NATURAL ENVIRONMENT RESEARCH COUNCIL

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HOWBERY PARK
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WATER RESOURCES SURVEY OF

NORTHERN OMAN

<u>PUMPING TESTS IN THE</u>

<u>WADI LANSAB</u>

Institute of Hydrology
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1. Introduction

Exploration of the Wadi Lansab was confined to the area downstream of the existing sources of supply. The object of the work was to determine the nature and thickness of the alluvial sediments, assess the aquifer potential and provide sufficient information to produce an estimate of the underground flow beneath the wadi.

Three sites were selected across the wadi some 400 m upstream of the main drainage outlet through the limestone outcrop. The sites were located adjacent to surface channels in areas relatively free of large surface boulders. 4½ inch diameter exploration boreholes were used as pilot holes. These were cased with 2 inch diameter torch slotted galvanised pipe and retained as water-level observation boreholes. Test wells were constructed 5 m from the pilot holes. They were drilled at 17½ inch diameter, cased with 9⅝ inch pipe and 7 inch bridge slotted screen.

2. Lithology of the Sediments

Previous drilling records indicated up to 30 m of gravel overlying either Lower Tertiary Limestones or Hawasina shales. No details regarding the lithological nature of the sediments were however available. To provide data the exploration programme collected strata samples during drilling, drillers logs and rate of penetration were recorded and geophysical logs were made in the boreholes prior to casing.

The results obtained show a pattern now becoming familiar for many sites in the Batinah. At the surface the driller recorded boulder gravels to depths of about 11 m. Lithological samples showed gravels with some sand and in places a little clay but generally a sequence of unconsolidated coarse clastic sediments was proved.

Fine grained sediment appears at a depth of about 11 m. Bands of orange clay up to about 3 m in thickness occur throughout the sequence. Drillers logs and lithological samples suggest that the gravel sequence probably includes a significant clay component. Gamma logs seem to confirm this with an increase of about 100 counts per second at 11 m. SP and single point resistivity in the small diameter boreholes provide the most detailed picture of an alternating gravel and clay sequence. Lenses of gravel up to about 10 m are separated by distinct clay bands varying in thickness from about 0.2 m to 3 m. High gamma backgrounds were recorded at the main clay horizons, a 3 m layer at a depth of 20 m being particularly noticeable.

There is some doubt regarding the true nature of the gravel lenses below a depth of 10 m. Surface exposures of older gravels show extensive secondary carbonate deposition weathering to a brown or orange colour. At depth rotary drilling is unlikely to produce strata samples which preserve any weakly cemented material and drilling indications could confuse weakly cemented gravels and gravels with clay. Our interpretation of the various data suggests that weakly cemented gravels with some clay occur in the Wadi Lansab between 10 m and 25 m below surface but we have no reliable measure of the extent of either component.

Below about 25 m the proportion of clay and/or carbonate cement appears to increase. Drilling records indicate some "conglomerates", "gravel and marble", and "gravel limestone" mixed with gravels and with varying proportions of clay. Lithological samples indicate fine to medium gravels in red, orange or brown clays but do not record the occurrence of significant carbonate cements. The geophysical logs show that at sites 1 and 2 clays and clayey gravels predominate below 25 m with only one band of gravel exceeding 5 m in thickness. At site 3 the sequence appears to comprise cleaner and thicker beds of gravel. Below 33 m the SP and resistivity logs failed to detect any prominent clay bands althought the gamma log shows four possible clay horizons.

Observation boreholes 1 and 3 were reported to reach limestone at depths of 55 m and 48 m respectively. Penetration was not sufficient to establish the geophysical characteristics of these Lower Tertiary beds although a significant increase in the natural gamma count was recorded at a depth of 48 m in borehole 3. At a depth of 54 m in borehole 1, fluid losses were recorded and the SP log suggests a possible fissure at this horizon.

A summary of the drillers logs and copies of the geophysical logs are shown in Figures A - F appended to this report. Below in table 1 - 3 a summary of all the various lithological data is given in the form of generalised sequences for each site.

Table 1

Generalised sequence Site 1

Depth (m)	Lithology
0-10	Gravel. Coarse sand and a little clay between 4 m and 7 m. Boulders throughout.
10-12	Orange clay
12-16	Gravel with boulders and orange/brown clay
16-17	Clay
17-20	Gravel, cemented at 18m, a little clay
20-23	Clay
23-24	Cemented gravels
24-30	Cemented gravels with boulders and clay
30-36	Gravel with boulders, sand and a little clay
37-54	Cemented gravels with numerous thin clay horizons
54-58	Limestone

Table 2

Generalised sequence Site 2

Depth (m)	Lithology
0-4	Gravel with boulders
4-11	Gravel with coarse sand to 8 m, brown clay from 9 - 11 m and boulders
11-19	Gravel with orange-red clay. Cemented at 18 m
19-22	Orange/brown clay with gravel and boulders
22-26	Gravel with some orange clay
26-28	Orange/red clay and sand
28-30	Gravel, some clay, cemented at 29 m
30-35	Orange / red clay with a little gravel.

Table 3

Generalised Sequence Site 3

Depth (m)	Lithology
0-5	Fine gravel, sand and boulders
5-8	Sand and Gravel with boulders
8-10	Gravel and boulders
10-14	Sand and gravel with a little clay
14-21	Clayey gravel
21-26	Gravel with boulders and a little clay
26-28	Clay
28-31	Gravel with red clay
31-32	Orange clay
32-36	Cemented gravel, some clay
36-40	Orange clay with gravel
40-47	Gravel and boulders
47-49	Limestone

3. Aquifer Properties

3.1 Occurrence of groundwater

Groundwater appears to have been encountered at 10 m or 10.5 m below surface. The rotary mud flush drilling method does not enable a more detailed description of any subsequent water bearing horizons. On completion the standing water levels were recorded at depths of between 8.4 m and 13.7 m. Sites 1and 2 were completed with water levels standing 0.5 m above the depth at which water was first encountered suggesting small artesian effects. At site 1 the water level prior to pumping stood 8.3 m to 9.0 m below the top of casing. By comparison with table 1 this seems to suggest that some water occurred in the upper gravel sequence above the clay horizon at 10 m. Water levels at site 2 were recorded at 11.7 m and 13.3 m below top of casing. This horizon seems to be below the main clay-free gravels. At site 3 the standing water level appears to be within the sands and gravels between 10 m and 14 m below surface, a sequence that seems almost certain to contain some clay or cemented material.

The aquifer potential was tested by setting screens in the deeper gravel layers. Constructions details are shown in Table 4. At site 1 screens were located in the deepest of the main gravel lenses between 28.7 m and 35.0 m below surface. This horizon immediately above cemented beds was the deepest tested. At site 2 a double screen was used. The upper was set at the base of the gravel between 15.7 m and 18.9 m below surface. The lower screen, between 21.4 m and 24.5 m, was set in the gravel lens below the 19 m - 22 m clay. Similar horizons were selected at site 3 with screens being located in the two main gravel lenses above the cemented gravels at 32 m.

3.2 Pumping Test Procedures

All boreholes were developed using airlift testing (Table 5). The yields obtained were less than 1 l/sec and the proposed step drawdown testing had to be abandoned. Constant rate testing for about 24 hours was attempted but at site 2 the yield of the borehole was too low to enable a controlled test to be made.

	Observation Borehole 1	Test Well No 1	Observation Borehole 2	Test Well No 2	Observation Borehole 3	Test Well No 3
Drilling Rig	Mayhew 1000	Failing 2000	Mayhew 1000	Failing 2000	Mayhew 1000	Failing 2000
Depth (m)	58	36	35	27	49	36
Diameter of hole (inches)	$5\frac{7}{8}$	$17\frac{1}{2}$	$5\frac{7}{8}$	$17\frac{1}{2}$	$5\frac{7}{8}$ to 5 m $4\frac{1}{4}$ to 49 m	$17\frac{1}{2}$
Casing diameter (inches)	$2\frac{1}{2}$	$9\frac{5}{8}$	$2\frac{1}{2}$	$9\frac{5}{8}$	2	$9\frac{5}{8}$
Casing at (m)	0-12	0-36	0-11		0-12	
Screen diameter (inches)	$2\frac{1}{2}$	10	$2\frac{1}{2}$	10	2	7
Screen at (m)	12-58	28.7-35.0	11-35	15.7-18.9 21.4-24.5	12-49	22-26 28-32
Screen	Torch slotted	Johnson	Torch slotted	Johnson	Torch slotted	Bridge slotted
Water struck (m)	10.5	?	10.5	?	10	?
Standing water level (m)	10	8.4	10	13	10	13.7
Water levels prior to testing (depth in m)	8.3	9.0	11.7	13.3	13.3	13.8

Table 4

Wadi Lansab, Construction Details of Test Wells

Table 5

Airlift Development

Test Well No 1	0.6 l/sec for 47 hours
Observation 1	0.6 l/sec for 10 hours
Test Well No 2	0.5 l/sec for 72 hours
Observation 2	0.5 l/sec for 6½ hours
Test Well No 3	
Observation 3	0.8 l/sec for 17 hours

Constant rate testing was carried out using a 4 inch submersible pump. Drawdown and recovery water level data were obtained from the pumped well and the observation borehole. Table 6 summarises the test results.

Table 6

Constant Rate Testing

	Yield (l/sec)	Length of Test (hours)	Maximum Drawdown (m)
Test Well 1	0.7	29	18.4
Test Well 2 (a)	0.7	0.5	4.2
(b)	0.5 - 0.7	1	5.2
Test Well 3	1.2	48	4.2

The test at site 1 was carried out with the pump set at 28 m below surface. Rest water level at the start of the test was at 9.0 m and drawdown after 29 hours was to within 1.2 m of the pump. Water level measurements were lost from 7 minutes to 30 minutes due to the water level dipper becoming trapped between the rising main and the casing. Some difficulty was experienced in controlling the abstraction rate and adjustments to the value had to be made after 5½ hours and 10 hours. Steady state conditions were not reached during the test and water levels continued to fall at a rate of about 0.7 m/day.

At site 2 the rest water level was 2.5 m above the top of the upper screen. For test purposes the water intake was therefore located between the screens in the cased section of the test well between 18.9 m and 21.4 m. A preliminary test at a rate of 0.7 l/sec was stopped after 36 minutes when drawdown in water level approached the pump intake. A second test was arranged after a period of 2 days during which water levels recovered following the preliminary test. The second test was run for 60 minutes during which time attempts were made to reduce abstraction to less than 0.7 l/sec and maintain a constant rate of abstraction. With yields of less than 0.7 l/sec the flow rate proved to be too small to control and subsequent testing of the site was abandoned.

Site 3 produced the best results. A yield of 1.2 l/sec was maintained for a period of 48 hours. Steady state conditions were rapidly established, water levels stabilising at 17.9 m below surface after about 1 hour.

3.3 Analysis of Test Data

Time drawdown techniques have been applied to the drawdown and recovery water level data from the test and observation boreholes at sites land 3. Estimates of transmissivity and storage have been obtained by application of the Hantush and Jacob leaky artesian method (after Walton) and the Jacob modified approach.

The formulae used for deriving T and S were as follows:

(a) Leaky Artesian

$$T = \frac{QW}{4\pi s} = 0.0796 \quad \frac{QW}{S}$$

and $$S = \frac{4tT}{r^2\theta}$$

(b) Jacob straight line

$$T = \frac{0.183Q}{\Delta s}$$

$$S = \frac{2.246tT}{r^2}$$

where T is the transmissivity in m^2/day

S is the coefficient of storage

Q is the discharge in m^3/day

r and s are the distance to the observation well and the drawdown in m.

t is time in days.

The results given in Table 7, show that very different values were obtained for transmissivity not only when site I is compared with site 3 but also when the observation well result is compared with the production well result. The variation at each site can be attributed to the differencesin design of the production well and the observation borehole. The observation boreholes were finished with fully perforated casing in order to allow in-situ fluid conductivity measurements to be taken during the pumping test. Water levels appear to have been affected by this design and the total drawdown in the observation boreholes was less than would have been obtained from a borehole with perforated casing at the same horizons as the production well screens.

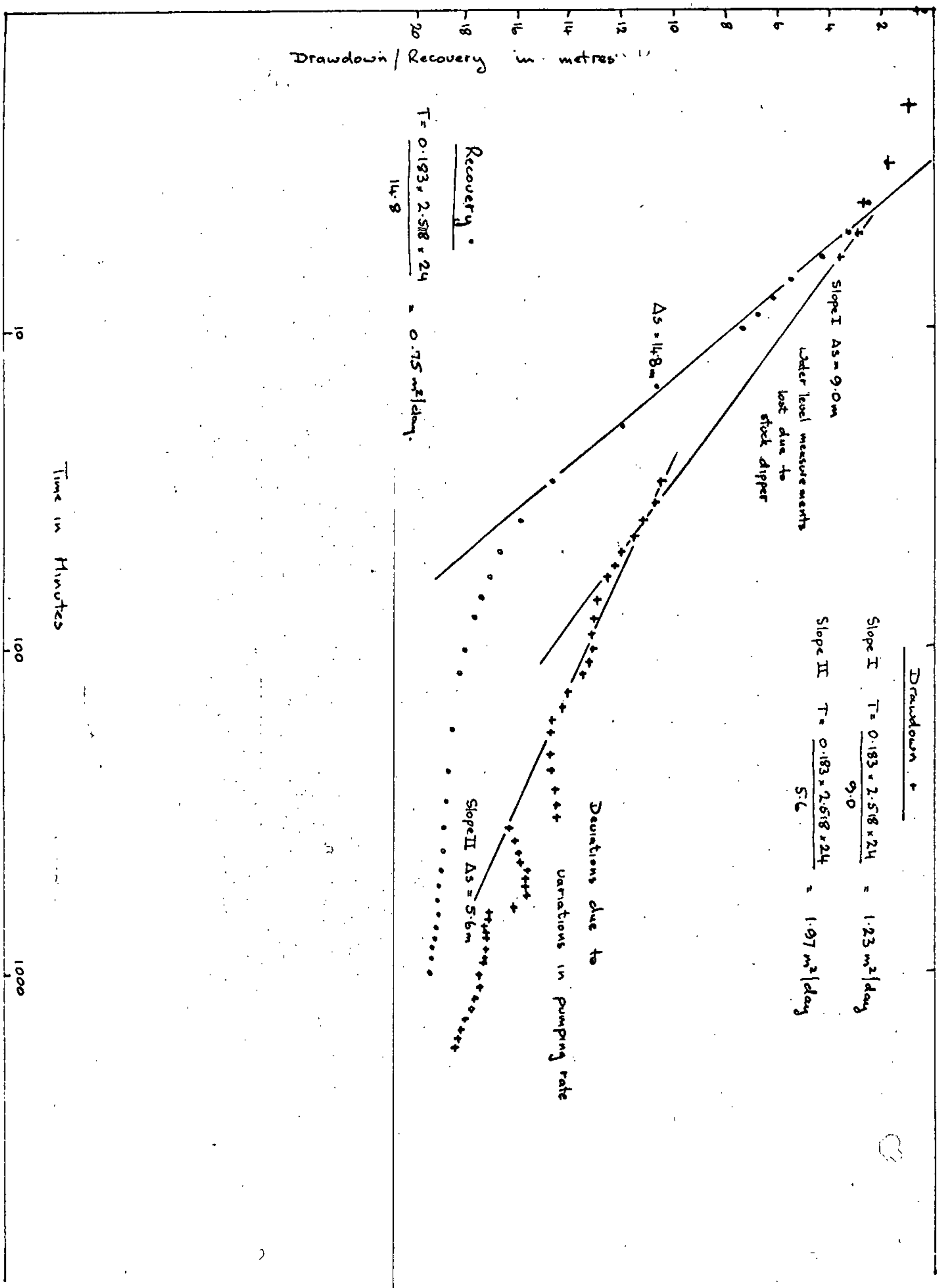
By way of explanation it should be pointed out that the fully perforated casing was deliberately used in order to monitor anticipated brackish water movement during the tests. The PD(0) records for their old wells in the vicinity indicated that they were abandoned after becoming brackish and a salinity problem was therefore anticipated. In fact fluid conductivity measurements in the boreholes during the pumping tests failed to indicate any water quality problems.

Analysis of the pumped well data yieldsaverage transmissivity estimates of 0.9 m^2/day and 7.7 m^2/day for sites 1 and 3 respectively. The solutions are shown in figures 1, 2, 4 and 5. Drawdown data produce the highest estimates of transmissivity, all solutions show characteristics which are similar to

Table 7

Wadi Lansab Test Pumping Results

	Hantush and Jacob solution		Jacob solution				
	Transmissivity (m^2/d)	Storage	Transmissivity (m^2/d)			Storage	
			drawdown	recovery	residual drawdown	drawdown	recovery
Test 1							
Observation well	5.1	0.004	7.7	4.7	-	0.003	0.003
Production well	-	-	1.2	0.8	0.8	-	-
Test 3							
Observation well	44.6	0.006	52.7	73.3	-	0.004	0.006
Production well	-	-	8.8	6.9	7.4	-	-



Wadi Lansab	Drawdown and Recovery Analyses Test Well No 1. Production Well Data.

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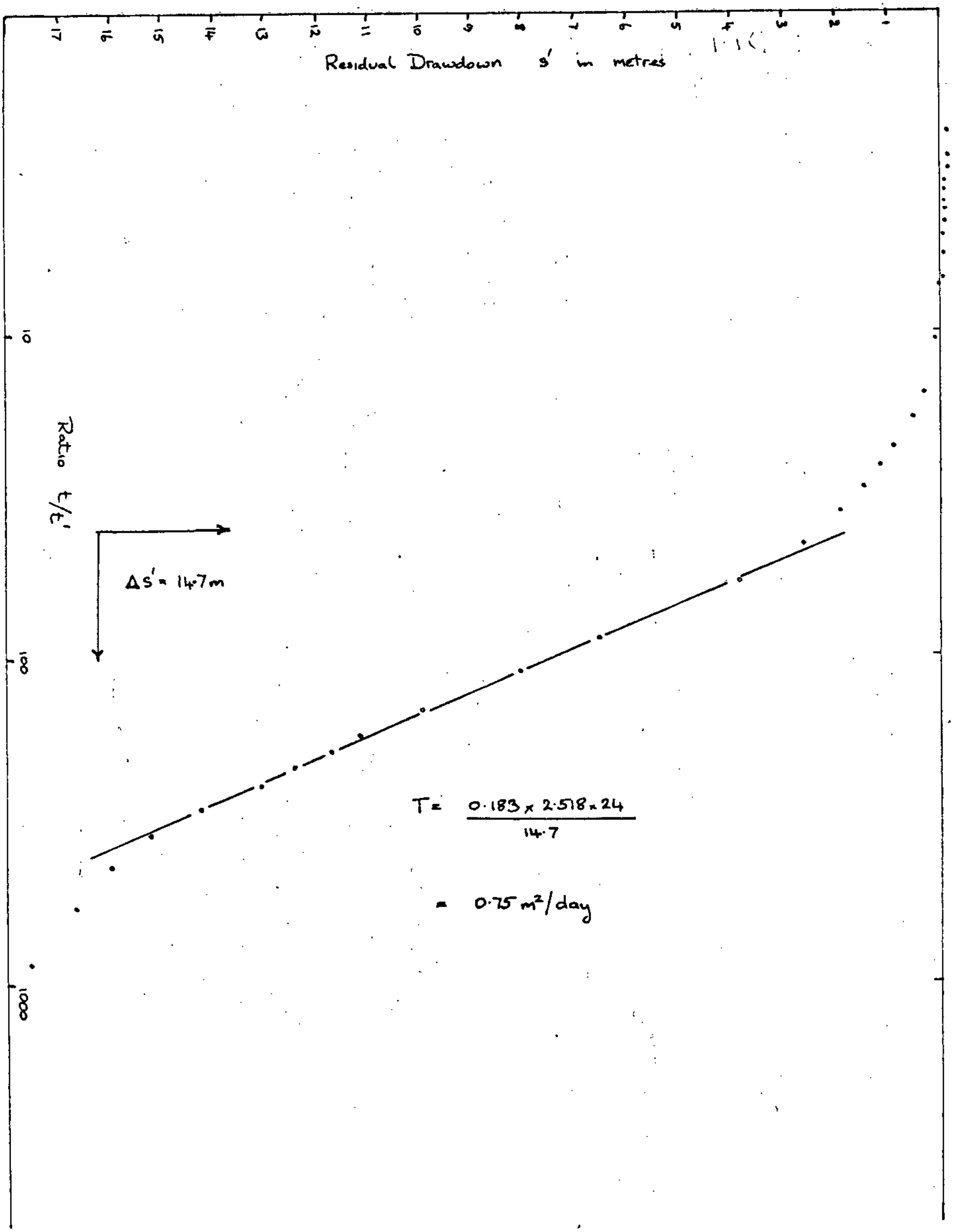
SCALE	DATE	DRAWN	Drawing Number
			FIG.1



Wadi Lansab: Residual drawdown analysis
Test Well No. 1. Production Well data.

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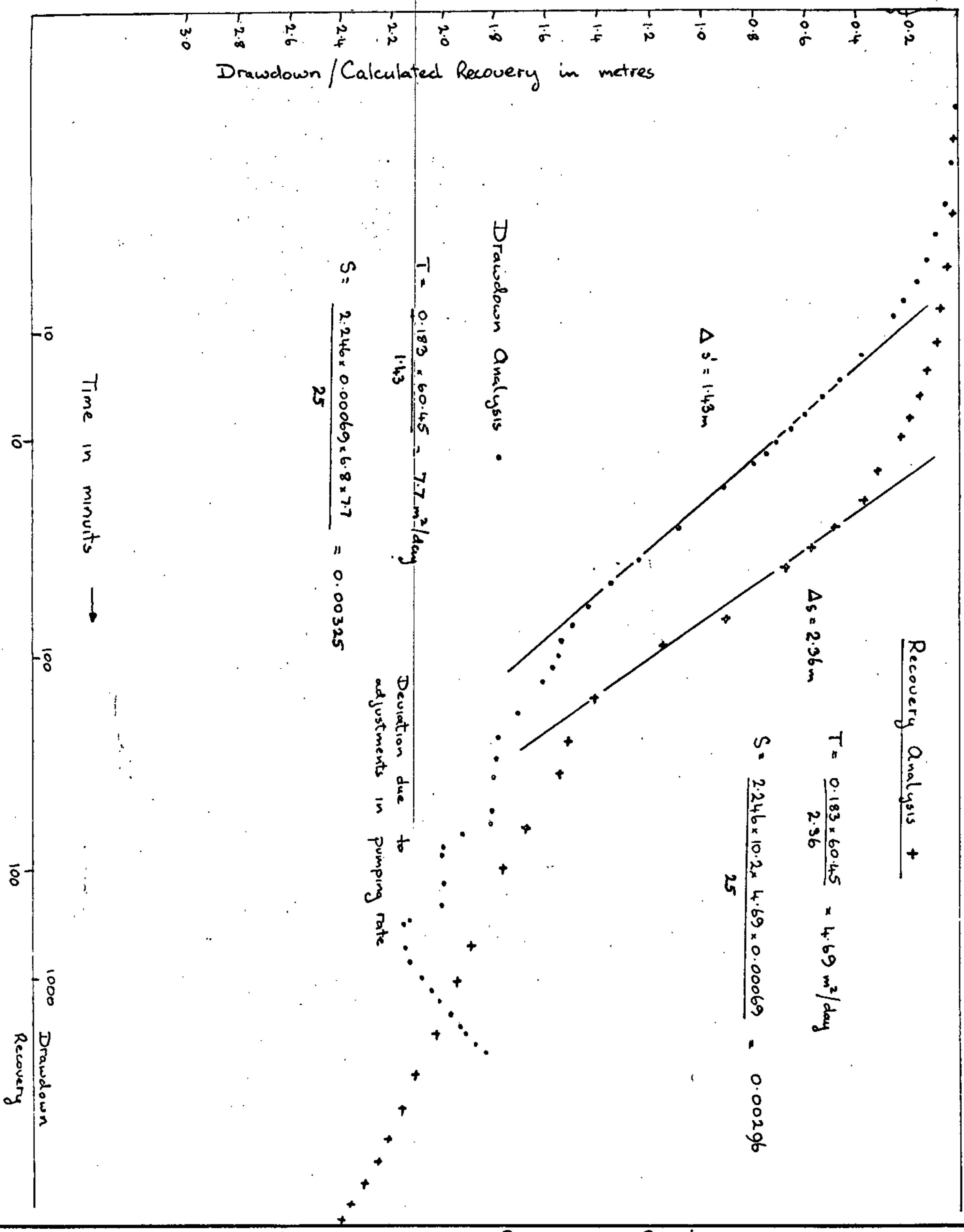
SCALE	DATE	DRAWN	Drawing Number
			FIG. 2



Wadi Lansab — Drawdown and Recovery Analyses
Test Well No 1. Observation borehole data.

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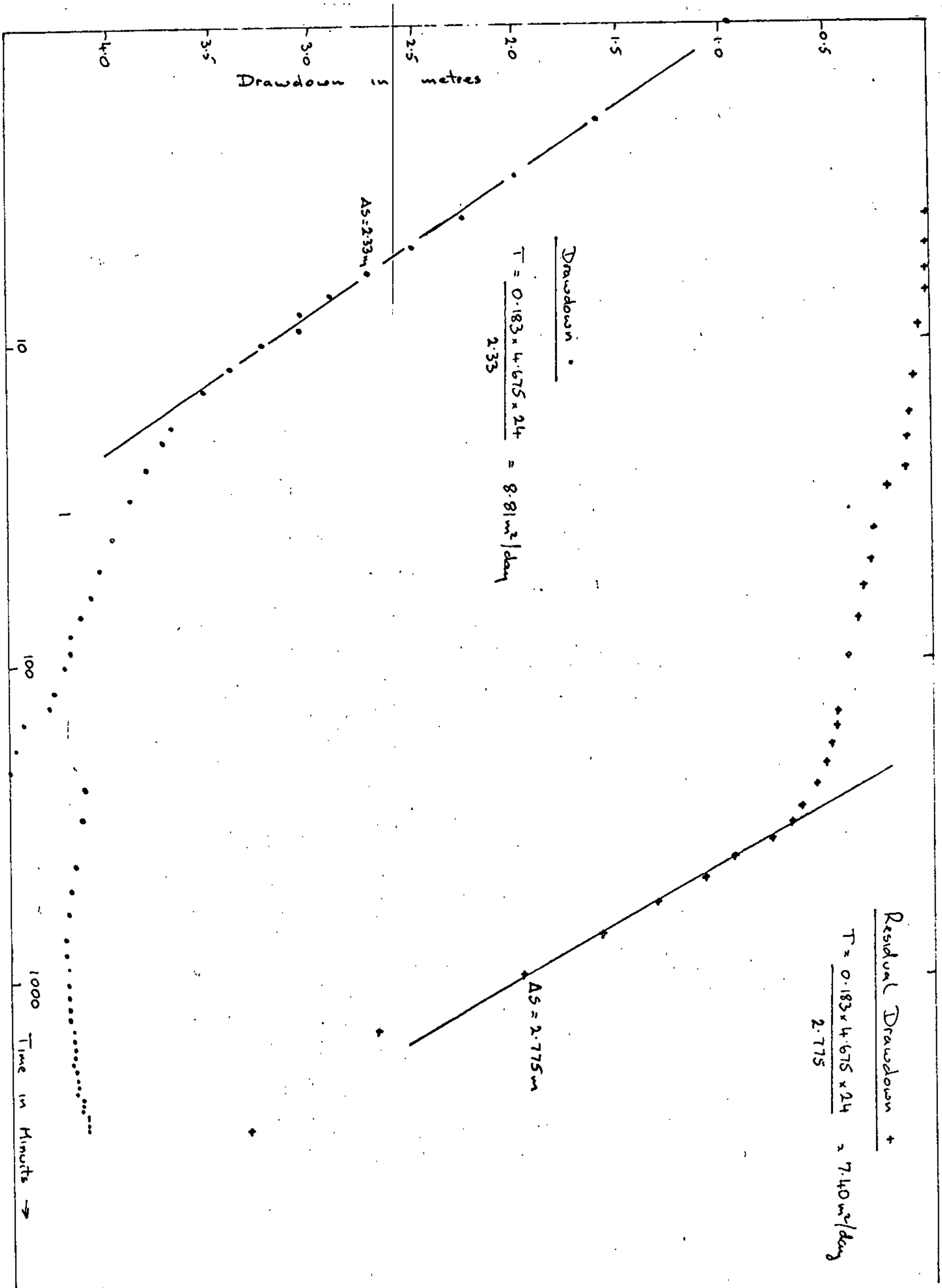
SCALE	DATE	DRAWN	Drawing Number
			FIG. 3



Drawdown and Residual Drawdown

Wadi Lansab Test Well No 3. Production Well Data.

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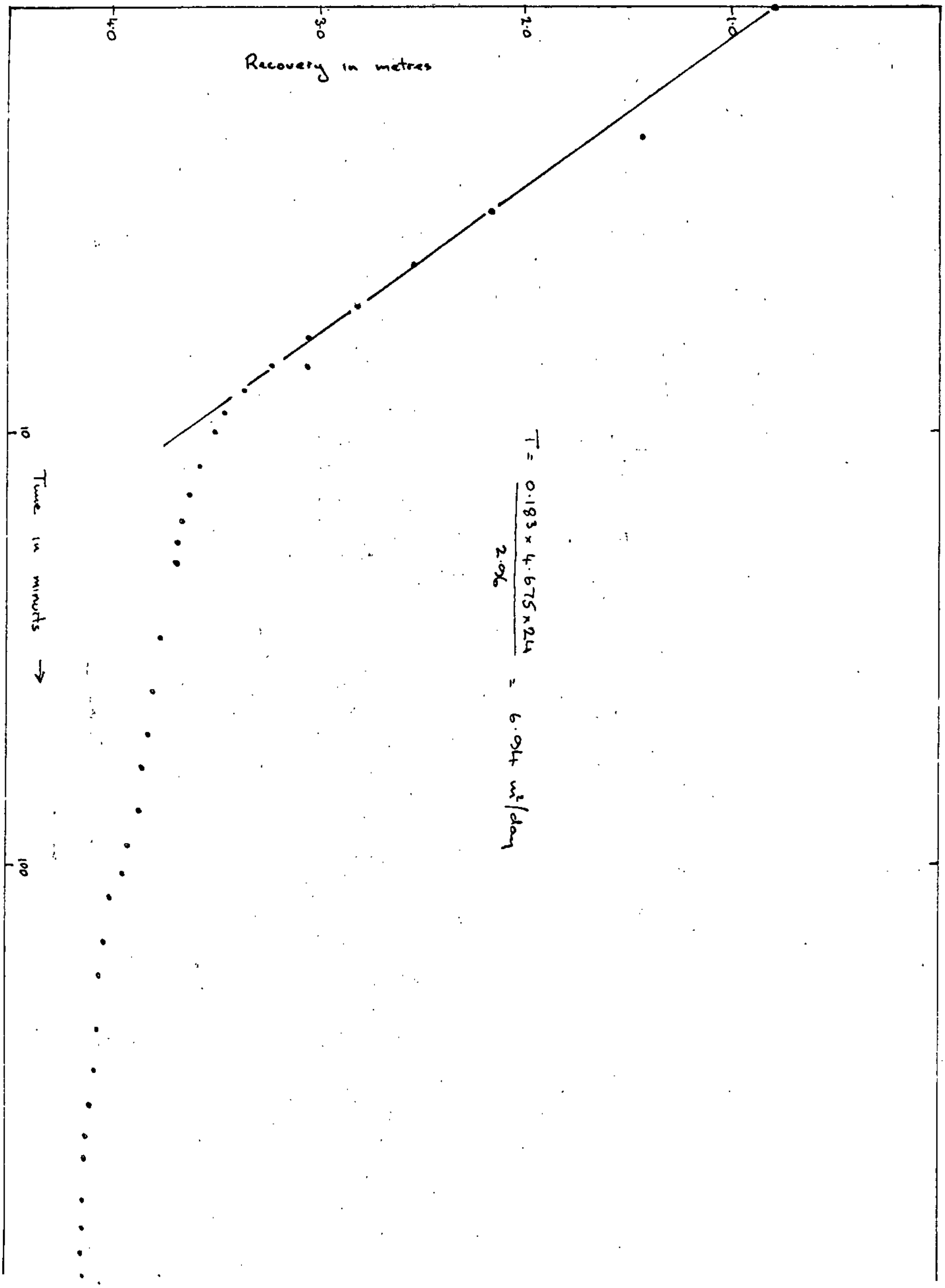
SCALE	DATE	DRAWN	Drawing Number
			FIG. 4



Wadi Lansab

Recovery Analysis
Test Well No 3. Production Well Data.

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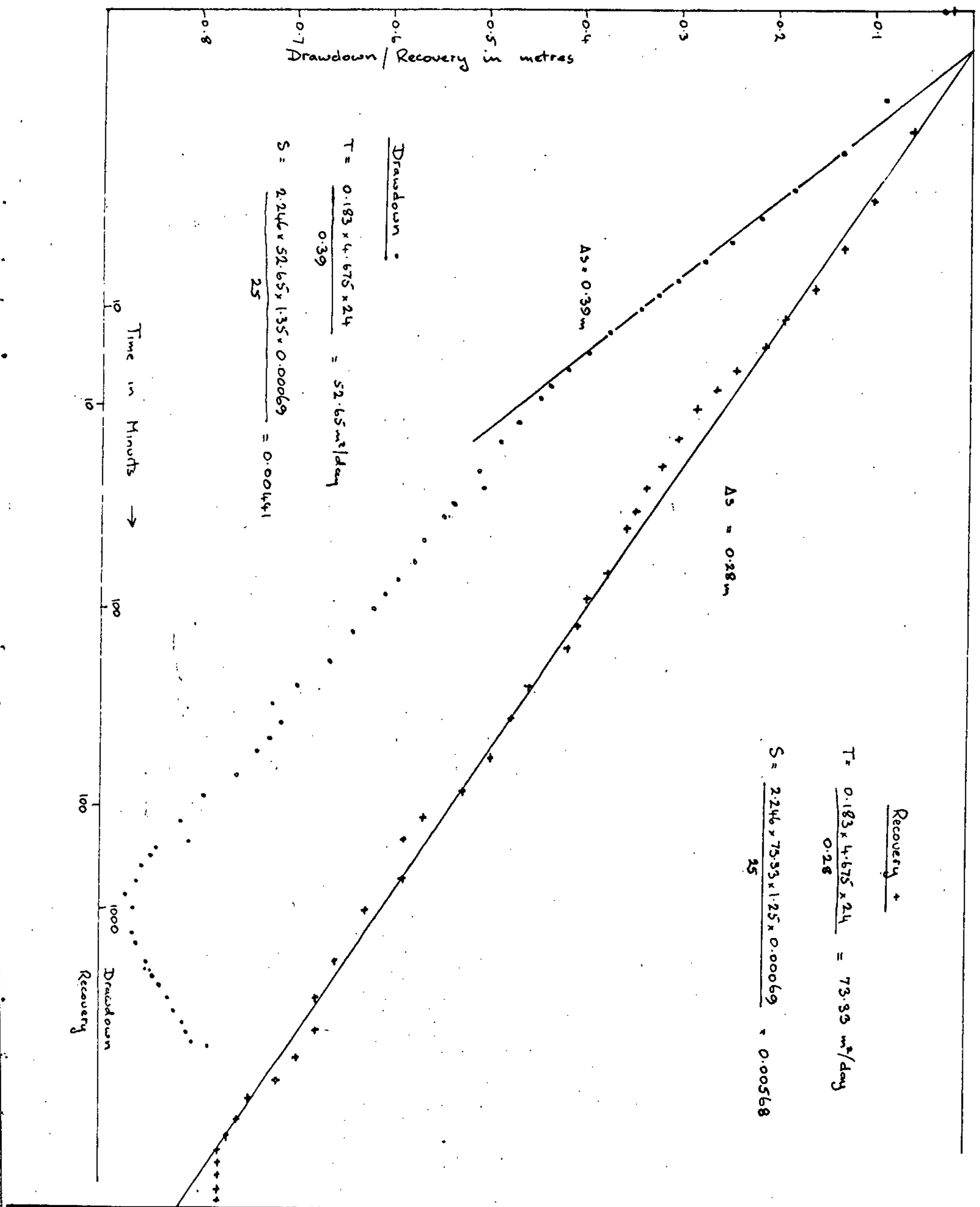
SCALE	DATE	DRAWN	Drawing Number
			FIG. 5



Wadi Lansab — Drawdown and Recovery Analyses
Test Well No 3 — Observation Borehole Data

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SCALE	DATE	DRAWN	Drawing Number
			FIG. 6

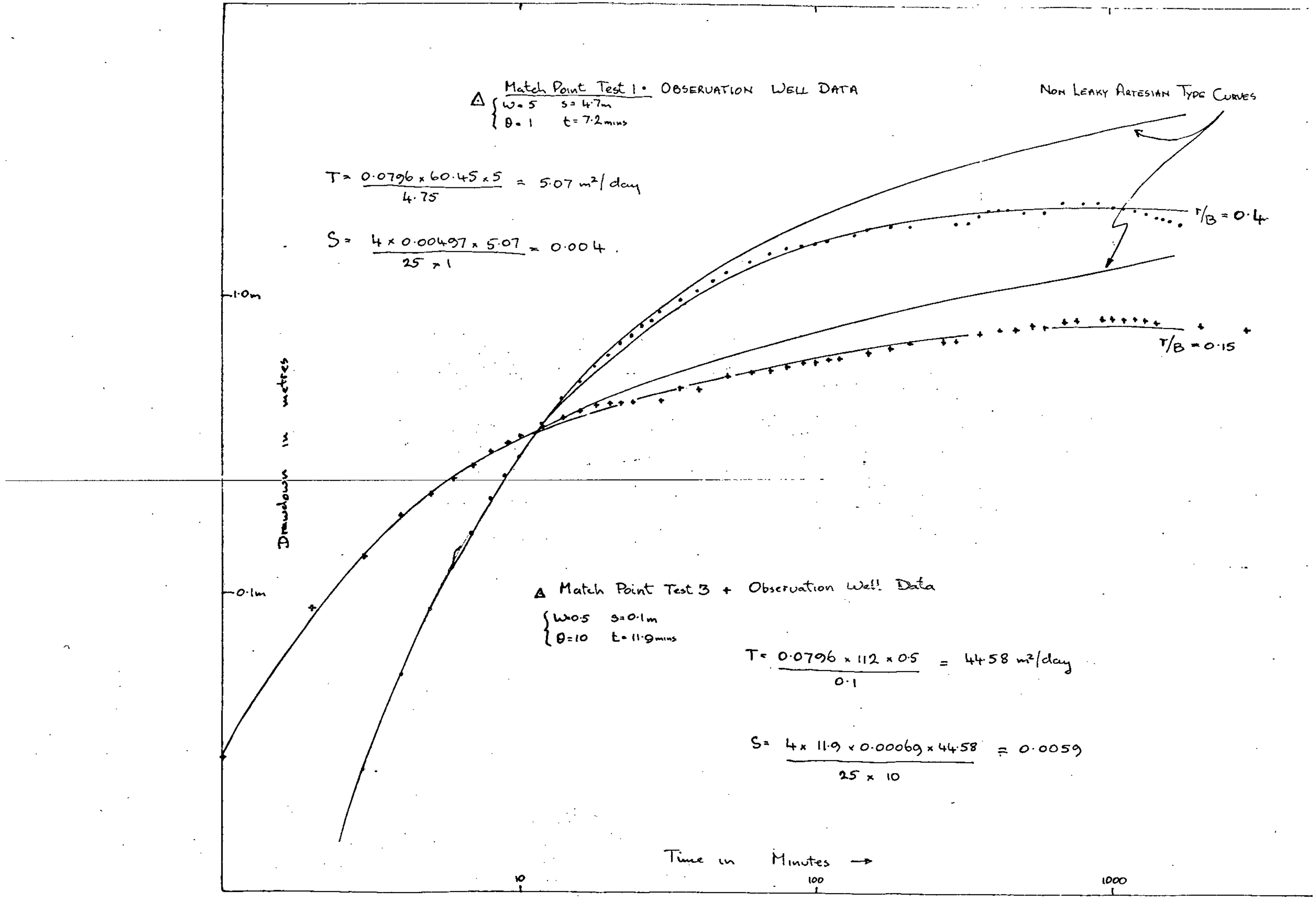
recharge boundary effects. The solutions obtained from similar Jacob straight-line solutions for the observation wells, figures 3 and 6, give average results of 6.2 m^2/day and 63.0 m^2/day. We consider that these results are better than the actual field transmissivity owing to the fully perforated casing and we are inclined toward the pumped well estimates as being more accurate.

Figure 7 shows the time/drawdown relationships for the observation wells. The early data fit the non-leaky type curves but deviations occur after about 15 minutes to give approximate matching of leaky artesian curves of r/B equal to 0.4 and 0.15. Solutions give T values of 5.1 m^2/day and 44.6 m^2/day which are in good agreement with the Jacob straight line solutions for the observation data.

Storage coefficients have been calculated from the observation well data. Values from 0.3% to 0.6% were obtained although the absolute validity of these must be questioned in view of the well design. The results, the first test estimates of storage, appear reasonable. They could indicate either a poor water table aquifer condition or a leaky artesian situation.

3.4 Discussion of Results

Although solutions obtained from pumping well data are likely to be influenced by such problems as fluctuations in pumping rate, well development during pumping, and various difficulties in measuring water levels, the results obtained are comparable with those from numerous other Batinah pumping tests in similar aquifers. The observation well results become more realistic if considered in terms of the hydraulic conductivity (permeability) which can be approximated by dividing the transmissivity values by the screened lengths of the individual wells. Site 1 yields values of 0.1 m/day or 0.2 m/day



Wadi Lansab: OBSERVATION WELL DATA.

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SCALE	DATE	DRAWN	Drawing Number FIG. 7.

while site 3 produces values between 0.9 m/day and 2.0 m/day.

Similar analyses of other tests in the Batinah give values of between 0.1 m/day and 3.0 m/day for wells with screens set in the "clayey gravel" type of aquifer lithology. The better producing wells normally have a production aquifer comprised of the clay-free, uncemented type of gravels found only above the water level in the Wadi Lansab. Conductivities of up to 50 m/day have been recorded in this type of lithology and we suggest that if significant recharge could raise the water level in the Wadi Lansab by 2 or 3 metres, much better yields could be obtained. Unfortunately we do not have any data to suggest that such a recovery could occur when the current drought is over and we interpret the test results as indicating that the Lansab gravels comprise a poor aquifer of little major economic value.

The slightly better results obtained at site 3 are compatible with the relatively clay and cement-free gravels of the eastern side of the wadi. An optimistic interpretation might conclude that these gravels occur as a buried channel of relatively large dimensions. However it is equally possible that the boreholes are located in a small pocket of gravel of very limited extent and there is not sufficient detailed experience available from any similar location in the Batinah to indicate which interpretation is the most likely. The geophysical survey of the area should enable some well founded interpretation to be made.

The identification of the aquifer as a possible leaky-artesian situation warrants further comment. The pumping tests were not of sufficient duration to indicate whether a true leaky-artesian aquifer exists, and a water table condition with delayed yield could equally well occur. Leaky-artesian aquifers have been studied mainly in situations where clearly defined aquifers and aquicludes have been recognised on geological grounds. Generally the sediments of the Batinah seem to comprise a multi-layered aquifer complex of permeable and less permeable lenses of limited extent. In this situation the vertical permeability will be very small by comparison with the horizontal permeability and a delayed yield effect could be produced.

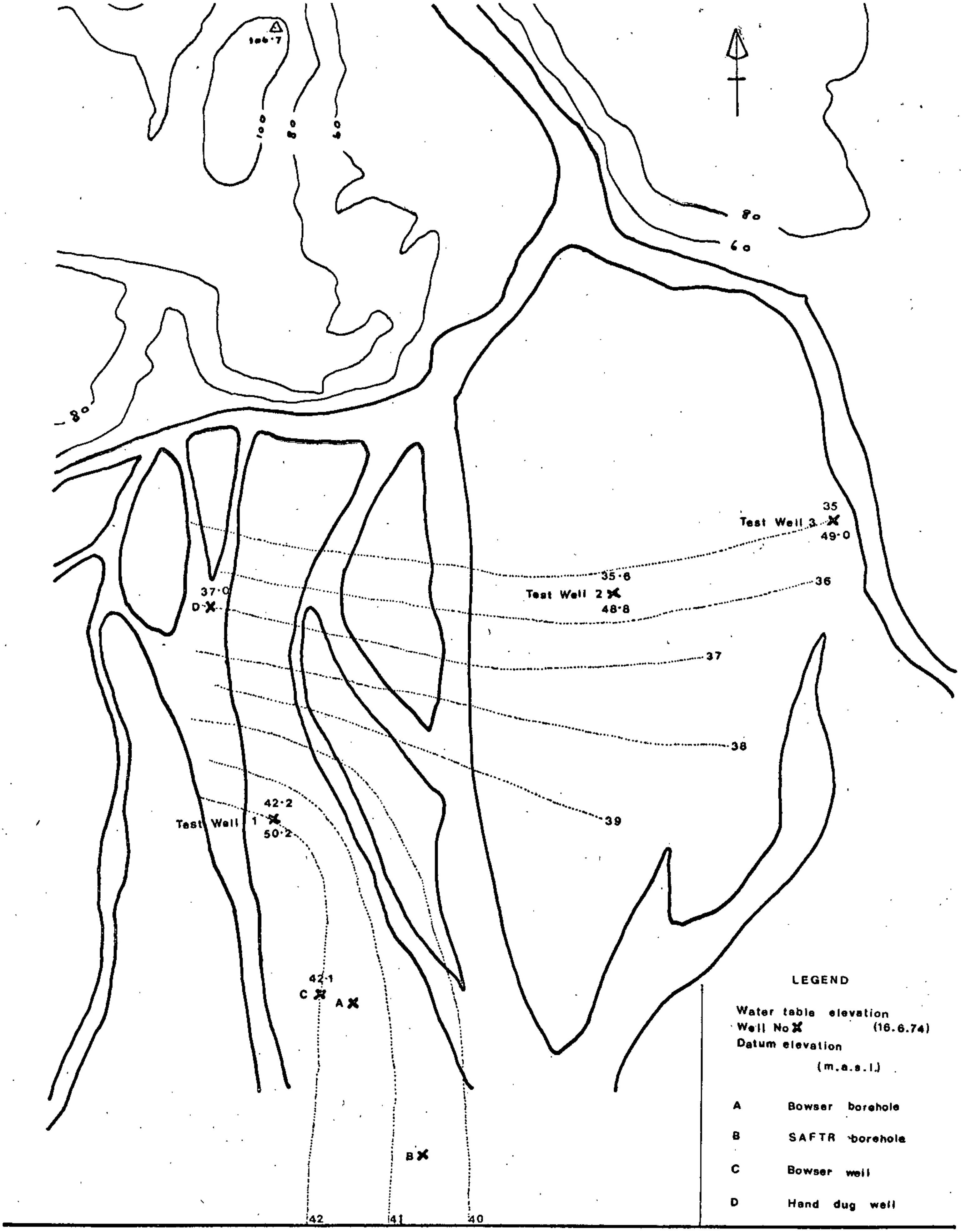
Longer and more carefully controlled pumping tests would be needed to determine the true aquifer state. Irrespective of the results of longer testing the estimates of transmissivity and hence of permeability are unlikely to change. However the determination of the storage coefficient at about 0.5 percent could be a major underestimate despite the apparent consistent results shown in Table 7.

4. Groundwater Resources

An estimate has been made of the availability of groundwater in the Wadi Lansab. It is based upon groundwater flow across the + 35 m water level contour as shown in Figure 8. The water table map has been constructed from field data collected while some boreholes were in production. The west to east gradient in the southern area may not therefore be such a strong feature of the natural flow pattern although the possibility exists of a buried channel between the SAFTR Borehole and site 3.

The most optimistic estimate that can be made is based upon a 40 m thick uniform aquifer having a hydraulic conductivity of 2 m/day ($T > 80$ m^2/day). Under these conditions groundwater flow would amount to about 1,300 m^3/day (0.5×10^6 m^3/annum). A more realistic model would consist of a buried channel of about 100 m width having a hydraulic conductivity of 2 m/day as compared with a value of 0.2 m/day over the rest of the wadi. Groundwater flow in the buried channel area would amount to 160 m^3/day and to 112 m^3/day elsewhere, giving a total flow of 0.1 x 10^6 m^3/annum.

These estimates give some indication of the general availability of groundwater under dry weather conditions. Very little water is present in the alluvial sediments and the water table map is probably a reasonably accurate representation of a major cone of depression around the original abstraction wells and boreholes. If additional boreholes are considered to be necessary it may be possible to develop a greater proportion of the total groundwater from sites in the vicinity of test borehole 3. There might also be some merit in considering the western edge of wadi between the Bedu well (site D in figure 8) and the limestone outcrop.



WADI LANSAB - WATER TABLE 16.6.74

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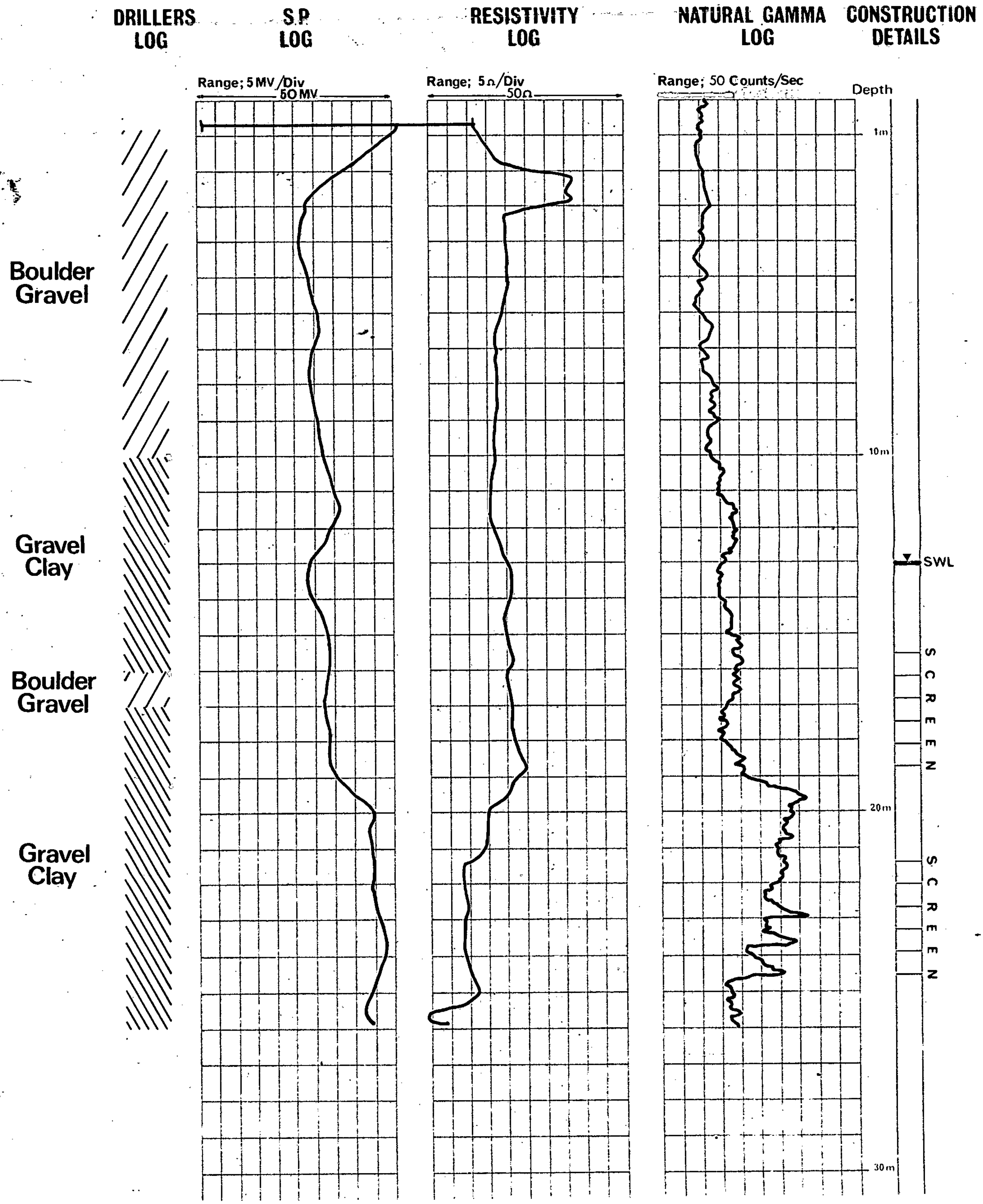
SCALE	DATE	DRAWN	Drawing Number
1:5,000	6.11.74	SFP	FIG 8

Figure C

Borehole Logs — Wadi Lansab Experimental Drilling

Borehole number :-T.W.2

Logged by D.J.Roos
Date :-20.3.74



Borehole Logs — Wadi Lansab Experimental Drilling

Borehole number :-Obs.2

Logged by D.J.Roos
Date :- 12.3.74

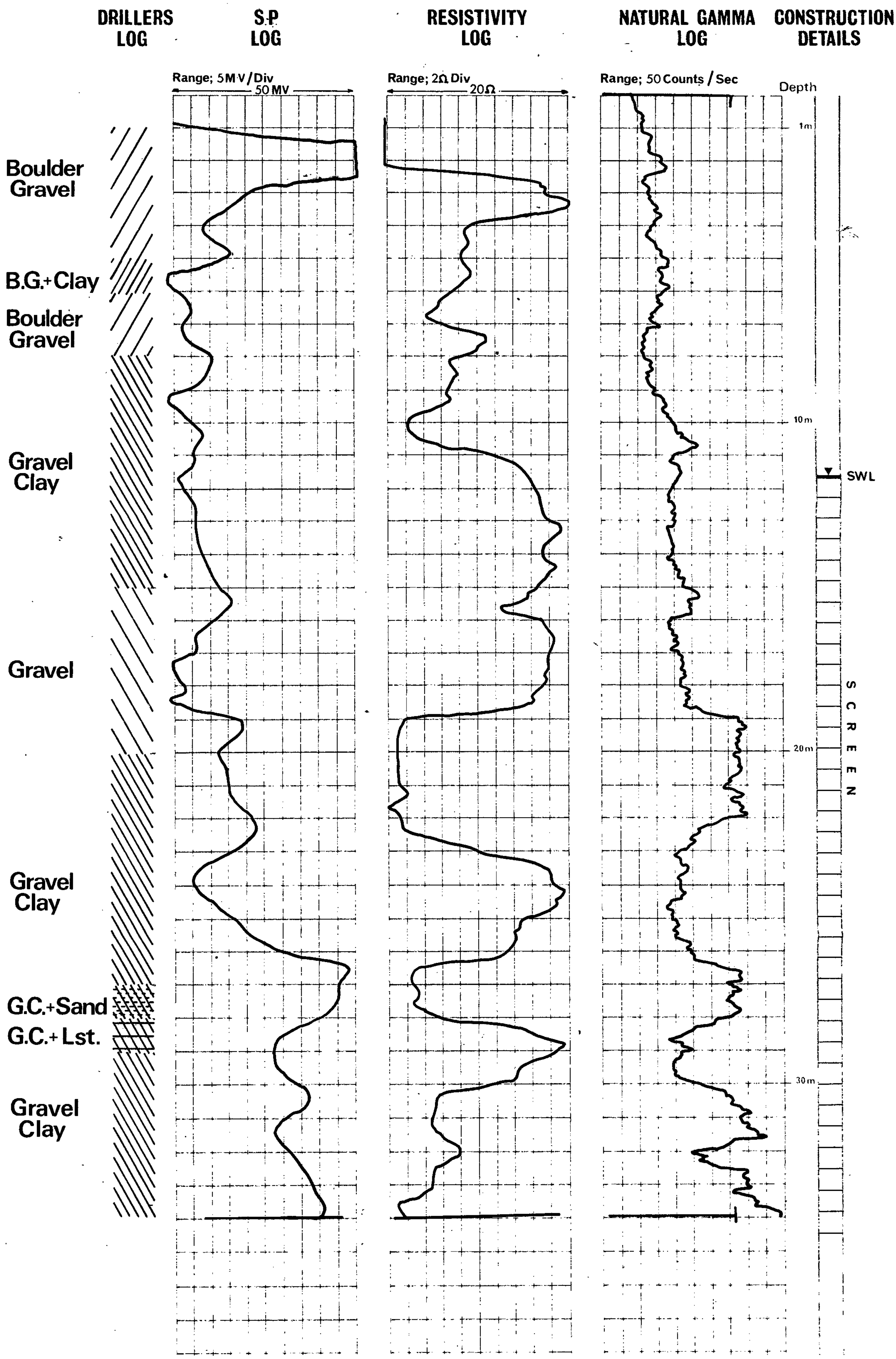


Figure A

Borehole Logs — Wadi Lansab Experimental Drilling

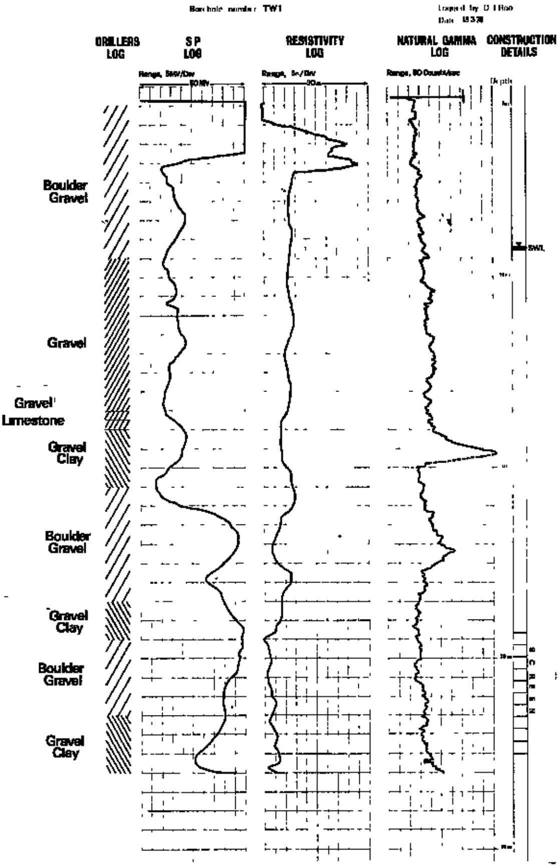


Figure 8

Borehole Logs — Wadi Lansab Experimental Drilling

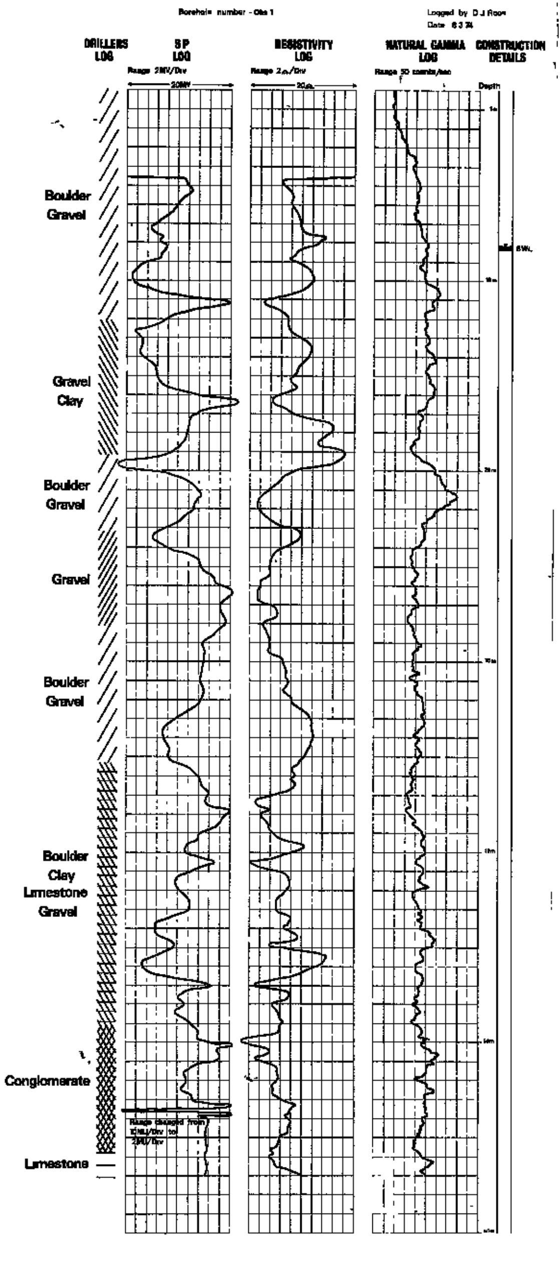
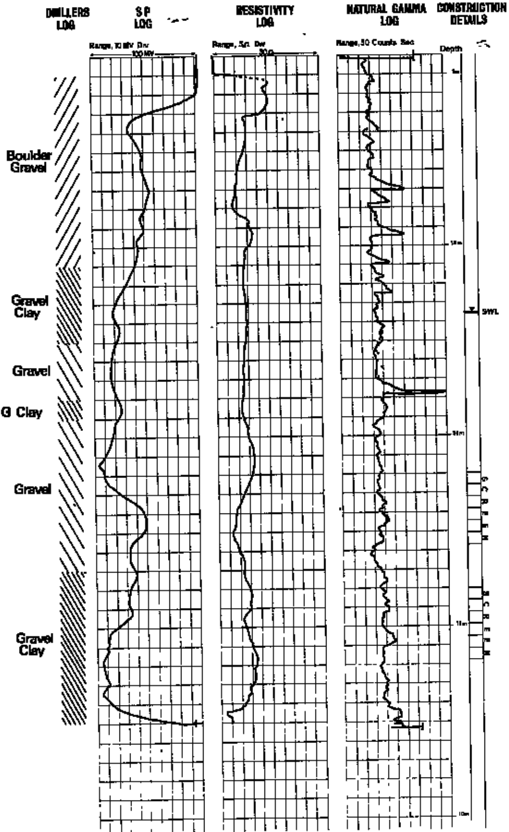


Figure 1

Borehole Logs — Wadi Lansab Experimental Drilling

Borehole number TW3

Logged by D J Ross
Date 27.3.78



Borehole Logs — Wadi Lansab Experimental Drilling