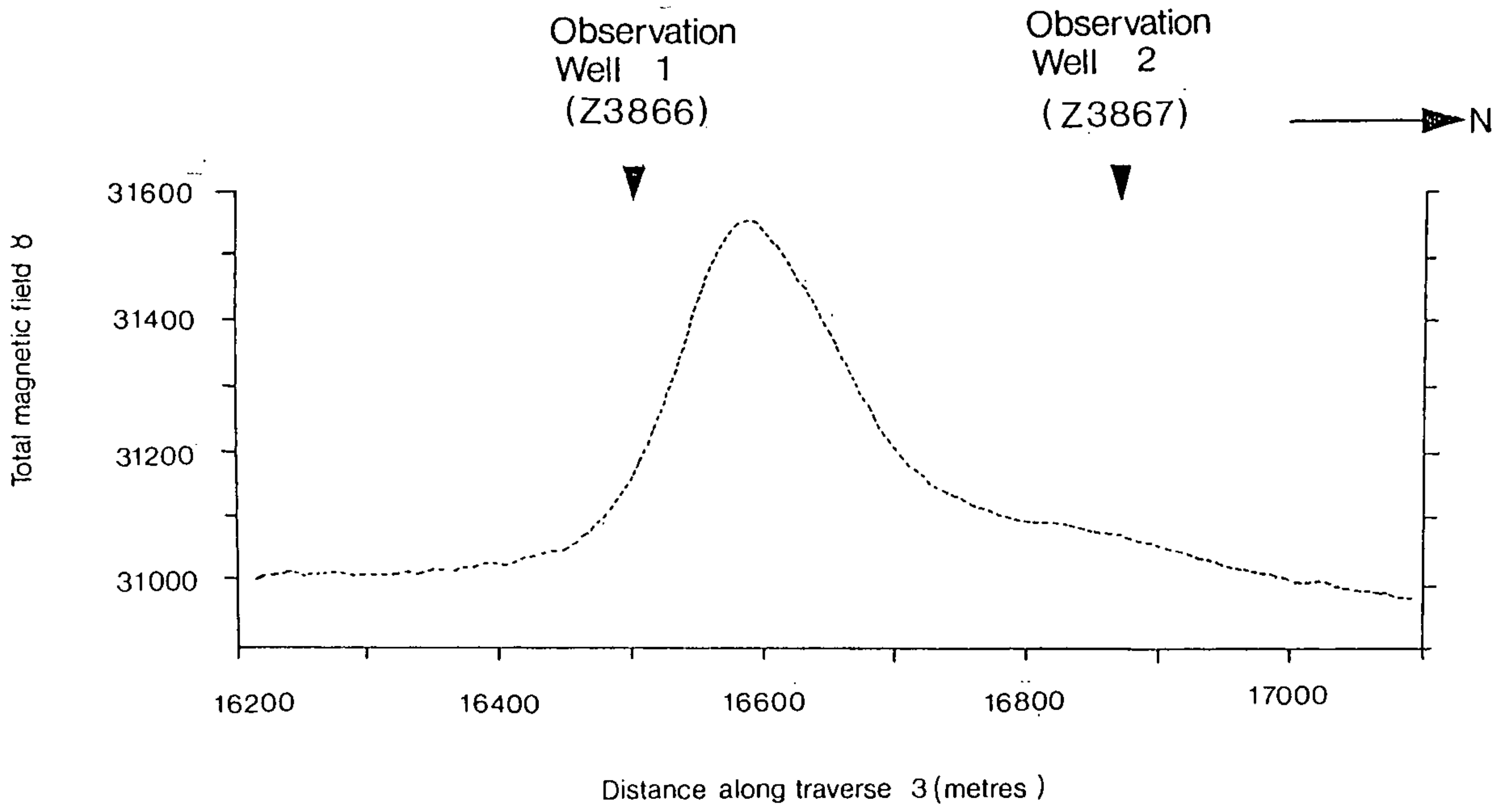
All three boreholes fully penetrate the Cave Sandstone and terminate in the Transition Beds. At this location the latter comprise of a variable series of green and pink silty sandstones and siltstones. Observation well 1 penetrates the Transition Beds for a thickness of over 40m.

Fluid column logging

In the pump well and observation well 1 temperature and conductivity logs were run under static conditions. In observation well 2 they were run under both static and pumped conditions, Figure A.3.36.

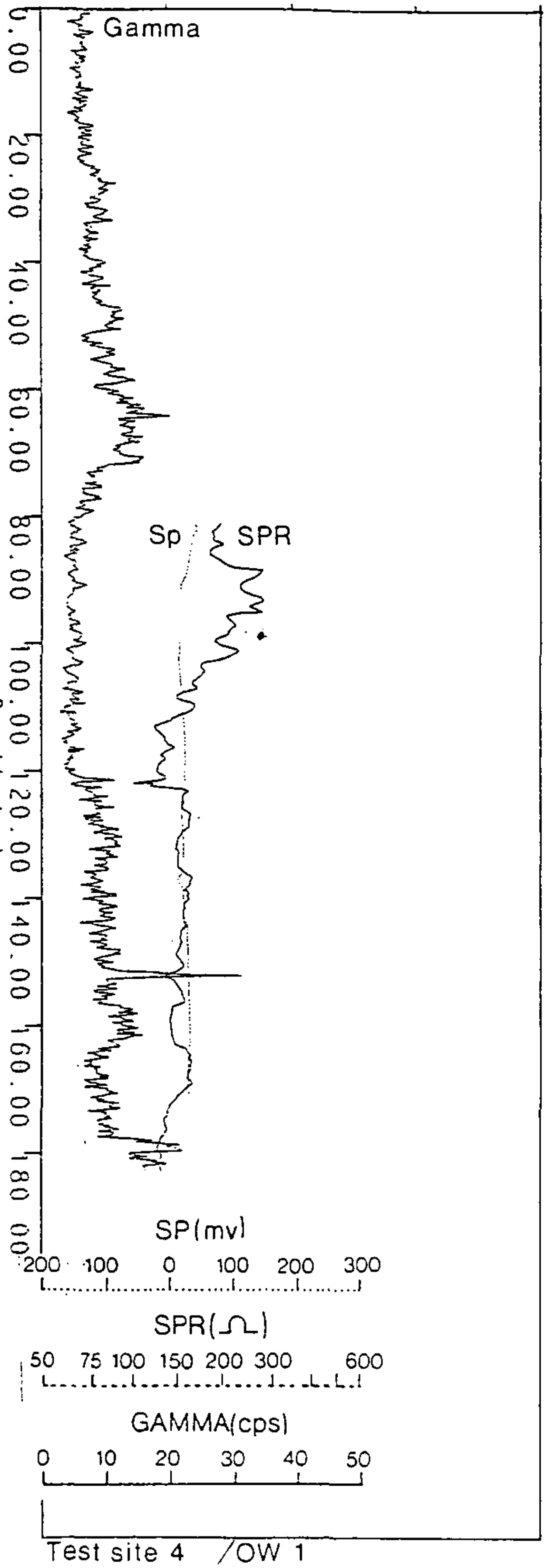
Observation Well 1

81 - 122m	no flow, ion exchange between the water in the borehole and clays in the basalts is taking place
122 - 132m	horizontal flow
132 - 148m	decreased horizontal flow
148 - 159m	increased, uniform, horizontal flow
Below 159m	a different type of water, lower horizontal flow



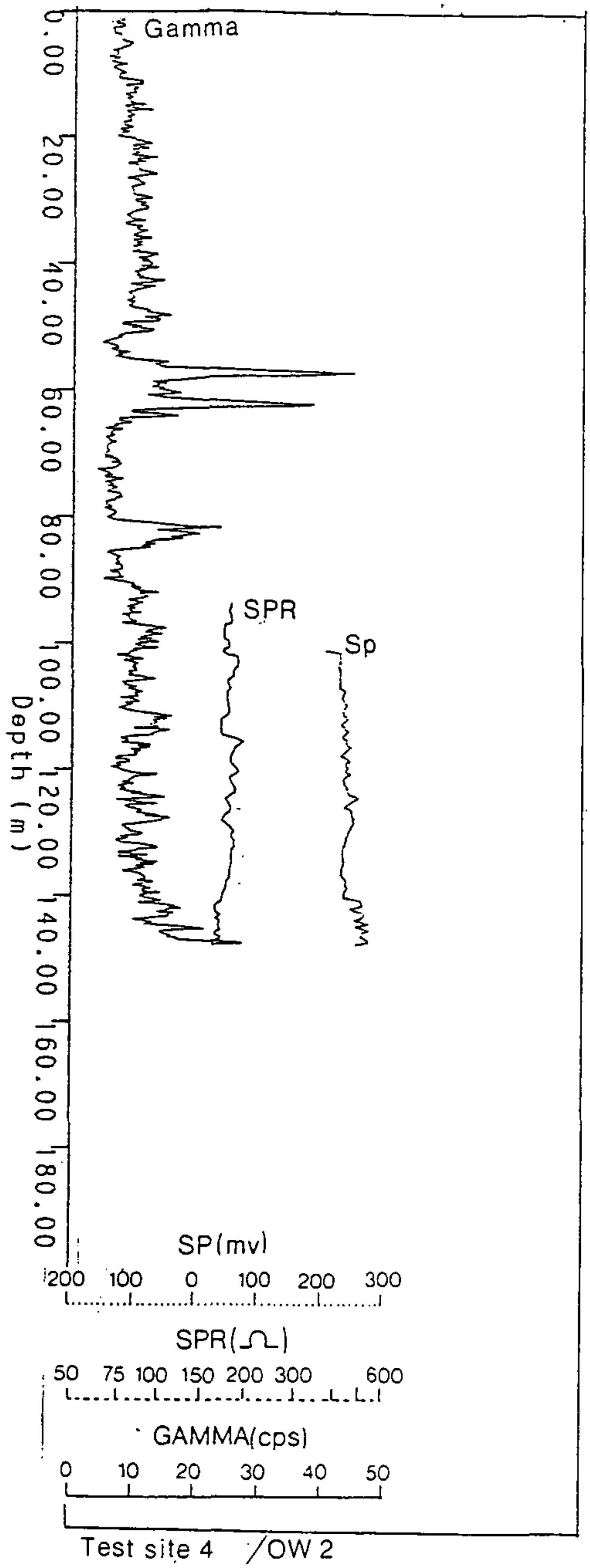
Magnetic Anomalies at Site 4

Figure **A.3.34**



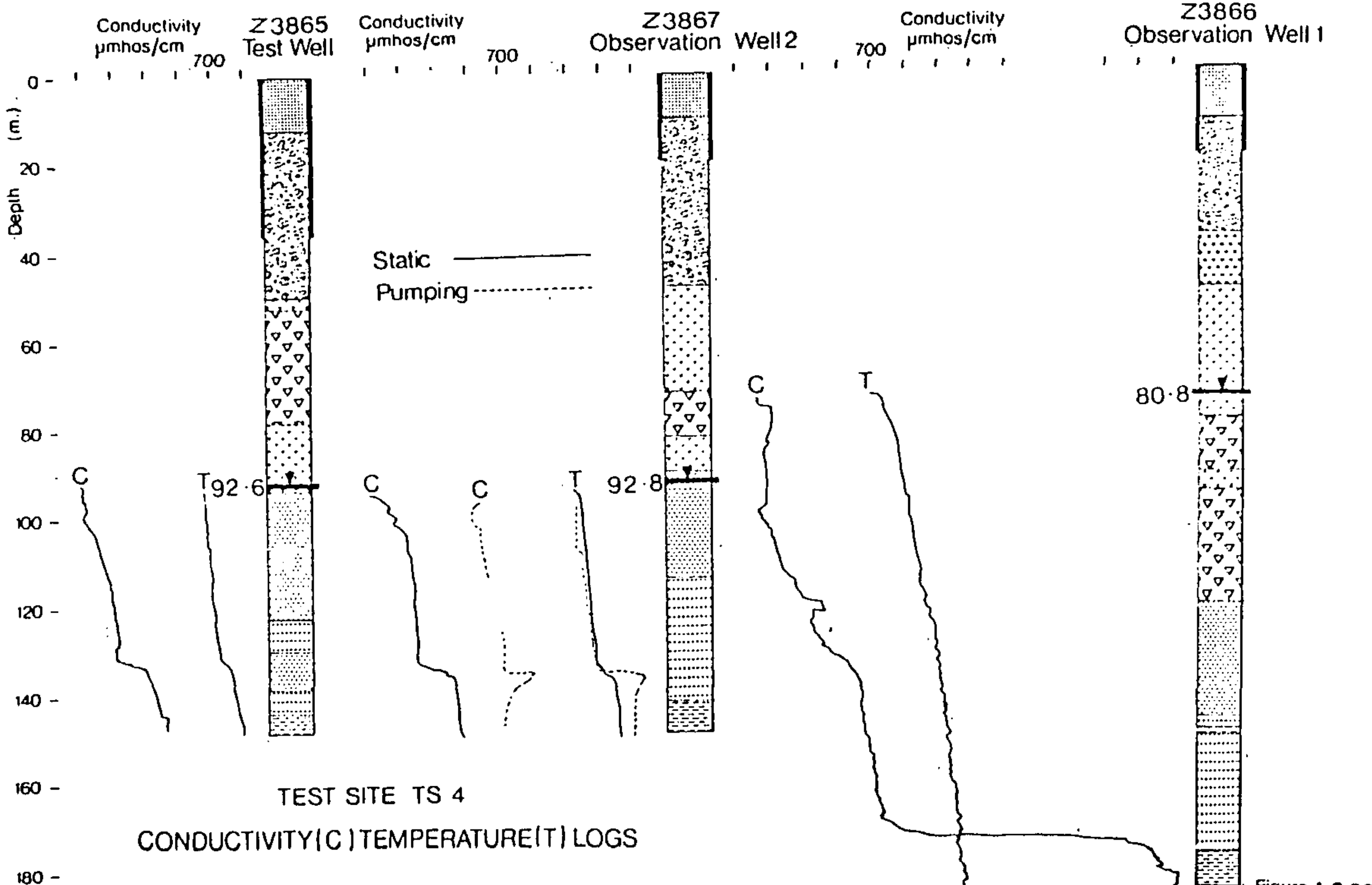
TEST SITE TS 4 FORMATION LOGS

Figure **A.3.35**



TEST SITE TS4 FORMATION LOGS

Figure **A.3 35**



TEST SITE TS 4

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3 36

There is no initial flow in this borehole

Observation Well 2

92 - 101m	horizontal flow
101 - 103m	decreased horizontal flow
103m	probable fissure
103 - 130m	downflow during pumping, decreased horizontal flow under static conditions
130m	probable fissure
130 - 132m	increased horizontal flow
132 - 139m	a different type of water
Below 139m	decreased horizontal flow

Pump Well

92 - 99m	horizontal flow
99 - 131m	decreased horizontal flow
Below 131m	a different type of water

Three points of interest emerge from these logs.

(a) where water from the Cave Sandstone is in the basalt, the conductivity is lowered by ion exchange with clays

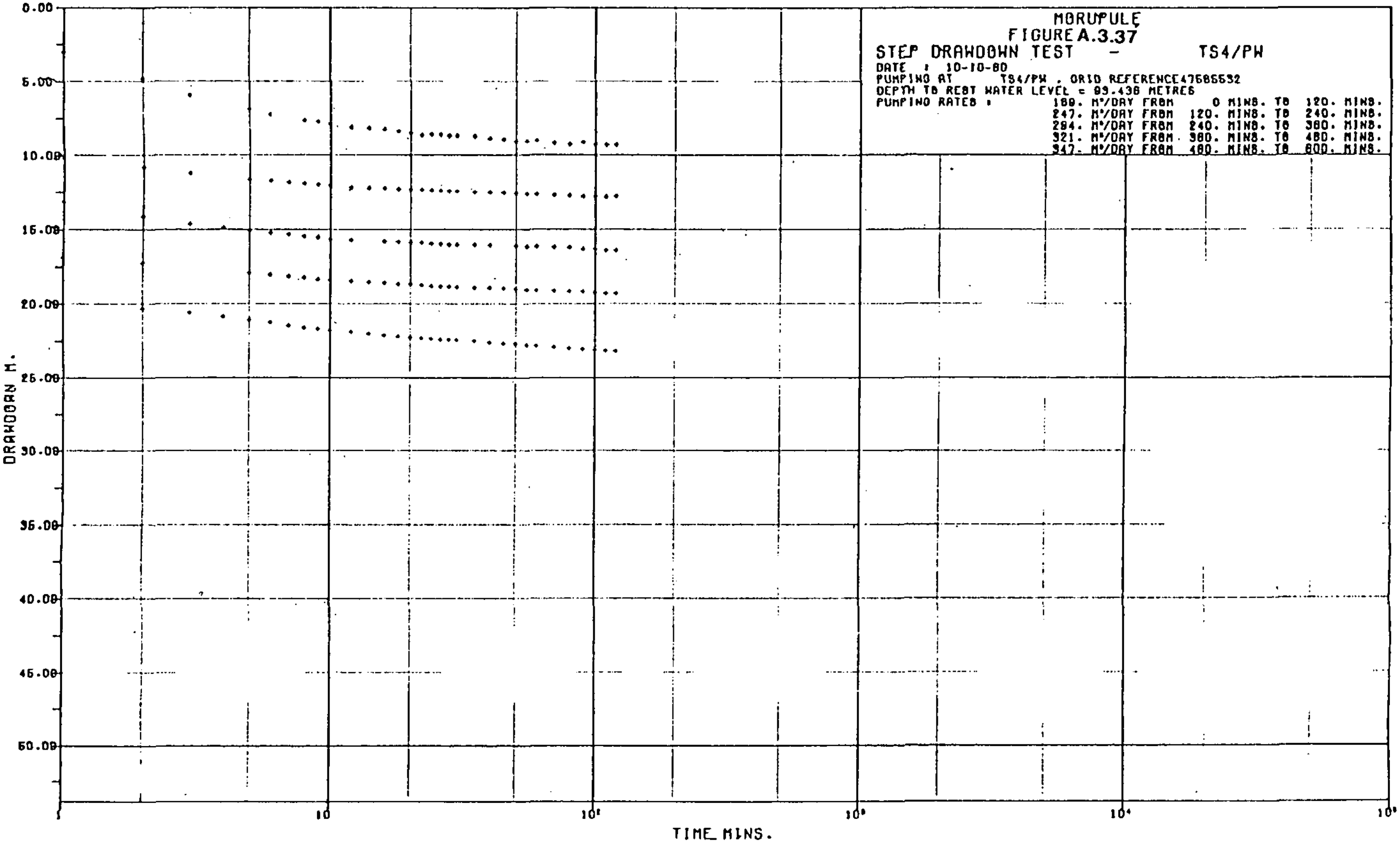
(b) where fissure flow occurs it is of secondary importance to intergranular flow.

(c) The upper 5m to 10m of the Cave Sandstone above slightly higher permeability according to the flow data evidence.

Pumping tests

At this site a five stage variable discharge test was carried out. Each stage lasted 120 minutes before the pump rate was increased, Figure A.3.37.

The test was solved, using Jacob's method, for the well and aquifer constants. It was also possible to use the first stage data to determine the aquifer characteristics in the nearest observation borehole. Transmissivity in the pump well was also determined using the Jacob method.



MORUPULE
FIGURE A.3.37
STEP DRAWDOWN TEST - TS4/PW
DATE : 10-10-80
PUMPING AT TS4/PW , GRID REFERENCE47586532
DEPTH TO REST WATER LEVEL = 93.436 METRES
PUMPING RATES :
169. M³/DAY FROM 0 MINS. TO 120. MINS.
247. M³/DAY FROM 120. MINS. TO 240. MINS.
284. M³/DAY FROM 240. MINS. TO 360. MINS.
321. M³/DAY FROM 360. MINS. TO 480. MINS.
347. M³/DAY FROM 480. MINS. TO 600. MINS.
DRAWDOWN M.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
TIME MINS.
1
10
10²
10³
10⁴
10⁵

Table A.3.11 Test Site TS4 Step Drawdown Test Results

Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t = 100 min (m^2/d)	Efficiency %
189	9.30	20.32	57.1
247	12.45	19.84	50.5
294	15.75	18.67	46.1
321	18.55	17.30	44.0
347	22.10	15.70	42.0

Aquifer Constant (B) 0.0253
Well Constant (C) 1.005×10^{-4}

Jacob Solutions

	Transmissivity (m^2/d)	Storage
PW	28	
OW2	59	1.0×10^{-4}

The line of best fit has been used to determine the aquifer and well losses as the data are not linear.

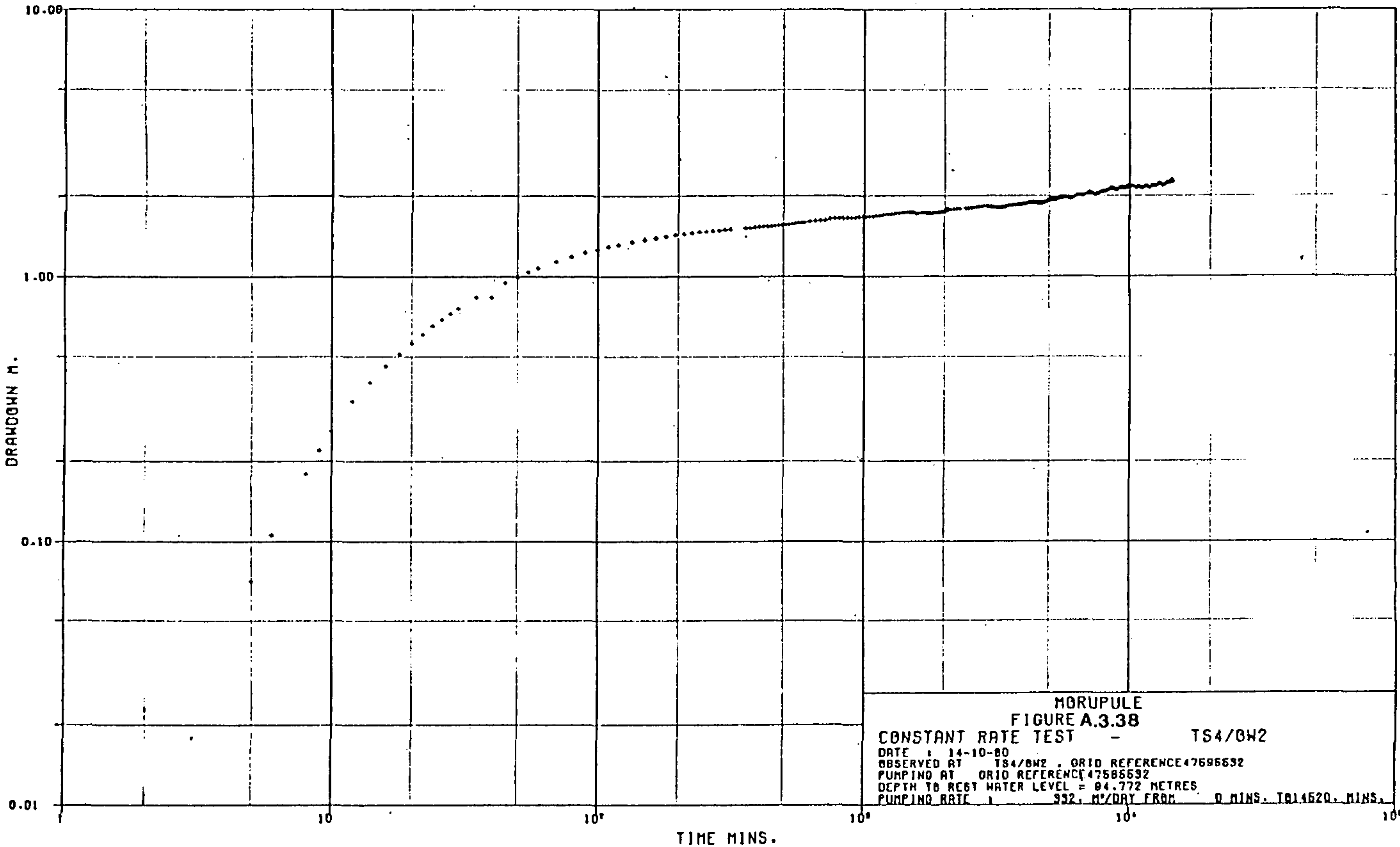
The constant rate test lasted for 242 hours (10.1 days) at a pump rate of 332 m^2/d. Observation borehole 1, situated 380m from the pump well, did not respond to the pumping.

The time drawdown graph, Figure A.3.38, indicates delayed yield. The Boulton method was used to determine the aquifer parameters of transmissivity and specific yield.

Table A.3.12 Test Site TS4 Constant Rate Test Results

	Transmissivity (m^2/d)	Storage	
OW2	56	1.0×10^{-4}	Jacob (early data)
	29	1.1×10^{-4}	Theis (early data)
	22	2.4×10^{-2}	Boulton (late data)

This test provides both transmissivity and storage for confined and unconfined conditions at this site.



MORUPULE
FIGURE A.3.38
CONSTANT RATE TEST - TS4/OW2
DATE : 14-10-80
OBSERVED AT TS4/OW2 . GRID REFERENCE47696632
PUMPING AT GRID REFERENCE47686632
DEPTH TO REST WATER LEVEL = 84.772 METRES
PUMPING RATE : 992. M³/DAY FROM 0 MINS. TO14620. MINS.
DRAWDOWN M.
10.00
1.00
0.10
0.01
TIME MINS.
1
10
10²
10³
10⁴
10⁵

A.3.8 Test Site TS5

Location

Site TS5 is 6 km to the west of the escarpment and lies on the basalt plateau. It is positioned on and is 11.6 km from the south end of geophysical traverse line 3, Figure A.3.39. Three wells, one pump well and two observation wells, both located at a distance of 100m from the pump well, were drilled at the site. The most northerly of the observation wells was abandoned at a depth of 76m without striking water; in the two remaining wells groundwater conditions are confined.

These wells were drilled to test the effects, upon pumping, of the dolerite dyke thought to exist at the site.

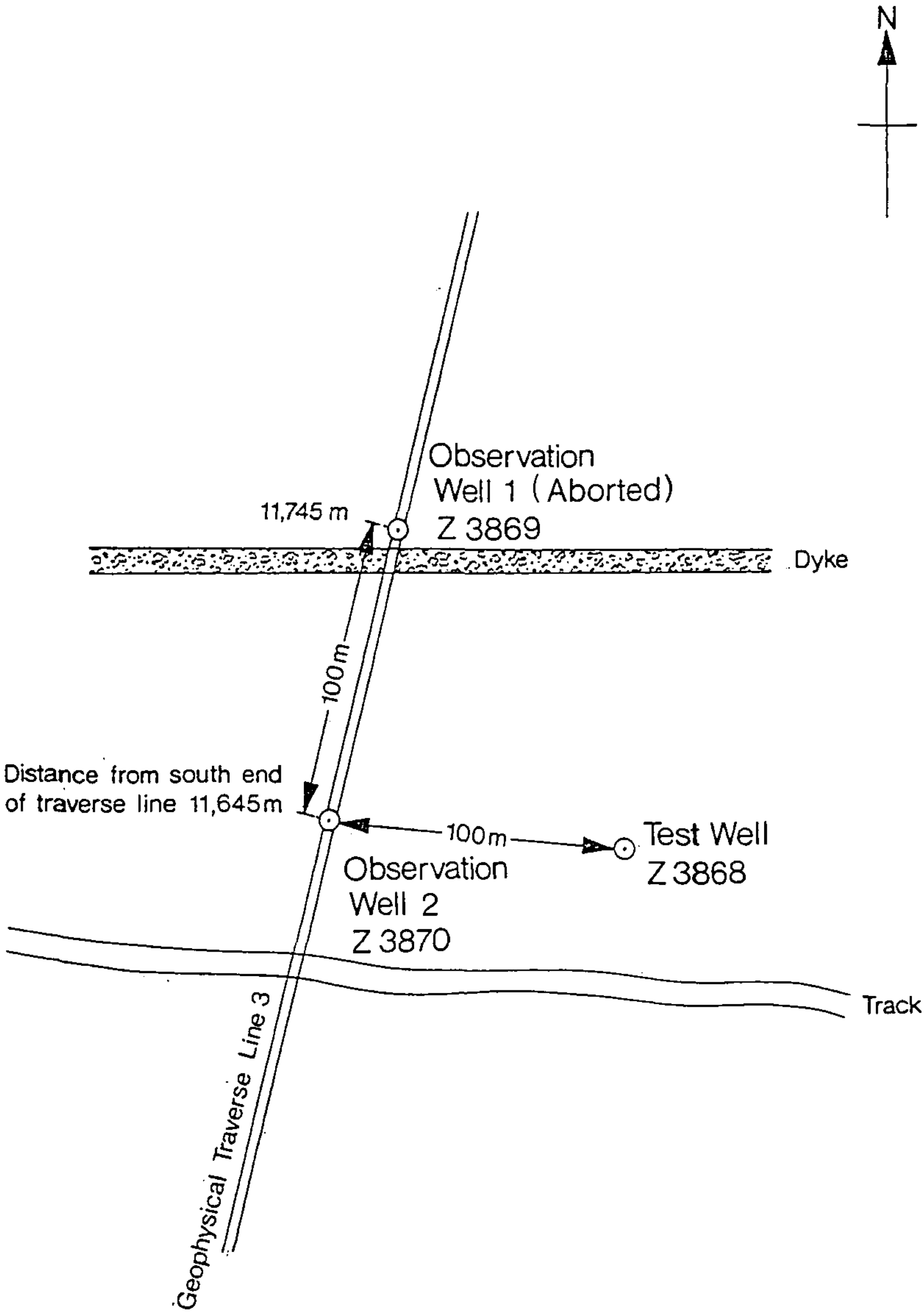
Geology

Both the pump well and observation well 2 penetrate the Kalahari Beds, the Drakensberg Basalt and terminate in the Cave Sandstone formation. Observation well 1, however, the most northerly of the wells, terminates in the upper half of the basalt succession. From the drilling returns of this borehole it is difficult to determine whether the succession is basalt or dolerit On the available evidence it is more likely to be basalt, Figure A.3.40.

The Kalahari Beds are 46m thick, the top 8m to 10m being unconsolidated yellow-orange sands. The rest of the beds are a variable series of yellow and white siliceous sandstones with subordinate silcrete, Figure A.3.41.

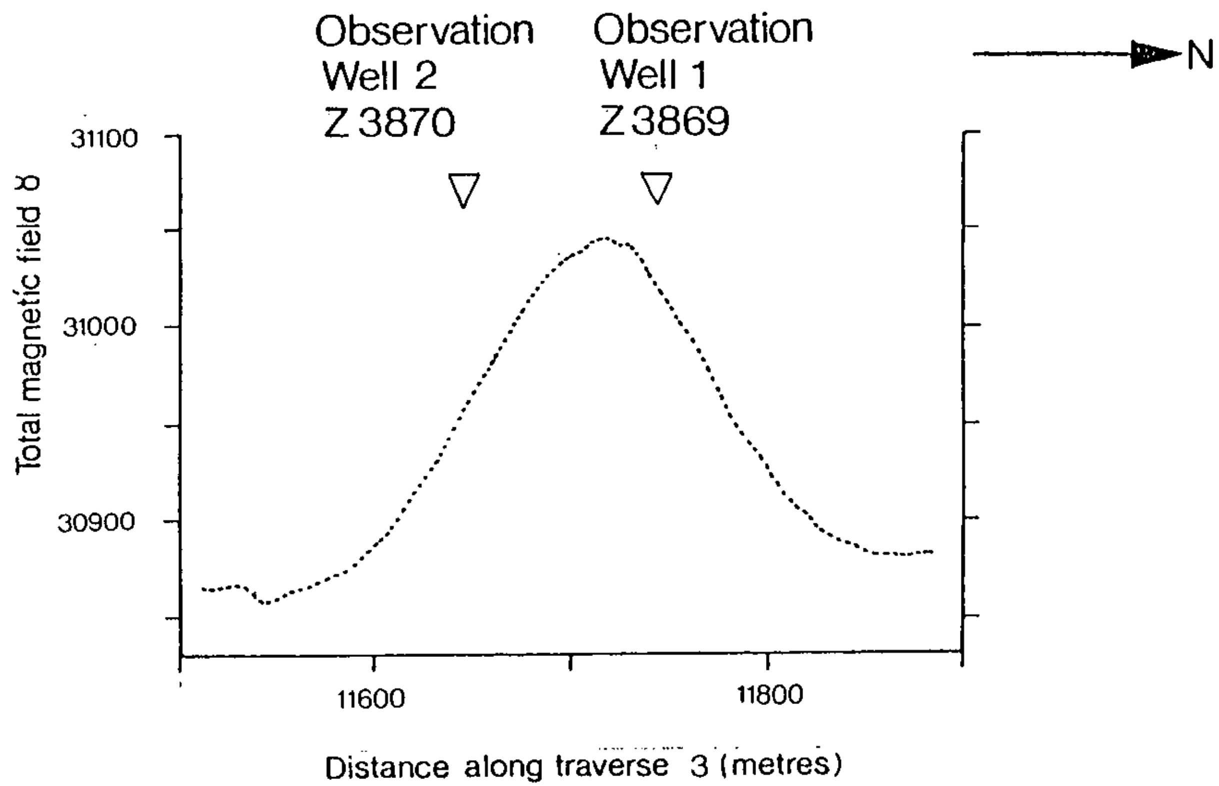
In all three wells the Kalahari Beds pass down into a sequence of weathered red-brown and fresh grey-black basalt. The thickness of the basalt ranges from 82m to 88m with the base lying between a depth of 128m to 134m. This indicates that there is no major faulting and little pre-basalt topographical relief at this site.

The upper 22 - 28m and lower 15 - 25m of the basalt are extensively weathered whilst the central 30 - 45m remain hard and unweathered. An interesting feature of this formation is shown by the geophysical log of observation well 2 and the pump well where these are several distinct gamma peaks, at depths of 64m, 67m, 71m, 86m and 110m, present, Figure A.3.42. In the pump well these gamma peaks are related to high resistance and low



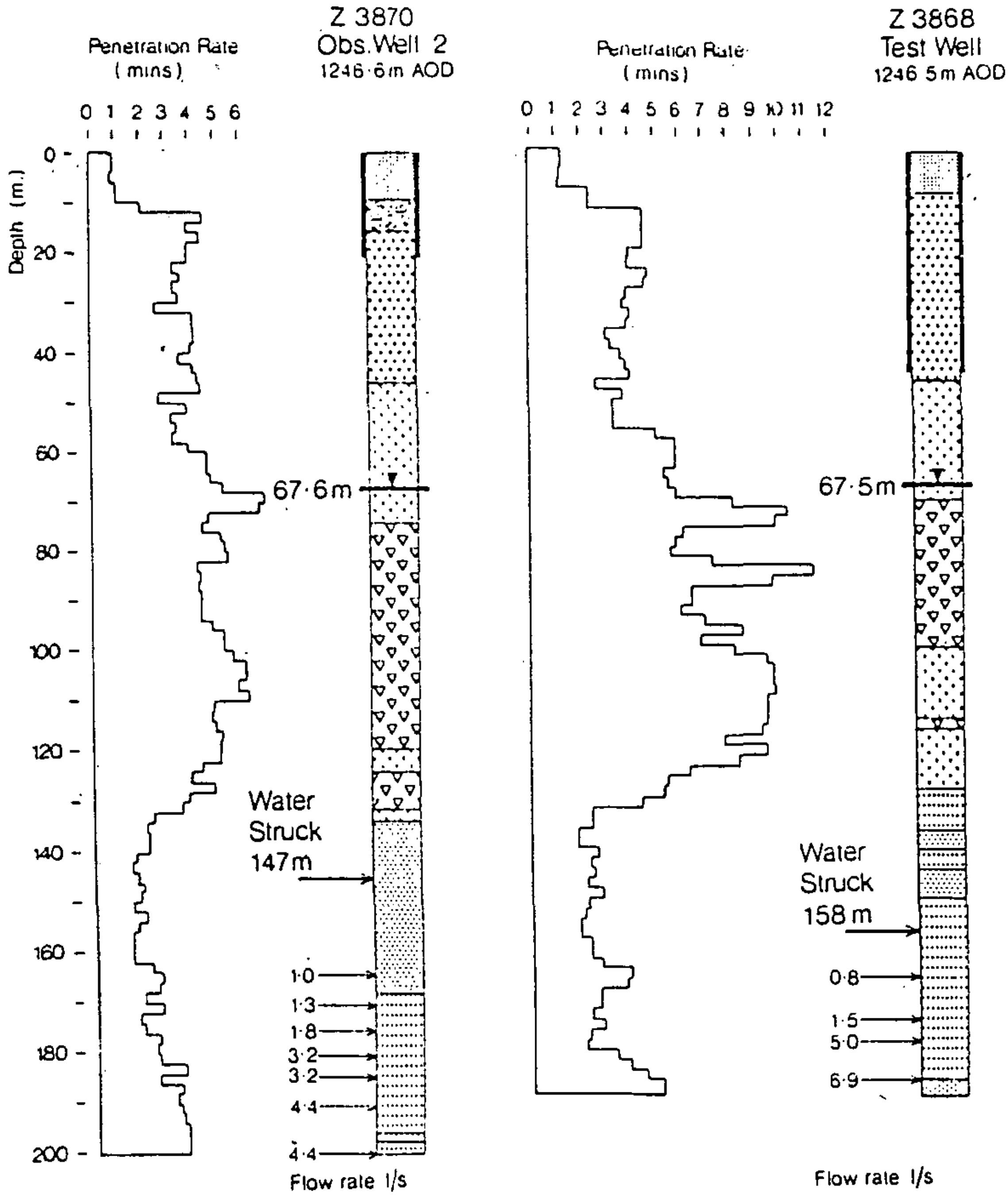
Test Site 5 : Location

Figure A.3.39



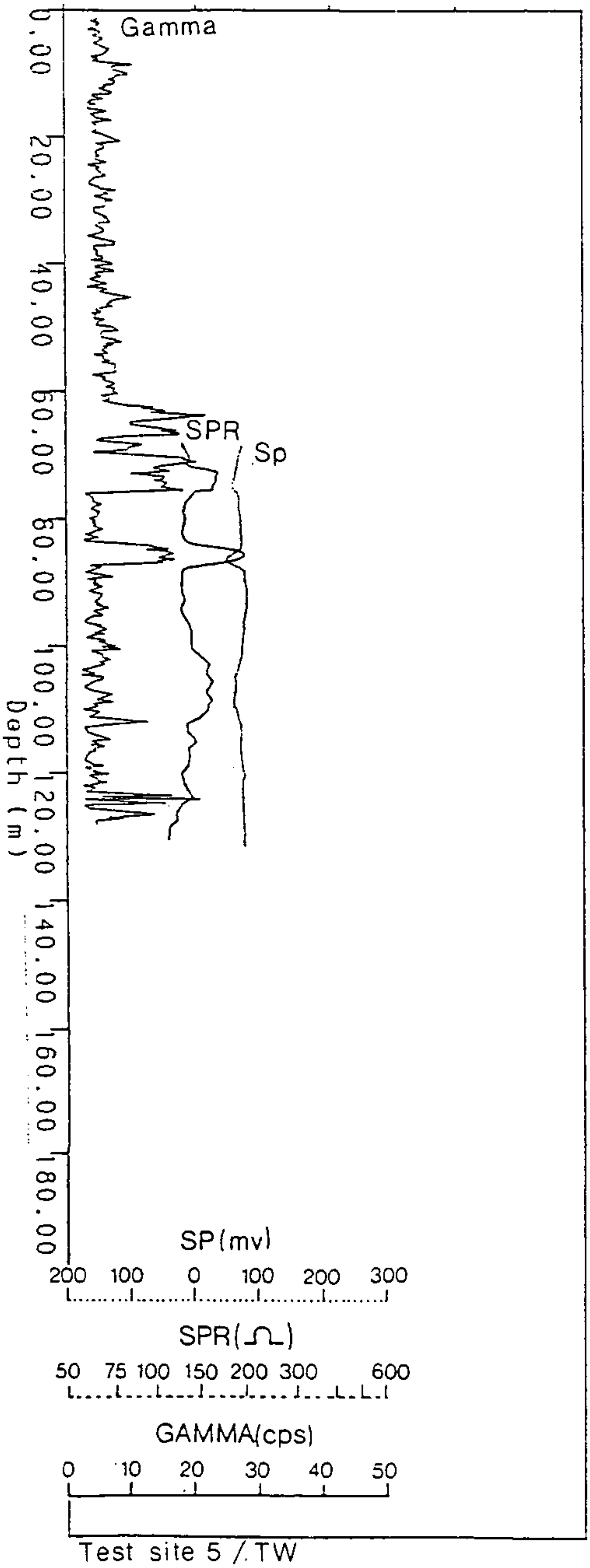
Magnetic Anomalies at Site 5

Figure **A.3.40**



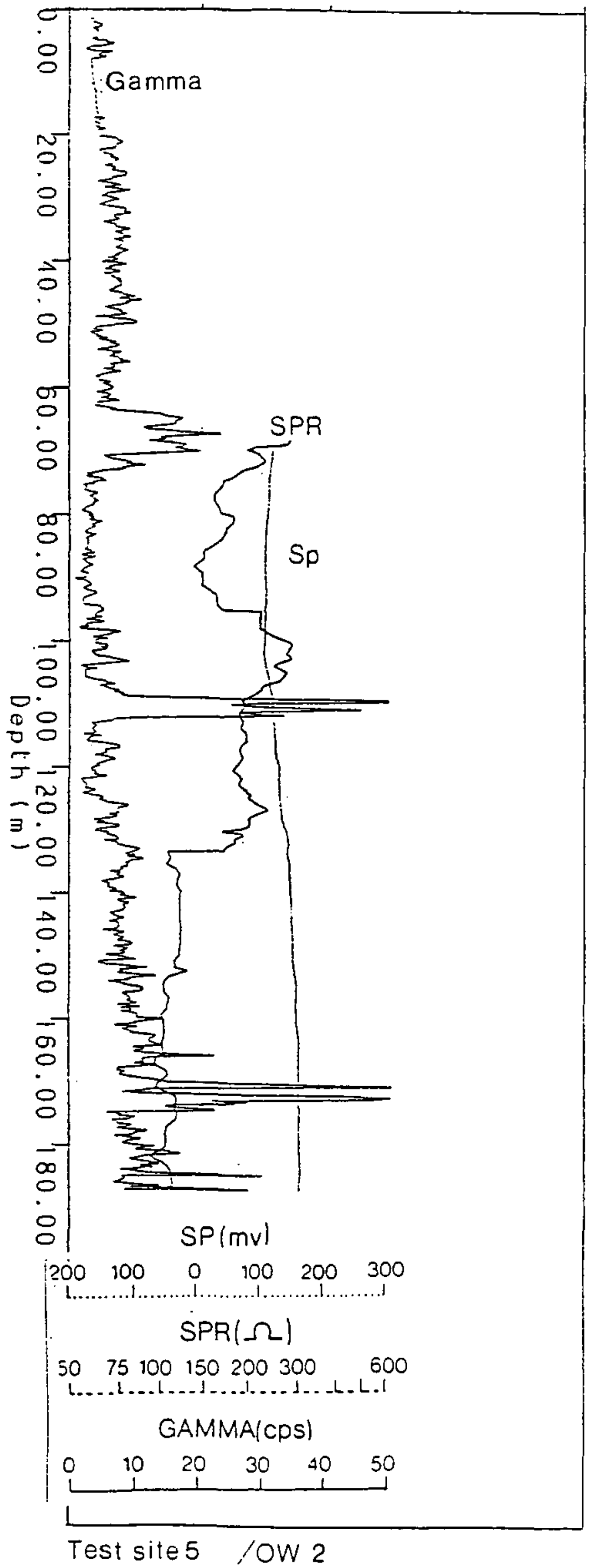
TEST SITE TS 5
LITHOLOGY AND DRILLING DETAILS

Figure
A.3.41



TEST SITE TS 5 FORMATION LOGS

Figure A3.42



TEST SITE TS 5 FORMATION LOGS

Figure A.3.42

self potential anomalies. A possible explanation is that the anomalies represent fossil soils developed on old basalt surfaces. These have subsequently been baked and hardened by later lava flows. High gamma peaks can be related to high potassium levels in the clay of fossil soils, while subsequent baking and hardening explains the high resistivity of the material.

Beneath the basalt is the Cave Sandstone which at this site, is penetrated for a thickness of 66m. The upper 22-33m comprises a sequence of massive, very fine grained, soft, white and pink calcareous sandstones. A sequence of soft, siliceous, pink silty sandstones dominate, with occasional thin siltstone horizons such as those located at depths of 168m and 170m by the gamma logs.

Fluid column logs

Temperature and conductivity logs were run only on observation well 2 where both static and pumped conditions were covered. The water level in this well stands in the basalt and lies 21m below the base of the Kalahari Beds, Figure A.3.43.

Observation Well 2

67-134m very low horizontal flow
134-148m horizontal flow
148-154m decreased horizontal flow
154m fissure
154-167m less horizontal flow
167-182m increased horizontal flow

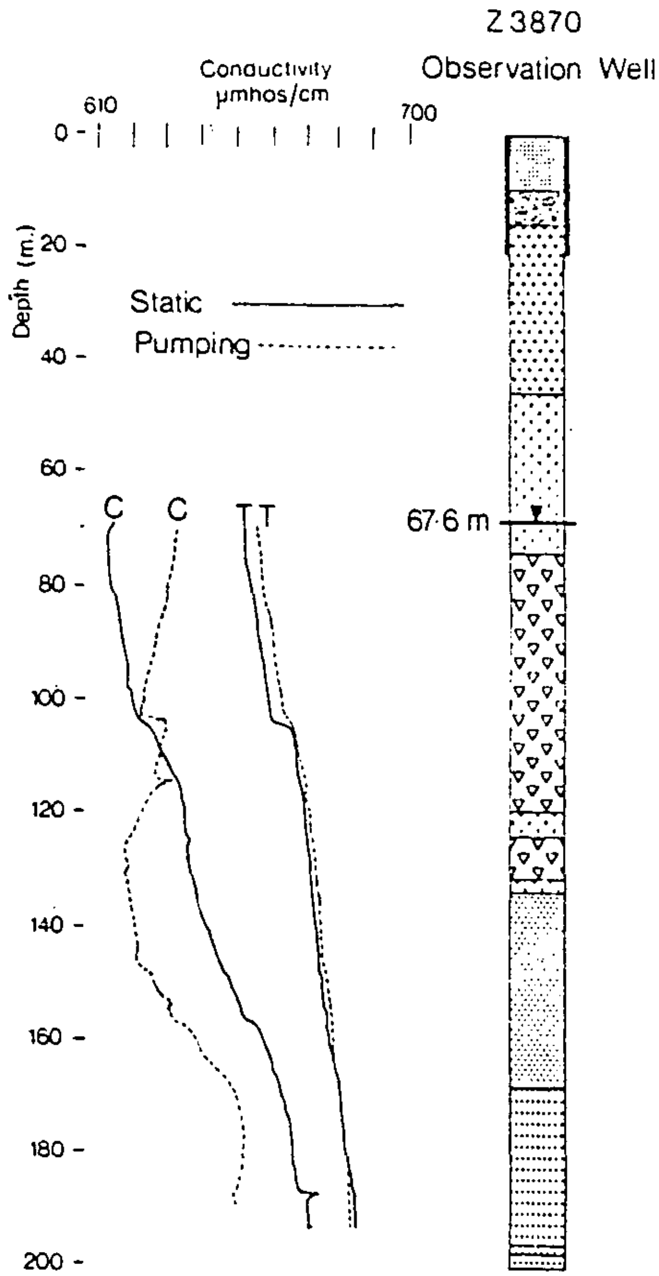
Below 182m decreased horizontal flow

There was no evidence of vertical flow

Pumping tests

At this site a five stage step drawdown test was carried out. Each stage lasted for 120 minutes before the pump rate was increased, Figure A.3.44.

The well and aquifer losses were solved for using the Jacob method. Only the Theis method provided solutions of transmissivity and storage for the observation borehole first stage data. The pump well transmissivity was derived for stage 1 by the Jacob method.



TEST SITE TS 5

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.43

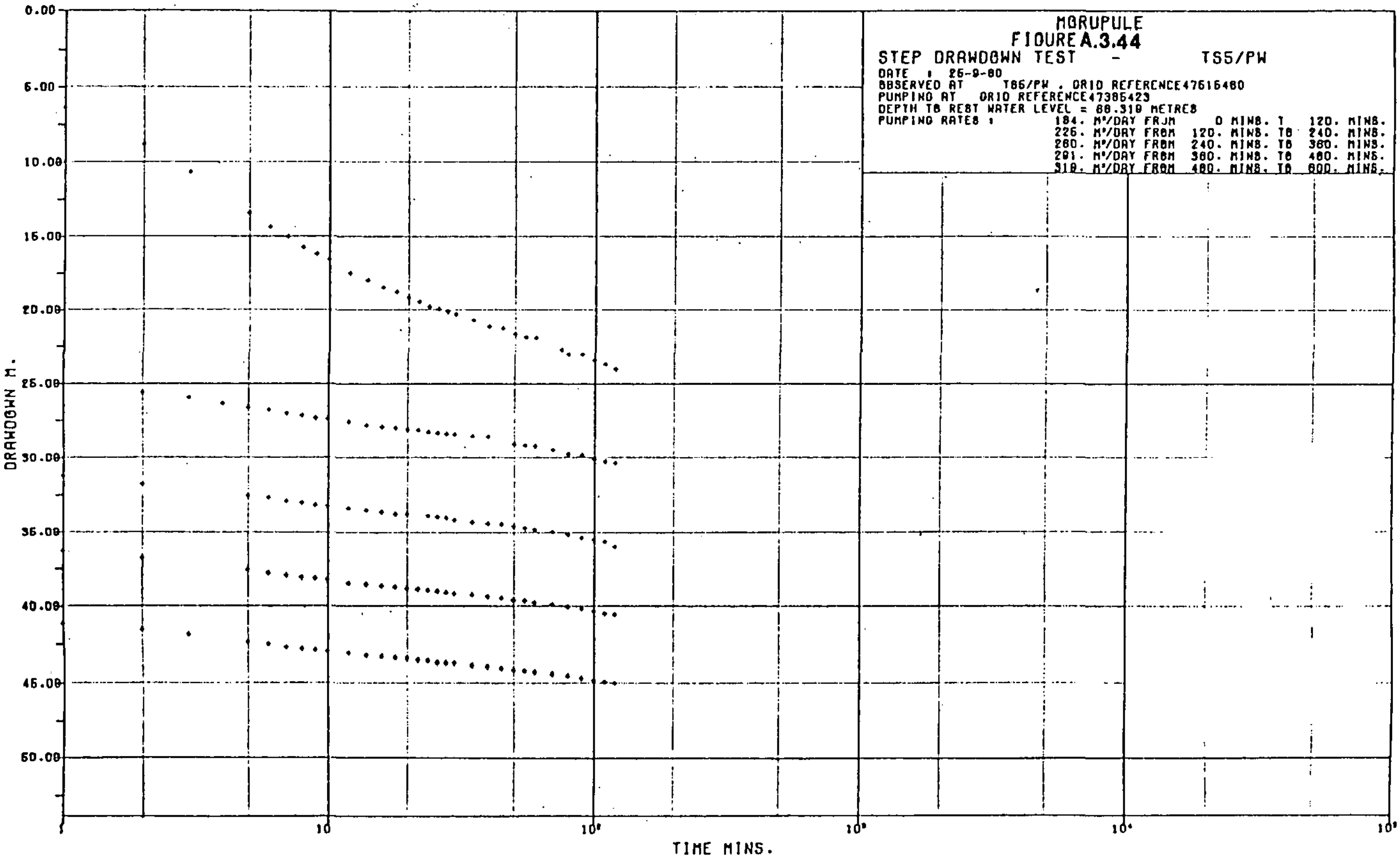

MORUPULE
FIGURE A.3.44
STEP DRAWDOWN TEST - TS5/PW
DATE : 25-9-80
OBSERVED AT TS6/PW . GRID REFERENCE47616480
PUMPING AT GRID REFERENCE47385423
DEPTH TO REST WATER LEVEL = 68.319 METRES
PUMPING RATES : 184. M³/DAY FROM 0 MINS. TO 120. MINS.
226. M³/DAY FROM 120. MINS. TO 240. MINS.
260. M³/DAY FROM 240. MINS. TO 360. MINS.
291. M³/DAY FROM 360. MINS. TO 480. MINS.
319. M³/DAY FROM 480. MINS. TO 600. MINS.
DRAWDOWN M.
TIME MINS.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
1
10
10²
10³
10⁴
10⁵

Table A.3.13 Test Site 5 Step Drawdown Test Results

Discharge (m^3/d)	Drawdown (m)	Specific Capacity at t = 100 min (m^2/d)	Efficiency %
184	23.5	7.83	95.9
225	28.2	7.98	95.1
260	32.6	7.98	94.3
291	36.9	7.89	93.7
318	40.7	7.84	93.1

Aquifer constant (B) 0.1186
Well Constant (C) 2.74×10^{-5}

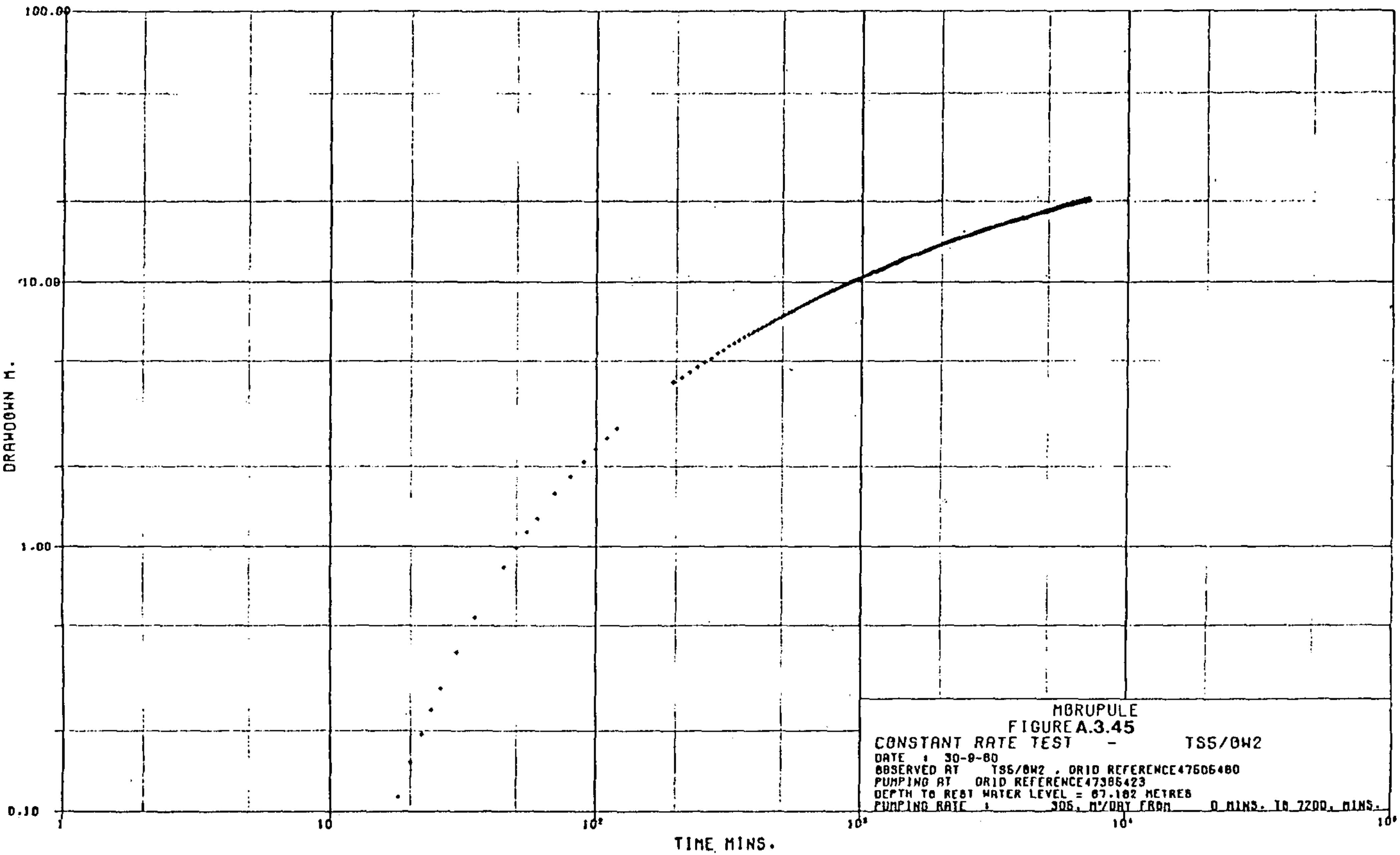
	Transmissivity (m^2/d)	Storage	
PW	5		Jacob
OW	8	0.8×10^{-4}	Theis

The constant rate test lasted for 120 hours (5 days) at a discharge of 305 m^3/d). The time drawdown graph, Figure A.3.45, indicates a barrier boundary. Stallman's image well method was used to solve the data for transmissivity and storage. The Jacob method does not strictly apply but the recovery transmissivities for both boreholes are included for comparison purposes only.

Table A.3.14 Test Site TS5 Constant Rate Test Results

	Transmissivity (m^2/d)	Storage	
PW	5		Jacob (recovery)
OW	11	1.0×10^{-4}	Stallman
	5		Jacob (recovery)

The barrier boundary is confirmed by the geophysical survey of the site, which places a dyke 100m from the boreholes.



MBRUPULE
FIGURE A.3.45
CONSTANT RATE TEST - TS5/OW2
DATE : 30-9-80
OBSERVED AT TS5/OW2 , GRID REFERENCE47506480
PUMPING AT GRID REFERENCE47386423
DEPTH TO REST WATER LEVEL = 67.182 METRES
PUMPING RATE : 306. M³/DAY FROM 0 MINS. TO 7200. MINS.
DRAWDOWN M.
100.00
10.00
1.00
0.10
TIME MINS.
1
10
10²
10³
10⁴
10⁵

A.3.9 Test Site TS6

Location

Site TS6 is 3km to the south of the northern edge of the escarpment and lies on the basalt plateau. It is positioned on and is 24 km from the south end of geophysical traverse line 3. Two wells, a pump well and an observation well 30m to the west, were drilled at this site. Figure A.3.46.

The site was chosen to test for aquifer properties under confined conditions and to test the hydraulic effects upon pumping of a dolerite dyke positioned 80m to the south of both wells, Figure A.3.47.

Geology

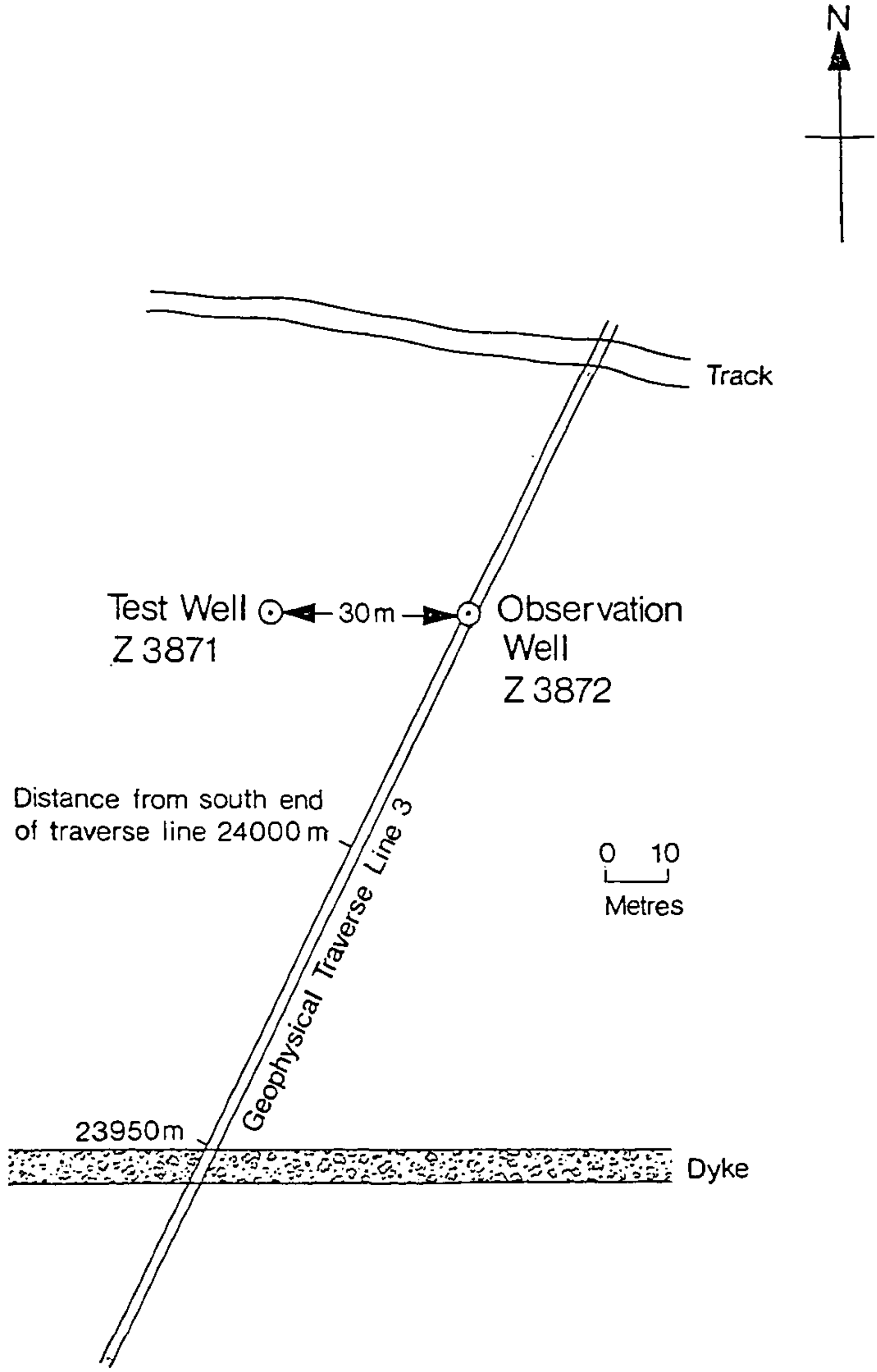
The site lies on the extensive Drakensberg Basalt plateau. Both wells penetrate the blanket of Kalahari Beds, the Drakensberg Basalt, the Cave Sandstone and terminate in the Transition Beds, Figure A.3.48.

At this site the Kalahari Beds are 26-28m thick. The unconsolidated yellow-orange sand is only 2m thick. This is in contrast to the more usual 10m. Underlying this thin cover of sand is a succession of white, yellow and pink siliceous sandstones and silcrete. This succession displays rapid vertical and lateral variations and defies correlation even over short distances.

The Kalahari Beds, in both wells, pass down into the Drakensberg Basalt formation, which is here between 116m and 120m thick. The base of the basalt lies between 144 and 146m and indicates no faulting and little pre-basalt relief between the two wells.

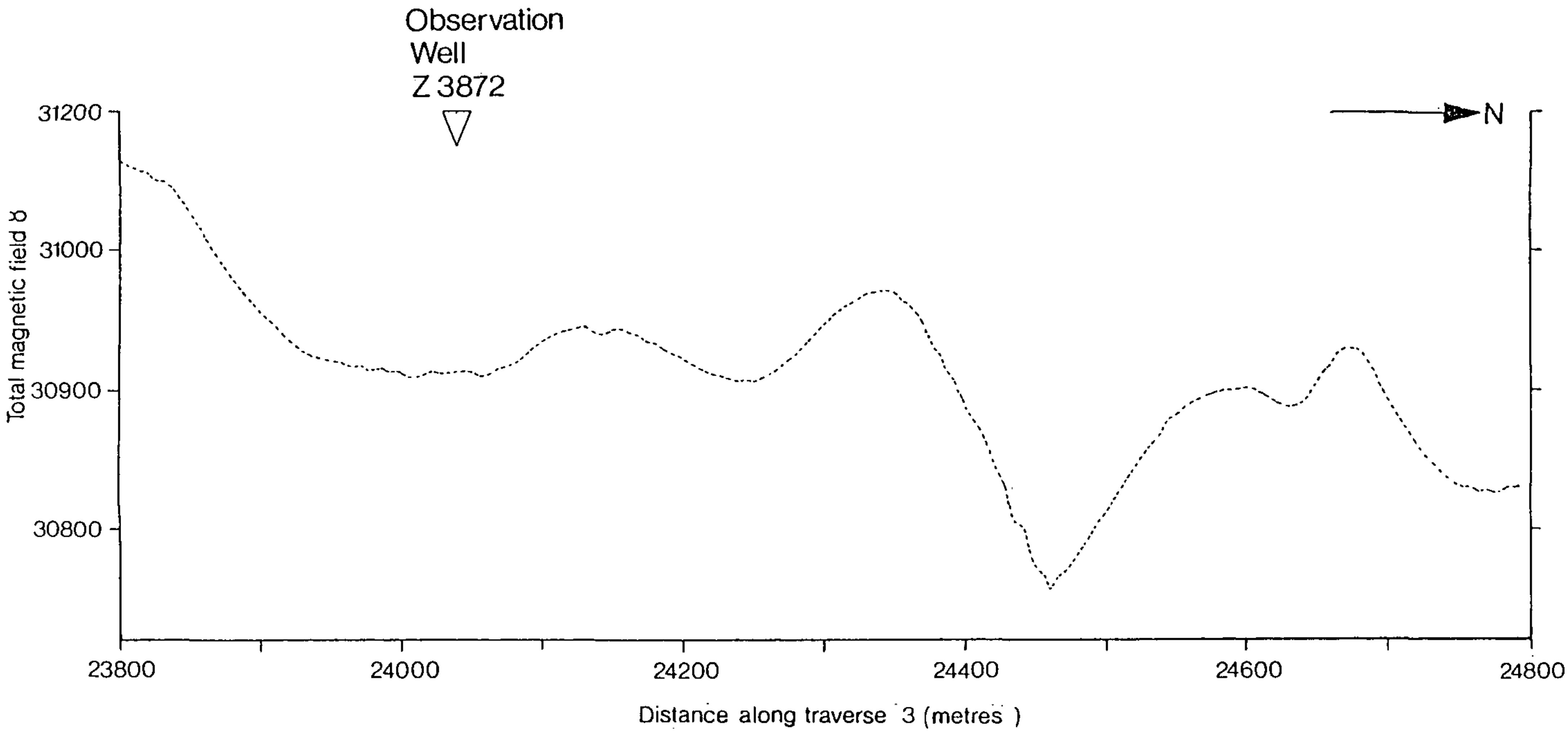
Where the basalt is weathered it takes on a red-brown colour which contrasts sharply with the grey-black appearance of the fresh basalt. Most of the basalt at this site is extensively weathered. Two zones, 60m to 80m and 132m to 145m, are unweathered. A more complicated picture is suggested by the rate of penetration logs, but the sample returns give a broad picture. The gamma log of the observation well shows little of interest in this formation, Figure A.3.49.

Underlying the basalt is the Cave Sandstone, which at this site has a



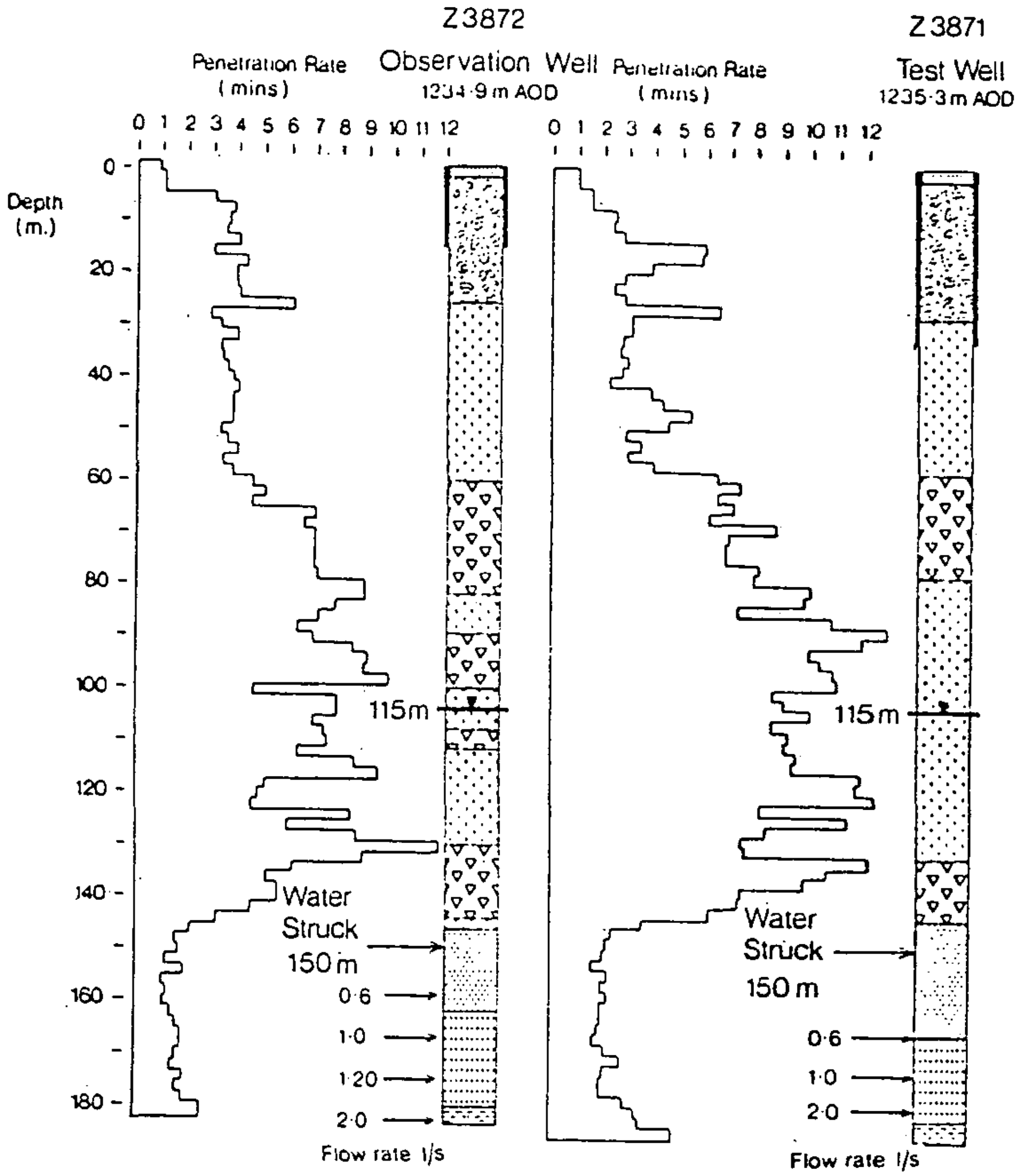
Test Site 6: Location

Figure **A.3.46**



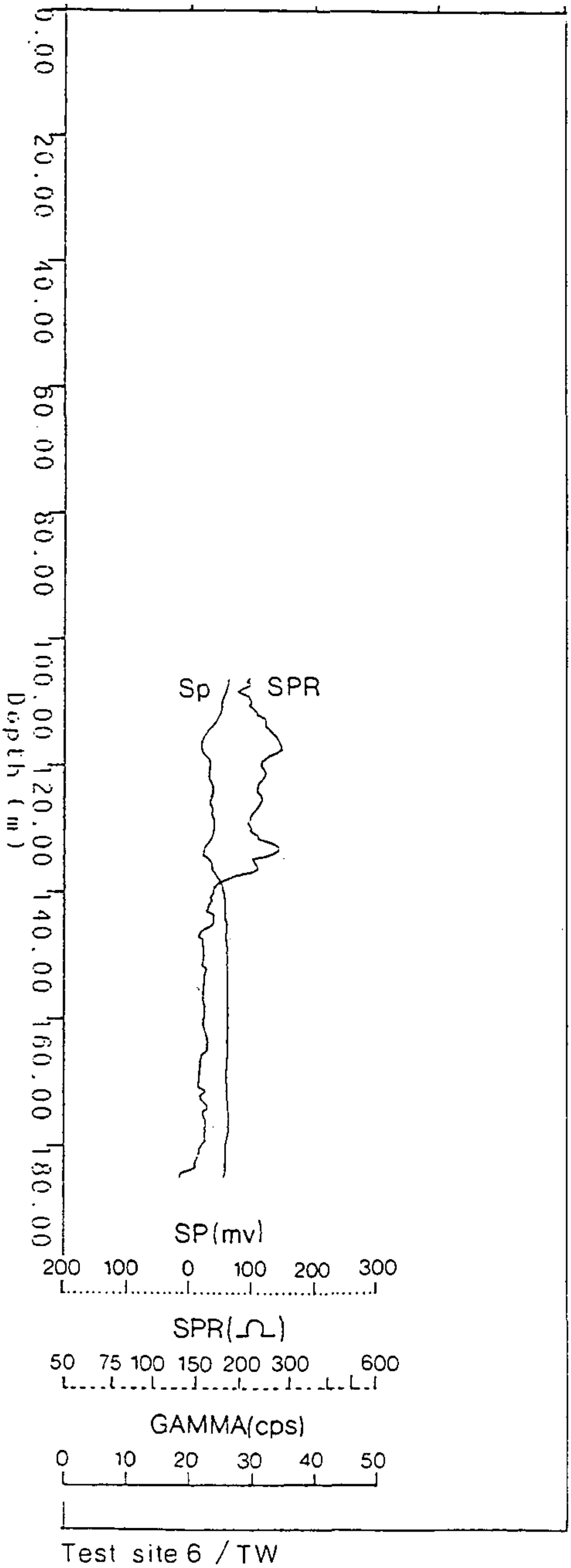
Magnetic Anomalies at Site 6

Figure **A.3.47**



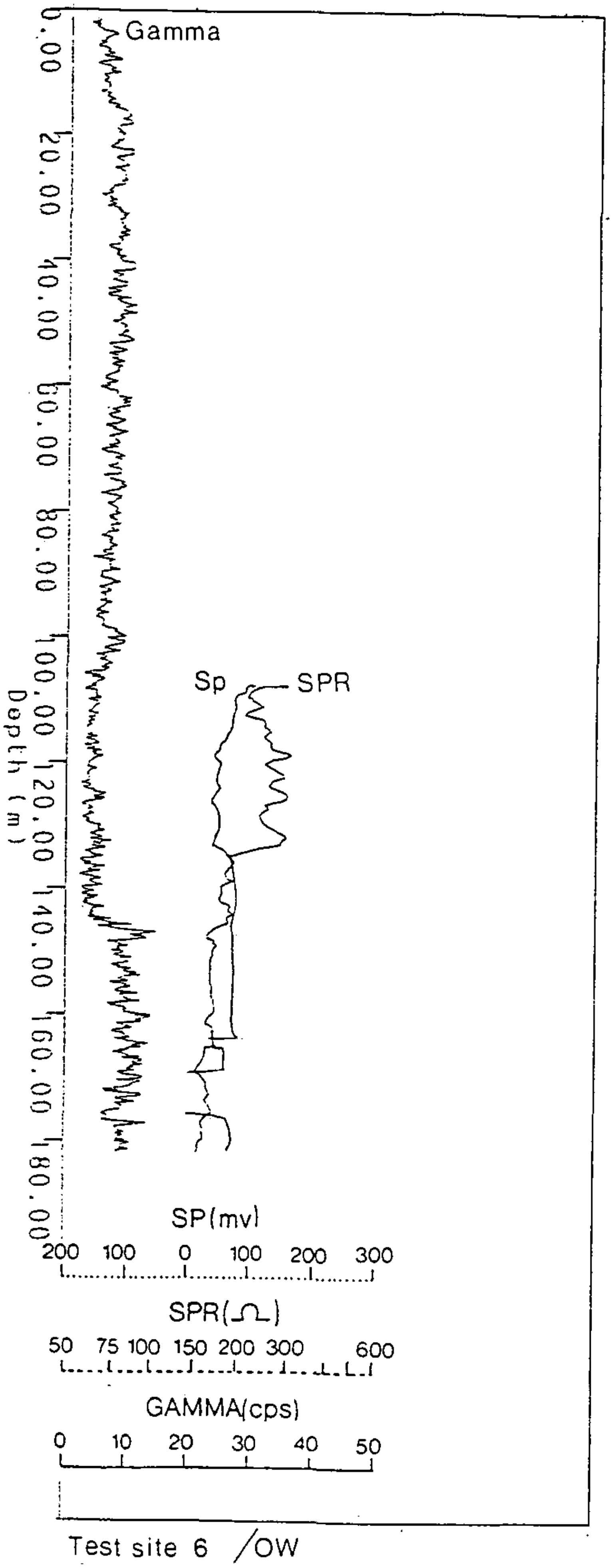
TEST SITE TS6
LITHOLOGY AND DRILLING DETAILS

Figure A.3.48



TEST SITE TS 6 FORMATION LOGS

Figure A3.49



TEST SITE TS 6 FORMATION LOGS

Figure A.3.49

very attenuated succession and is only 36 - 38m thick. This is 50m less than the thickness of the Cave Sandstone at site SYB only 7 km to the south west. It is not possible to determine if this variation in thickness is due to structural control during sedimentation or to pre-basalt erosion.

The upper 16m to 21m of the formation at this site are a sequence of pink and white siliceous sandstones. The remainder is dominated by pink and white silty sandstones and sandy siltstones.

The underlying Transition Beds, which are penetrated for a thickness of 5m; are a series of hard grey, green and red siltstones. It is possible to recognise them from their slower rate of penetration as well as their colour.

Fluid column logs

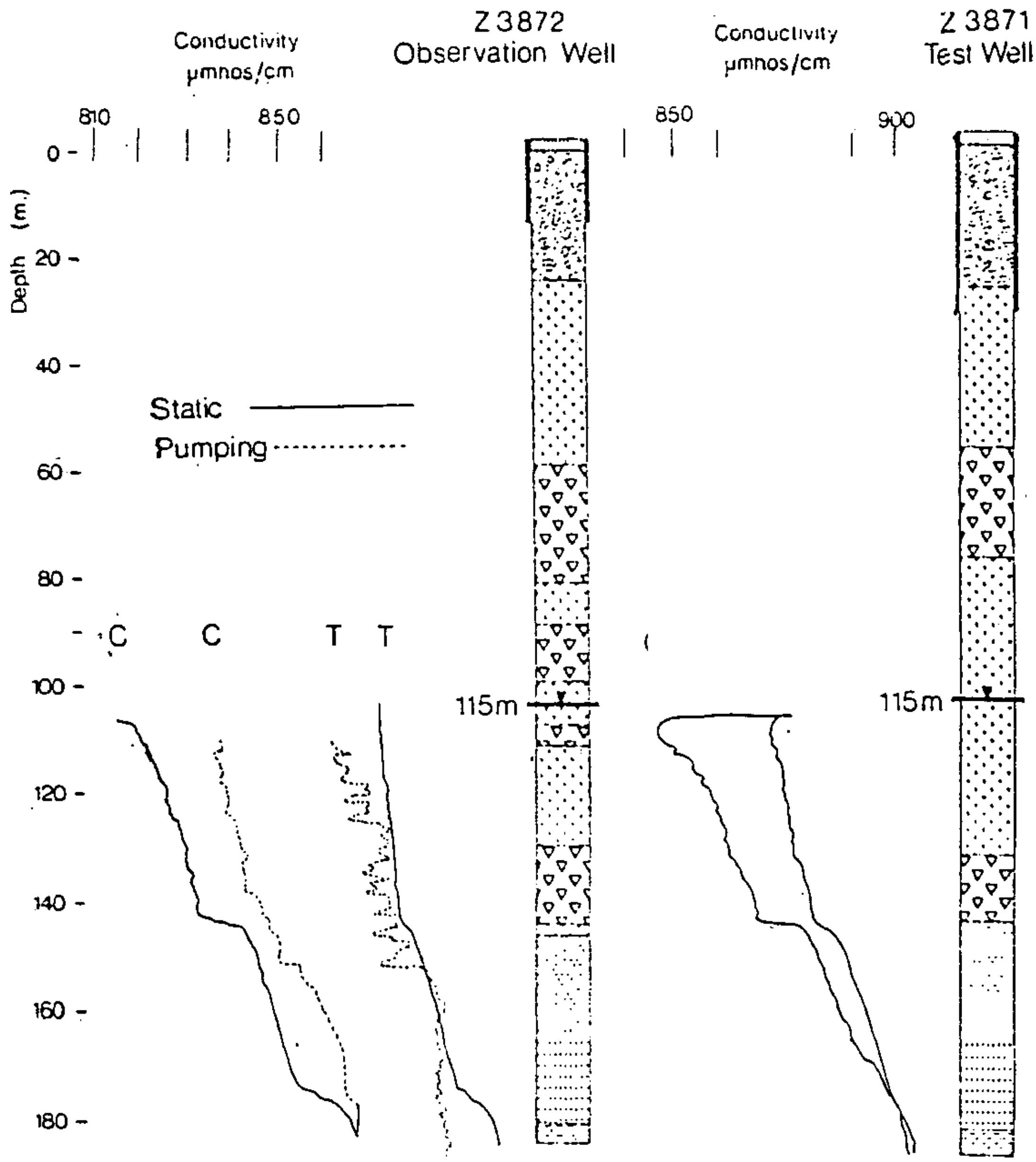
In the observation well water was struck 10m above the base of the basalt. It then rose to stand within the basalt at a depth of 104m, this is 44m below the base of the Kalahari. In the pump well water was struck 3m below the base of the basalt, in the Cave Sandstone, and rose to stand at the same level as in the observation well.

Temperature and conductivity logs were run under both static and pumped conditions in the observation well, but only under static conditions in the test well, Figure A.3.50.

Observation well

104 - 145m	horizontal flow from narrow horizons. There is ion exchange between the borehole water and the clays in the basalt.
145 - 153m	horizontal flow
153 - 167.5m	decreased uniform horizontal flow
167.5 - 175m	horizontal flow, mainly from narrow horizons
175 - 177m	increased horizontal flow
Below 177m	a different type of water

Water enters this borehole from the basalt at 74.2m which corresponds to a zone of fresh basalt.



TEST SITE TS6

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.50

Pump well

104 - 144m	horizontal flow from narrow horizons. There is ion exchange between the clays in the basalt and the borehole water.
144 - 168m	horizontal flow
168 - 176m	horizontal flow from narrow horizons
Below 176m	on different type of water.

The most important information to be gained from this site is the contribution to flow provided by the basalt. Evidence of flow beneath the water table is provided by fluid column logs. That flow takes place from the basalt above the water table is confirmed by the cascading water and by the intermittent operation of fluid column logging equipment above the water table; these observations were made at the end of a week of intense but scattered thunderstorms in the area.

Pumping tests

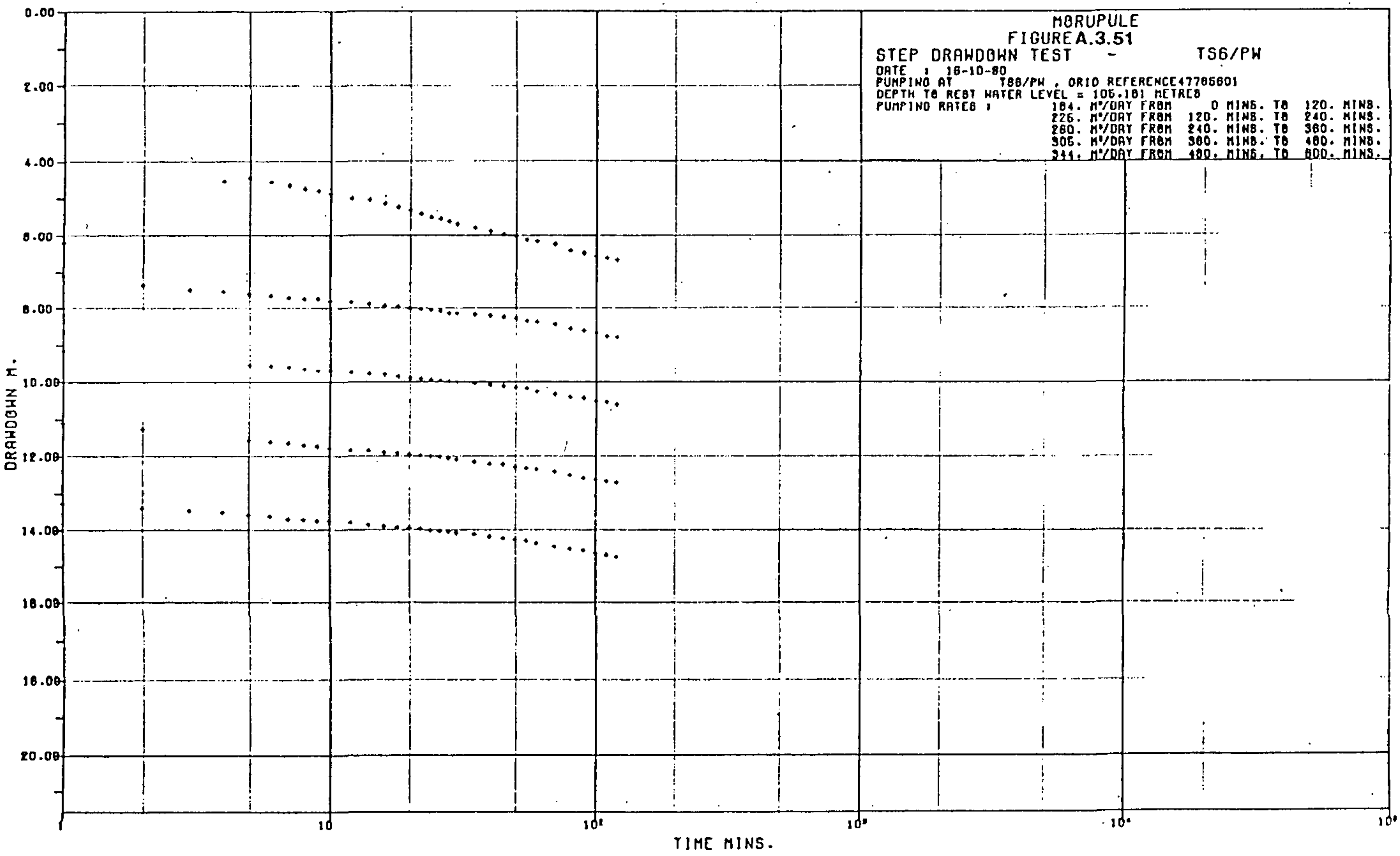
A five stage step drawdown test was carried out at this site. The duration of each was 120 minutes before the pump rate was increase, Figure A.3.51.

The test was solved, using Jacob's method, for the aquifer and well losses. It was also possible to use the first stage data to determine the aquifer characteristics in the observation borehole and transmissivity in the pumped well using the Jacob method.

Table A.3.15 Test Site TS6 Step Drawdown Test Results

Discharge (m^3/d)	Drawdown (m)	Specific capacity at t = 100 min (m^2/d)	Efficiency %
184	6.54	28.13	90.7
225	8.18	27.51	88.9
260	9.72	26.75	87.4
305	11.50	26.52	85.5
344	13.18	26.10	84.0

Aquifer constant (B) 0.0321
Well Constant (C) 1.78×10^{-5}



MORUPULE
FIGURE A.3.51
STEP DRAWDOWN TEST - TS6/PW
DATE : 16-10-80
PUMPING AT TS6/PW , GRID REFERENCE47765601
DEPTH TO REST WATER LEVEL = 105.161 METRES
PUMPING RATES :
164. M³/DAY FROM 0 MINS. TO 120. MINS.
226. M³/DAY FROM 120. MINS. TO 240. MINS.
260. M³/DAY FROM 240. MINS. TO 360. MINS.
305. M³/DAY FROM 360. MINS. TO 480. MINS.
341. M³/DAY FROM 480. MINS. TO 600. MINS.
DRAWDOWN M.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TIME MINS.
1
10
10²
10³
10⁴
10⁵

Jacob Solutions for Stage 1

	Transmissivity m^2/d	Storage
PW	20	
OW	21	0.5×10^{-4}

In order to establish the pumping conditions over a longer time a constant rate test was also carried out. The test lasted for 96 hours (4 days) with a pump rate of 332 m^3/d.

The log-log graph, Figure A.3.52, displays a typical barrier boundary form. The Stallman image well method has been used to solve for transmissivity and storage.

Table A.3.16 Test Site TS6 Constant Rate Results

	Transmissivity m^2/d	Storage
PW	21	Jacob (recovery)
OW	26	6.7×10^{-4} Stallman

The log-linear graph show a form which is consistent with a barrier boundary. The site geophysics indicate a dyke 80m from both boreholes.

A.3.10 Test site TS1

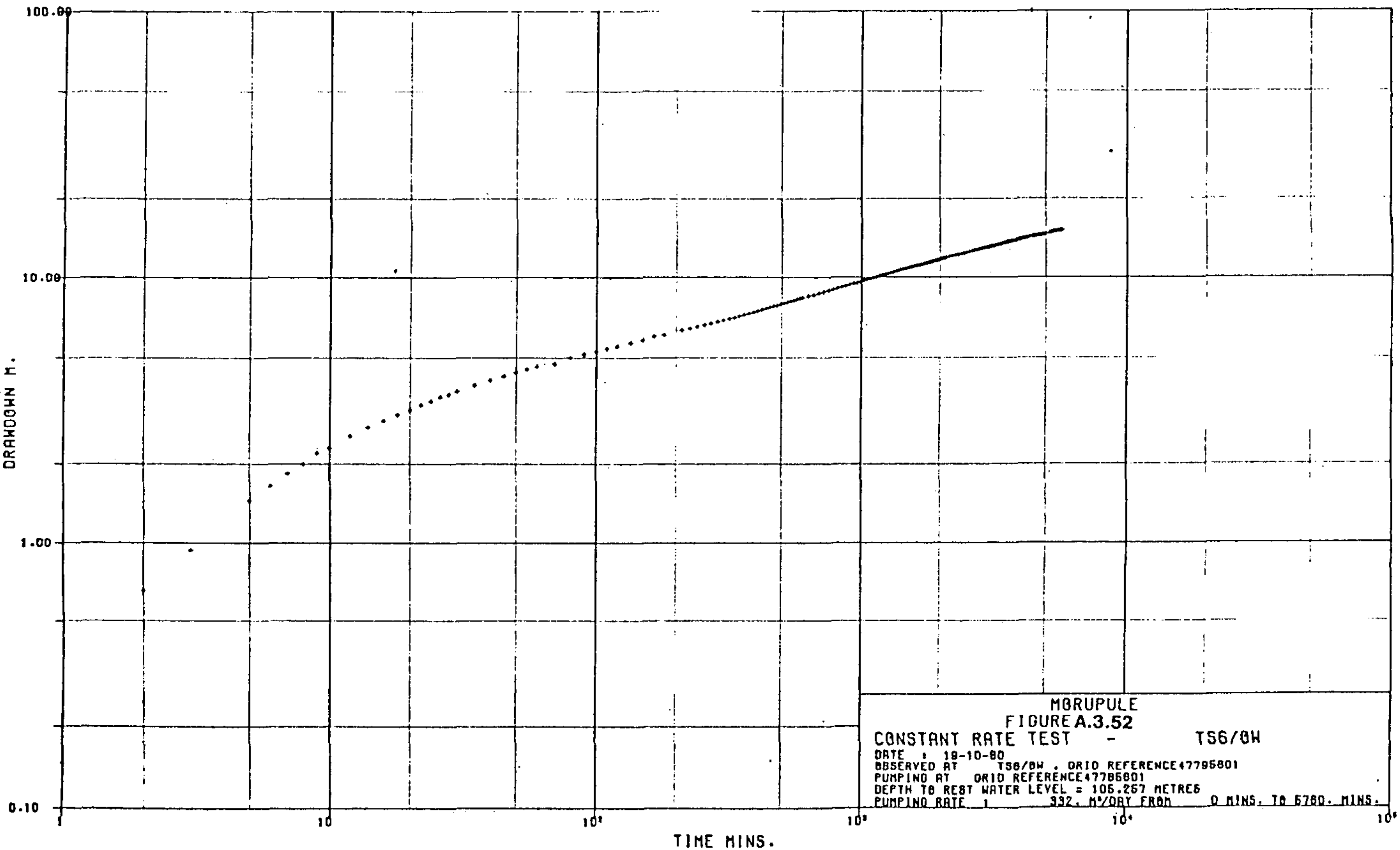
This site is positioned on and is 7 km from the south end of geophysical traverse line 2, Figure A.3.53. It was drilled as a test well but was abandoned dry at a depth of 200m.

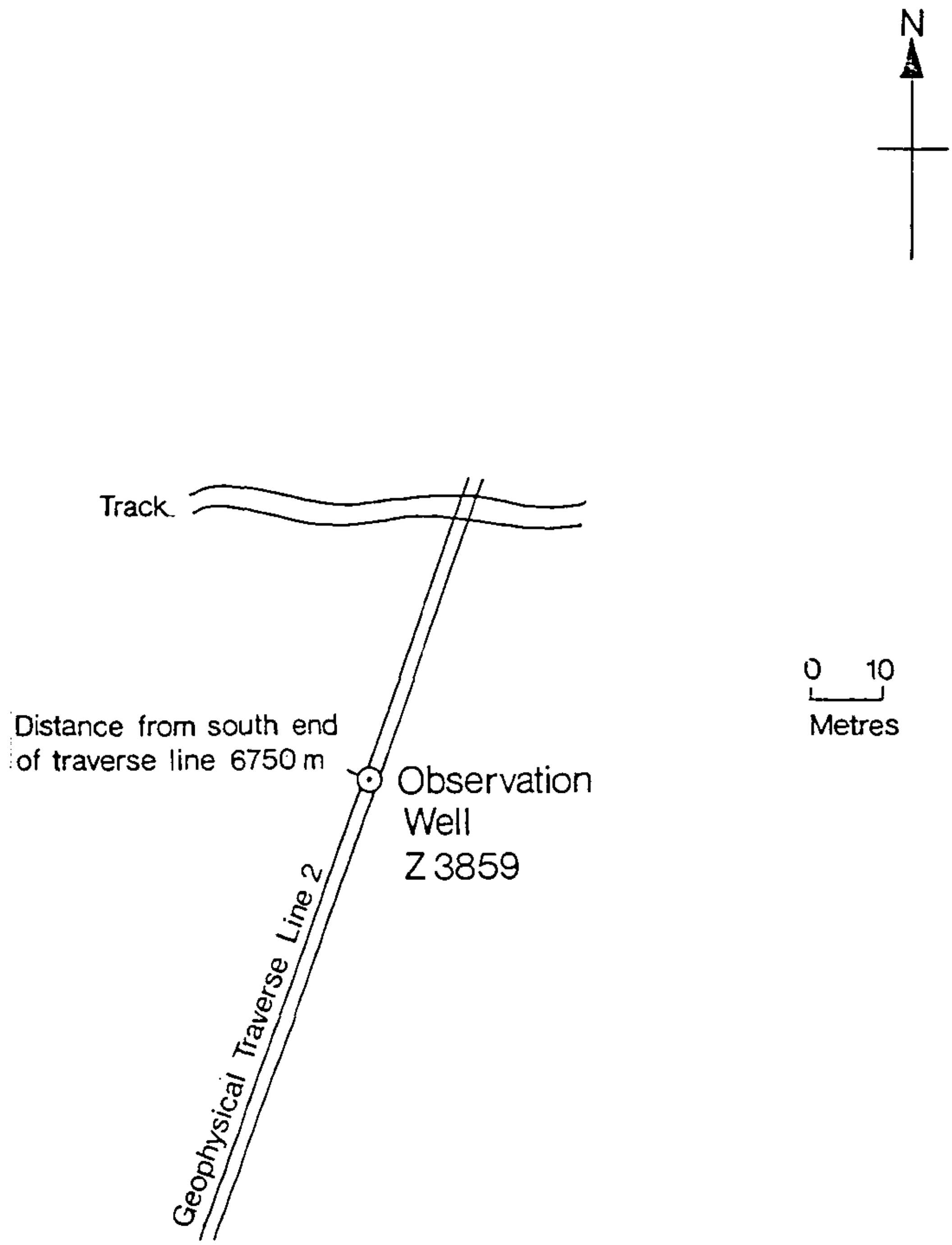
Geology

The well penetrates 32m thickness of Kalahari Beds and finishes at 200m in Drakensberg Basalt, Figures A.3.54 and A.3.55.

The upper 10m of the Kalahari beds are a series of yellow-orange very fine grained unconsolidated sands. These overlie soft white calcareous and siliceous sandstones which grade downward into underlying basalt.

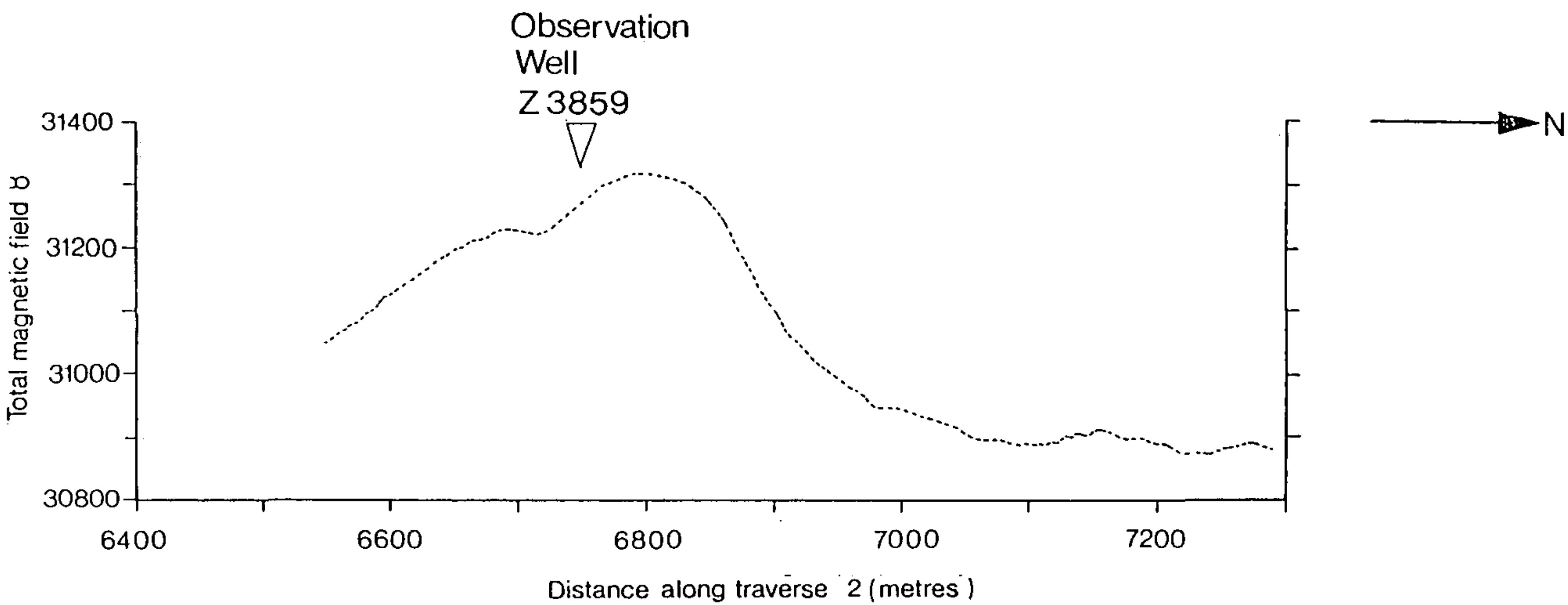
A total basalt thickness of 168m was penetrated of which only 35m is unweathered; the remainder all shows some degree of weathering. The rate of


100.00
10.00
1.00
0.10
DRAWDOWN M.
1
10
10²
10³
10⁴
10⁵
TIME MINS.
MORUPULE
FIGURE A.3.52
CONSTANT RATE TEST - TS6/OW
DATE : 19-10-80
OBSERVED AT TS6/OW , GRID REFERENCE47795801
PUMPING AT GRID REFERENCE47786801
DEPTH TO REST WATER LEVEL = 106.257 METRES
PUMPING RATE 1 332. M³/DAY FROM 0 MINS. TO 5760. MINS.



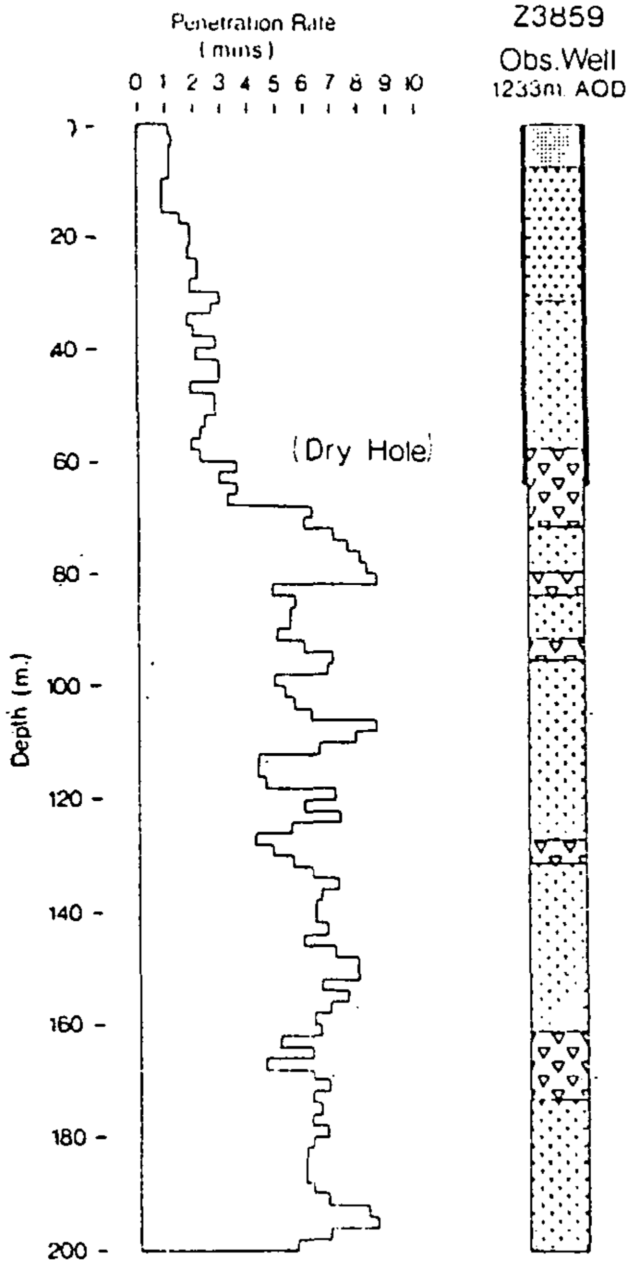
Test Site 1

Figure **A.3.53**



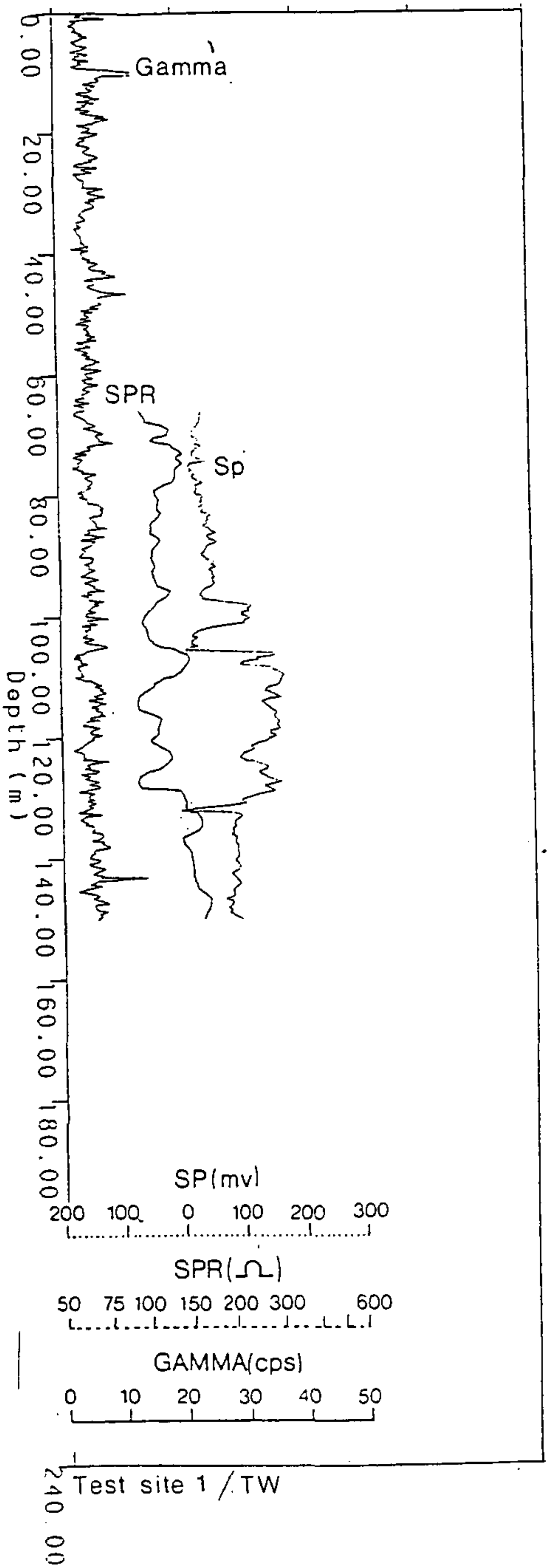
Magnetic Anomalies at Site 1

Figure **A.3.54**



TEST SITE TS 1: LITHOLOGY AND DRILLING DETAILS

Figure A.3.55



TEST SITE TS 1 FORMATION LOGS

Figure A3.59

penetration log shows that the most weathered zone is the upper 35m, penetration rates are almost twice as fast as elsewhere. Where weathered the basalt takes on a red-brown or grey brown colour in contrast to the black or grey appearance of unweathered samples. Glassy basalts, probably representing the chilled margin of individual flow are present at three horizons, 128-132m, 140-142m and 162-174m. Elsewhere both fine, coarse and amygdaloidal types occur with calcite and dolorite the most common secondary minerals.

A.3.11 Exploration site Ex 7

Location

This borehole is located 6 km to the west of Mabeleopodi and 7 km to the NNW of Paje. It is sited on the escarpment at the headwaters of the Sookose river.

Geology

The borehole penetrates a thin cover of weathered basalt before passing through the Cave Sandstone formation and terminating in the Transition Beds, Figure A.3.56.

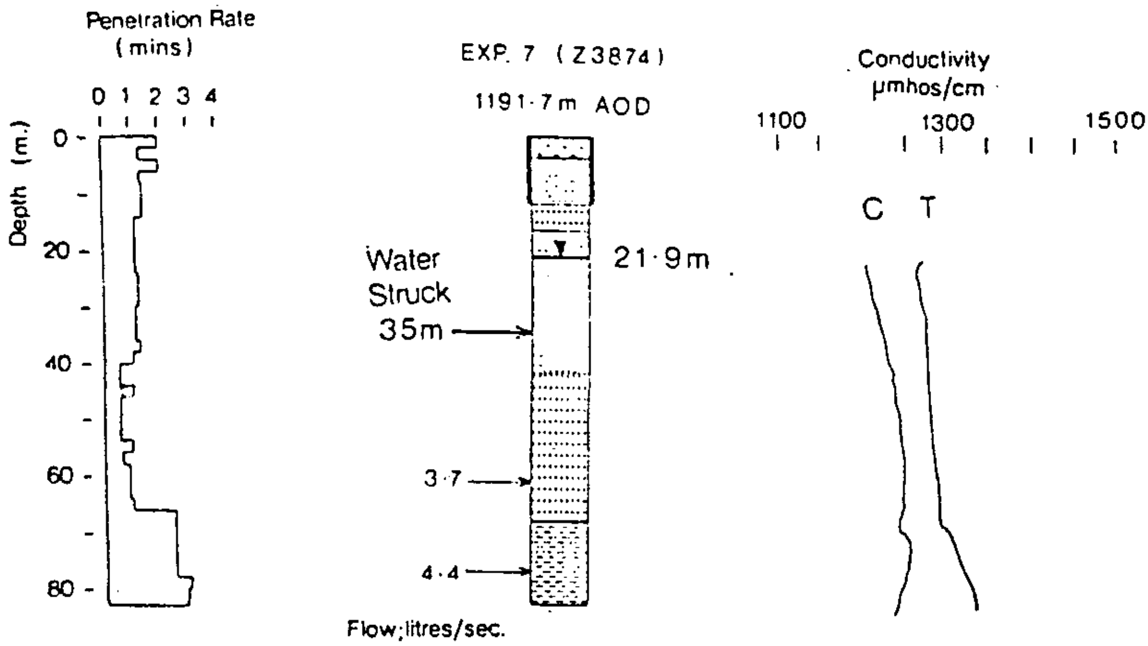
The cover of weathered basalt is 4m thick. It is not known if this represents basalt weathered in situ, or if it is the product of soil creep down the escarpment.

The Cave Sandstone is 67m thick and can be divided into two main lithological units.

(1) An upper sandstone unit, 38m thick, in which pink and white siliceous very fine grained sandstones dominate with subordinate amounts of silty sandstone.

(2) A lower silty sandstone unit, 29m thick, in which pink and white soft siliceous sandstones dominate. The gamma log in Figure A.3.56 indicates that the lower 20m is more silty than the upper 9m. Unusually this silty unit has a faster penetration rate than the overlying sandstones.

The underlying Transition Beds were penetrated for 13m and comprise a



EXPLORATION 7 LITHOLOGY DRILLING DETAILS;

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure
A.3.56

succession of soft, pink, brown, silty sandstones and red and green siltstones. They are easily identified on both the gamma log, which indicates very high clay content, and the rate of penetration log, Figure A.3.60.

Fluid Column Logs

Water was struck in this borehole at a depth of 35m, the water subsequently rising to the standing water level at 12.5m.

The fluid column logs, Figure A.3.56, show that there is no vertical movement of water in the borehole. They also show that there is only weak flow from the water table to a depth of 48m. This corresponds to the upper sandstone unit and the top 7m of the lower silty sandstone unit. Between 48m to 63.5m there is much stronger flow, this zone falls within the lower silty sandstone horizon.

Below 68m there is an abrupt change in both temperature and conductivity, indicating the presence of a different type or age of water. Below this depth flow is much reduced.

In conclusion several points may be emphasised.

(1) Flow in the lower silty sandstone unit is stronger than in the overlying sandstone horizons.

(2) There are two different types or ages of water with an interface at 68m.

(3) The Transition Beds show very little flow and are relatively impermeable.

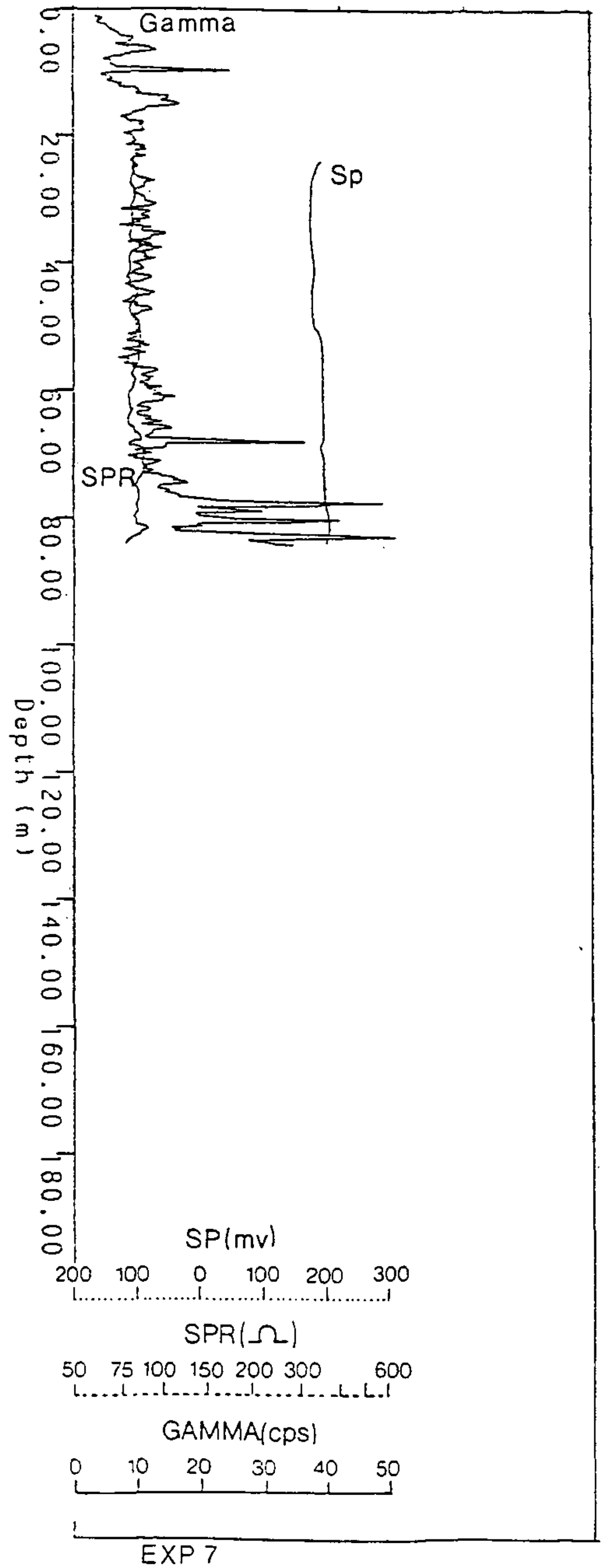
A.3.12 Exploration site Ex 9

Location

This borehole is located on the outcrop of the Cave Sandstone in the floor of a small valley 2km west of Taukome Hill.

Geology

The borehole penetrates 10m of alluvial deposits, passes through 68m of Cave Sandstone and finishes at 130m in a series of silty sandstones



EXP7 FORMATION LOGS

Figure **A.3.60**

and siltstones assigned to the Transition Beds, Figure A.3.57, A.3.61.

The alluvial cover includes fine sand, clays and clay with gravel. These deposits may represent fluvial material laid down during an earlier wetter period.

The Cave Sandstone formation can be divided into two main lithological units:

(a) An upper sandstone unit which is 40m thick. It consists mainly of pink and white siliceous and calcerous sandstones. The unit is characterised by rapid penetration rates and a low clay content which is seen in the gamma log, Figure A.3.57.

(b) A lower unit, 28m thick, which has a higher silt content. The dominant lithologics are pink and white, soft silty sandstones which are occasionally calcerous.

The Transition Beds are a series of green, red and white sandy siltstones and one distinguished by their colour and low permeability as shown by the fluid column logs. Although referred to as the Transition Beds it may be that at this site the underlying Red Beds have also been penetrated.

Fluid column logs

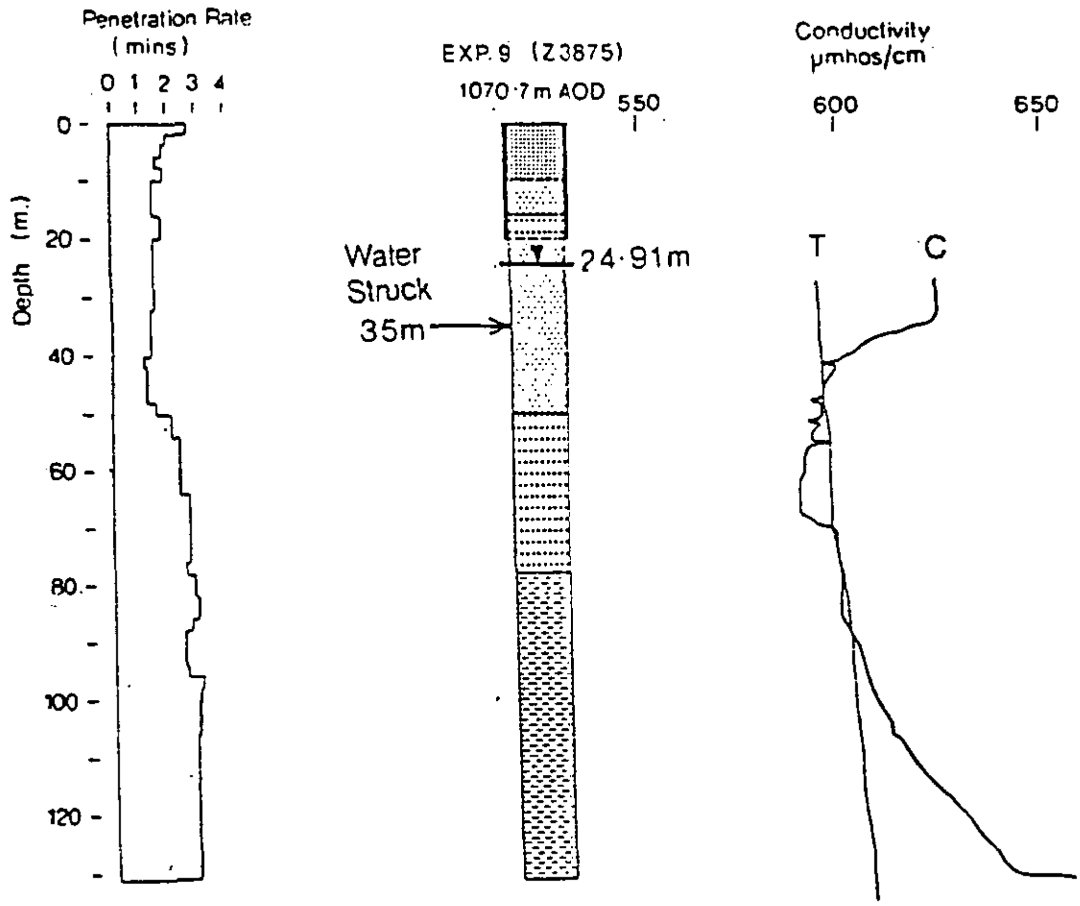
Water was struck at a depth of 35m and the standing water level in 24.9m. In the borehole are two major zones of flow.

(a) From the water table at 24.9m to 32m which represents the top half of the upper sandstone unit.

(b) From 59m to 84m which corresponds to most of the lower silty sandstone unit.

There is little flow from 32m to 59m except from fissures located at 40, 46.5, 49 and 53.7m. Below 84m the flow is greatly reduced and is confined to narrow bands at 93, 104 and 112m.

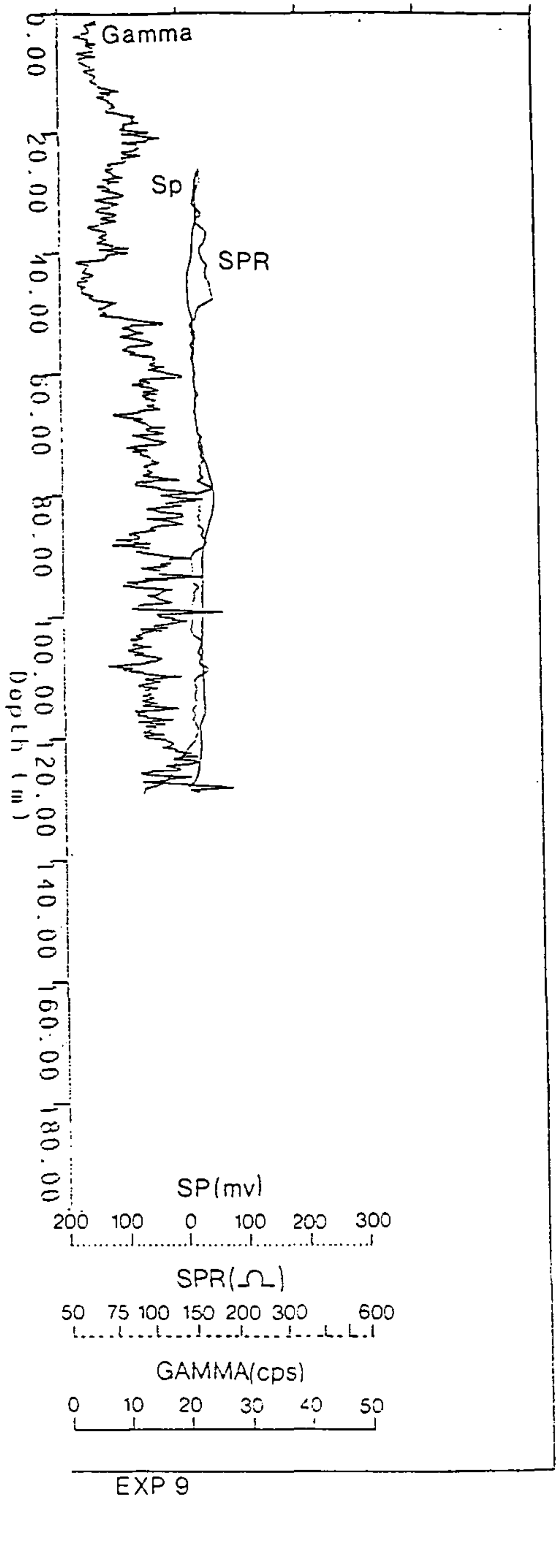
There are several points of interest arising fom the fluid column logs.



EXPLORATION 9 LITHOLOGY; DRILLING DETAILS;

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure A.3.57



EXP 9 FORMATION LOGS

Figure A.3.61

(a) Most of the flow in the upper unit is confined to the top 7m and to three fissures.

(b) The lower sandstone unit appears to produce fairly uniform flow throughout its entire thickness.

(c) The Transition Beds have low flow

(d) There are present two types, or ages, of water with contrasting temperature and conducitivity. The interface between them is at 68m.

A.3.13 Exploration site Ex 10

Location

This borehole is sited on the basalt outcrop at the foot of the scarp and is located 3 km to the north of Paje in the valley of the Sookose river.

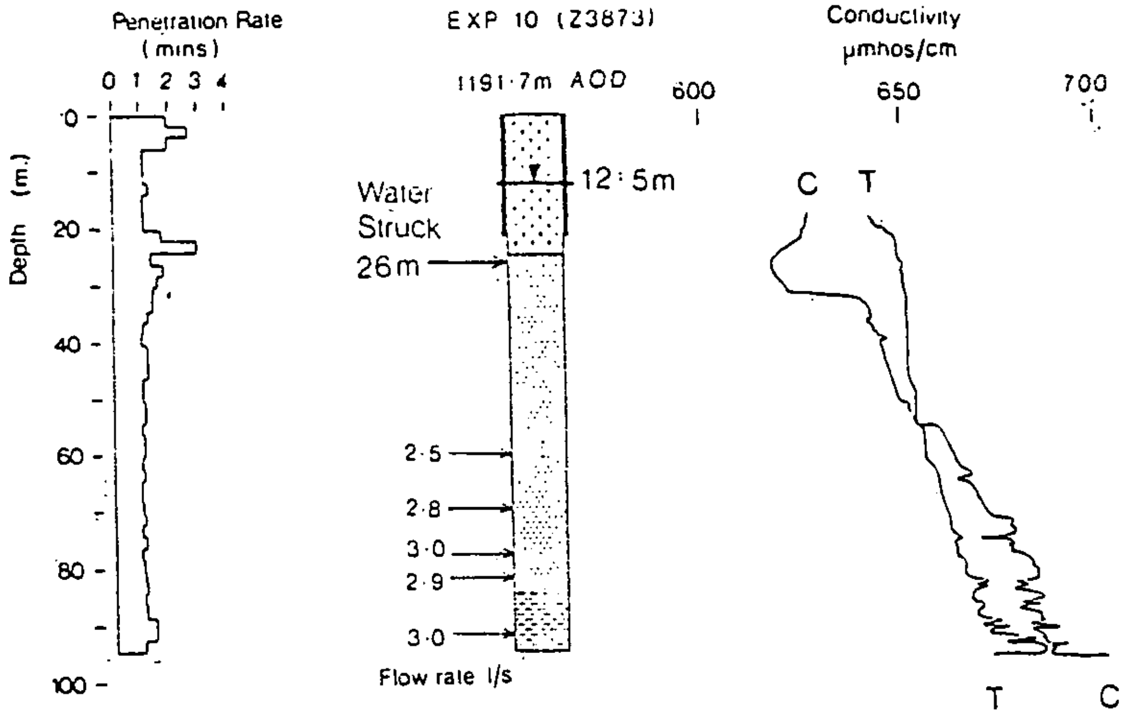
Geology

The borehole penetrates 24m of weathered basalt before passing through the Cave Sandstone and terminating in the Transition Beds.

The basalt succession is 24m thick and very extensively weathered. The degree of weathering is such that the drilling rates are as fast as the underlying Cave Sandstone, Figure 4.3.58. Much of the sequence are grey-brown weathered basalts with variable amounts of secondary chlorite, zeolite and calcite.

The underlying Cave Sandstone formation is 60m thick. The succession comprises a sequence of very fine to fine grained pink and white siliceous and calcareous sandstones which become more silty with depth. The gamma log, Figure A.3.62, demonstrates that the increase in silt content is gradual and that there are significantly more silts in the bottom 10m. Rates of penetration throughout the formation are uniform.

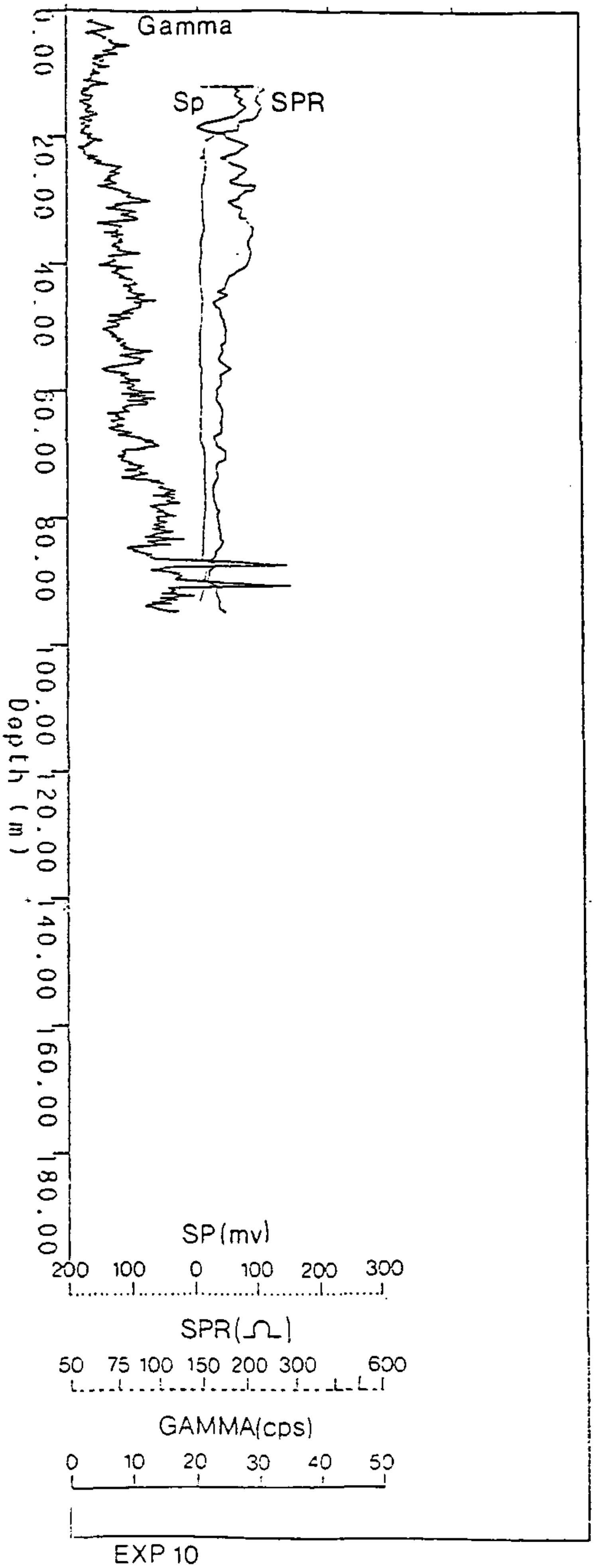
The Transition Beds are dominantly green and maroon siltstones with subordinate silty sandstones. Drilling rates for this formation are slightly higher and the clay content significantly higher than overlying beds.



EXPLORATION 10 LITHOLOGY; DRILLING DETAILS;

CONDUCTIVITY (C) TEMPERATURE (T) LOGS

Figure
A.3.58



EXP10 FORMATION LOGS

Figure A.3.62

Fluid column logs

Water was struck at the contact of the basalt and Cave Sandstone at 25m. The standing water level is 12.5m

The most significant feature of the logs, Figure A.3.56, are the presence of a series of beds giving relatively high flows. These horizons, each about 0.4m thick, are at 72.7, 80.1, 81.1, 84.7, 86.0, 88.3 and 90.0m. The horizons occur in the lower 10m of the Cave Sandstone and the upper 7m of the Transition Beds.

Other features in the logs are:

24 - 29m	horizontal flow
48.5m	possible change in minerology
47 - 53m	flow down the borehole
53 - 59m	flow up the borehole

In conclusion it seems that the zones of highest flow in the Cave Sandstone are the upper 5m and the lower 10m where the flow is restricted to several horizons. Between conditions seem to be fairly uniform with less flow taking place.

A.4 CHEMISTRY AND STABLE ISOTOPE DATA

A.4.1 Chemistry data

The results of the chemical analysis of 57 water samples taken from the investigation boreholes are listed together with a location index. The analyses were carried out by the Geological Survey, Botswana.

The suitability of water for domestic and agricultural purposes has been classified. The domestic class is established using the WHO International Standards for Drinking Water. Class 1 has all constituents below the highest desirable level and class 3 has one or more constituents exceeding the maximum permissible level. The agricultural class is based on the US Salinity Laboratory system using the Sodium-Adsorption Ratio and electrical conductivity.

A.4.2 Stable isotope data

The results of 59 samples taken during the investigation are listed. The analysis was carried out at the Institute of Hydrology/Institute of Geological Sciences stable isotope laboratory.

MORUPULE
CHEMISTRY SAMPLES
LOCATION INDEX

SAMPLE	GRID REF	WELL	
146	42445421	SYA/PW	140M (AIRLIFT SAMPLE)
147	42445421	SYA/PW	180M (AIRLIFT SAMPLE)
190	42445421	SYA/PW	CONST.RATE TEST 210 MIN (FAILED AT 240 MIN)
215	42445421	SYA/PW	CONST.RATE TEST 21660 MIN
148	44825534	TS3/PW	STEP TEST 150 MIN (STAGE 1)
144	44825534	TS3/PW	STEP TEST 2310 MIN (STAGE 4)
142	44825534	TS3/PW	CONST RATE TEST 120 MIN
143	44825534	TS3/PW	CONST RATE TEST 4530 MIN
139	44825535	TS3/OW	140M (AIRLIFT SAMPLE)
134	44825535	TS3/OW	198M (AIRLIFT SAMPLE)
188	46075487	TS2/OW1	201M (AIRLIFT SAMPLE)
184	46075488	TS2/PW2	172M (AIRLIFT SAMPLE)
252	46075488	TS2/PW2	STEP TEST 110 MIN (STAGE 1)
256	46075488	TS2/PW2	CONST RATE TEST 60 MIN
259	46075488	TS2/PW2	CONST RATE TEST 4680 MIN
260	46075488	TS2/PW2	CONST RATE TEST 5760 MIN
145	47315555	SYB/PW	180M (AIRLIFT SAMPLE)
180	47315555	SYB/PW	STEP TEST 90 MIN (STAGE 1)
181	47315555	SYB/PW	STEP TEST 600 MIN (STAGE 4)
216	47315555	SYB/PW	CONST RATE TEST 3345 MIN (FAILED AT 12930 MIN)
219	47315555	SYB/PW	CONST RATE TEST 100 MIN
220	47315555	SYB/PW	CONST RATE TEST 1170 MIN
222	47315555	SYB/PW	CONST RATE TEST 5700 MIN
227	47315555	SYB/PW	CONST RATE TEST 17200 MIN
229	47315555	SYB/PW	CONST RATE TEST 25380 MIN
246	47315555	SYB/PW	CONST RATE TEST 34440 MIN
140	47325556	SYB/OW2	184M (AIRLIFT SAMPLE)
187	47505480	TS5/OW2	200M (AIRLIFT SAMPLE)
186	47515480	TS5/PW	189M (AIRLIFT SAMPLE)
224	47515480	TS5/PW	STEP TEST 355 MIN (STAGE 3)
228	47515480	TS5/PW	CONST RATE TEST 210 MIN
230	47515480	TS5/PW	CONST RATE TEST 2770 MIN
231	47515480	TS5/PW	CONST RATE TEST 7170 MIN
182	47585532	TS4/PW	148M (AIRLIFT SAMPLE)
247	47585532	TS4/PW	STEP TEST 254 MIN (STAGE 3)
250	47585532	TS4/PW	CONST RATE TEST 135 MIN
254	47585532	TS4/PW	CONST RATE TEST 8700 MIN
258	47585532	TS4/PW	CONST RATE TEST 14500 MIN
183	47595532	TS4/OW2	149M (AIRLIFT SAMPLE)
185	47595532	TS4/OW2	186M (AIRLIFT SAMPLE)
133	47665434	EX 7	83M (AIRLIFT SAMPLE)
251	47785601	TS6/PW	STEP TEST 475 MIN (STAGE 4)
255	47785601	TS6/PW	CONST RATE TEST 60 MIN
257	47785601	TS6/PW	CONST RATE TEST 5760 MIN
253	47785601	TS6/PW	CONST RATE TEST 8700 MIN

MORUPULE
CHEMISTRY SAMPLES
LOCATION INDEX

141	47805414	EX 10	94M (AIRLIFT SAMPLE)
135	48115452	SYC/OW1	106M (AIRLIFT SAMPLE)
137	48115452	SYC/PW	DEPTH UNKNOWN (AIRLIFT SAMPLE)
218	48115452	SYC/PW	STEP TEST 150 MIN (STAGE 1)
217	48115452	SYC/PW	STEP TEST 570 MIN (STAGE 4)
221	48115452	SYC/PW	CONST RATE TEST 190 MIN
223	48115452	SYC/PW	CONST RATE TEST 1500 MIN
225	48115452	SYC/PW	CONST RATE TEST 7300 MIN
226	48115452	SYC/PW	CONST RATE TEST 14500 MIN
249	48115452	SYC/PW	CONST RATE TEST 37440 MIN
138	48135453	SYC/OW2	85M (AIRLIFT SAMPLE)
136	49135399	EX 9	131M (AIRLIFT SAMPLE)

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		42445421	42445421	42445421	42445421	44825534
WELL NUMBER		SYA/PW	SYA/PW	SYA/PW	SYA/PW	TS3/PW
SAMPLE		146	147	190	215	142
DATE		7 AUG 80	7 AUG 80	5 AUG 80	25 AUG 80	29 JUL 80
BASIN						
AQUIFER		3	3	3	3	2
SOURCE		2	2	2	2	2
DEPTH		140.0	180.0			
TOTAL SOLIDS		434.	442.	440.	430.	454.
ELEC. COND.		640.	670.	680.	710.	710.
PH		8.32	7.53	7.71	7.50	7.43
CATIONS	CA	1.65	1.65	1.85	1.70	1.55
	MG	.82	.99	1.32	1.32	.82
	NA	4.35	4.70	3.74	4.09	5.13
	K	.12	.12	.10	.18	.09
ANIONS	CO3	.00	.00	.47	.00	.00
	HCO3	3.80	3.84	3.61	4.39	4.47
	SO4	.46	.40	.19	.37	.29
	CL	2.68	2.71	2.40	2.57	2.65
	NO3	.18	.08	.06	.06	.08
F (MG/L)		.40	.30	.70	.30	.50
SIO2 (MG/L)		36.00	35.00	50.00	51.00	26.00
DOMES. CLASS		1	1	1	1	1
AGRIC. CLASS		C2S1	C2S1	C2S1	C3S1	C3S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF	44825534	44825534	44825534	44825535	44825535
WELL NUMBER	TS3/PW	TS3/PW	TS3/PW	TS3/OW	TS3/OW
SAMPLE	143	144	148	134	139
DATE	1 AUG 80	7 AUG 80	7 AUG 80	7 AUG 80	7 AUG 80
BASIN					
AQUIFER	2	2	2	2	2
SOURCE	2	2	2	2	2
DEPTH				198.0	140.0
TOTAL SOLIDS	448.	462.	462.	588.*	404.
ELEC. COND.	700.	710.	710.	850.	700.
PH	7.45	7.45	7.54	8.00	7.88
CATIONS CA	1.55	1.65	1.65	1.90	1.65
MG	.82	.99	.82	.58	.82
NA	5.05	5.09	5.05	5.87	5.09
K	.09	.09	.09	.11	.10
ANIONS CO3	.00	.00	.00	.00	.00
HCO3	4.52	4.52	4.39	4.25	5.00
SO4	.46	.54	.48	1.33	.40
CL	2.59	2.62	2.65	3.27	2.31
NO3	.08	.08	.10	.03	.08
F (MG/L)	.50	.50	.50	.50	.50
SIO2 (MG/L)	26.00	26.00	25.00	23.00	30.00
DOMES. CLASS	1	1	1	2	1
AGRIC. CLASS	C3S1	C3S1	C3S1	C3S1	C3S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		46075487	46075488	46075488	46075488	46075488
WELL NUMBER		TS2/OW1	TS2/PW2	TS2/PW2	TS2/PW2	TS2/PW2
SAMPLE		188	184	252	256	259
DATE		14 AUG 80	14 AUG 80	19 OCT 80	22 OCT 80	3 OCT 80
BASIN						
AQUIFER		3	3	3	3	3
SOURCE		2	2	2	2	2
DEPTH		201.0	172.0			
TOTAL SOLIDS		280.	278.	254.	254.	258.
ELEC. COND.		450.	430.	450.	450.	450.
PH		8.46	8.52*	7.95	8.05	8.00
CATIONS	CA		.20	.25	.25	.25
	MG	.25	.16	.16	.16	.16
	NA	4.35	4.35	4.09	4.09	4.09
	K	.05	.04	.05	.04	.05
ANIONS	CO3	.63	.80	.63	.60	.60
	HCO3	3.56	3.33	3.36	3.43	3.44
	SO4	.10	.10	.29	.27	.29
	CL	.56	.31	.39	.39	.39
	NO3	.05	.05	.02	.02	.00
F (MG/L)		.20	.20	.20	.20	.20
SIO2 (MG/L)		10.00	13.00	15.00	13.00	12.00
DOMES. CLASS		1	2	1	1	1
AGRIC. CLASS		C2	C2S2	C2S2	C2S2	C2S2

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		46075488	47315555	47315555	47315555	47315555
WELL NUMBER		TS2/PW2	SYB/PW	SYB/PW	SYB/PW	SYB/PW
SAMPLE		260	145	180	181	216
DATE		26 OCT 80	7 AUG 80	14 AUG 80	14 AUG 80	30 AUG 80
BASIN						
AQUIFER		3				
SOURCE		2			2	
DEPTH			180.0	11.0	19.3	
TOTAL SOLIDS		252.	298.	576.*	392.	500.
ELEC. COND.		450.	370.	970.	610.	815.
PH		8.10	7.61	7.18	7.38	7.10
CATIONS	CA	.20	1.90	5.59*	3.24	4.14*
	MG	.16	.74	2.63	1.56	2.06
	NA	4.09	1.44	1.52	1.35	1.52
	K	.05	.06	.09	.07	.10
ANIONS	CO3	.63	.00	.00	.00	.00
	HCO3	3.39	2.25	5.03	3.20	4.00
	SO4	.27	.06	.02	.02	.08
	CL	.39	1.69	4.91	2.88	3.81
	NO3	.02	.11	.02	.02	.02
F (MG/L)		.20	.20	.10	.30	.20
SIO2 (MG/L)		10.00	43.00	55.00	48.00	56.00
DOMES. CLASS		1	1	2	1	2
AGRIC. CLASS		C2S2	C2S1	C3S1	C2S1	C3S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		47315555	47315555	47315555	47315555	47315555
WELL NUMBER		SYB/PW	SYB/PW	SYB/PW	SYB/PW	SYB/PW
SAMPLE		219	220	222	227	229
DATE		14 SEP 80	15 SEP 80	18 SEP 80	27 SEP 80	2 OCT 80
BASIN						
AQUIFER						
SOURCE						
DEPTH						
TOTAL SOLIDS		396.	400.	390.	388.	372.
ELEC. COND.		670.	665.	650.	630.	630.
PH		7.22	7.30	7.26	7.28	7.25
CATIONS	CA	3.24	3.24	3.14	3.04	2.89
	MG	1.56	1.56	1.48	1.48	1.48
	NA	1.44	1.48	1.44	1.52	1.44
	K	.09	.10	.10	.10	.08
ANIONS	CO3	.00	.00	.00	.00	.00
	HCO3	3.36	3.38	3.28	3.33	3.16
	SO4	.06	.04	.10	.19	.06
	CL	3.19	3.10	3.05	2.93	2.93
	NO3	.03	.02	.02	.00	.02
	F (MG/L)	.20	.20	.30	.00	.80
	SIO2 (MG/L)	50.00	48.00	49.00	52.00	52.00
DOMES. CLASS		1	1	1	1	1
AGRIC. CLASS		C2S1	C2S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF	47315555	47325556	47505480	47515480	47515480
WELL NUMBER	SYB/PW	SYB/OW2	TS5/OW2	TS5/PW	TS5/PW
SAMPLE	246	140	187	186	224
DATE	8 OCT 80	7 AUG 80	14 AUG 80	14 AUG 80	20 SEP 80
BASIN					
AQUIFER					
SOURCE					
DEPTH		184.0	200.0	189.0	
TOTAL SOLIDS	390.	268.	338.	318.	338.
ELEC. COND.	630.	370.	605.	550.	570.
PH	7.05	7.60	8.12	8.00	7.54
CATIONS CA	2.84	1.65	2.05	1.90	2.00
MG	1.64	.74	1.48	1.56	1.48
NA	1.39	1.52	2.52	1.91	1.91
K	.08	.06	.06	.05	.07
ANIONS CO3	.33	.00	.40	.33	.00
HCO3	2.80	2.03	2.72	2.00	2.56
SO4	.21	.08	.04	.04	.12
CL	2.85	1.80	2.79	2.90	2.96
NO3	.00	.08	.11	.06	.05
F (MG/L)	.20	.30	.20	.20	.20
SIO2 (MG/L)	56.00	43.00	28.00	31.00	30.00
DOMES. CLASS	1	1	1	1	1
AGRIC. CLASS	C2S1	C2S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		47515480	47515480	47515480	47585532	47585532
WELL NUMBER		TS5/PW	TS5/PW	TS5/PW	TS4/PW	TS4/PW
SAMPLE		228	230	231	182	247
DATE		30 SEP 80	2 OCT 80	5 OCT 80	14 AUG 80	10 OCT 80
BASIN						
AQUIFER						
SOURCE						
DEPTH					148.0	
TOTAL SOLIDS		320.	322.	320.	380.	418.
ELEC. COND.		580.	580.	590.	580.	670.
PH		7.64	7.47	7.65	7.77	7.61
CATIONS	CA	1.85	1.85	1.95	2.94	3.59
	MG	1.56	1.56	1.64	1.15	1.56
	NA	1.96	1.87	1.87	1.74	1.22
	K	.14	.07	.07	.09	.08
ANIONS	CO3	.00	.00	.00	.57	.23
	HCO3	2.72	2.67	2.72	2.84	4.11
	SO4	.15	.04	.08	.04	.17
	CL	2.93	2.79	2.88	2.31	2.28
	NO3	.06	.05	.05	.00	.00
F (MG/L)		.10	.10	.10	.10	.10
SIO2 (MG/L)		30.00	28.00	26.00	54.00	72.00
DOMES. CLASS		1	1	1	1	1
AGRIC. CLASS		C2S1	C2S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL

** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF	47585532	47585532	47585532	47595532	47595532
WELL NUMBER	TS4/PW	TS4/PW	TS4/PW	TS4/OW2	TS4/OW2
SAMPLE	250	254	258	183	185
DATE	14 OCT 80	20 OCT 80	24 OCT 80	14 AUG 80	14 AUG 80
BASIN					
AQUIFER					
SOURCE				2	
DEPTH				149.0	186.0
TOTAL SOLIDS	418.	420.	424.	360.	402.
ELEC. COND.	700.	700.	700.	590.	660.
PH	7.43	7.01	7.03	7.79	7.88
CATIONS CA	3.59	3.64	3.54	2.79	2.89
MG	1.56	1.48	1.48	1.32	1.07
NA	1.22	1.26	1.35	1.83	2.65
K	.09	.08	.09	.09	.08
ANIONS CO3	.23	.00	.23	.33	.23
HCO3	4.11	4.39	4.16	3.08	3.36
SO4	.17	.17	.23	.10	.15
CL	2.31	2.23	2.23	2.40	2.85
NO3	.00	.00	.00	.02	.02
F (MG/L)	.10	.10	.10	.10	.10
SIO2 (MG/L)	69.00	64.00	61.00	54.00	40.00
DOMES. CLASS	1	1	1	1	1
AGRIC. CLASS	C3S1	C3S1	C3S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		47665434	47785601	47785601	47785601	47785601
WELL NUMBER		EX 7	TS6/PW	TS6/PW	TS6/PW	TS6/PW
SAMPLE		133	251	253	255	257
DATE		7 AUG 80	16 OCT 80	20 OCT 80	21 OCT 80	23 OCT 80
BASIN						
AGUIFER		3				
SOURCE		2				
DEPTH		83.0				
TOTAL SOLIDS		724.*	404.	252.	250.	250.
ELEC. COND.		1140.	750.	480.	440.	470.
PH		7.20	7.22	7.47	7.55	7.62
CATIONS	CA	8.43*	2.15	.65	.65	.55
	MG	.99	1.15	.25	.25	.25
	NA	1.52	3.87	3.31	3.31	3.31
	K	.13	.07	.06	.05	.06
ANIONS	CO3	.00	.00	.23	.23	.23
	HCO3	3.43	5.80	2.16	2.20	2.16
	SO4	.33	.10	.10	.10	.10
	CL	7.47*	1.72	1.89	1.86	1.89
	NO3	.10	.00	.00	.00	.00
F (MG/L)		.00	.10	.20	.20	.20
SIO2 (MG/L)		21.00	35.00	18.00	17.00	15.00
DOMES. CLASS		2	1	1	1	1
AGRIC. CLASS		C3S1	C3S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF	47805414	48115452	48115453	48115453	48115453
WELL NUMBER	EX 10	SYC/OW1	SYC/PW	SYC/PW	SYC/PW
SAMPLE	141	135	137	217	218
DATE	7 AUG 80	7 AUG 80	7 AUG 80	4 SEP 80	4 SEP 80
BASIN					
AQUIFER		3	3	3	3
SOURCE		2	2	2	2
DEPTH	94.0	106.0			
TOTAL SOLIDS	374.	360.	374.	350.	390.
ELEC. COND.	550.	490.	540.	570.	630.
PH	7.62	7.40	7.30	7.40	7.22
CATIONS CA	3.09	3.69	3.19	3.64	4.24*
MG	2.14	.82	1.56	1.40	1.64
NA	1.22	1.09	1.44	.83	.83
K	.02	.08	.07	.10	.08
ANIONS CO3	.00	.00	.00	.00	.00
HCO3	6.11	4.67	4.39	5.08	6.16
SO4	.12	.25	.17	.10	.06
CL	.45	.99	1.66	1.13	.96
NO3	.08	.02	.08	.02	.00
F (MG/L)	.10	.10	.00	.10	.10
SIO2 (MG/L)	52.00	39.00	41.00	45.00	48.00
DOMES. CLASS	1	1	1	1	2
AGRIC. CLASS	C2S1	C2S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		48115453	48115453	48115453	48115453	48115453
WELL NUMBER		SYC/PW	SYC/PW	SYC/PW	SYC/PW	SYC/PW
SAMPLE		221	223	225	226	249
DATE		17 SEP 80	18 SEP 80	22 SEP 80	27 SEP 80	13 OCT 80
BASIN						
AQUIFER		3	3	3	3	3
SOURCE		2	2	2	2	2
DEPTH						
TOTAL SOLIDS		360.	374.	372.	360.	348.
ELEC. COND.		575.	570.	570.	570.	600.
PH		7.25	7.40	7.25	7.23	7.07
CATIONS	CA	3.89*	3.89*	3.89*	3.74*	3.59
	MG	1.40	1.40	1.48	1.40	1.56
	NA	.83	.78	.74	.78	.78
	K	.08	.08	.07	.09	.06
ANIONS	CO3	.00	.00	.00	.00	.00
	HCO3	5.16	5.16	5.08	5.06	5.00
	SO4	.08	.10	.10	.15	.10
	CL	1.13	1.13	1.13	1.13	1.07
	NO3	.02	.02	.03	.00	.00
F (MG/L)		.10	.10	.10	.10	.10
SIO2 (MG/L)		42.00	41.00	42.00	43.00	54.00
DOMES. CLASS		2	2	2	2	1
AGRIC. CLASS		C2S1	C2S1	C2S1	C2S1	C2S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE

PROJECT WELLS ONLY

CHEMISTRY SUMMARY

GRID REF		48135453	49135399
WELL NUMBER		SYC/OW2	EX 9
SAMPLE		138	136
DATE		7 AUG 80	7 AUG 80
BASIN			
AQUIFER			3
SOURCE		2	2
DEPTH		85.0	131.0
TOTAL SOLIDS		342.	636.*
ELEC. COND.		500.	840.
PH		7.35	7.70
CATIONS	CA	3.69	2.25
	MG	1.32	3.13
	NA	.91	4.78
	K	.06	.02
ANIONS	CO3	.00	.00
	HCO3	4.67	9.00
	SO4	.10	.17
	CL	1.13	1.13
	NO3	.10	.03
F (MG/L)		.00	.40
SIO2 (MG/L)		41.00	51.00
DOMES. CLASS		1	2
AGRIC. CLASS		C2S1	C3S1

* CONCENTRATION EXCEEDS W.H.O. HIGHEST DESIRABLE LEVEL
** CONCENTRATION EXCEEDS W.H.O. MAXIMUM PERMISSIBLE LEVEL

MORUPULE
STABLE ISOTOPES
LOCATION INDEX

GRID REF	SAMPLE	WELL	O-18	H-2	
39685618	1	A1	-5.4	-39.	
40915139	7	A27	-5.0	-30.	
42445421	31	SYA/PW	-5.4	-37.	CD1
42445421	39	SYA/PW	-5.7	-35.	CD 1200HR
42625285	10	A47	-5.5	-33.	
42785563	2	A7	-5.8	-38.	
42795341	5	A20	-5.5	-34.	
44165266	6	A25	-6.1	-38.	
44165396	4	A19	-5.9	-38.	
44175139	9	A31	-6.1	-40.	
44185452	3	A15	-5.6	-34.	
44825534	32	TS3/PW	-5.8	-36.	ST STAGE1
44825534	33	TS3/PW	-5.9	-35.	CD
44855175	8	A28	-5.7	-36.	
44865532	15	B11	-5.9	-35.	
44995359	24	B34	-6.1	-40.	
45505160	29	B64	-4.6	-37.	
45555191	27	B58	-4.7	-32.	
45595474	17	B17	-6.1	-38.	
45885311	25	B36	-5.8	-36.	
46075488	53	TS2/PW2	-6.3	-43.	CD 60MIN
46075488	54	TS2/PW2	-6.3	-41.	CD 5760MIN
46135416	21	B27	-6.1	-40.	
46285258	26	B45	-5.5	-40.	
46375558	13	B8	-5.9	-37.	
46805569	12	B6	-6.1	-38.	
46845231	59	1378	-5.9	-40.	
46905423	20	B25	-5.8	-39.	
47055465	18	B18	-6.3	-36.	
47305549	14	B10	-6.0	-39.	
47315555	36	SYB/PW	-6.2	-39.	ST 1015HRS
47315555	38	SYB/PW	-6.4	-40.	ST 1930HRS
47315555	37	SYB/PW	-6.2	-39.	ST 1100HRS
47315555	40	SYB/PW	-6.2	-42.	CD 100MIN
47315555	41	SYB/PW	-6.0	-38.	CD 1170MIN
47315555	42	SYB/PW	-6.1	-38.	CD 5700MIN
47315555	43	SYB/PW	-6.1	-40.	CD 17200MIN
47315555	44	SYB/PW	-6.2	-40.	CD 25380MIN
47385480	16	B16	-6.3	-41.	
47515480	49	TS5/PW	-6.4	-41.	ST (STAGE 3)
47515480	50	TS5/PW	-6.4	-40.	CD 210MIN
47515480	51	TS5/PW	-6.4	-39.	CD 2800MIN
47515480	52	TS5/PW	-6.4	-40.	CD 7170MIN
47585532	55	TS4/PW	-6.6	-44.	CD 135MIN
47585532	56	TS4/PW	-6.5	-44.	CD 14500MIN
47615172	28	B61	-5.7	-33.	
47785601	57	TS6/PW	-6.2	-41.	CD 1560MIN
47785601	58	TS6/PW	-6.2	-42.	CD 5760MIN

MORUPULE
STABLE ISOTOPES
LOCATION INDEX

47825383	23	B30	-5.1	-35.	
47875478	30	MAB	-6.5	-41.	
48115453	34	SYC/PW	-6.5	-41.	ST 1000HRS
48115453	35	SYC/PW	-6.3	-40.	ST 1700HRS
48115453	45	SYC/PW	-6.4	-42.	CD 190MIN
48115453	46	SYC/PW	-6.7	-42.	CD 1500MIN
48115453	47	SYC/PW	-6.4	-42.	CD 7300MIN
48115453	48	SYC/PW	-6.3	-43.	CD 14500MIN
48315444	19	B21	-4.9	-31.	
49265622	11	B3	-6.0	-39.	
49585401	22	B28	-5.7	-39.	

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