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Natural Environment Research Council

British Geological Survey

HYDROGEOLOGY

RESEARCH GROUP

BASEMENT AQUIFER PROJECT

Progress Report for 1987-1988

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PROGRESS REPORT FOR 1987-1988 : BASEMENT AQUIFER PROJECT

E P Wright

1. BACKGROUND TO PROJECT

1.1 Hydrogeology of Crystalline Basement Rocks and Reasons for Focus

Crystalline rocks have a widespread extent, approximately 30% in global cover, and are of particular importance in the tropical and subtropical regions of Africa, South America and South Asia (Figure 1.1). They occur in a wide variety of physiographic and climatic regions.

Current and planned developments of crystalline rock aquifers are on a large scale and overall very costly. Because of the generally low productivity of boreholes and wells in these aquifers, development is mainly for rural water supply using a point source distribution. Basic service cover (25 lcpd) for Africa's 360 million people averages 38% and includes only 26%* of the rural population. Up to a million water points may be needed to simply meet Decade basic requirements with costs in the range 10-20 thousand million dollars. It is estimated that the majority of the rural population of Sub-Saharan Africa will have to rely on groundwater from basement aquifers for basic domestic supply.

To summarise the reasons for the importance of the basement aquifers: widespread extent, relatively low cost of exploitation because of shallow depth to groundwater; in many areas no alternative sources of supply.

1.1.1 Key issues relating to development.

(i) Shallow depth: increases vulnerability to pollution but groundwater as compared with surface water does have natural protection against pollution.

(ii) Relatively small storage in thin, extensive but frequently discontinuous aquifer systems. Hence vulnerable to reduction in recharge which may be associated with climatic trends or land use changes. Aquifer occurrence closely associated with surface vegetation and soils and climate. However, even this limited storage does have some protection against climatic cycles of short duration which would have a major effect on surface water sources.

(iii) The borehole failure rate is at present typically of the order of 30%. This represents a major financial consideration.

(iv) Maintenance of boreholes and pumps is an increasing problem with the increasing scale of development. The World Bank Global Handpump Project designed to produce a VLOM (village level of maintenance) pump recognises this problem to some extent but there are other issues.

* 1983 Water Decade assessment

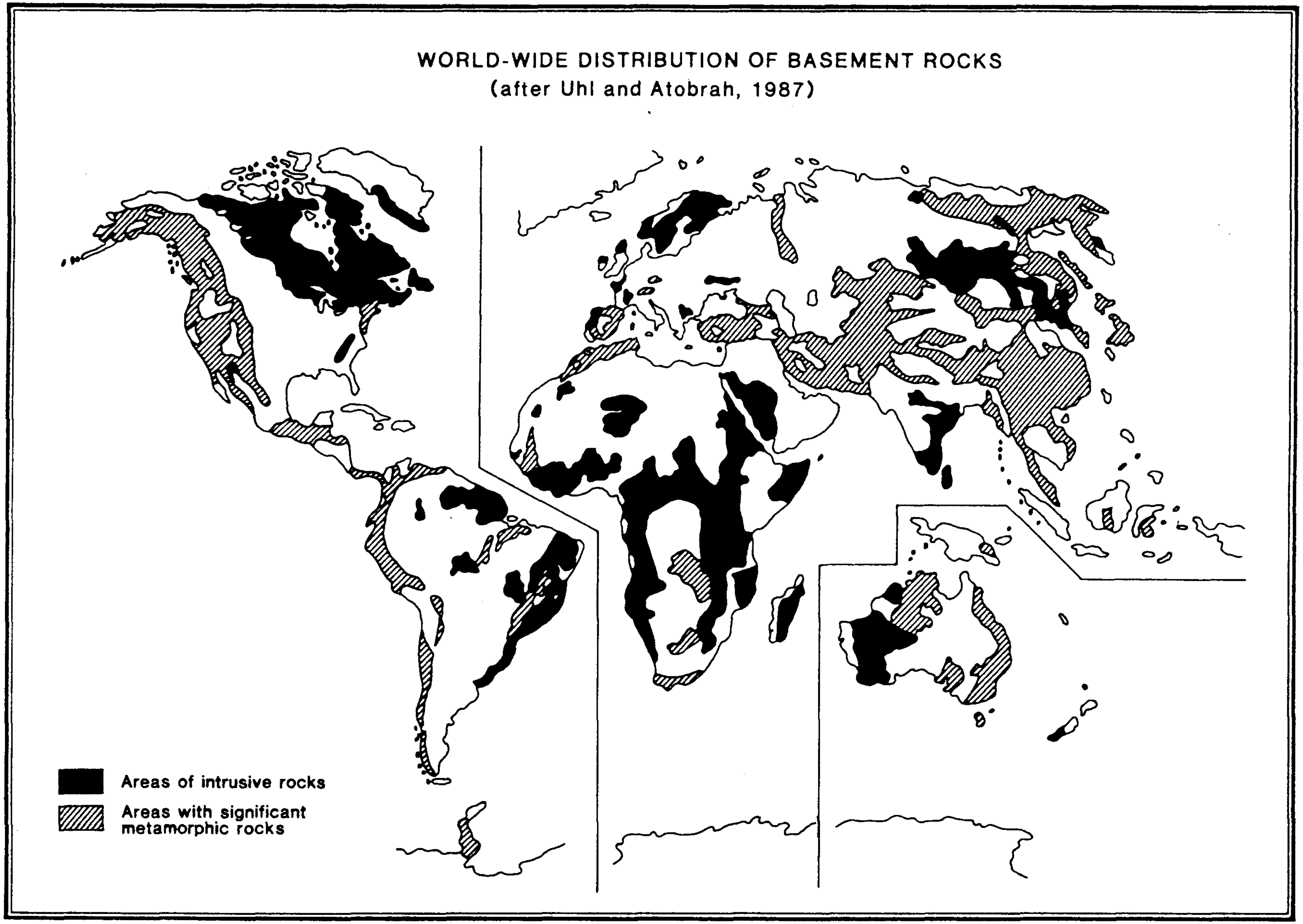

WORLD-WIDE DISTRIBUTION OF BASEMENT ROCKS
(after Uhl and Atobrah, 1987)
Areas of intrusive rocks
Areas with significant metamorphic rocks

Figure 1.1

(v) Relevant Questions: Is the present method of development for rural water supply the best method? Are there circumstances in which some form of piped distribution would be more convenient and also cheaper? Can the risks of deterioration of the shallow groundwater resource in relation to climatic or land use changes be evaluated and to what extent prevented?

1.1.2 Resource potential.

Current and planned developments are mainly to provide point sources of supply for rural communities, using water points fitted with handpumps. This development is partly related to economics and partly a result of the low productivity of boreholes/wells in basement aquifers.

Total abstraction for a typical rural population in the savanna region of Africa is equivalent to less than 1 mm/a recharge to the regional area. There is evidence that actual recharge is considerably larger, perhaps up to 150 mm/a in areas with rainfall in the range 700-1000 mm. Aquifer discharge is by groundwater runoff (a smaller component) and by groundwater discharge by evapotranspiration (the larger component).

These surplus amounts could be made available for other usage, notably urban supply or small scale irrigation if abstraction is feasible and cost effective.

1.2 The Need for Research

The issues raised above are clear demonstration of the need for research.

The studies on crystalline rocks will overlap to varying extent onto other rock types, notably volcanic and consolidated sedimentary rocks. There are significant differences between basement and these other aquifers which need to be highlighted, most notably the nature and extent of the weathering zone in the former.

1.3 Current Research

Systematic experimental and analytical studies are in progress in a few countries on groundwater occurrence and flow in fissured rocks. The studies are mainly in the context of geotechnical investigations: dam sites, tunnels, mine dewatering, and now latterly radioactive waste disposal. Most of these studies are being carried out in shield areas in high latitude countries.

Most current research comprises statistical and general observational studies relating primarily to borehole locating and borehole yields in basement rocks and usually associated with water supply development projects.

The former studies have some relevance to water supply and hydrogeology but to a restricted extent and with more applicability to water supply in the high latitude regions where there is a general absence of the weathered overburden (regolith) which is typical of the tropical regions. The studies in the second group are inevitably constrained by the immediate needs of development - time and a concern for costs. Our own programme of research is an attempt at more systematic studies which focus on particular issues and problems. Ideally would wish to combine these studies with development programmes to obtain a better mix.

1.4 BGS/ODA Research Programme

The British Geological Survey in association with national organisations in Zimbabwe, Malawi and Sri Lanka is currently engaged on research into basement hydrogeology. Africa is the continent of main emphasis because of the particular importance of the basement aquifers. Zimbabwe, Malawi and Sri Lanka were selected for special studies because of the predominance of basement rocks and our other involvements there.

1.5 Research Programme Summary

State of the Art Reviews on the hydrogeology of basement aquifers have been prepared on the following topics:

(i) The weathering profile
(ii) The application of surface geophysical techniques
(iii) The role of geochemistry
(iv) The use of remote sensing techniques

Simultaneously with the preparation of these desk studies, detailed questionnaires were sent round to all the countries in Africa which had a significant basement outcrop area. Replies were received from seven countries (Kenya, Tanzania, Malawi, Mozambique, Zimbabwe, Botswana and Ghana). A summary review of the responses has been prepared and despatched to all countries participating. The questions were designed to obtain factual data and the main concepts and development progress. Certain of the more important issues are listed below.

(i) Geophysical techniques are used in most countries for borehole siting.

(ii) Borehole success rate, usually rated at 0.25 l/sec yield, is typically in the range 50-70%.

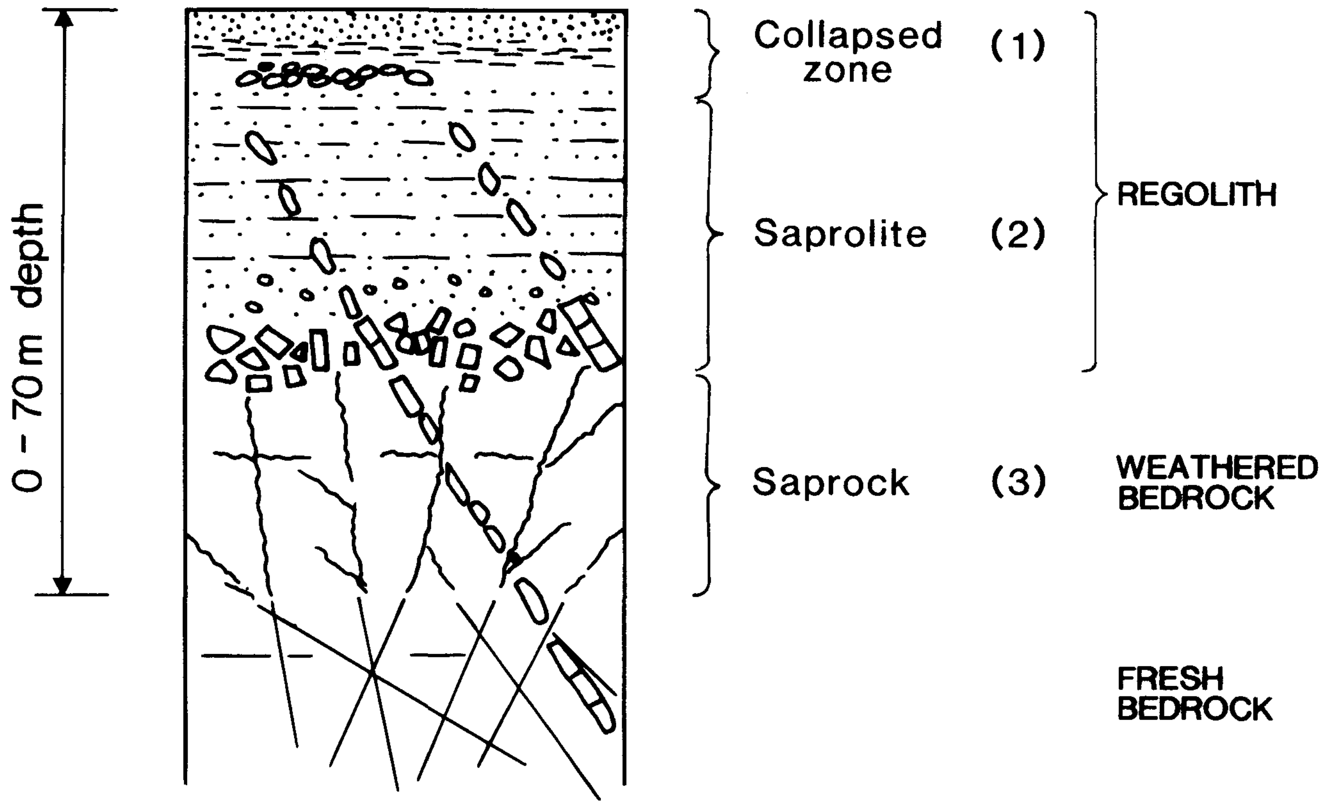
(iii) Recharge rates are estimated as 5-10% of rainfall or in two cases between 50 and 250 mm/a.

1.6 Country Programmes

1.6.1 Malawi.

Discussions will refer frequently to lithological subdivisions of the weathered overburden and these are shown in the accompanying diagram (Figure 1.2). In Malawi, the regolith thickness is typically quite substantial, 20-30 m or more.

Research studies have centred around three project areas (Figure 1.3) which have been amalgamated and extended for a broader regional assessment. The project areas are sites of Malawi Government



Typical weathered profile above crystalline basement rocks.

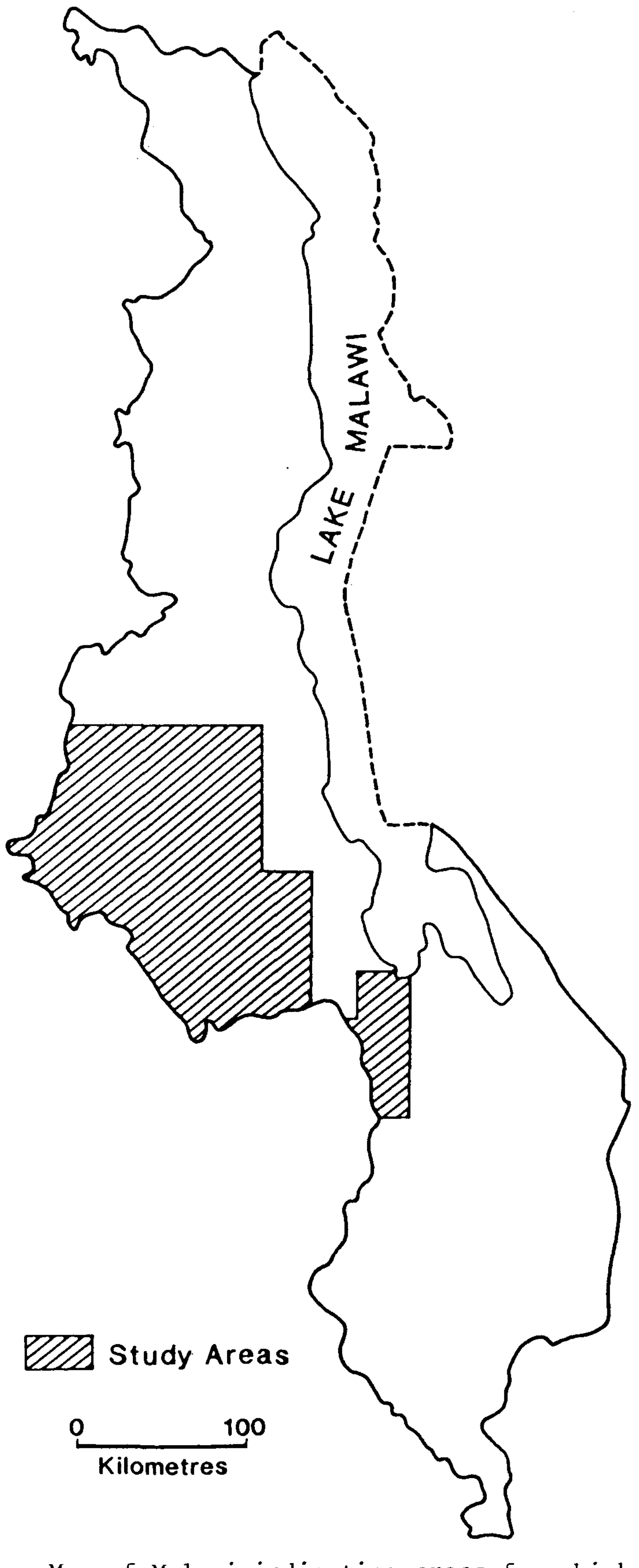
Notes:

(1) Collapsed zone. This may show marked lateral variations but is generally sandy on watershed areas with illuviated clay near the base and sometimes a 'stone line'; on valley slopes, colluvial material accumulates and in dambos, secondary clay minerals predominate. Slope bottom laterites may also occur which can result in perched water tables. Permeabilities vary in accordance with lithology although on watersheds the collapsed zone normally occurs above the water table.

(2) Saprolite is derived by in-situ weathering from the bedrock but is disaggregated. Permeability commonly increases at lower levels due to paucity of secondary clay minerals.

(3) Saprock is weathered bedrock. Original features are likely to be more open than in the fresh bedrock and in the absence of illuviated clay, permeability could be high.

Figure 1.2



Map of Malawi indicating areas for which borehole data has been collected.

Figure 1.3

integrated development projects which differ from more standard dispersed development projects by a concentration of lighter weight drilling rigs, mainly cable tool, with boreholes being completed in the regolith and often sited without the use of geophysics.

Although the success rates in both integrated projects and standard borehole programmes are exceptionally high (90%), the former project boreholes are cheaper but with some indications of marginal specific capacity values. In view of the critical problem of maintenance, the question may be asked whether a handpump operating at deep pumping levels would require substantially more maintenance than one operating at shallow pumping levels. Maintenance problems in the past were markedly affected by sand pumping but this effect has been recently much reduced by better design of gravel pack.

Summary of research studies:

(i) Problems of water quality (sulphate, fluoride, iron) in basement groundwaters.

(ii) Since boreholes in the integrated project areas are being mainly completed in the regolith, any information on the thickness or lithological characteristics of the regolith which can be derived by indirect means could be of value. Correlations have been attempted with the following features.

- Extrapolation of lineament density patterns into areas of thick regolith which show a paucity of such features in consequence of the thickness of cover.

- Correlation of thickness etc. with terrain analysis which separates the different phases in a main erosional surface.

- Correlation with 'dambo'* shapes, sizes and areal cover.

(iii) Detailed hydrogeological, geological and geophysical studies made in cross sections of dambos in different evolutionary state. Cored boreholes and shallower auger holes have been used as basic lithological control.

- Mineralogy, pore fluid geochemistry and physical properties of core material.

- Installation of two dimensional piezometric network in cross section of dambo to interfluves; subsequent seasonal monitoring of water levels; geochemical sampling in saturated aquifer. Consideration of flow directions and water levels from observed data and mineralogical indications are anomalous.

- Borehole geophysical logging. Spectral gamma and resistivity proved to be the most diagnostic.

* Dambos are flat, seasonally waterlogged valley lands which may or may not have a central stream; they are most common in the savanna plainlands of sub-Saharan Africa underlain by crystalline rocks.

- Surface geophysical correlations by traversing across the same section using seismic, electromagnetic and resistivity techniques.

(iv) Hydrological studies - More extensive dambo surveys using hand augers to obtain data on water levels, fluid geochemistry and near surface lithology. Regarded as exploration tool when high sulphate waters anticipated on interfluves. Vegetational and surface soil indicators (termite mounds, groundwater discharge patterns observed).

(v) Catchment studies - Thirteen existing gauged catchments selected in Malawi from total network to give range of basement rocks and rainfall variation. Other features noted include areas and types of dambos. Monthly sampling of runoff and rainfall for geochemical analysis. Chloride to provide recharge indicators and other ions as indicators of rock weathering interactions. Surface runoff and areal rainfall data will be analysed with main emphasis on low flows in order to obtain any correlations with geology (base flow index, recession, multiple regression).

(vi) Data base - Boreholes in an area from Lake Malawi to the Mozambique border which encompasses all three project areas have been computerised and are being used for correlative studies and statistical analyses.

1.6.2 Zimbabwe. (Figure 1.4)

(i) Background

- Regolith generally thinner than in Malawi, often less than 10 m.

- Standard boreholes typically cased through regolith and completed open hole or slotted screen without gravel pack in the saprock or bedrock.

- Resistivity profiling and sounding used for borehole siting in combination with air photographs and generally located on an observed lineament.

- Highest success in lower lying areas and some correlation of yields with main basement rock groups, highest in the basement schists and lowest in the gneisses.

- Drilling depths, c. 60-70 m.

(ii) Borehole exploration and yield studies

- Selection of main study area in southern Zimbabwe (200 x 150 km) at junction of craton and mobile belt. Several thousand boreholes exist, mostly Government drilled, but also including two recent aid-funded consultant projects (EEC/Japanese) with good basic data. Success rates in these two projects have been 60% and 70% respectively (assuming yield of 0.25 litres/sec).

- Borehole (and dug well) data base set up and records edited and computerised.

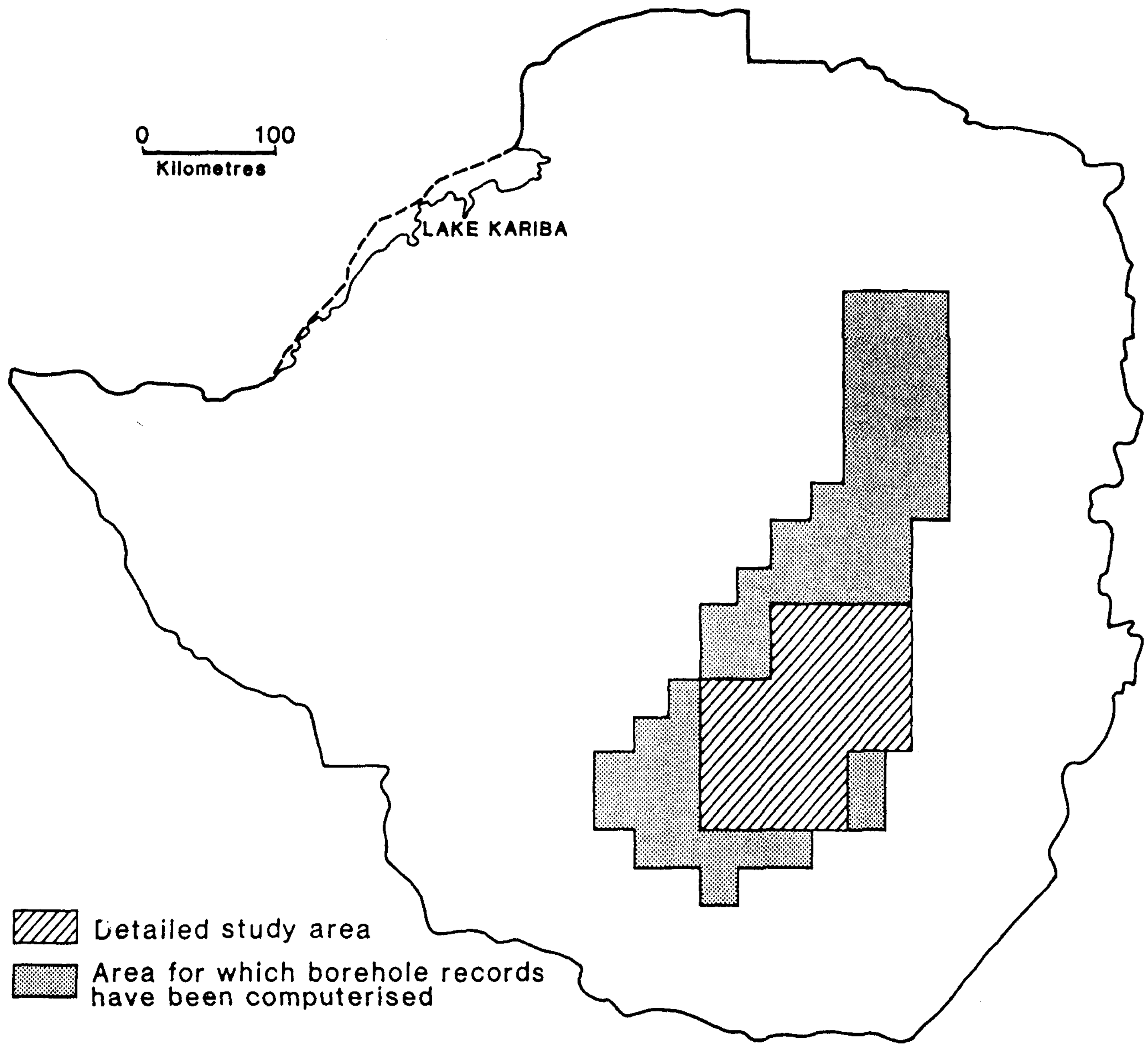


Figure 1.4 Map of Zimbabwe indicating areas studied by BGS.

- Structural analysis of the project area including the production of a lineament map based on satellite imagery (scale 1:250,000) and slope ratios on kilometre square grid.

- Plotted location of all dry and low yielding boreholes and all very high yielding boreholes.

- Selection of study areas which include main basement rock groups (schists, older gneisses and older granites, younger intrusive granites, mobile belt gneisses) and which have a high concentration of dry or low yielding boreholes.

- Study areas subjected to detailed analysis (terrain, air photo, borehole yield and lithology). Geology plotted from any larger scale maps and all boreholes and wells plotted. Lineaments digitised and lineament density maps prepared. Drainage patterns categorised and analysed.

- Borehole sites visited and general hydrogeological and structural observations made.

- Selected numbers used for detailed geophysical surveys with particular emphasis on dry or low yielding boreholes. Surface and borehole geophysical techniques used. The objectives of the surveys were as follows: (a) to allow comparisons between the different techniques, (b) to ascertain whether more detailed geophysical studies would have resulted in either a rejection of a dry borehole location or a small but significant shift in the precise site, (c) to give particular consideration to sites away from valley lines where there is a higher proportion of dry holes but locations often more conveniently sited in relation to the village, (d) to identify width (and orientation) of fracture zones and whether features in the geophysical responses gave any indication of fracture fillings which could affect aquifer parameters and (e) to ascertain whether regolith thickness varied over the fracture zone.

(iii) Catchment studies - Fourteen catchments selected with similar criteria as those described for Malawi but with greater climatic variability and a wider range of erosional surfaces (African, Post-African, Pliocene).

(iv) Dambo discharge analysis - A dambo being used for an agricultural study in which rainfall-runoff-evaporation is being measured. Studies expanded to include hydrochemistry of rainfall and runoff but more importantly, groundwater discharge areas surveyed by ground radiation thermometers to allow correlation with TM imagery (Landsat V).

(v) Data base - A strip of terrain stretching from latitude 17 30'S to about latitude 21 00'S (Figure 1.4) and incorporating the Masvingo Project area is being subjected to detailed borehole data base analysis in combination with general geology and terrain analysis. The 'strip' also incorporates the recent series of collector wells.

1.6.3 Sri Lanka.

A more limited programme of work was carried out here concentrating on specific objectives in relation to geophysical techniques of exploration and the geochemistry of saline waters.

(i) Geophysical studies

- Comparative use of EM, seismic and resistivity profiling and soundings in determining thickness of regolith and differentiation of sub units.

- Breaks in curves of VES soundings are used locally as fracture indicators. Examination of validity of correlating surface surveys and core drilling.

(ii) Geochemistry - Consideration of the origin of certain saline waters in basement aquifers in Sri Lanka. Thought to be derived from previous climatic epoch which resulted in increasing concentration by evapotranspiration. Study involving age determinations and knowledge of origin may indicate feasibility of remedial actions.

1.7 Acknowledgements

Separate reports on specific topics are being produced by other members of the Basement Aquifer Team and are to be submitted shortly. The emphasis in this report is on the recent drilling programme associated with the Masvingo Borehole Project. The site plans which are included here have been prepared by Dr D Greenbaum as part of his structural studies. The geophysical surveys were carried out by Mr I Smith and Mr M Rains of the British Geological Survey (BGS) and Mr A Mavurayi and Mr C Muzimbaranda of the Zimbabwe Government Ministry of Energy, Water Resources and Development (MEWRD). These were carried out in part during June-July 1987 but also some surveys were made by the two Zimbabwe geophysicists during the period of the drilling programme. Some of the survey measurements are reproduced here. The remainder will be reproduced subsequently in Mr Smith's own report.

The drilling programme was supervised by Mr P Rastall with the drilling crew, including the senior driller, for the Hands-England rig provided by the Zimbabwe Government. The Zimbabwe drilling team must be commended for their very praiseworthy efforts under difficult operating conditions. The BGS drill rig was operated by Mr Rastall and his assistant Mr B Morengwa.

Mr K H Murray and the writer carried out the main field hydrogeological studies, including the radon surveys. The equipment for the latter was obtained on loan from Dr M Crow of the Overseas Geology Division and his help in this matter, which included a full field demonstration, is gratefully acknowledged. The borehole logging was carried out by Mr D Oliver, employed on contract to BGS and he will be providing a separate report.

Finally, acknowledgement should be made to Mr P Sinnett-Jones, Chief Hydrogeologist of the MEWRD for providing essential logistic and administrative support and also to Mr R Sothinathan, the Provincial Water Engineer, for similar provisions in Masvingo.

2. WORK PROGRAMME: 1987-88

2.1 Malawi

2.1.1 Chimimbe dambo.

During 1987-8 there has been some auger drilling, borehole geophysics and in-situ hydraulic conductivity measurements. The auger drilling proved of little value due to the equipment's inability, despite motor power, to drill through gravel bands or stone lines, hard bands and the like. Routine monthly water level measurements were carried out in the Chimimbe (and Chikobwe) piezometer arrays (which commenced in September 1986 by staff of the Ministry of Works).

Some further laboratory studies have been carried out on the mineralogy and pore fluid hydrochemistry of core material from the Chimimbe dambo collected during a previous field season.

Reports submitted on 1987-8 programme:-

Report WN/88/3, February 1988. Hydrogeological Investigations at Chimimbe Dambo, Malawi, in May-June 1987. D J Allen.

2.1.2 Data base.

Work on the data base of the Malawi Study Areas (Figure 1.3) has now been completed and a report is in preparation.

2.1.3 Catchment studies.

A programme of monthly monitoring had been initiated which required the sampling of runoff and rainfall (at one station per catchment) in 13 catchments. Samples are being collected by staff or attached observers of the Ministry of Works. Some of the subsequent chemical analyses are being carried out in the Malawi Government Laboratory and some in the BGS Laboratory at Wallingford. The programme has been poorly implemented with large gaps in the sampling. As full a set as possible was collected by BGS staff during a field visit in July 1987, following on the Basement Aquifer Workshop. Various reports are in preparation additional to the one listed below.

Low Flow Analysis of Selected Catchments in Malawi and Zimbabwe. A Preliminary Report. J Meigh (IH), December 1987.

2.2 Zimbabwe

2.2.1 Data base.

Work has been completed in the Zimbabwe Study Area (Figure 1.4) and a report is in preparation.

2.2.2 Catchment studies.

A similar programme to that outlined for Malawi is in progress in Zimbabwe with sampling being carried out by observers attached to the Ministry of Energy, Water Resources and Development (MEWRD) with the samples being forwarded to the UK for chemical analysis. Flow and areal estimates of rainfall are also being provided to allow rainfall-runoff analysis to be carried out.

2.2.3 Chisengeni dambo study.

A TM satellite image computer compatible tape of the scene which includes the Chisengeni dambo has been obtained from NASA during an overflight in August 1987. The data are being analysed and correlated by correlation with ground measurements of radiation data and hence with Penman calculations of potential evapotranspiration derived from a climate station record on the same site.

2.2.4 Masvingo project.

The main emphasis of the Zimbabwe programme during this last year has been on this particular study and the results of the work is described in more detail in the present report.

1987-8 Reports.

(i) WD/OS/87/15, E P Wright. Report on the June-July 1987 Field Investigations in Masvingo Project Area.

(ii) D H Griffiths, September 1987. Mapping weathered basement rocks in Zimbabwe using a microprocessor controlled resistivity traversing system. A Progress Report.

3. THE MASVINGO BOREHOLE PROJECT

3.1 Background

The Project Area extends over some 30,000 sq km in southern Zimbabwe and straddles the boundary between the Zimbabwe craton and the Limpopo mobile belt. The oldest rocks are in excess of 3500 million years and the youngest include dyke intrusives of Karoo age, apart from some recent alluvial sediments of minor extent. The weathered overburden on the Post African erosion surface which extends over the greater part of the Project Area is relatively thin and most boreholes are completed in the saprock or fractured bedrock. Preliminary details of all the Project Area boreholes are shown in Table 3.1. The low percentage of failed government boreholes must be regarded with some reservation since it is known that not all failed boreholes are included in the records. Despite this possible underestimate the overall mean value of failed boreholes of 34% is close to the general mean of failure rates of basement boreholes in Africa, according to the answers received on a circulated questionnaire to a number of countries.

In order to select areas for more detailed study, all dry or low yielding boreholes were plotted on the 1:250,000 map and also all high yielding boreholes (>1 l/sec). Study areas were selected in the major rock groups (Figure 3.1) which have either a concentration of dry/low yielding boreholes or a concentration of high yielding boreholes.

Lineament maps have been prepared of the study areas using air photographs, and borehole data records have been edited and computerised to allow statistical analysis. Selected data are shown in Table 3.2. These data demonstrate that the highest yields are generally obtained in the area underlain by greenstones or younger granites. Yield of boreholes in the granulite facies of the Limpopo mobile belt are the most varied. Selected study areas have also been subjected to field investigations which have included further geophysical surveys over a number of failed/low yielding boreholes. Some of these holes have also been logged by a range of downhole geophysical tools. These selected study areas are C, E, F, G and J. As can be seen from Table 3.2, success rates range from 60% in Area G to only 31% in Area F.

3.2 Programme Objectives

The main objective of the study is to evaluate the significance of an improved knowledge of the areas of detailed study in terms of borehole success rate and borehole yields. There are various ways in which such results might be expressed.

(i) An increased 'success' rate for the same amount of time spent on siting (3/4 hours per site) and with the standard techniques (resistivity profiling and soundings).

(ii) As above but with different methodology (e.g. electromagnetics or seismic) but no increase in exploration costs.

TABLE 3.1 Details of Masvingo Province boreholes

Sited by	Number of Boreholes drilled	Dry holes	Specific capacity <0.0081/sec/m	Failures c-C2 + c-C3	% Failures	Specific Capacity ≥0.11/sec/m	% high specific capacity
Government	697	90	102*	192	27	319*	46
Japanese	131	42	24	66	50	17	13
Hydrotechnica	370	88	58	146	39	81	22
TOTAL	1198	220	184	404	34	417	35

*Specific capacity data was not available for the government holes, therefore yields of < 0.25 l/sec and ≥ 1.01/sec had to be used instead of the quoted low and high specific capacity values

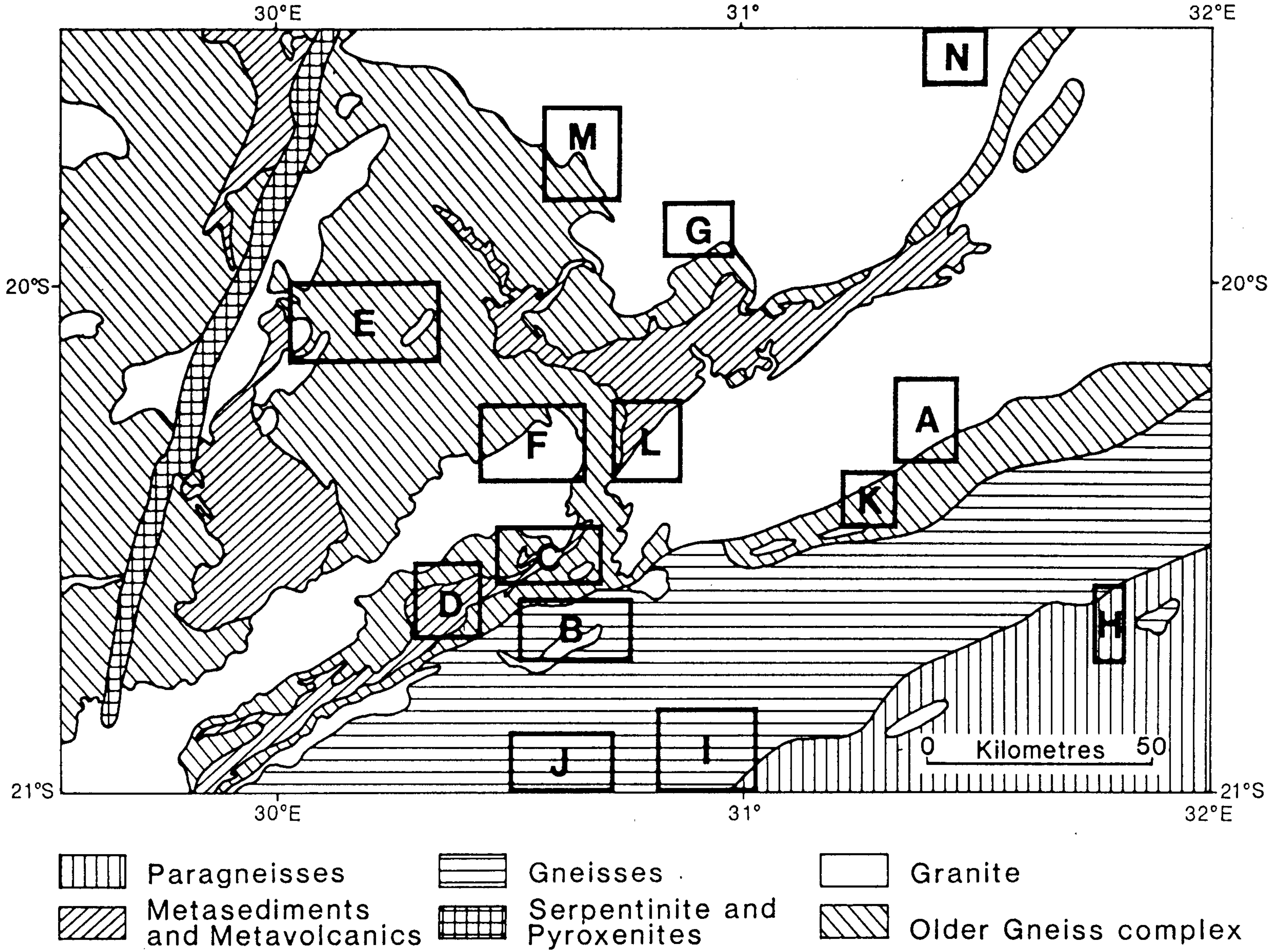


Figure 3.1 Regional geology and locations of the 14 sub-areas in Masvingo and Midlands Provinces, Zimbabwe.

TABLE 3.2 Statistical summary of borehole data for all 14 areas.

Area	Main rock type	Number of boreholes with yield data	Number of dry boreholes	Mean* yield (l/s)	Mean* depth (m)	Mean depth* to base of saprolite (m)	Mean* specific capacity (l/s/m)	Mean* depth to water (m)	Mean* saturated thickness of saprolite (m)	Success Rate (%)† yield ≥0.25 l/s	Success Rate (%)† specific capacity ≥0.008 l/s/m
A	Zimbabwe granite/ older gneiss	18	4	0.496	38.5	18.5	0.100	3.5	15.0	56 (50)	56 (50)
B	Limpopo Belt gneisses	34	8	0.644	45.7	16.3	0.103	10.9	9.0	50 (42)	53 (45)
C	Chibi granite/ younger granite/ older gneiss/green-stone	36	9	0.968	47.1	21.5	0.161	10.9	10.4	58 (49)	56 (47)
D	Greenstones/gneiss	32	8	1.467	46.9	26.1	0.608	17.6	6.6	69 (69)	67 (67)
E	Ancient gneiss	51	18	0.816	44.5	22.9	0.065	15.0	10.9	43 (38)	50 (45)
F	Chibi granite/older gneiss	25	5	0.346	47.9	17.4	0.060	8.5	6.5	32 (31)	41 (39)
G	Younger granite	18	5	1.162	42.9	8.1	0.151	6.2	1.5	67 (60)	60 (53)
H	Limpopo Belt gneisses	9	5	0.210	56.0	36.0	0.003	27.4	24.8	22 (20)	22 (20)
I	Limpopo Belt gneisses	19	6	0.572	51.4	no data	0.028	18.1	no data	32 (32)	32 (32)
J	Limpopo Belt gneisses	34	2	1.314	46.5	22.6	0.068	14.5	7.8	76 (70)	77 (71)
K	Older gneiss	14	1	0.728	41.6	21.5	0.085	5.2	15.3	71 (56)	71 (56)
L	Greenstone/older gneiss/granite	22	1	1.921	44.0	9.5	0.065	8.7	1.5	82 (51)	89 (53)
M	Younger granite/ older gneiss	37	0	1.427	42.1	17.9	0.071	9.9	7.4	92 (92)	93 (93)
N	Younger granite	19	3	1.214	39.0	17.2	0.170	7.1	10.4	68 (48)	79 (56)

* These figures refer to genuine data, and exclude dry boreholes.

† These figures refer to all data, the first number is the success rate for boreholes with yield data and the number in brackets the success rate if the boreholes with no yield data are included and assumed to be failures.

(iii) An increased 'success' rate but with higher exploration costs in consequence of longer time inputs and/or different exploration methodology. Cost-benefit comparisons would need to be made to demonstrate comparative effectiveness.

(iv) Establishing in difficult/marginal areas of a better appreciation of the constraints to water supply and the criteria of development feasibility which may be different from those which are applicable more generally.

Methods (i) to (iii) can be demonstrated most clearly and unambiguously in a development programme in which a substantial number of boreholes are to be drilled. Method (iv) applied more appropriately in the studies being carried out in the Masvingo project area although the results can, it is hoped, be extrapolated more generally.

3.3 Borehole Siting in Zimbabwe in Basement Rocks

The Zimbabwe Master Plan identifies calculated electrical resistivity (from vertical electrical soundings) as the single most important guideline in optimising borehole siting procedures. The following correlations are stated to exist for resistivity values in the weathered overburden aquifers with basement rocks.

< 20 ohm m	Clays with limited groundwater potential	x
20-100 " "	Optimum weathering and optimum groundwater potential	xxxx
100-150 " "	Medium conditions and medium potential	xxx
150-250 " "	Little weathering and poor potential	xx
>250 " "	Negligible potential	x

The Master Plan quotes Astier (UN Report) that the following relationship has been demonstrated by extensive research.

Thickness of Overburden	Success Rate	
<10 metres	0%	x
10-20 metres	25%	xx
20-25 metres	45%	xxx
>25 metres	70%	xxxx

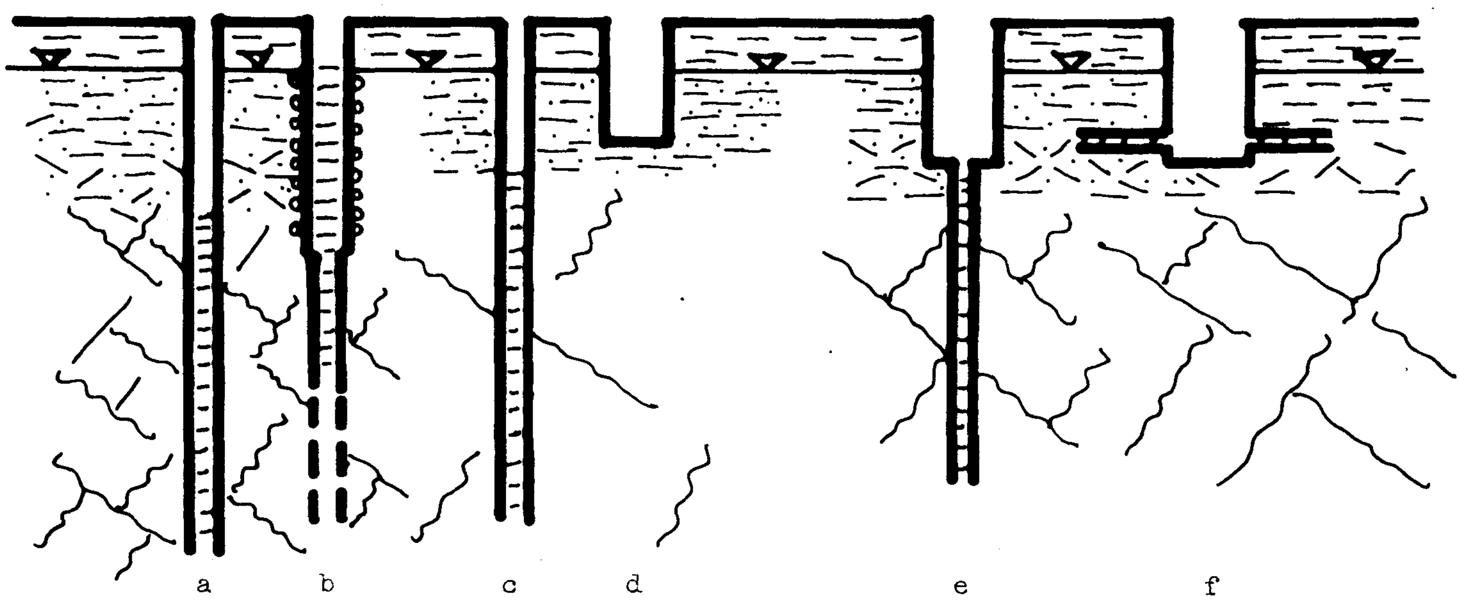
These two criteria, appropriate resistivity and thickness of overburden, in combination with an available drawdown (saturated thickness of weathered overburden) of at least 20 m constitute the essential siting criteria for (70%+) 'success' rate. In the recent Mashonaland Crash Programme in which several hundred boreholes were sited using these criteria, some 52% of all sites investigated by VES soundings were rejected as not meeting the basic criteria. Although the implications in terms of the supply programme were not stated, it is implied that many locations could not be provided with a borehole supply since the conditions could not be identified. Dug wells were usually suggested as an alternative source although without particular sites being identified.

The concept of a successful borehole by Master Plan criteria is exemplified in Figure 3.2. The sustained yield of a borehole is dependent on an appropriate combination of transmissivity and storage. The storage is mainly contained within the upper regolith (collapsed zone and upper saprolite), assuming that the water table is within this part of the profile. The basal saprolite and the saprock have low storativity but higher permeability. With thinner regolith, such as occurs on the Post-African surface of erosion, common over the greater part of the Project Area, there is much greater likelihood of failure due to inadequate storativity within the cone of depression. The effect is enhanced as soon as the initial cone reaches the base of the regolith when the reduced storativity of the saprock begins to have more influence. This constraint can be counteracted only if the transmissivity is sufficiently high for the cone of depression to have a lower gradient and to spread widely and therefore to draw upon the storativity of the thin regolith over a wider area. This is the main objective in locating a borehole on a strong lineament on the assumption that it indicates a fracture zone of high transmissivity. Geophysical surveys will help to evaluate the geometry of the fracture zone, width and dip, but are less informative in relation to permeability. The location of the fracture zone is mainly identified by resistivity profiling or EM traversing. VES surveys on a fracture zone cannot readily be interpreted in terms of the rock properties of a narrow zone. It should be emphasised that the overburden as defined by the VES probably includes the regolith and to some degree the saprock when this is significantly weathered. Fractures in the underlying bedrock cannot easily be identified, if at all. Thus geophysical siting by the VES survey emphasises mainly the storativity in the saturated overburden with an assumption that where the latter is thick (>20 m), the transmissivity is likely also to be adequate.

Various other factors need to be taken into account when considering the hydraulic response of boreholes targeted on fracture zones below thin regolith.

(i) Width and inclination of the fracture zone. Most boreholes are drilled vertically and intersecting a narrow vertical zone requires precise location. With a dipping fracture zone, the angle of dip has to be taken into account to ensure intersection below the water table and 'access' will inevitably be reduced in accordance with the dip. Many fracture zones are the sites of stream channels which reduces drilling accessibility. Angled boreholes can increase the probability of success in a number of obvious ways - drilling along the dip of the fracture; drilling to intersect the fracture below an inaccessible stream 'site'; greater probability of intersecting sets of vertical fractures. The precise nature of fracture zones is not known with certainty and better information would assist borehole design planning.

(ii) Variations in regolith thickness and water level elevations away from the borehole site. Boreholes in valley areas have a higher success ratio than sites nearer the watersheds. There are



Water table can vary in position. This can affect well or borehole performance.

a Borehole completed in fractured bedrock

b Borehole completed in overburden (with gravel pack) and in fractured bedrock.

c Borehole completed in bedrock but unsuccessful because there are few fractures.

d Dug well at same location as 'c', but successful since drawing upon aquifer in overburden and making use of large storage.

e Dug well above vertical borehole in fractured rock.

f Dug well with radial collector boreholes drilled in overburden.

Figure 3.2 (a-f) Basic designs of boreholes, dug wells and collector wells constructed in aquifers within crystalline basement rocks.

several reasons for this. Valleys tend to follow zones of structural weakness which may be associated with high transmissivity. Valleys are commonly groundwater discharge areas and the effect of solution is likely to increase permeability. Water levels will occur at shallower depths and within the regolith. By contrast, watershed sites will tend to have deeper water levels and thinner saturated regolith. Boreholes will need to be drilled deeper and fractures reduce at depth. Where the water table is more steeply dipping, as is likely in watershed areas, the cone of depression will be constrained by the dip.

An increasing thickness of saturated regolith encountered within the cone of depression increases the likelihood of sustained yield. This situation can occur for example below the foot of an inselberg or on a broad watershed with saprolite of lower permeability resulting in higher water levels.

3.4 Radon Surveys

3.4.1 Radon occurrence.

Granitic rocks contain low, variable but significant concentrations of uranium minerals which release radon by decay. Radon being a gas tends to migrate towards the surface, either entrained in solution or by diffusion. There are three isotopes of radon which include more particularly Radon (s.s) 222 with a half-life of 3.82 days and Thoron 220 with a half-life of 55 seconds. Only Radon 222 has a sufficiently long half-life to be entrained or diffused over an appreciable distance and therefore is the most suitable of the radon isotopes to be used as a natural tracer. With migration by entrainment in a fractured medium, concentrations will indicate those fracture systems exhibiting significant fluid movement, i.e. the more transmissive fracture zones. Diffusion in the overlying unsaturated zone in the overburden above the fractured medium will tend to mask the fracture location; masking will also be effected by heavy clay overburden constrained in this instance by the slow fluid movements in the clay formation and the relatively short half-life. Downward recharge of more recent precipitation, either directly or via surface runoff will also reduce the observed anomaly.

3.4.2 Radon measurement.

Radon concentrations are comparatively easy to measure. The particular equipment used in the Masvingo project is an EDA-RD 200 model detector coupled to a hollow steel probe which is driven some 10-30 cm into the soil. The soil gas is pumped into the detector, a silver-activated, zinc-oxide-coated chamber with a photomultiplier counter. Both radon 222 and thoron 220 can be determined from the same set of measurements and appropriate calculations. In this report only the radon calculations will be listed.

The surveys were carried out across the lineaments, usually along a traverse EM34 line, and with intervals of 10/20 metres. Because of limitations of time, it was not possible to carry out what would have been valuable studies on repeatability, varying and smaller intervals, results of longitudinal traverses, etc. There were some general correlations of the radon anomalies with EM34 conductive vertical anomalies, as will be seen in subsequent figures in this report, but there were also some significant contrasts which are likely to have a geological explanation. Conductive anomalies are likely to be minor or absent with thin saturated overburden, even when above fractured bedrock, whereas this situation would be more readily detected by radon concentrations. Radon concentrations could prove an important ancillary exploration tool for borehole siting in basement rocks.

3.5 Drilling

The experimental drilling was carried out with a trailer-mounted Hands-England 20 Air Hammer Rig belonging to the Zimbabwe Government and the BGS 'horizontal' collector well rig, both under the supervision of Mr P Rastall. There were certain disadvantages in both rigs' operations. The HE20 was able initially to drill vertical holes only and it was difficult to tow with the BGS Bedford truck because of incompatibility of the tow bar. There was no support vehicle with the rig. For the shorter moves, the rig was towed by a BGS Landrover although the size and weight of the trailer-mounted rig was really excessive for the low powered Landrover. For longer moves, a lorry had to be hired from the Provincial Water Engineer in Masvingo. Logistic support for both rigs and for all drilling materials, fuel etc. had to be provided by the BGS Landrovers and the Bedford truck. Since boreholes were being drilled at widely separate locations in both Masvingo and Midlands province this constraint caused substantial difficulties and delays in the work programme. Each rig had its own large compressor and water bowser.

The collector well rig is not ideally suited for vertical operations or for deep borehole drilling. It has not the power to lift a long length of drill rod (40 metres is the limit) and since the drill rods are only 0.75 m in length, drilling operations are slow as compared to a normal rig. The tooling of the collector well rig was also relatively small and when the 6 inch hammer bit was broken, no spare was available.

The HE20 was subsequently altered by Mr Rastall to allow it to drill an angled hole and this eased the situation.

A final problem related to development. No development tools, surge block, jetting tool, etc. was available. A surge block was fabricated but was lost after a short time in operation. It is difficult to assess the effect of this insufficiency. However there were at least two low yielding boreholes which produced very 'muddy' water and were subsequently abandoned. It is possible that with improved development techniques, these may have become viable.

3.6 Sites Investigated

A number of sites (17) in four of the study areas have been investigated and subsequently drilled. The sites were in the main from lists provided by the Provincial Water Engineer, Masvingo or the District Administrators of Chibi and Neshoro Districts. These locations required a water supply either because no borehole existed or, in the majority of cases (11), because a dry borehole had been drilled previously or a borehole had failed subsequent to a period of operation. The latter locations will obviously be difficult for exploration since the more obvious sites will already have been surveyed and rejected (or drilled) in the previous drilling programme.

Table 3.3
List of Sites Investigated

		Map	Grid Reference
AREA C			
1.	Chikofa Primary School	2030 D1	2446/77216
2.	Chikore School	2030 D1	2543/77296
3.	Rungai B.C.	2030 D1	2553/77222
AREA E			
1.	Madangombe School	2030 A2	2193/77788
2.	Maramba School	2030 A2	22270/776820
AREA F			
1.	Chibi B.C.	2030 B3	2392/77535
2.	Chinambiri School	2030 B3	2458/77552
3.	Mhatiwa School	2030 B3	24875/774730
AREA G			
1.	Matatire School	1930 D4	2775/78023
2.	Nanwi School	1930 D4	2819/77968
3.	Nemarundwe School	1930 D4	2828/78015
4.	Zimuto Mission	1930 D4	27402/77935
AREA J			
1.	Sarahura B.C.	2030 B3	2448/76775
2.	Chikadze School	2030 B3	2538/76778

AREA G

Area G is underlain mainly by younger granites with some older gneiss outcrops in the south-west corner. Twenty boreholes have been drilled in Area G of which two have no yield data and five are dry or very low yielding, corresponding to a failure rate of 28%.

The mean thickness of the regolith is some 14 metres but the mean saturated thickness is less than a metre, the result of a high infiltration capacity of the granite regolith. The main aquifer is within saprock which must have sufficient storativity to give sustained borehole yields.

3.7 **Nanwi School** (Figure 3.3)

Background.

Existing borehole: EEC 54B [2819/77968]
Total depth: 30.2 m
Saprolite: 7.3 m
Rest water level: 4.4 m
Yield: 0.270 l/sec

The borehole gives an adequate yield but is rather far from the school. It is nonetheless the most obvious site in the area and a nearer site on the watershed proved dry.

The purpose of any drilling closer to the school would be to evaluate the significance of a clearly defined lineament. If a borehole is located precisely on a lineament, it could overcome the constraints of more limited storage in the overburden. The site selected is to the west of the school where the position of the lineament can be precisely located. There is much rock outcrop and clearly rock barrier boundaries will also exercise a constraint.

Geophysical study.

Various EM34 traverses were carried out and VES surveys. EM34-T1 crosses the drilled site and is shown in Figure 3.4. The lineament on the air photograph and the narrow ground feature correlates with a poorly developed conductive anomaly and a negligible overburden.

Radon survey.

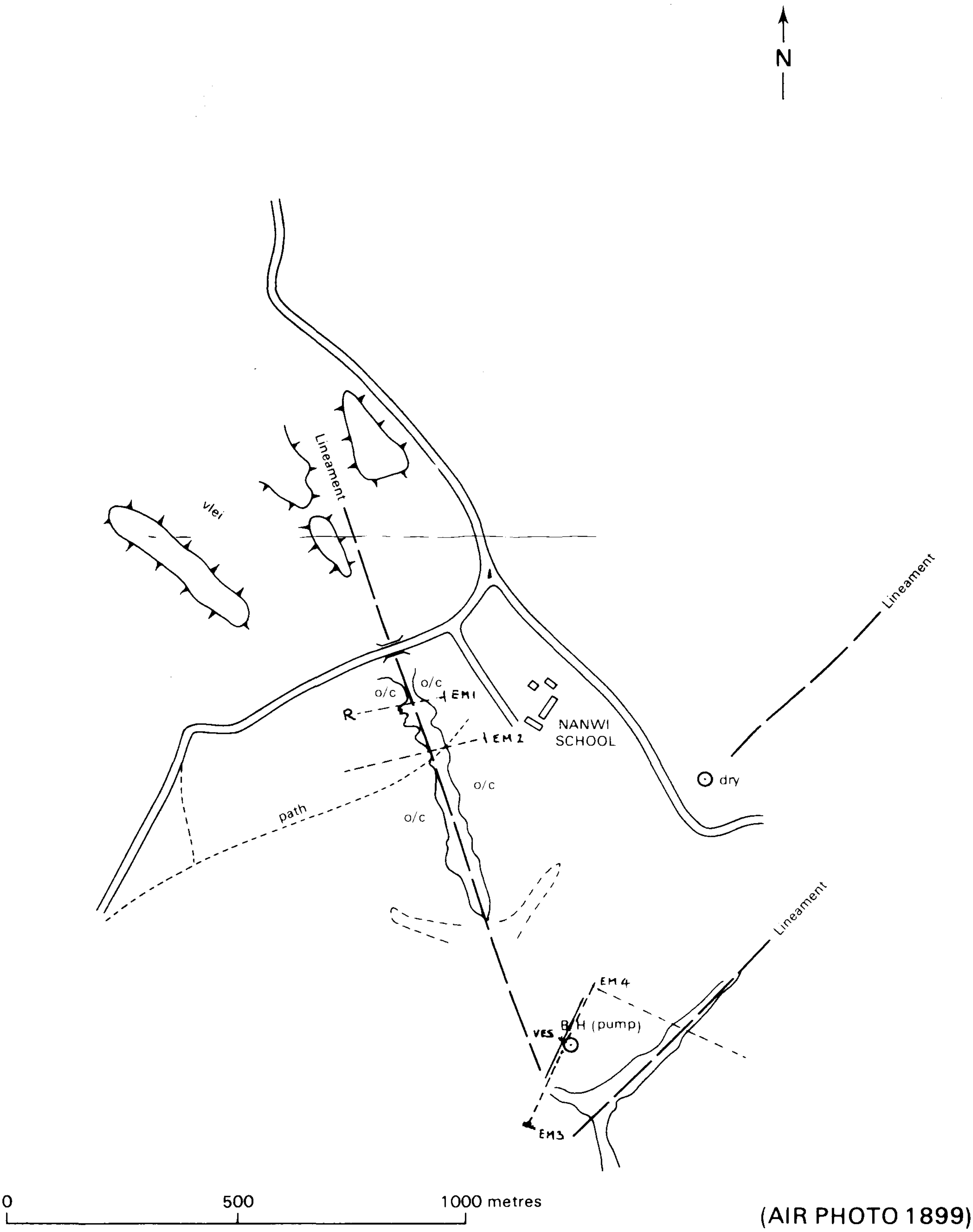
The radon traverse shows two fairly small anomalies which occur on either side of the observed lineament and could indicate parallel open fractures on either side of a tight central zone.

Drilling (Figure 3.5) G.R. TN 815 975

An inclined borehole was drilled from a location 2 m to the east of the gully wall at a 30^{o} angle (to the vertical) to 283^{o}m. The main water strikes at 15 and 21 m (equivalent to 8 and 11 m horizontal distance respectively) occur to the west of the observed lineament and close to the radon anomaly. The borehole produced an adequate handpump yield but because it had been drilled at 95 mm diameter due to the failure of the only available 150 mm bit for the BGS rig, it could not be completed as a production borehole.

A second borehole (vertical/150 mm Ø) was therefore drilled above the site at which the inclined borehole struck a groundwater supply

NANWI SCHOOL: AREA G: MAP 1930 D4



(AIR PHOTO 1899)

Figure 3.3

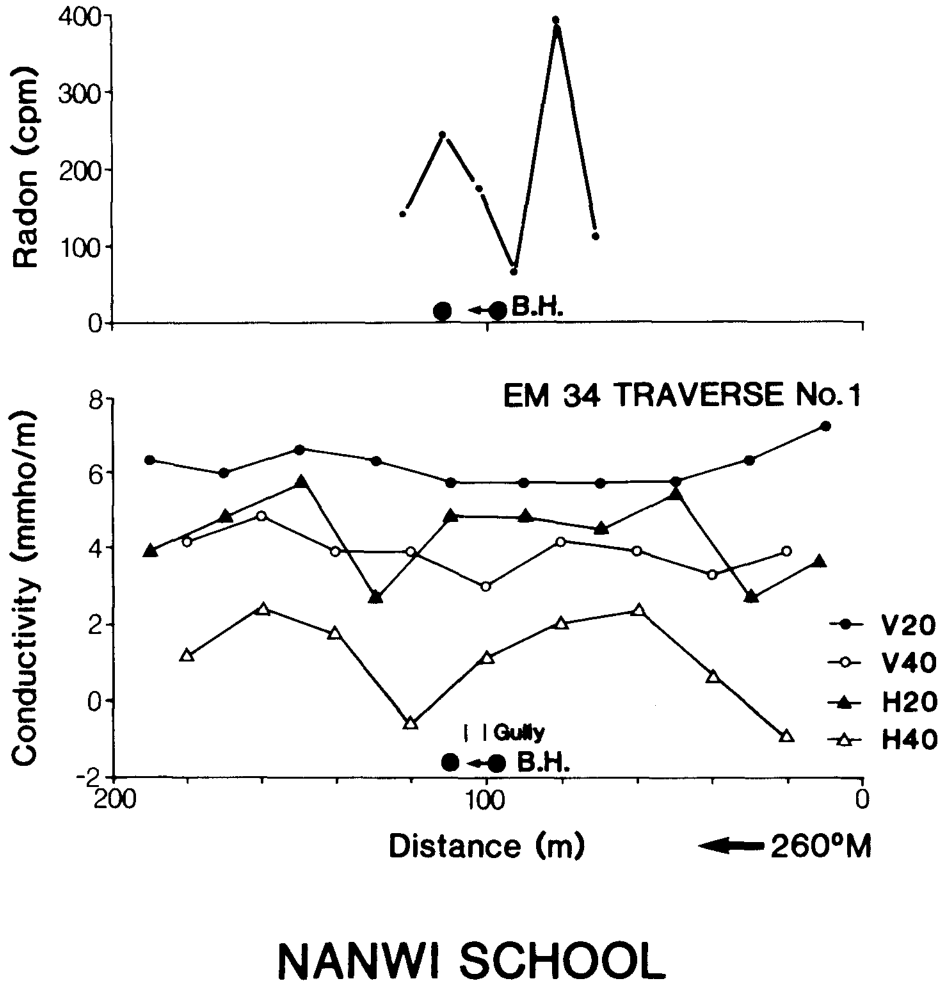

400
300
200
100
0
Radon (cpm)
B.H.
EM 34 TRAVERSE No.1
8
6
4
2
0
-2
Conductivity (mmho/m)
V20
V40
H20
H40
Gully
B.H.
200
100
0
Distance (m)
260°M
NANWI SCHOOL

Figure 3.4

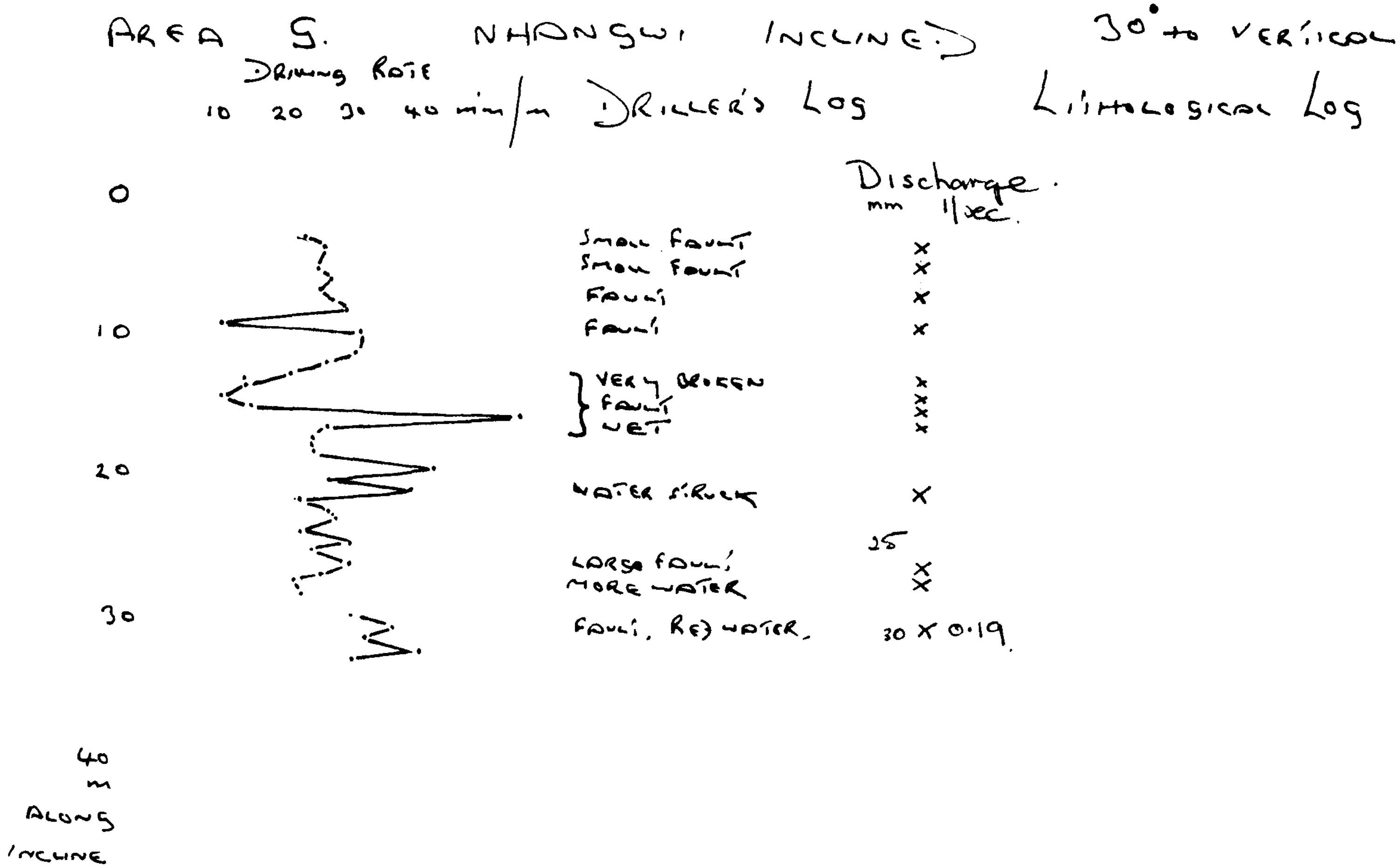

AREA 5. NHANGWI INCLINED 30° to VERTICAL
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm l/sec.
0
10
20
30
40
m
ALONG
INCLINE
SMALL FAULT
SMALL FAULT
FAULT
FAULT
VERY BROKEN
FAULT
WET
WATER STRUCK
25
LARGE FAULT
MORE WATER
FAULT, RED WATER.
30 X 0·19

Figure 3.5

(Figure 3.6). It will be noted that the drilling rate is appreciably faster when operating vertically as compared to inclined drilling.

Yields and pumping tests. (Figure 3.6ii)

Both boreholes produced drilling yields of c. 0.19 l/sec. The vertical hole was tested at 0.275 l/sec for 8 hours and therefore suitable for a handpump. The result is surprising considering that the hole is drilled into fractured but almost wholly fresh bedrock and must indicate that the borehole is being able to draw upon storage which probably occurs in overburden at some distance from the borehole site. Whether this yield can be maintained during production remains to be seen.

3.8 **Nemarundwe School** 1930 D4 (Figure 3.7)

Background.

Existing borehole: EEC 56
Total depth: 30.3 m
Saprolite: 6.1 m
Rest water level: 4.0 m
Yield: 0.32 l/sec

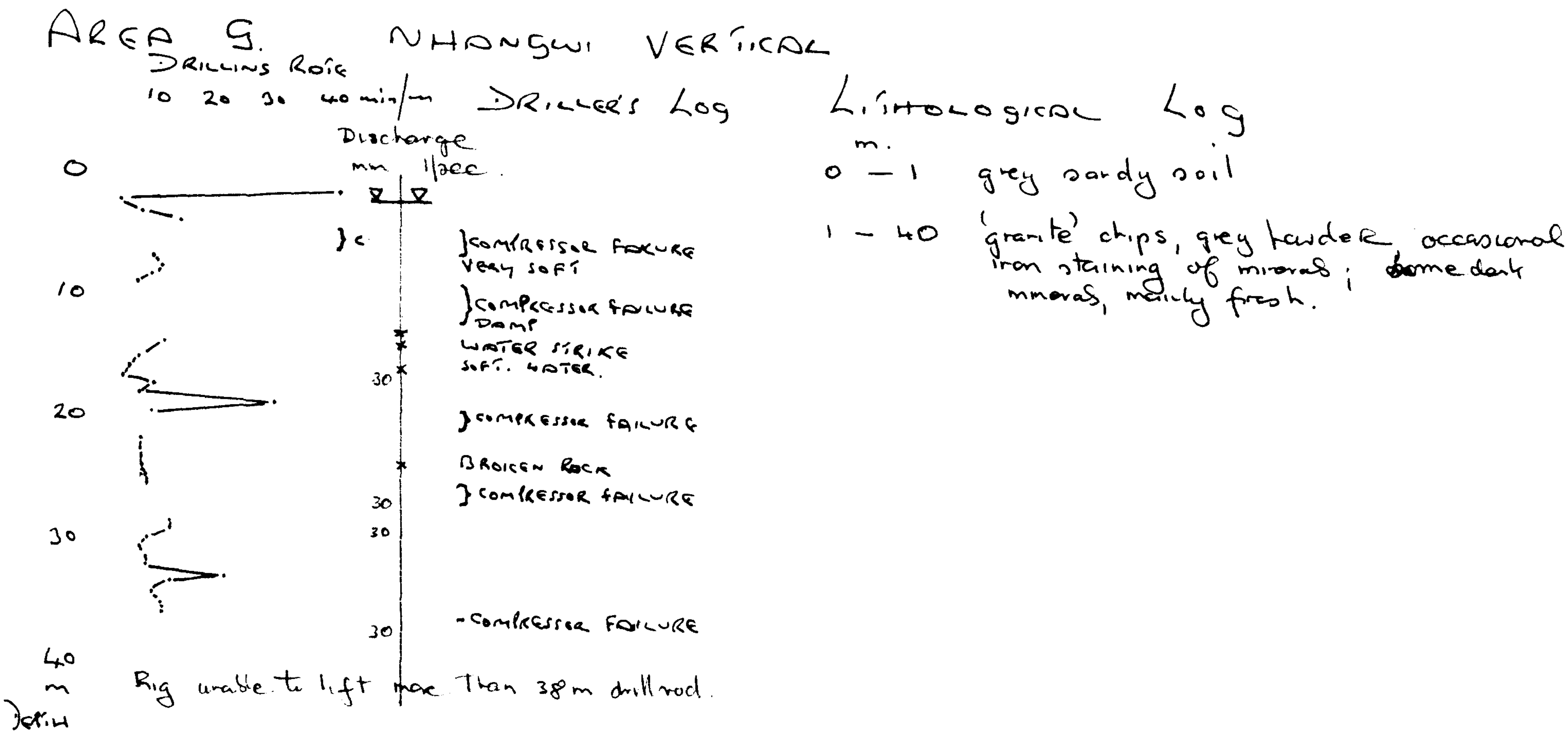
The borehole yield is adequate but the site is some distance away and beyond a flat valley which floods in the wet season. Both the Primary School and the Secondary School to the west of the road are largely dependent on this distant borehole.

An alternative site for a borehole/well is in the valley which trends south east from the school. The valley appears to follow a lineament. The catchment area is obviously smaller in sites closer to the school and a borehole's effectiveness would depend on the water level gradient and the transmissivity/storage of the aquifer and lineament system.

To the south of the Secondary School there is a dug well in a valley which trends due west to the deeply incised main north-south stream valley. It is surprising that shallow water levels exist at this site which has a high elevation not much lower than the watershed. The reason might relate to a rock barrier down valley. The dug well is not a high producer and the school is contemplating having it deepened. Information on the saprolite thickness would be valuable.

Geophysical surveys.

In 1986, two EM traverses (EM34-T1 and T2) were measured in the northern area of the south-east trending valley which demonstrated only weak anomalies. Two additional traverses, EM34-T3 and T4, were measured in 1987, further to the south-east which show slightly more marked anomalies of the vertical fracture type. Figure 3.8 shows the more southerly of the two latter traverses which was pegged in the centre of the anomaly. A VES made close to the small garden (see site map) gave a depth to bedrock of 6 m.



AREA 9. NHANGWI VERTICAL
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm l/sec
0
10
20
30
40
m
Depth
}COMPRESSOR FAILURE
VERY SOFT
}COMPRESSOR FAILURE
DAMP
WATER STRIKE
SOFT. WATER.
30
}COMPRESSOR FAILURE
BROKEN ROCK
30
}COMPRESSOR FAILURE
30
30
-COMPRESSOR FAILURE
Rig unable to lift more than 38m drill rod.
m.
0 – 1 grey sandy soil
1 – 40 (granite) chips, grey powder, occasional iron staining of minerals; some dark minerals, mainly fresh.

Figure 3.6(i)

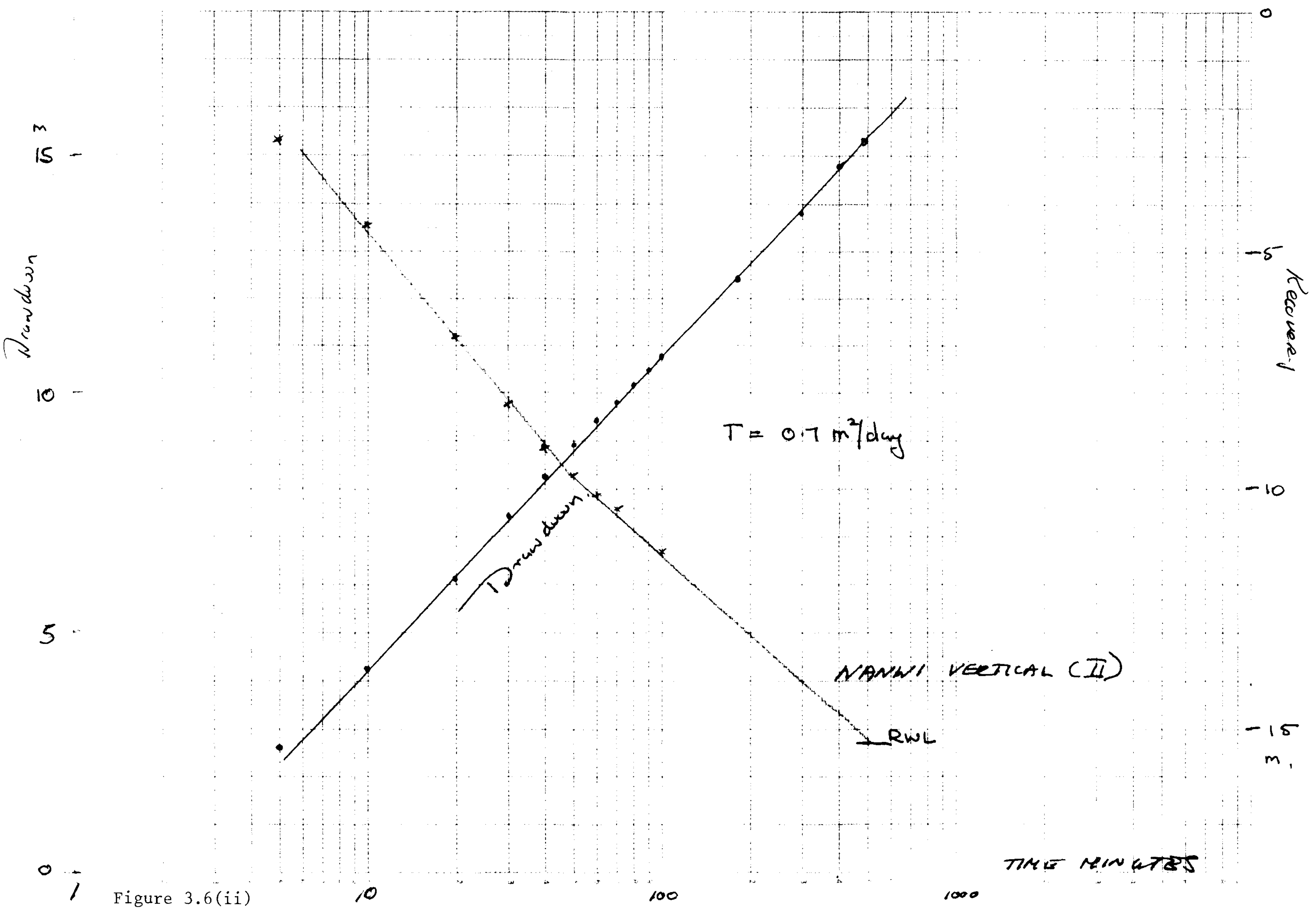
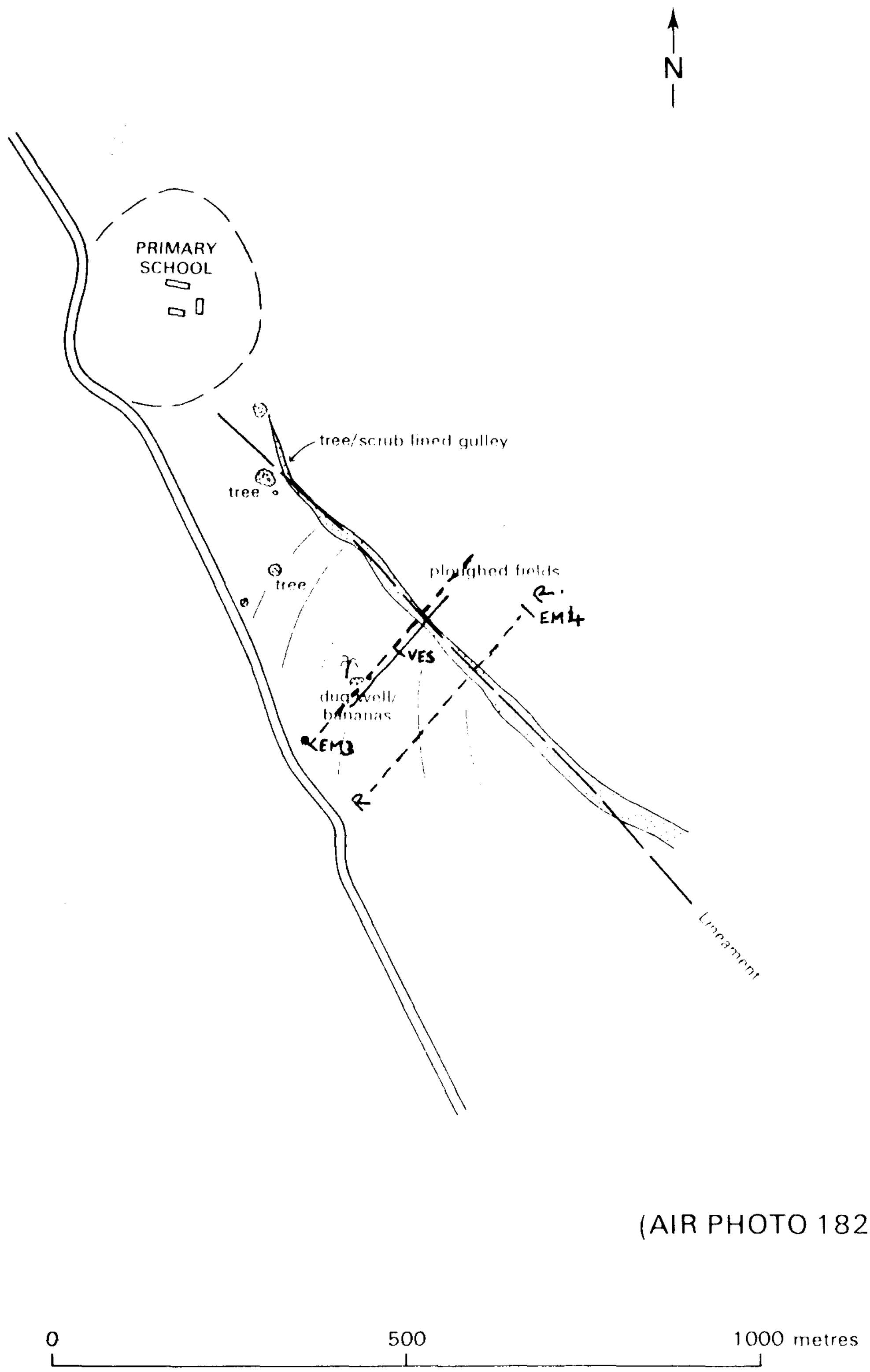

T = 0.7 m²/day
NANWI VERTICAL (II)
Drawdown
Recovery
RWL
TIME MINUTES
m.
0
5
10
15
10
100
1000

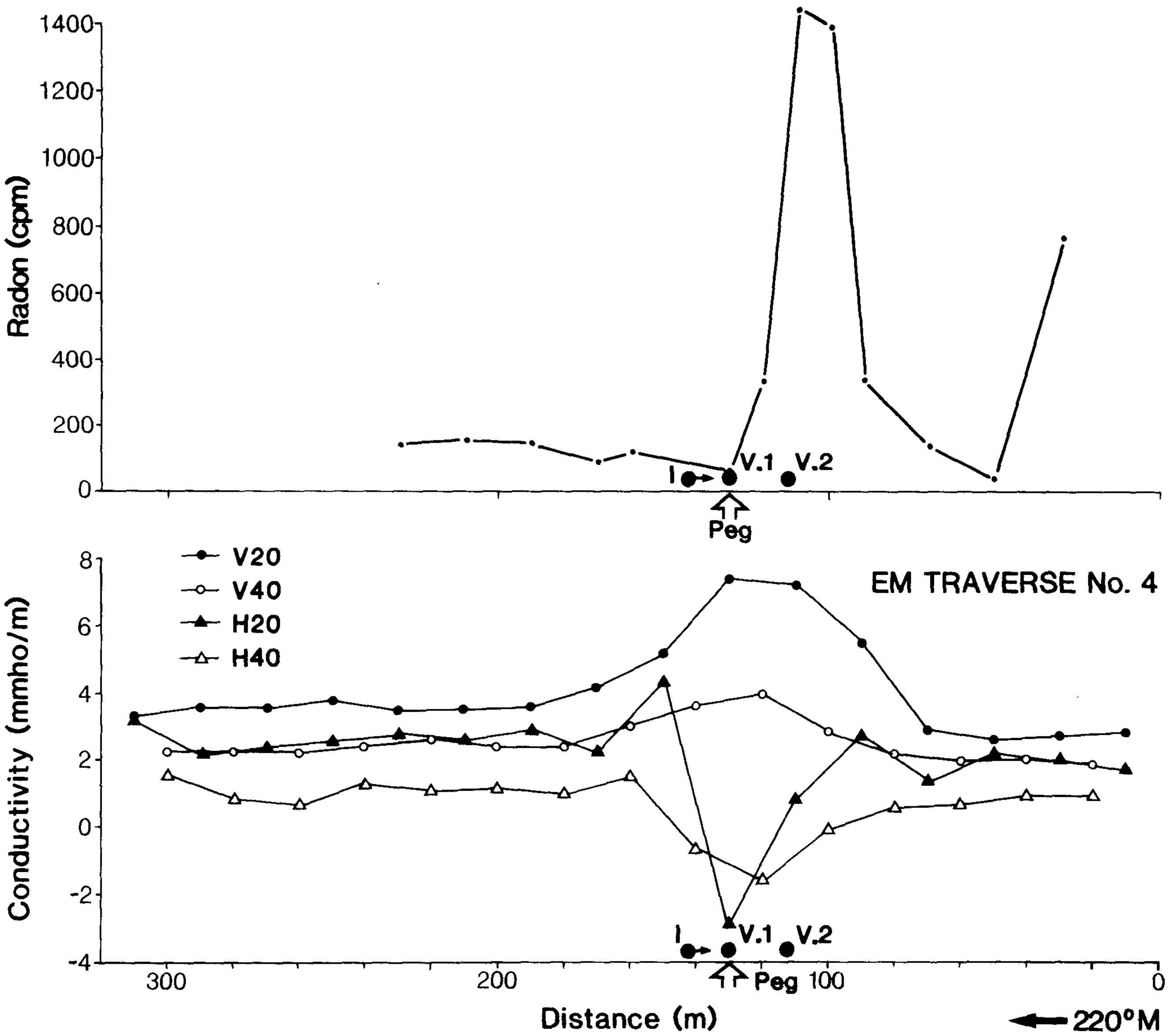
Figure 3.6(ii)

NEMARUNDWE SCHOOLS: AREA G: MAP 1930 D4



(AIR PHOTO 1825)

Figure 3.7



NEMARUNDWE

Figure 3.8

A VES along a line parallel to the valley and close to Nemarundwe II indicated bedrock at 5.25 m, as follows:

Layer	Thickness (m)	Resistivity (ohm-m)
1	1.25	1100
2	4.00	165
Infinity		

Radon survey.

A radon traverse was carried out along the line of EM34-T4 and the results are also shown in Figure 3.8. A large anomaly occurs to the north-east of the pegged site and close to the edge of the slightly incised gully which is closer to the air photograph lineament. The pegged site has a lower anomaly.

Drilling.

Three holes were drilled, two vertical (one on the pegged site and one on the maximum radon anomaly) and the third, inclined hole, which commenced some 10 m to the south-west of the pegged site and was directed along the line of the traverse at 41° to the vertical.

3.8.1 Nemarundwe I (Figure 3.9) G.R. TP 831 008

The drilling rate suggested weathered material to 10/13 m depth with the first water strike at 13 m, although damp at 3 m. Fresh granite occurs below 13 m. These figures do not correspond closely with the VES survey. Eventual static water level on 9 October was 4.15 m below casing top and 3.03 m below ground level.

3.8.2 Nemarundwe II (Figure 3.10)

The drilling rate suggested weathered rock to 6 m (consistent with the VES) and hard rock below. The main water strike at 13 m is similar to Nemarundwe I and occasional fractures were found at depth below 30 m but with little water.

3.8.3 Nemarundwe III - inclined (Figure 3.11)

This borehole was drilled with a 90 mm hammer and the BGS rig since the replacement 150 mm hammer had not yet arrived. The hole was slower to drill but encountered the main water at the same vertical depth (13 m). The borehole encountered a marked fracture close to Nemarundwe II at its final depth which was maximum drillable by the BGS rig. Had the hole been continued it is possible that a better yield might have been obtained.

Pumping tests.

Nemarundwe I gave intermittent flow during drilling as also did the inclined hole, but Nemarundwe II was virtually dry. Nemarundwe I was pump tested for 100 minutes at an initial rate of 0.29 l/sec

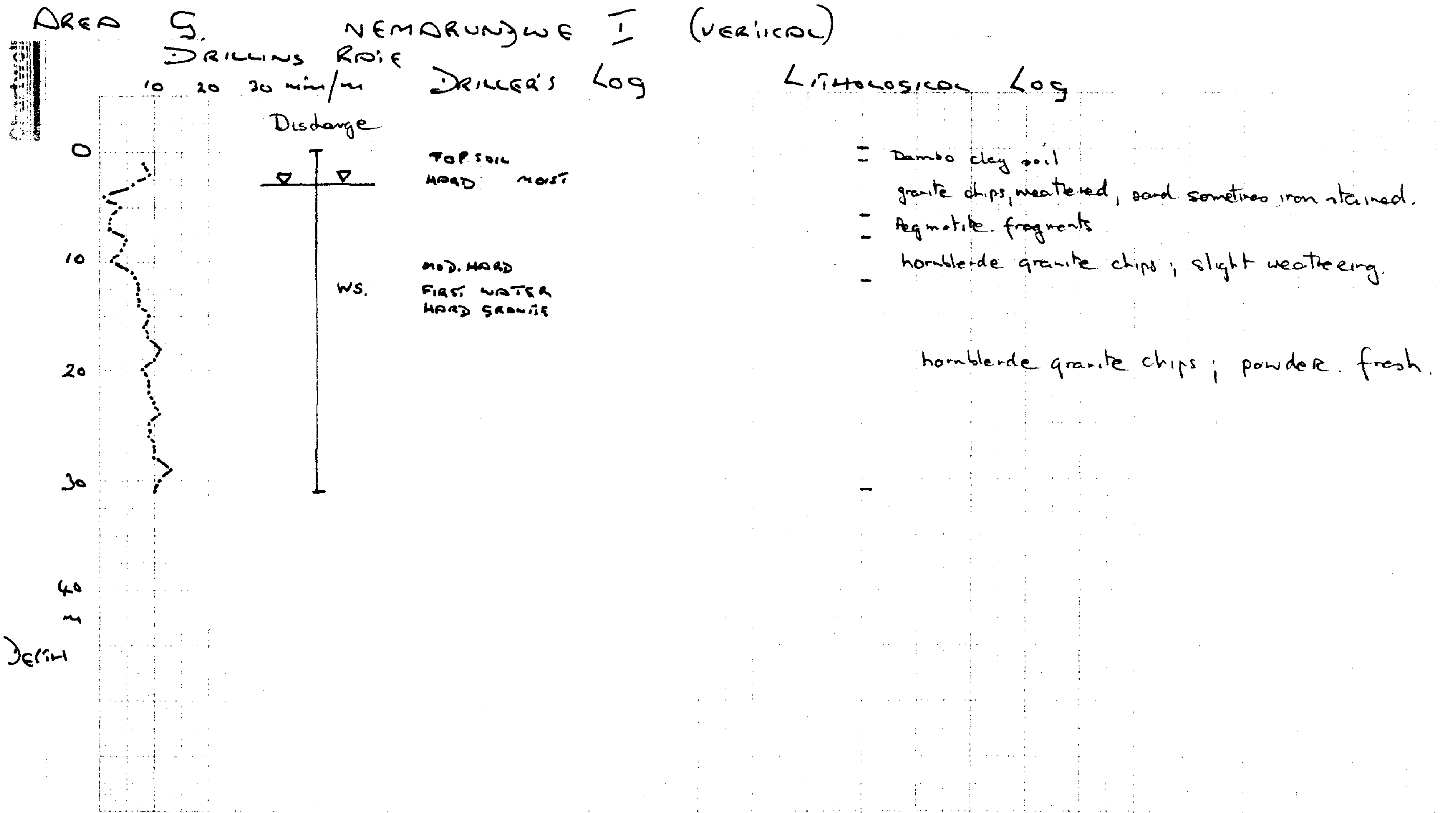

AREA 5. NEMARUNJWE I (VERTICAL)
DRILLING RATE
10 20 30 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
0
10
20
30
40
m
DEPTH
TOP SOIL
HARD MOIST
MOD. HARD
WS.
FIRST WATER
HARD GRANITE
Dambo clay soil
granite chips, weathered, sand sometimes iron stained.
Pegmatite fragments
hornblende granite chips; slight weathering.
hornblende granite chips; powder. fresh.

Figure 3.9

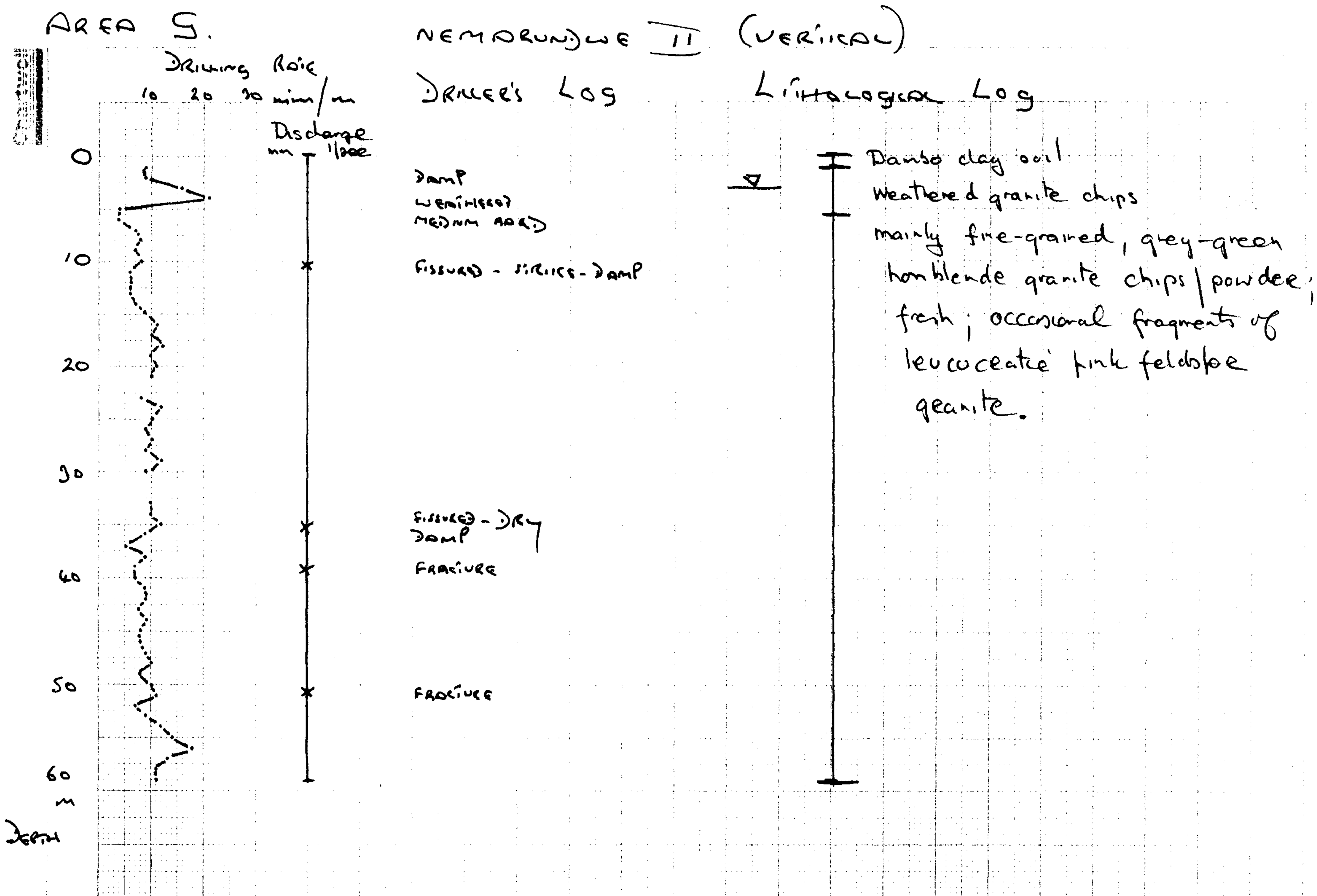

AREA 5.
NEMARUNDWE II (VERTICAL)
Drilling Rate
10 20 30 min/m
Discharge
mm – l/sec
Driller's Log
Lithological Log
0
10
20
30
40
50
60
m
Depth
Damp
Weathered
Medium hard
Fissured - Strikes - Damp
Fissured - Dry
Damp
Fracture
Fracture
Dambo clay soil
Weathered granite chips
mainly fine-grained, grey-green hornblende granite chips/powder; fresh; occasional fragments of leucocratic pink feldspar granite.

Figure 3.10

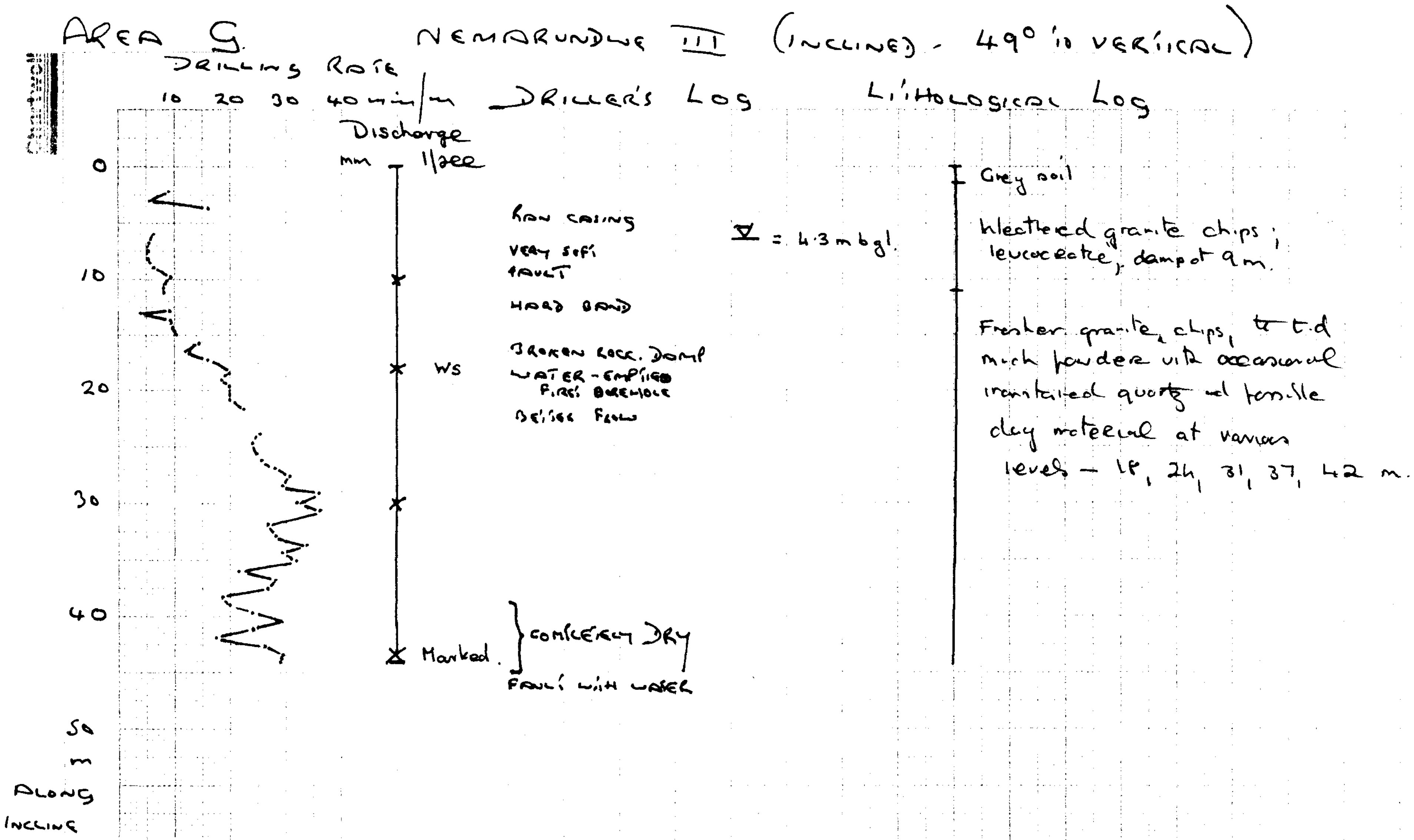

AREA G. NEMARUNDWE III (INCLINED - 49° to VERTICAL)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm 1/sec
0
10
20
30
40
50
m
ALONG
INCLINE
RAN CASING
VERY SOFT
FAULT
HARD BAND
BROKEN ROCK. DAMP
WS
WATER - EMPTIED FIRST BOREHOLE
BEFORE FLOW
Marked.
COMPLETELY DRY
FAULT WITH WATER
▽ = 4.3 m b g l.
Grey soil
Weathered granite chips; leucocratic; damp at 9 m.
Fresher granite chips, t.d. much powder with occasional iron stained quartz and possible clay material at various levels - 18, 24, 31, 37, 42 m.

Figure 3.11

for 38 minutes after which the pumping level reached pump suction and the rate dropped rapidly to .015 l/sec. The results of the drawdown and recovery data are shown in Figure 3.12. A boundary effect became apparent after 20 minutes resulting in a rapid increase in drawdown rate. On the assumption of a dug well of 1 m radius excavated to the base of the weathered zone at 13 m, there would be less than one metre depth of water in the well after 12 hours recovery. The calculation should be carried out again after the borehole has been developed and a longer recovery test analysed although present data does not favour the cost of a deep well construction on the site. It was not possible to test the inclined hole because the diameter was too small and the inclined handpump was not available at the time but there would be merit in further tests on this hole since there was evidence of more intersection of fractures.

3.9 **Matatire School** 1930 D4 (Figure 3.13)

Background.

Existing boreholes: JP 5490 [2783/78023]
Total depth: 55 m
DRY
: EEC 303 [2775/78023]
Total depth: 32.0 m
Saprolite: 0.9 m
Rest water level: +0.6 m (positive head)
Yield: 0.42 l/sec
Lithology: granite

The main borehole supply at EEC 303 is some distance from the school and is well used by the community and the school. An additional borehole in another direction and possibly nearer the school would serve the general requirements of the school and the community.

The recommended site for survey is in the valley which tends to the south-east. Locations further down the valley are likely to become increasingly favourable hydrogeologically since water levels will tend to be shallower and the effects of recharge more advantageous. Exploration should be designed to identify the position of the lineament and the thickness of the saprock since the saprolite is likely to be thin. Sites selected for drilling should preferably not be subject to flooding. The greeness of the grass, the large phreatophyte trees, including the Makuti tree, indicates the presence of shallow groundwater. The valley is marginally less favourable than that in which EEC 303 is located since the former has a steeper gradient to discharge locations in a larger stream.

The dambo soils have significant clays and could be irrigated if the water supply was adequate. A collector well would be of interest. Remnants of the old rice paddies are apparent.

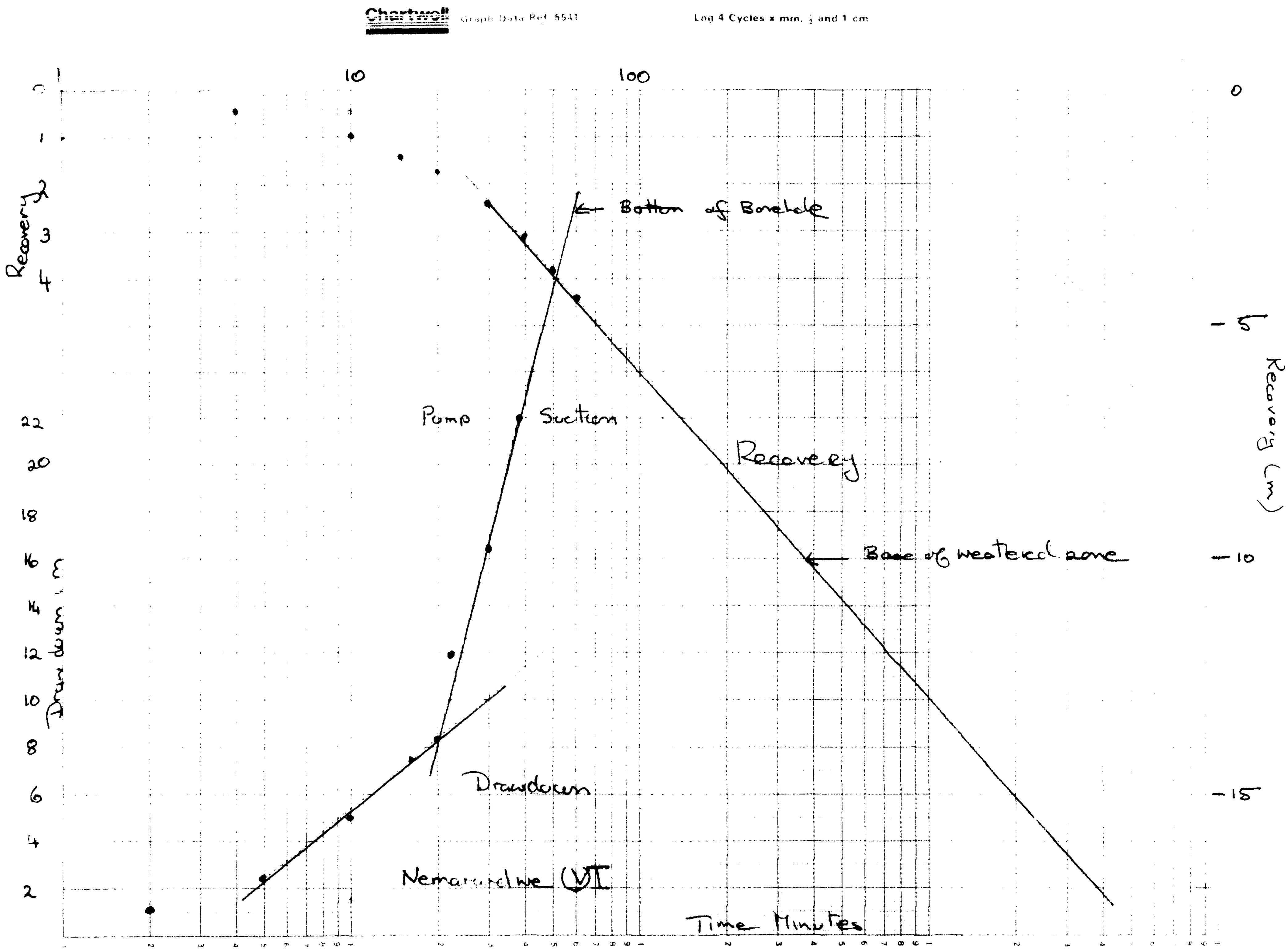

Chartwell Graph Data Ref 5541
Log 4 Cycles x mm, ½ and 1 cm
Bottom of Borehole
Pump Suction
Recovery
Base of weathered zone
Drawdown
Nemarundwe (VI)
Time Minutes
Recovery
Drawdown (m)
Recovery (m)

Figure 3.12

MATATIRE SCHOOL: AREA G: MAP 1930 D4

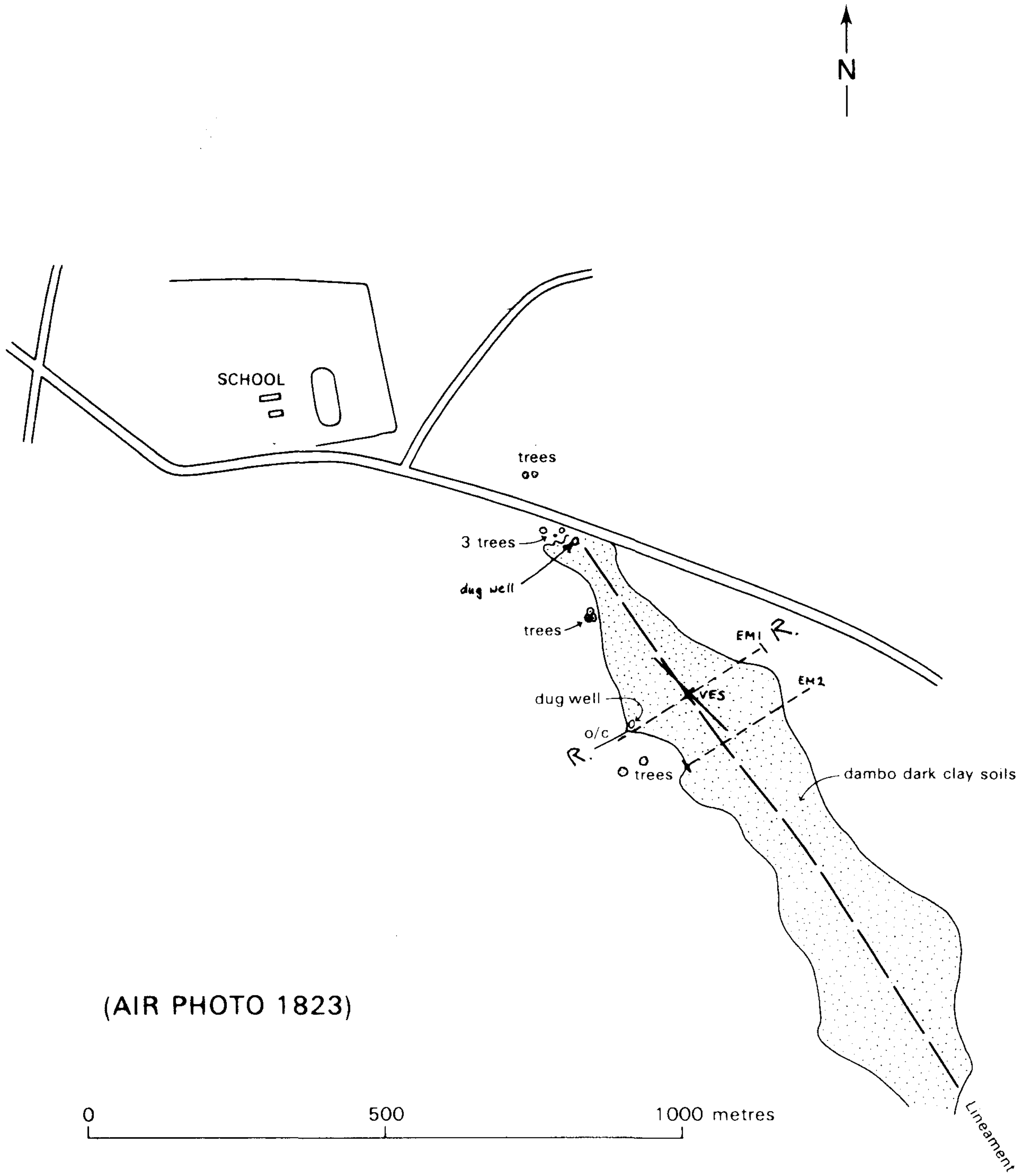


Figure 3.13

Geophysical survey.

Two EM traverses and a VES were carried out. Both traverses showed vertical sided conductive anomalies suggestive of thicker conductive material over a narrow fracture zone. The more favourable northerly traverse was pegged (Figure 3.14). The VES in the vicinity of the pegged site gave the following result.

Layer	Thickness (m)	Resistivity (ohm-m)
1	0.40	2,000.00
2	2.50	25.00
3	20.00	250.00
Infinity		10,000.00

The thickness of the weathered overburden is close to the acceptable limit of the Master Plan criteria, assuming that the greater part is saturated.

Radon survey.

Initial background: 30 counts
Traverse line: 195° m parallel to EM34-T1
Maximum anomaly: 758 at 20 m west of peg

A similar shaped anomaly to that shown in the EM profile was obtained, slightly offset to the west side.

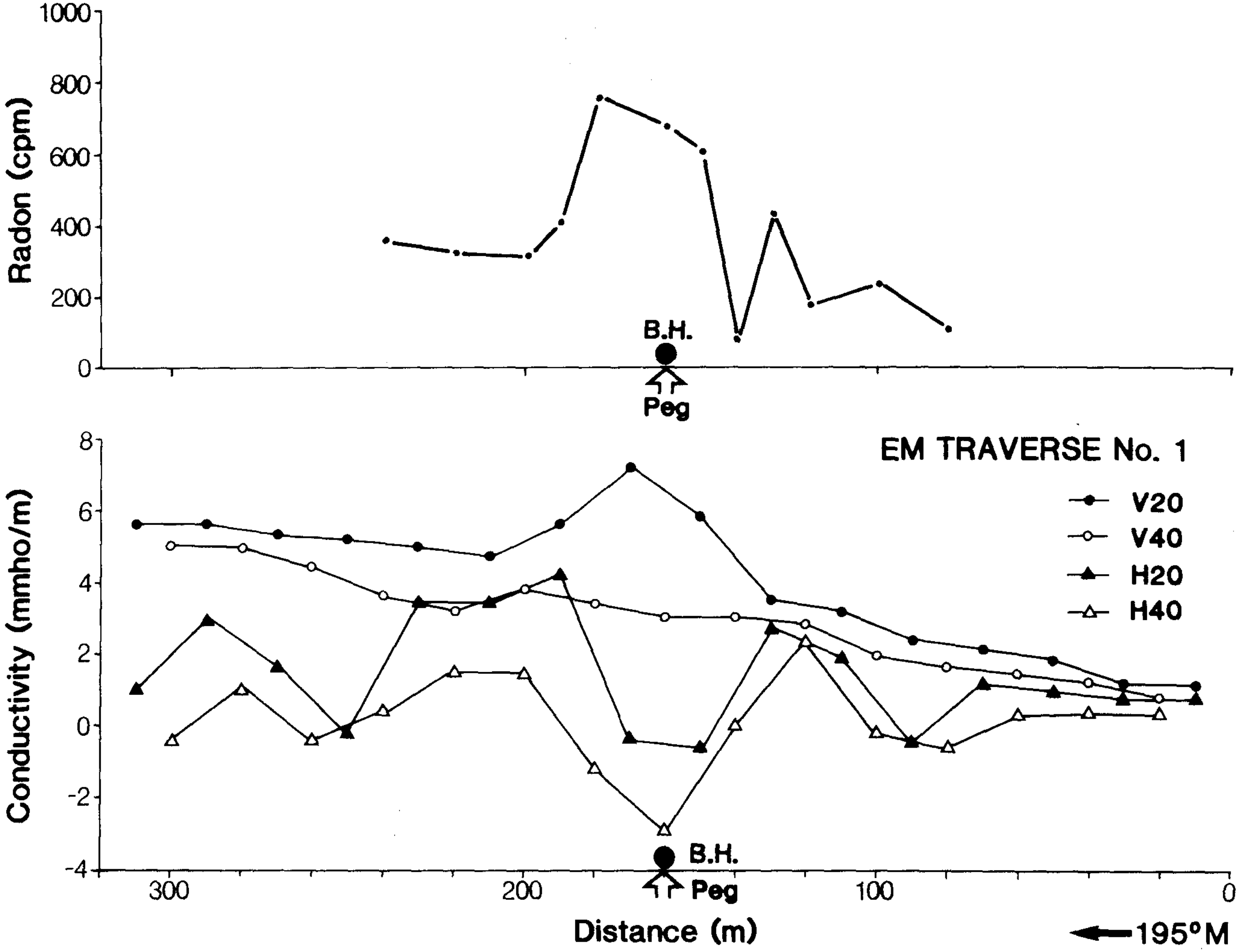
Drilling. (Figure 3.15) G.R. TP 793 018

The main fractures were encountered between 50 and 60 metres. The drilling rate indicates a change from softer (more weathered) to harder rock at around 33 metres, rather deeper than had been predicted by the geophysical survey. An adequate yield was obtained whilst air lifting during drilling operations. The borehole was cased and screened to total depth since there was a danger of collapse. The lithological log shows more fragmentary quartz/feldspar material to some 14 metres with granite chips below. Some clay material occurs down to 50 m with a more prominent weathered band at 27-32 metres.

Pump testing. (Figure 3.16)

SWL: 3.55 m below datum (0.5 m agl)
Pump suction: 52.56 m
Duration: 6 hours
Discharge (i): 0.25 l/sec for 4 hours
(ii): 0.15 l/sec stabilised at 6 hours
Final drawdown: 49 m
Water quality: 120 microsiemens
Specific capacity at 5 hours: 0.005 (by extrapolation)

The calculated transmissivity is low (0.1 m^2/day). The four hour discharge at 0.25 l/sec can be regarded as marginally acceptable and the borehole could be fitted with a handpump. Both Matatire and Nemarundwe would be suitable sites for collector wells.



MATATIRE SCHOOL

Figure 3.14

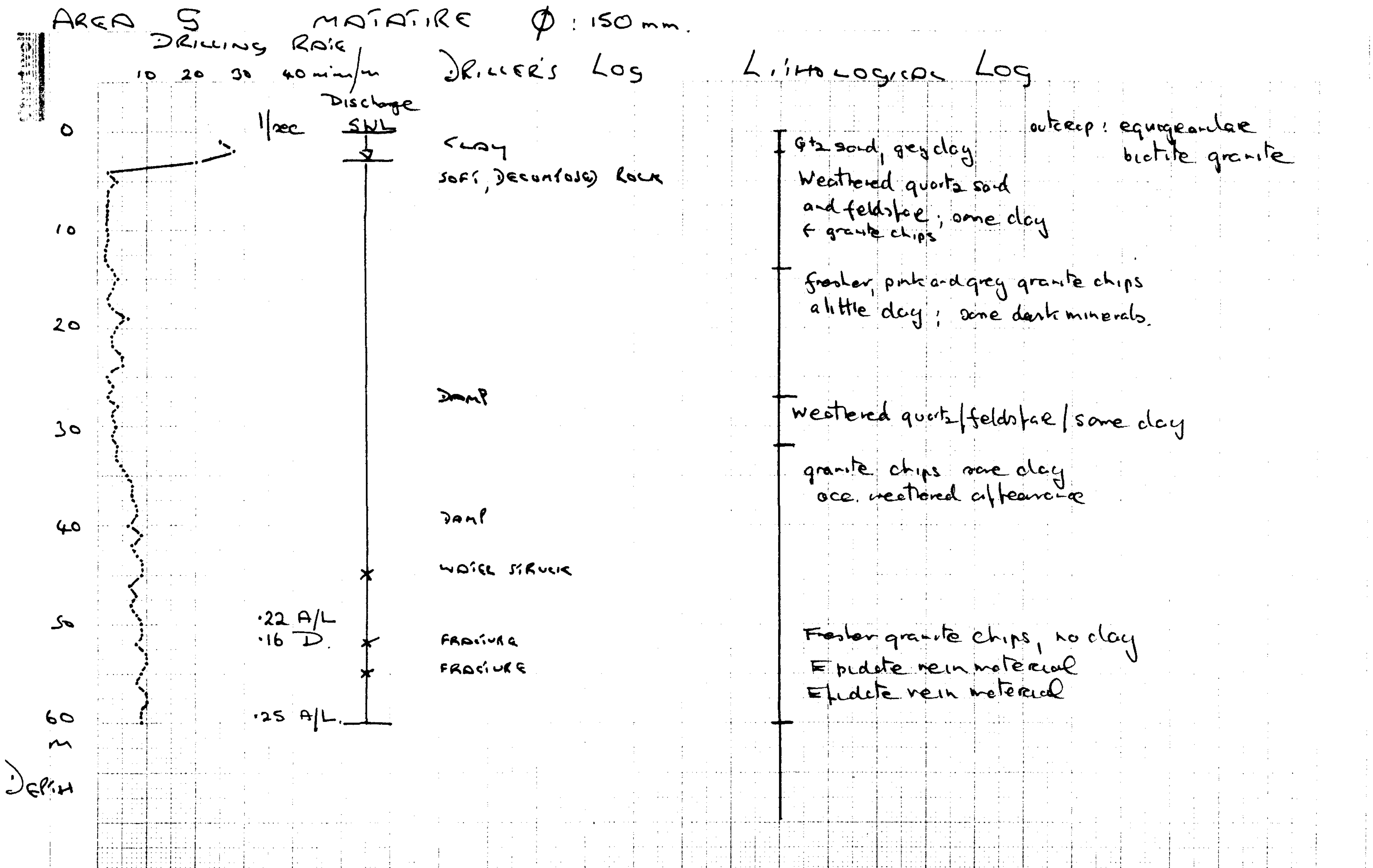

AREA 5 MATATIRE Ø : 150 mm.
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
l/sec
SWL
0
10
20
30
40
50
60
m
DEPTH
CLAY
SOFT, DECOMPOSED ROCK
DAMP
DAMP
WATER STRUCK
·22 A/L
·16 D.
FRACTURE
FRACTURE
·25 A/L.
outcrop : equigranular biotite granite
Qtz sand, grey clay
Weathered quartz sand and feldspar ; some clay & granite chips
fresher, pink and grey granite chips a little clay ; some dark minerals.
weathered quartz/feldspar/some clay
granite chips some clay occ. weathered appearance
Fresher granite chips, no clay
Epidote vein material
Epidote vein material

Figure 3.15

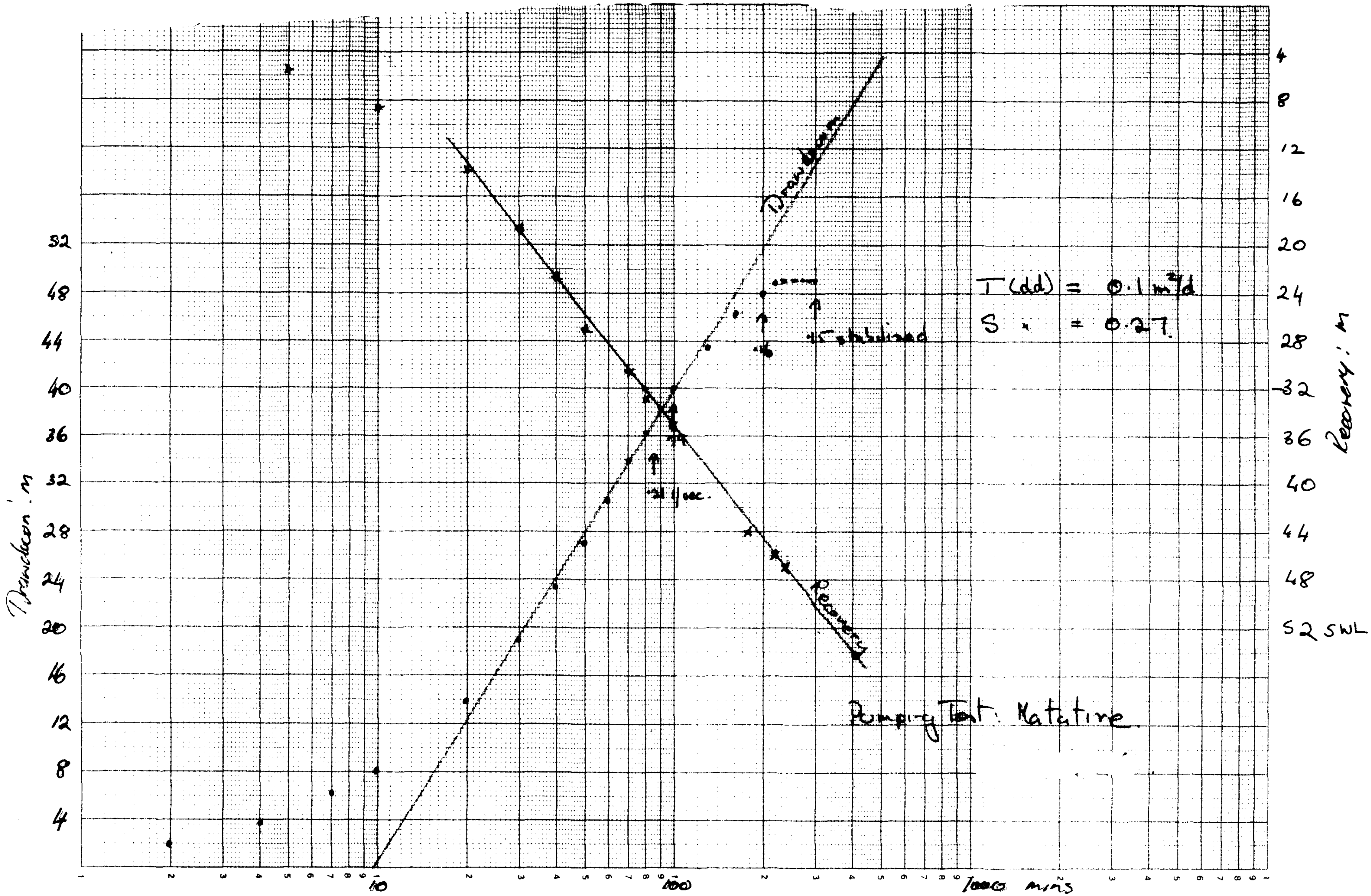

Drawdown
Recovery
T (dd) = 0·1 m²/d
S " = 0.27
stabilized
Pumping Test: Matatine
52 SWL
Drawdown : m
Recovery : m
10
100
1000 mins

Figure 3.16

3.10 Zimuto Mission 1930 D4 (Figure 3.17)

Background.

Existing boreholes: Two occur which are fitted with motor pumps. Additional boreholes are required for the Blind School and for the Railway Siding.

Two locations were selected for detailed survey:-

(i) the valley which trends SE from the Blind School. Extensive outcrops of granite gneiss occur near the junction with the main stream and these might form a barrier which would back up water levels upstream. A possible site could occur at the intersection of the main lineament along the valley and an orthogonal metadolerite dyke.

(ii) the second site for survey is on an intersecting stream system further to the east, both of which occur on lineament trends.

3.10.1 Blind School.

Geophysical survey.

Three EM-34 traverses were carried out, one longitudinal and two transverse. The pegged site was on the more northerly transverse traverse (EM34-T1) and the plot is shown in Figure 3.18. A VES close to the pegged site gave the following result:-

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.30	350.00
2	2.00	25.00
3	20.00	100.00
Infinity		10,000.00

The overburden thickness is thus slightly less than that demanded by the Master Plan criteria.

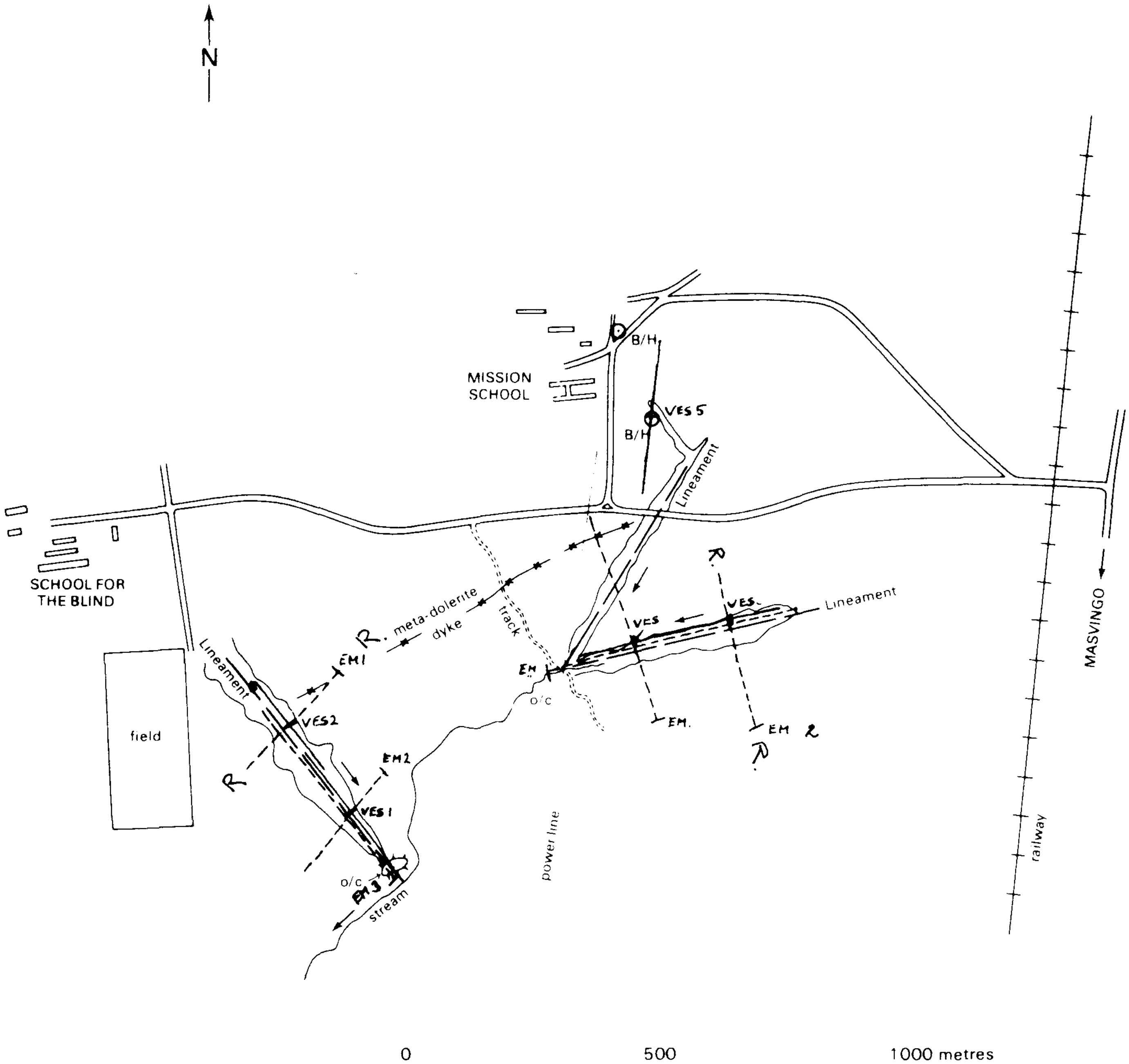
Radon survey. (Figure 3.18).

A traverse was carried out along EM34-T1 on the same line and across the pegged site.

Background: 66 counts, 29.09.87
Maximum anomaly: 785

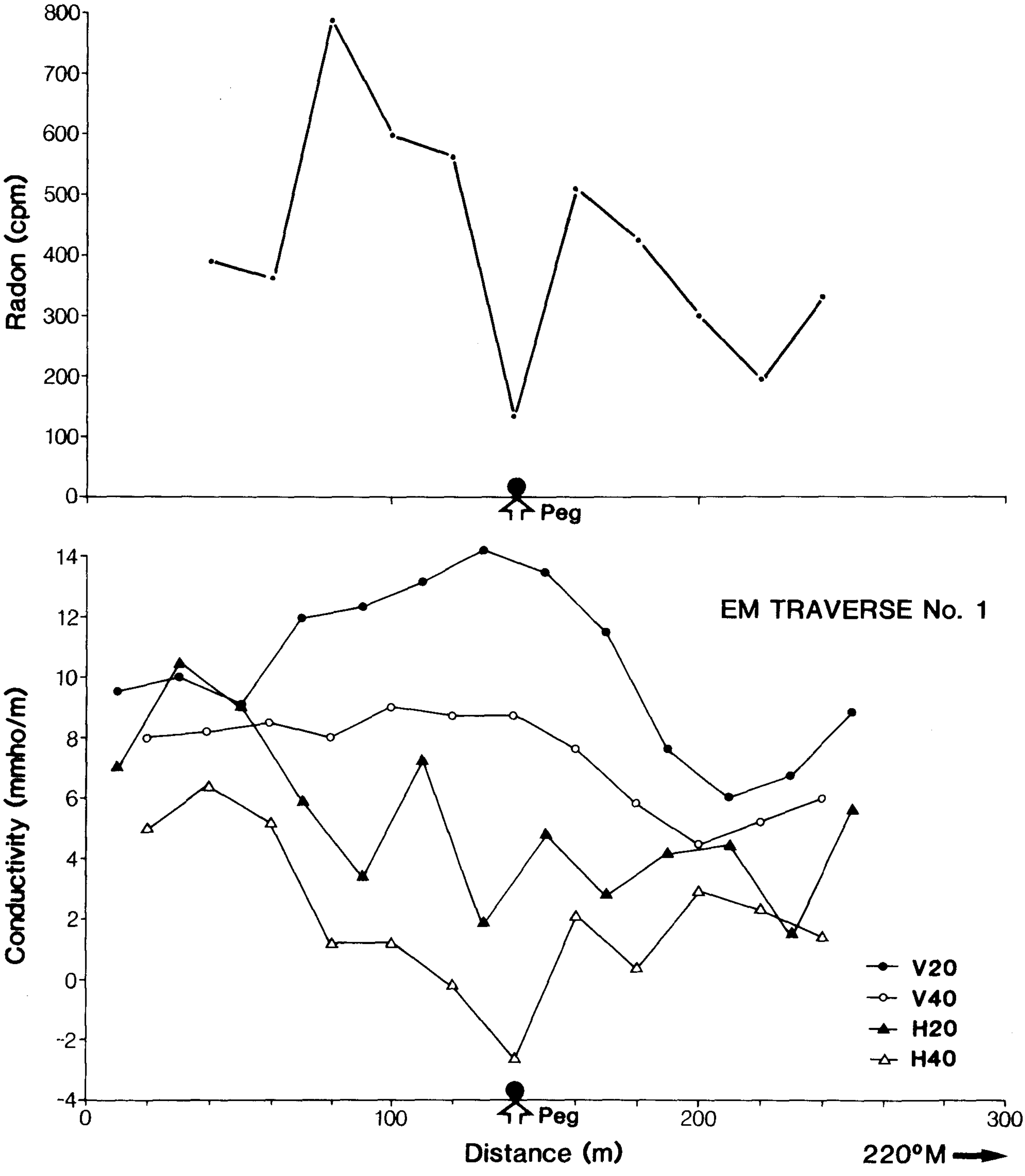
The pegged site gave a low radon count, little more than double the background. However there had been substantial rain the night before and the pegged location had been affected by much surface runoff. A repeat reading at the pegged site several days later gave a count of 287 for a background reading of 56. Although this is higher than before, it seems likely that the main radon anomaly occurs some 60 m to the NE.

ZIMUTO MISSION: AREA G: MAP 1930 D4



(AIR PHOTO 1972)

Figure 3.17



ZIMUTO B.S.

Figure 3.18

Drilling. (Figure 3.19) G.R. TN 734 924

The lithological and drillers log indicate weathered rock to 11-13 m which is less than predicted from the geophysical measurements. The yield during drilling increased substantially at 40 m and remained the same (90 mm over notch) to total depth.

Pumping test. (Figure 3.20)

SWL: 4.25 m bgl on 30 November 1987
Duration: 6 hours
Discharge rate: 0.32 l/sec
Final drawdown: 4.18 m
Quality: 580 microsiemens
Five hour specific capacity: 0.077 l/sec/m

The drawdown and recovery plots are shown in Figure 3.20. A recharge boundary is apparent at 100 minutes and the level has stabilised by 360 minutes. Full recovery is probable at around 130 minutes. With the available drawdown a higher yield is feasible, and a more extended test at a greater rate would be needed to determine a safe yield for motorised pumping.

3.10.2 Zimuto Siding.

Geophysical survey.

The EM measurements exhibited irregular variations suggestive of core stones. Although no site was pegged, the prefered location from the geophysical survey is on the northern side of the lineament on traverse 2 (Figure 3.21) where a VES shows 28 m of weathered overburden.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.25	500.00
2	8.00	40.00
3	20.00	100.00
Infinity		10,000.000

Radon survey.

Background: 13 counts
Maximum anomaly: 67 counts

The radon measurements are all of a generally low order but an anomaly exists to the north of the stream line and some 20-30 m distant. The borehole was sited in this interval.

Drilling. (Figure 3.22) G.R. TN 740 926

Weathered rock occurs down to 24 m which corresponds with the geophysical survey, although the water level is deep at 20 m. The lithological log is also comparable. Outcrops close by are of

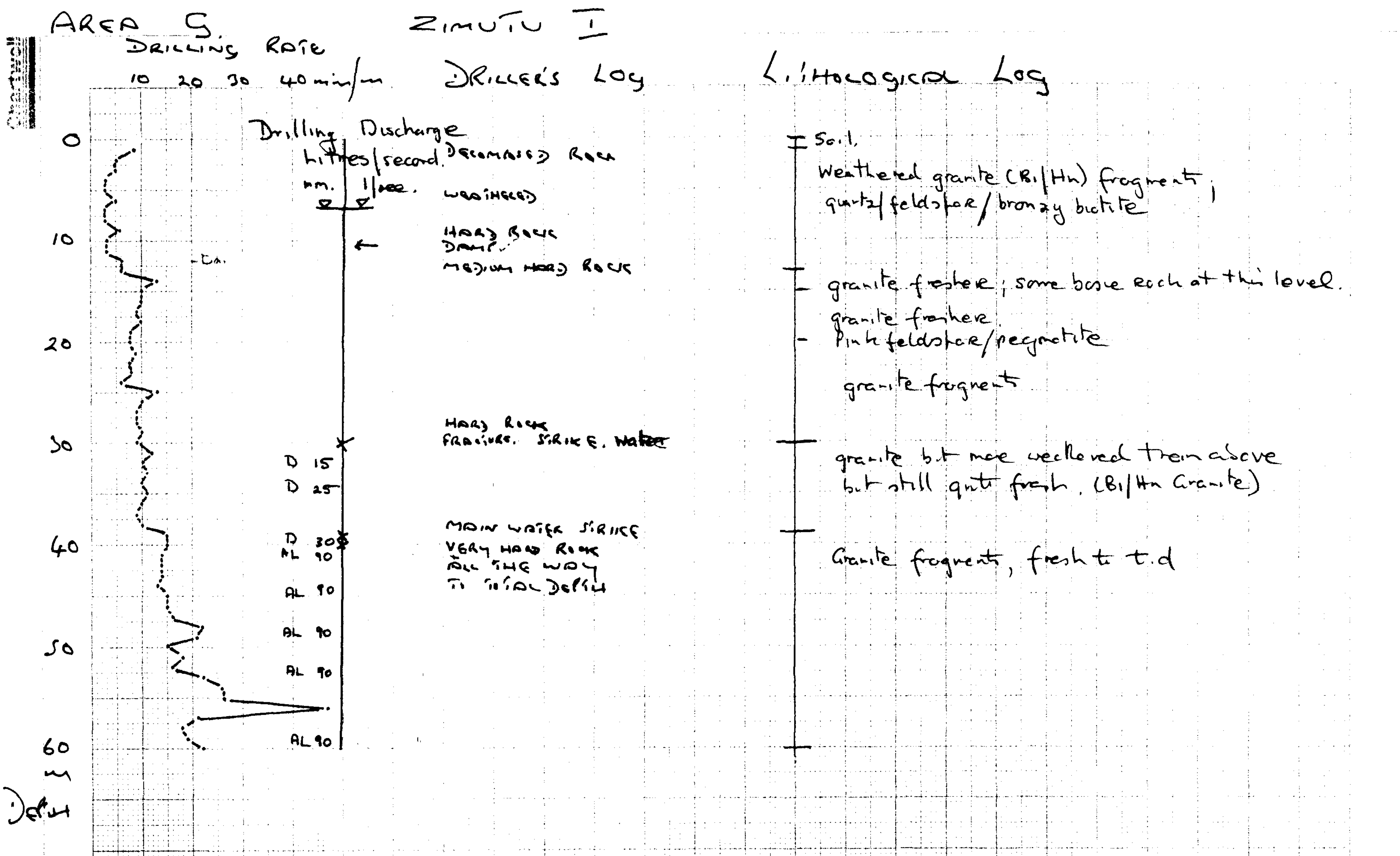

AREA 5 ZIMUTU I
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Drilling Discharge
Litres/second
0
10
20
30
40
50
60
m
Depth
DECOMPOSED ROCK
WEATHERED
HARD ROCK
DAMP
MEDIUM HARD ROCK
HARD ROCK
FRACTURE. STRIKE. water
D 15
D 25
D 30
AL 90
AL 90
AL 90
AL 90
AL 90
MAIN WATER STRIKE
VERY HARD ROCK
ALL THE WAY
TO TOTAL DEPTH
Soil.
Weathered granite (Bi/Hn) fragments, quartz/feldspar/bronzy biotite
granite fresher; some basic rock at this level.
granite fresher
Pink feldspar/pegmatite
granite fragments
granite but more weathered than above but still quite fresh. (Bi/Hn Granite)
Granite fragments, fresh to t.d

Figure 3.19

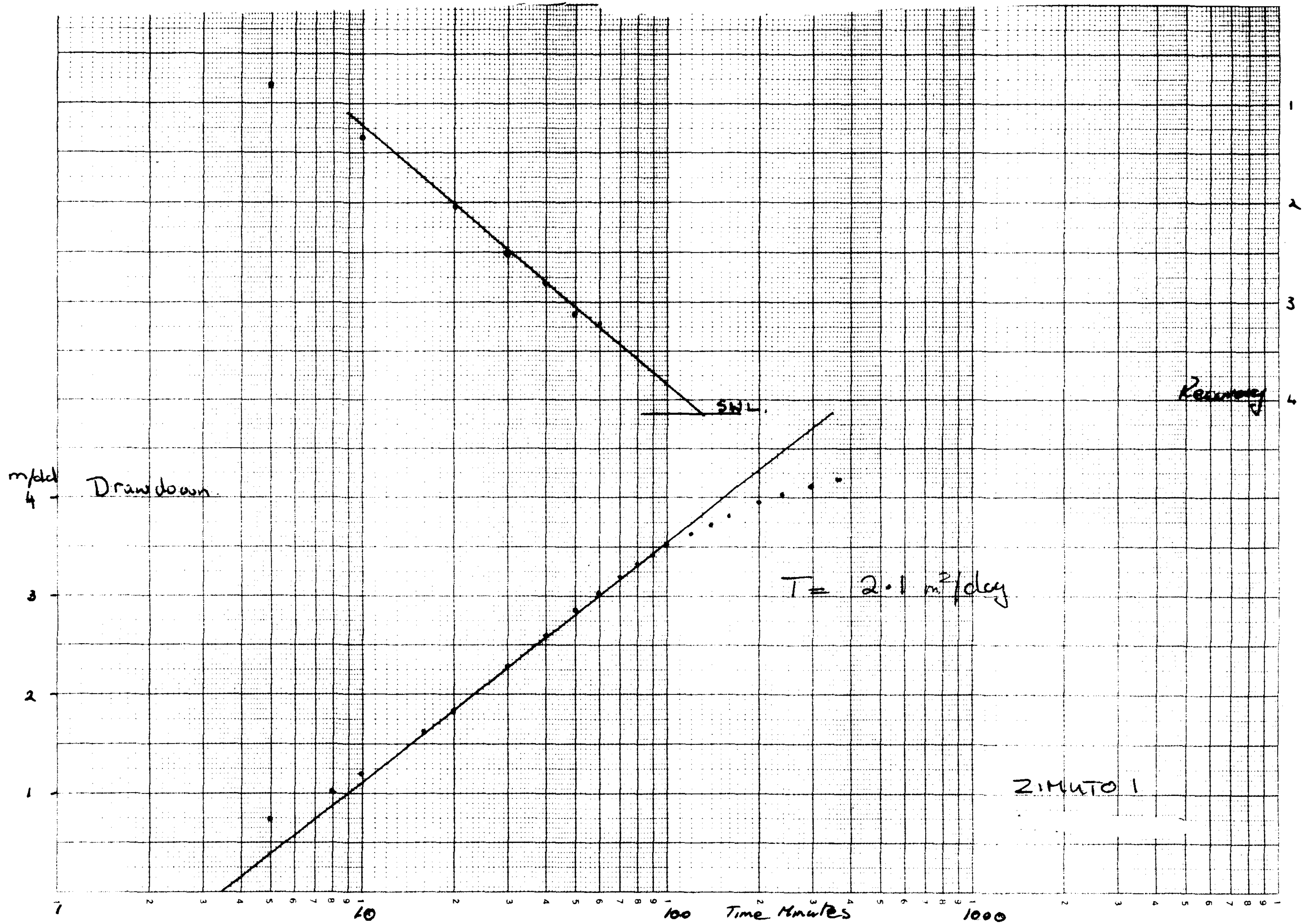
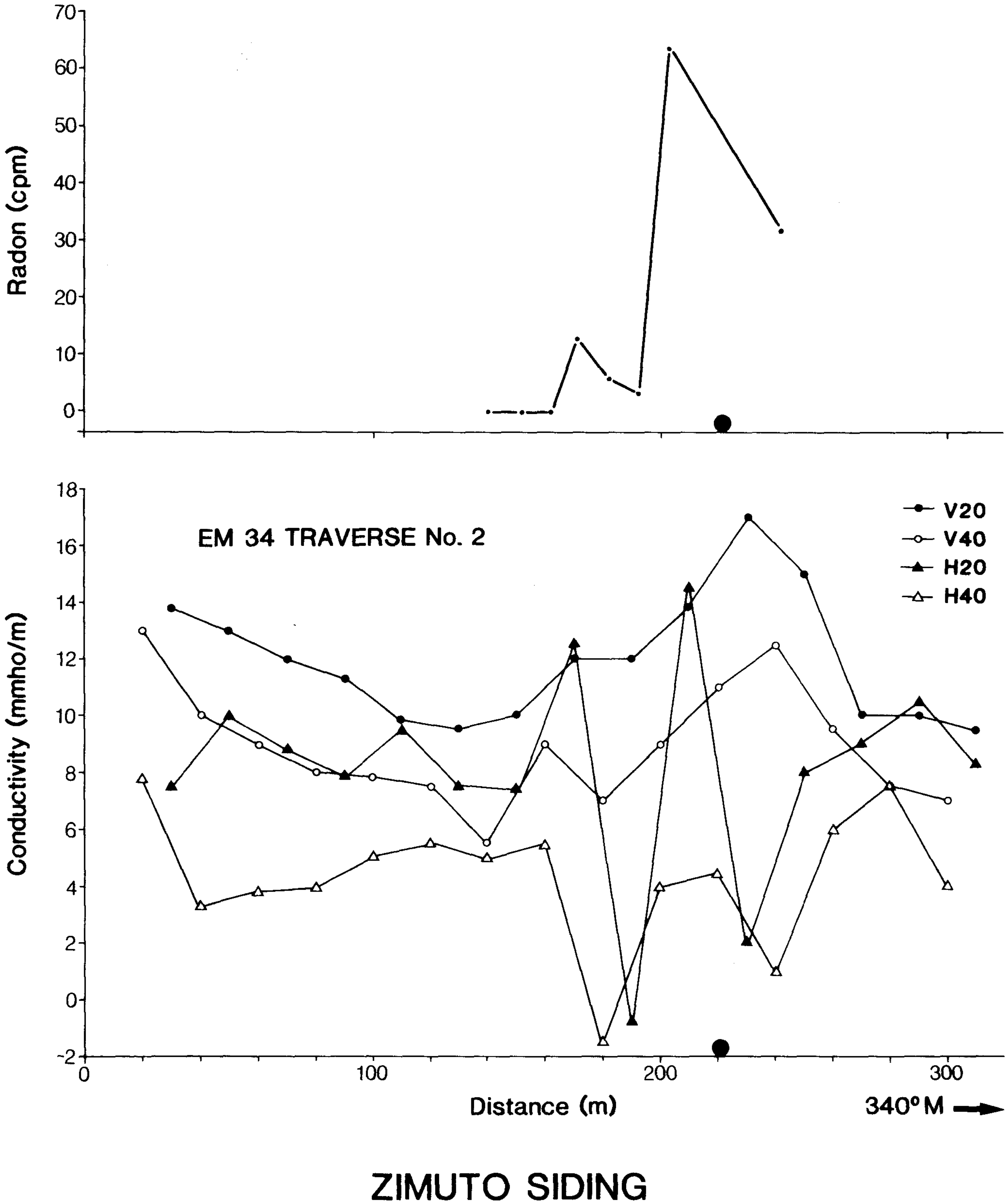

m/dd
Drawdown
SWL
Recovery
T= 2·1 m²/day
ZIMUTO 1
Time Minutes
1
10
100
1000

Figure 3.20



Radon (cpm)
70
60
50
40
30
20
10
0
Conductivity (mmho/m)
18
16
14
12
10
8
6
4
2
0
-2
EM 34 TRAVERSE No. 2
V20
V40
H20
H40
0
100
200
300
Distance (m)
340°M
ZIMUTO SIDING

Figure 3.21

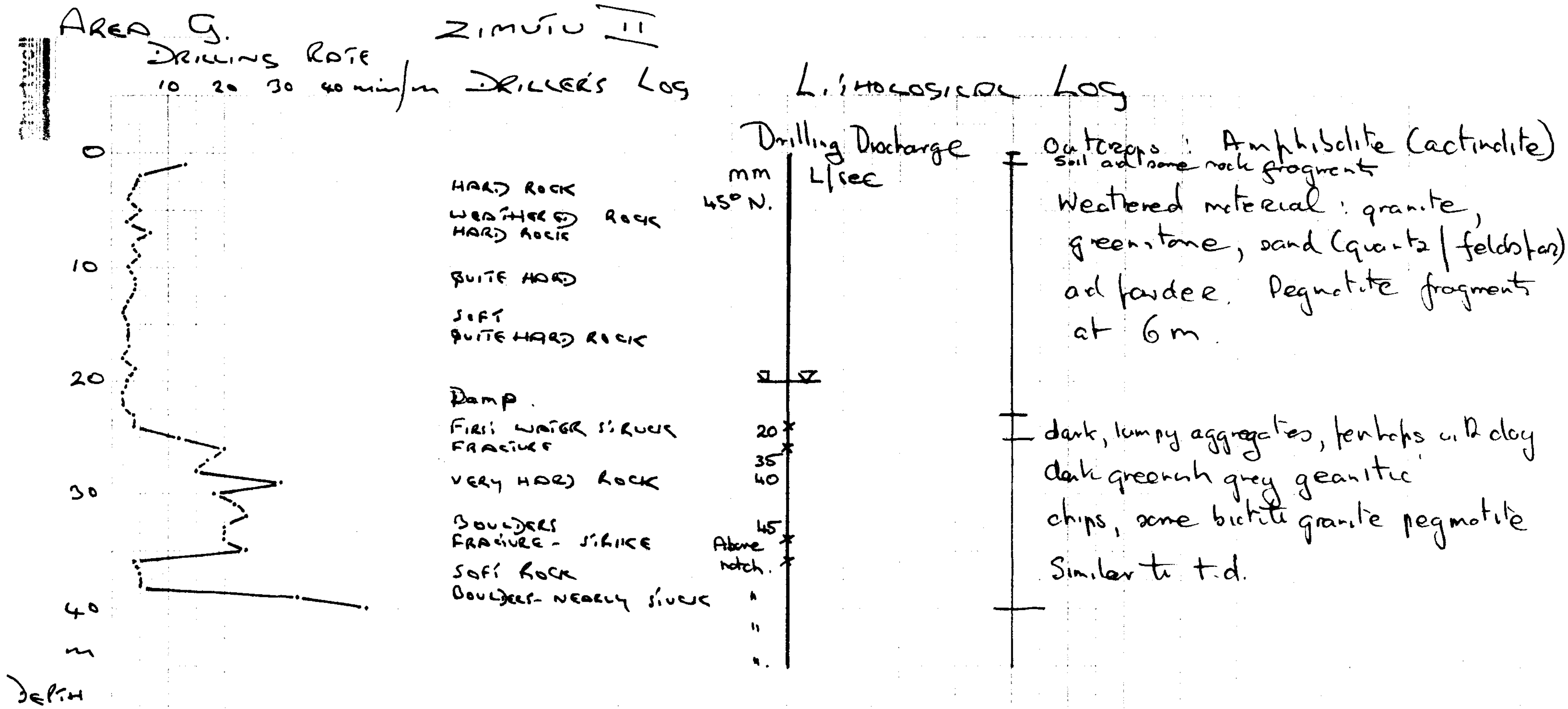

AREA G.
ZIMUTU II
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Drilling Discharge
mm
L/sec
45° N.
0
10
20
30
40
m
DEPTH
HARD ROCK
WEATHERED ROCK
HARD ROCK
QUITE HARD
SOFT
QUITE HARD ROCK
Damp.
FIRST WATER STRUCK
FRACTURE
VERY HARD ROCK
BOULDERS
FRACTURE - STRIKE
SOFT ROCK
BOULDERS - NEARLY STUCK
20
35
40
45
Above notch.
Outcrops: Amphibolite (actinolite)
Soil and some rock fragment
Weathered material: granite, greenstone, sand (quartz/feldspar) and powder. Pegmatite fragments at 6 m.
dark, lumpy aggregates
dark greenish grey granitic chips, some biotite granite pegmatite
Similar to t.d.

Figure 3.22

amphibolitic rock. The weathered upper section includes some granitic material and basic rock fragments; the lower section is of greenish grey granite or syenite with more pegmatite. An intermediate layer consisting of dark lumpy aggregates corresponds with the water strike.

Pumping test.

The drilling discharges were in excess of the 45^{0} notch and of the order of 5/6 litres/sec. Drilling had to be terminated at 40 m because of the high inflow of water and the possibility of collapsing. The drillers log referred to the presence of 'boulders' and the drill string almost became stuck on several occasions.

The main test was carried out on 28 November 1987.
Pump suction: 38 m
Duration: 7 hours
Discharge rate: 0.55 l/sec
Final drawdown: 0.375 m
5 hour specific capacity: 1.57 l/sec/m

The pumping test was carried out at 0.55 l/sec although the well could probably have been pumped at several litres/sec, perhaps in excess of 10. Since a motorised pump is planned, a test at a higher pumping rate is recommended.

AREA F

Area F is floored by older gneisses and younger granites. Of the 26 boreholes drilled, (25 with yield data), the failure rate is very high (68-69%). The mean regolith thickness is 17 m but the mean saturated regolith thickness is less than 7 m.

3.11 Chibi Business Centre 2030 B3 (Figure 3.24)

There are no existing boreholes in the immediate area of the Business Centre which receives a piped supply from a surface reservoir. The supply is said to be inadequate. There is the possibility of locating a high yielding borehole or collector well in the close vicinity.

The recommended site for survey is in a valley which emerges from an upland area to the south of Chibi and which occurs on a strong fissure system which appears to intersect upland flat valleys which might well provide sustained storage. There is clear evidence of shallow groundwater from the occurrence of green grass and phreatophytic trees and reeds.

Geophysical survey. (Figure 3.25)

Two transverse EM traverses were carried out to the north of the road and a VES between the traverses on the west side. EM34-T1 is shown in Figure 3.25 together with a radon survey along the same line. The VES values are not encouraging and the site was not pegged. The low resistivities indicate clayey material above

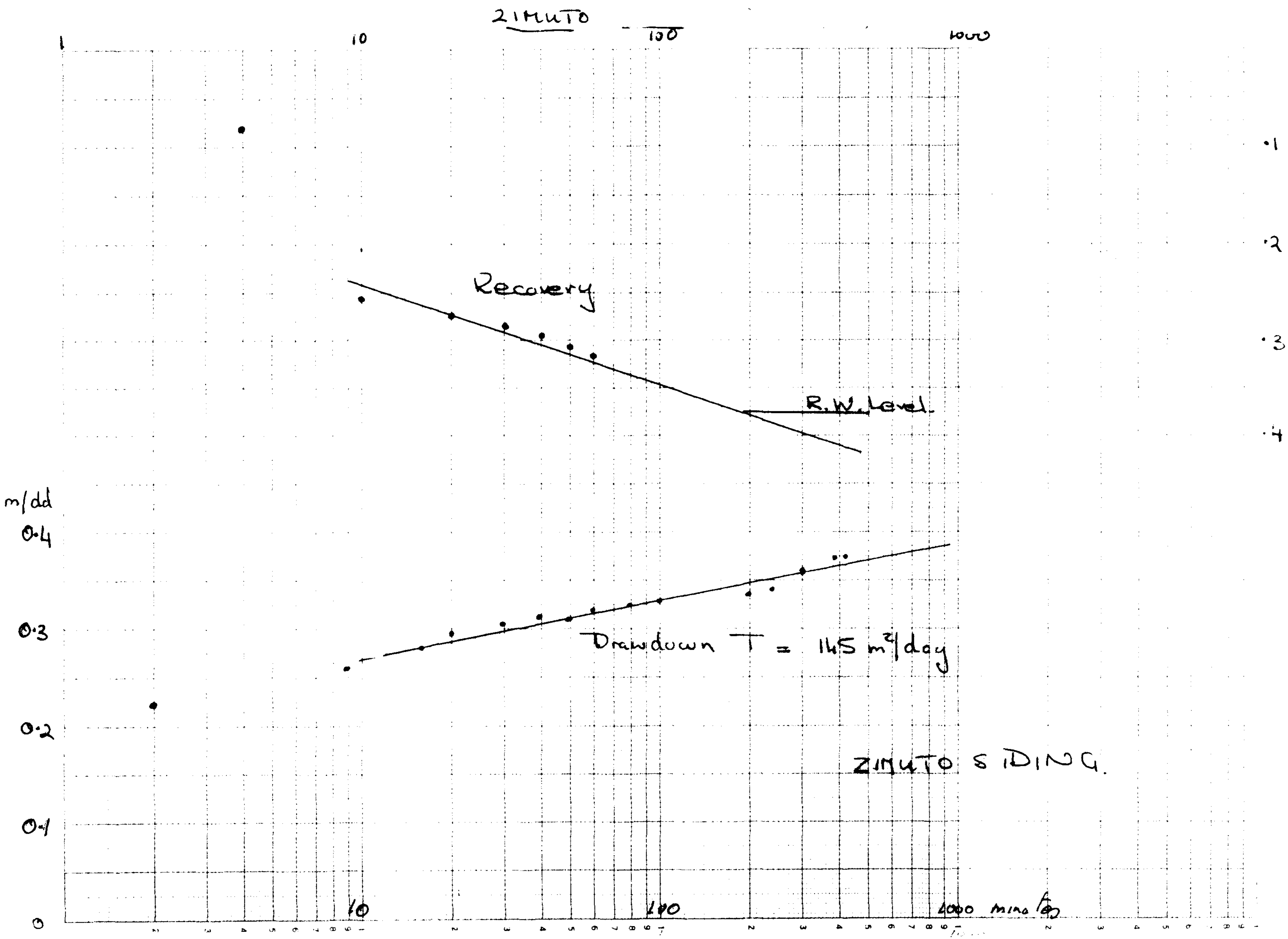
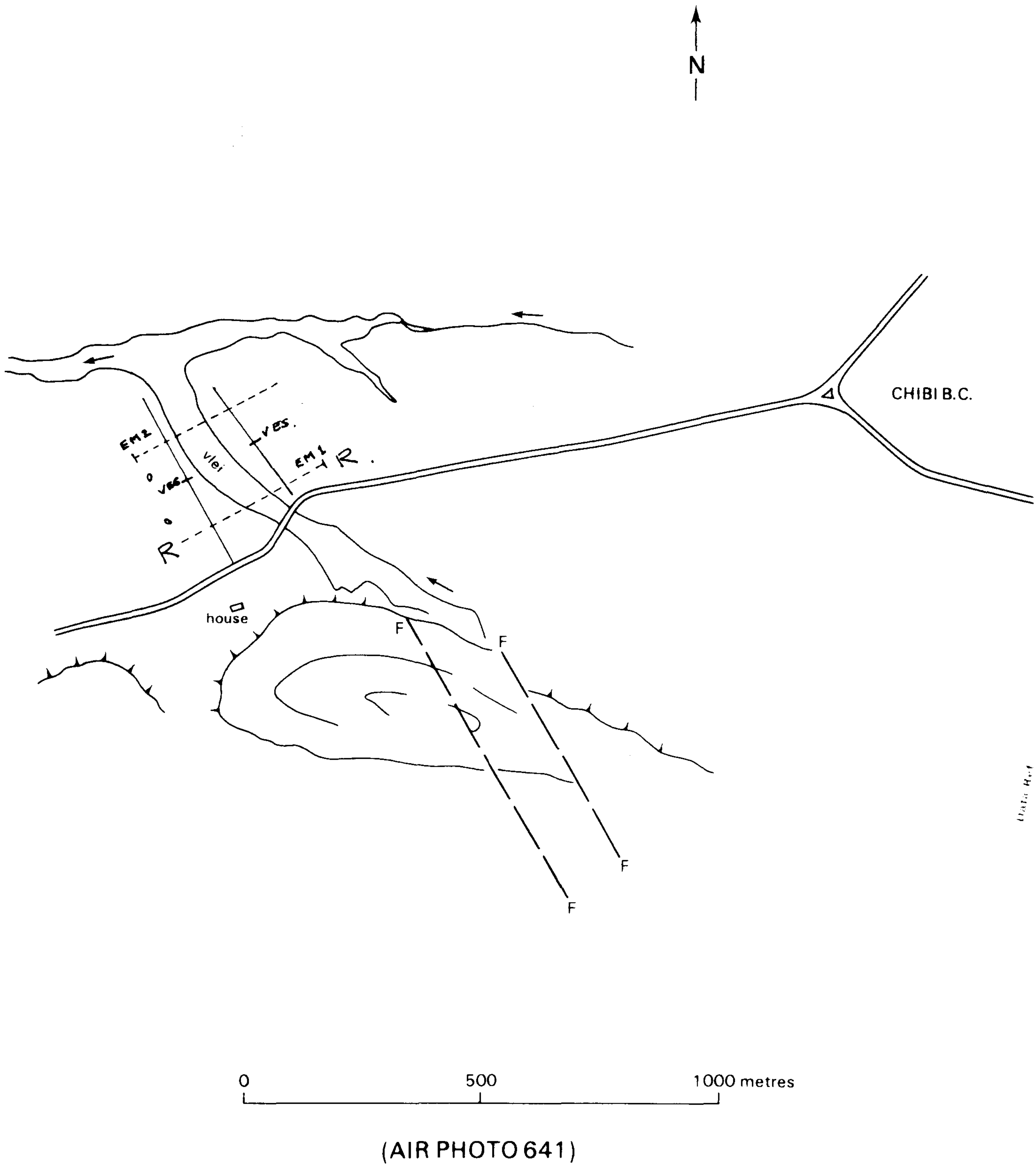

ZIMUTO
1
10
100
1000
Recovery
R.W. Level
·1
·2
·3
·4
m/dd
0·4
0·3
0·2
0·1
0
Drawdown T = 145 m²/day
ZIMUTO SIDING.
10
100
1000 mins

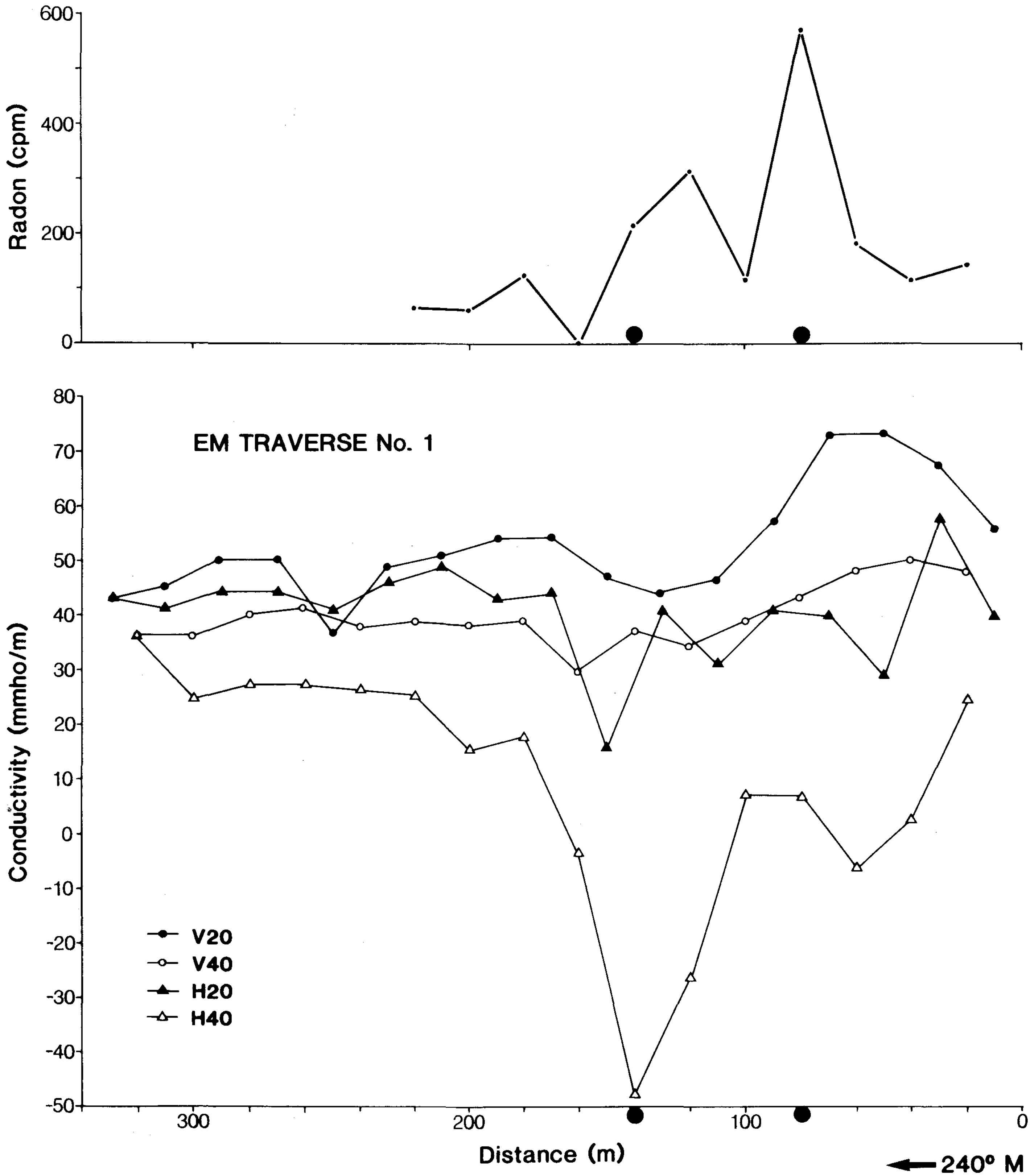
Figure 3.23

CHIBI B.C.: AREA F



(AIR PHOTO 641)

Figure 3.24



CHIBI SW

Figure 3.25

shallow bedrock and the results clearly do not meet the Master Plan criteria.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.45	1100.00
2	4.00	35.00
3	6.00	4.00
Infinity		5000.00

Radon survey.

Background value: 41 counts
Maximum anomaly: 578 counts

The radon counts on the flat valley floor and across the vertical EM anomaly were generally low but this could be an effect of the dambo clay inhibiting upward movement of radon in the soil air. Sites were selected for drilling on the maximum radon anomaly and in the centre of the valley close to the EM anomaly. A second VES was carried out on the east side in the vicinity of the proposed borehole, Chibi I, and gave the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.48	150.00
2	7.20	10.50
3	40.0	105.00
Infinity		-

3.11.1 Drilling. Borehole I (Figure 3.26) G.R. TN 389 524

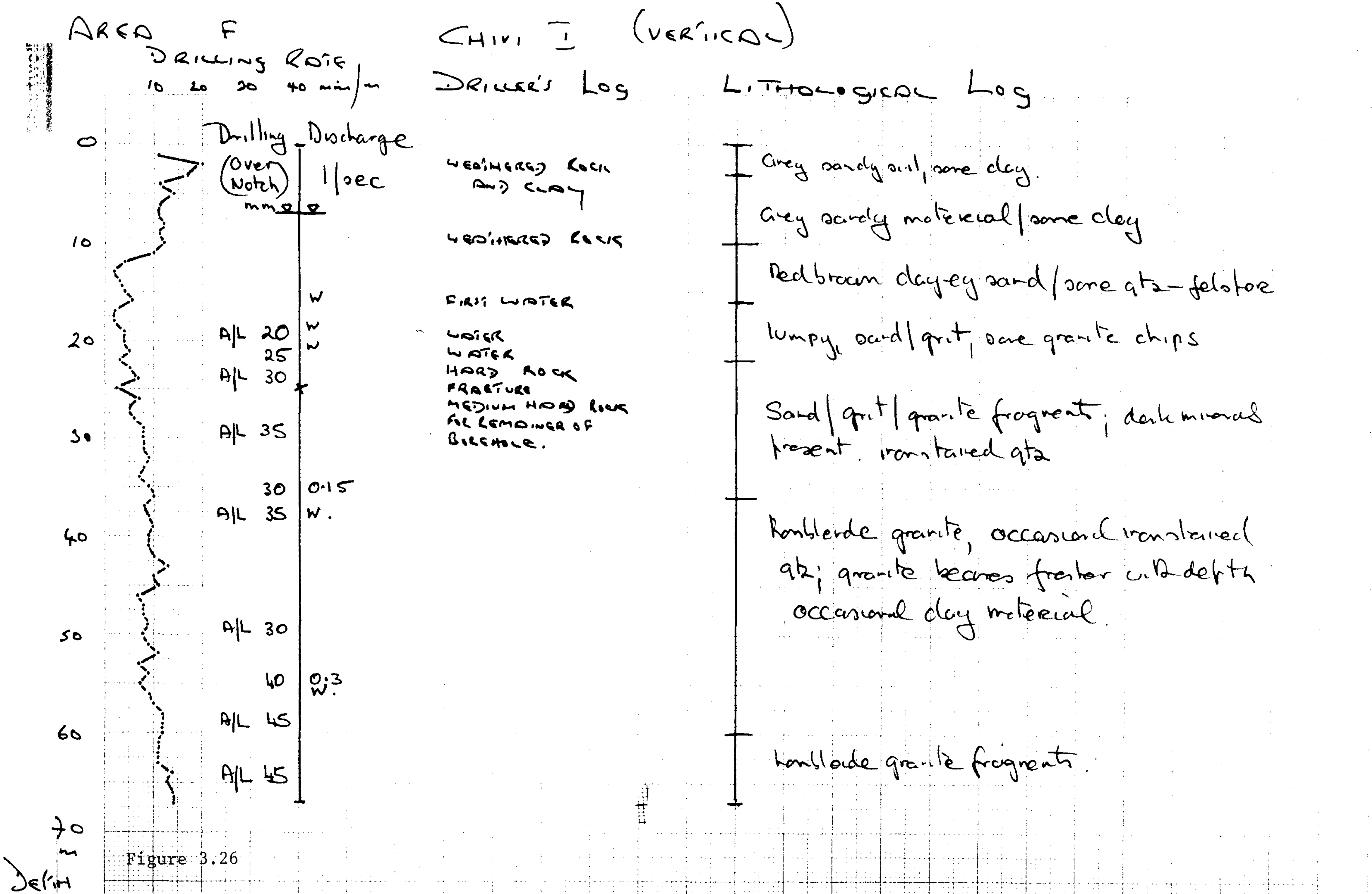
The drilling rate indicated softer (weathered) rock to 28 m and transitional into harder rock between 28 and 40 metres. This gives some correspondence with the VES in the vicinity and a rather surprising contrast with the VES on the opposite valley side.

The samples show a reasonable correspondence with the drilling log and include mainly sand/grit with occasional granite chips to 36 m and a variable degree of weathering. Below this level, some weathering persists but dark minerals now become apparent and the granite fragments are fresher.

Pumping test. (Figure 3.27)

Date: 19.10.87
Duration: 4 hours 20 minutes
Discharge: initially at 0.57 l/sec dropping to 0.27
SWL: 7.44 m below casing top
Final drawdown: 23.56
5 hour specific capacity (mean): .018 l/sec/m

The data indicate a low transmissivity value of 0.44 m^2/day. The yield is adequate for a handpump but not for a motorised pump unless a collector well was constructed.



AREA F
CHIVI I (VERTICAL)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Drilling Discharge
(Over Notch)
l/sec
WEATHERED ROCK AND CLAY
WEATHERED ROCK
FIRST WATER
WATER
WATER
HARD ROCK
FRACTURE
MEDIUM HARD ROCK FOR REMAINDER OF BOREHOLE.
A/L 20
25
A/L 30
A/L 35
30
0.15
A/L 35
W.
A/L 30
40
0.3 W.
A/L 45
A/L 45
Grey sandy soil, some clay.
Grey sandy material/some clay
Redbrown clayey sand/some qtz-feldspar
lumpy sand/grit, some granite chips
Sand/grit/granite fragments; dark minerals present. ironstained qtz
occasional clay material.
0
10
20
30
40
50
60
70
m
Depth

Figure 3.26

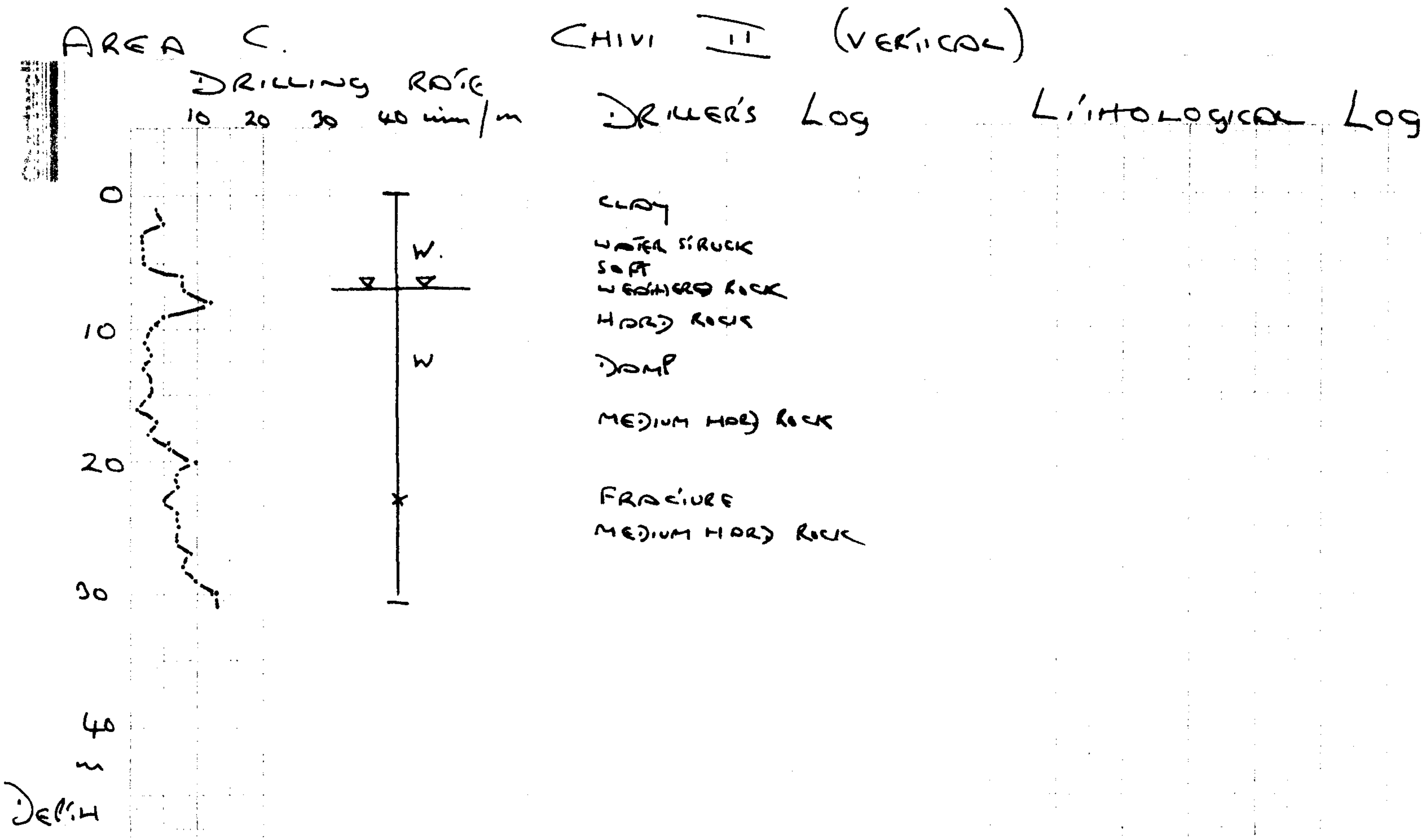

AREA C.
CHIVI II (VERTICAL)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
0
10
20
30
40
m
DEPTH
W.
W
CLAY
WATER STRUCK
SOFT
WEATHERED ROCK
HARD ROCK
DAMP
MEDIUM HARD ROCK
FRACTURE
MEDIUM HARD ROCK

Figure 3.27

3.11.2 Chibi II. (Figure 3.28) G.R. TN 388 524

Holes were drilled in the central dambo area with a view to ascertaining whether the vertical anomaly occurred on the site of a transmissive fracture system. An angled hole was initially attempted but had to be abandoned at 10 m due to the difficulty of drilling through collapsing sand and clay. A second vertical hole on the site attained 31 m, mostly in weathered rock but with a few fractures being encountered and negligible water.

To summarise, the radon survey appears to have identified the location of a borehole with a modest yield. A collector well on the same site is the best option for an improved yield.

3.12 Chinambiri School (= Old Mazorodze School) 2030 B3 (Figure 3.29)

Background.

Existing borehole: GEMS 3084 [2458/77552]
Total depth: 45.0 m
Saprolite: 18.0 m
Rest water level: 20.0 m
Yield: 0.208 l/sec

The borehole site is on or near to a lineament trending north-west but fairly close to the watershed. Water levels are deep and there appears to be no saturated saprolite. The key criteria is whether the site is on sufficiently high transmissivity to locate adequate storage in the near vicinity.

Alternative sites: The first alternative site could be close to the existing borehole but located more precisely on the lineament.

A second alternative site is further down the valley to the NW. Constraints will be effected by the barrier boundaries of the rocky adjacent hills. A successful site for a borehole will require adequate thickness of saturated regolith and a significant lineament effect to counteract the barrier effects; for a protected dug well there must be an adequate thickness (c. 10 m) of diggable saturated saprolite. Valley floor has dark soils and no obvious outcrop which looks favourable.

The third alternative site is to the east of the school on an intersection of fracture systems, some of which are occupied by dolerite dykes. There is much rock outcrop in the general vicinity which would indicate a paucity of groundwater storage and this could be a major constraint. This site is only feasible for a borehole.

3.12.1 Geophysical survey. Existing borehole site 1 (Figure 3.30)

EM34 traverses were run across the existing borehole site and an alternative site for a borehole selected close by but designed to more precisely intersect the lineament and inclined. The VES on the site gave poor results and clearly success would depend on intersecting a sufficiently transmissive fracture sustem.

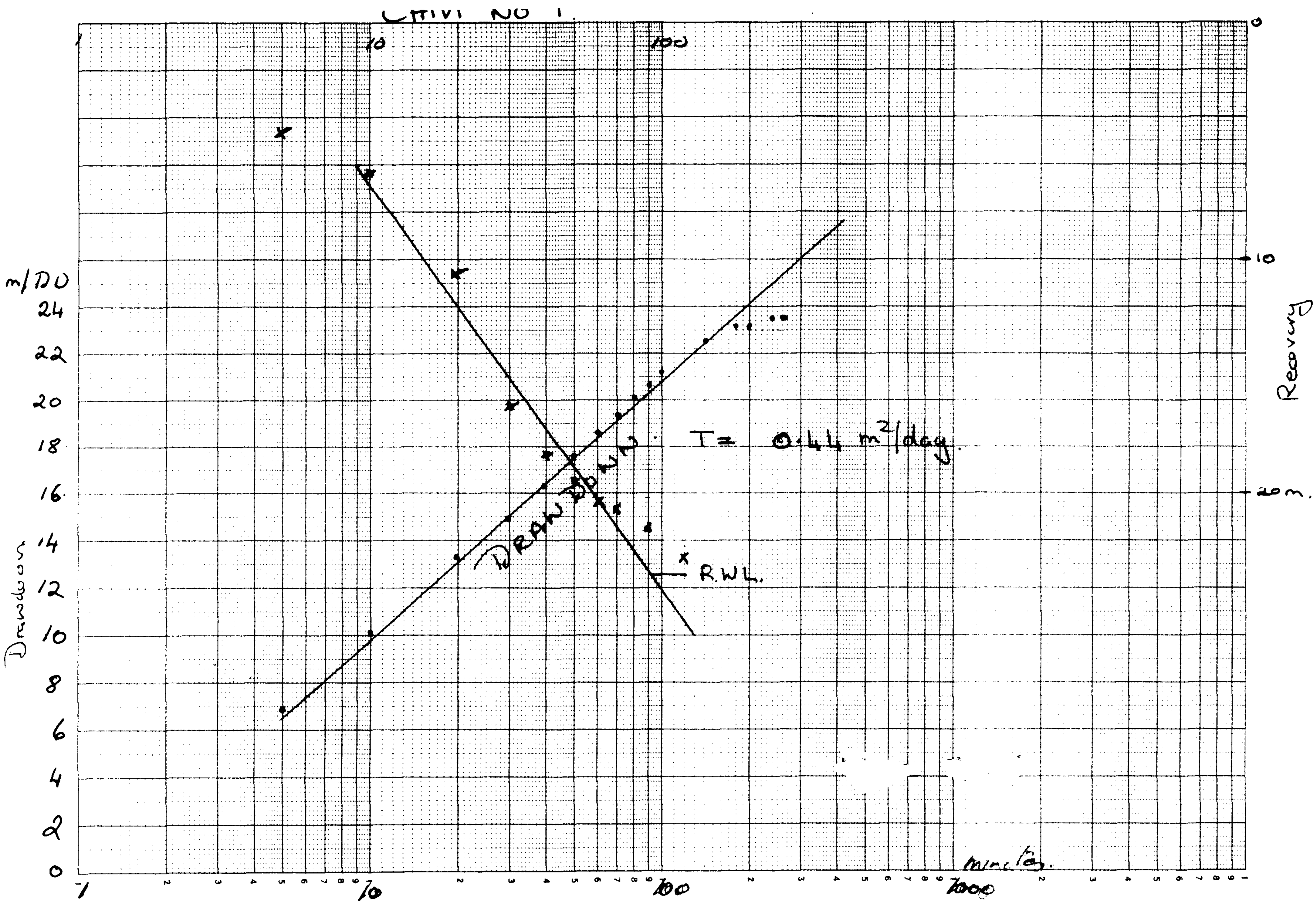
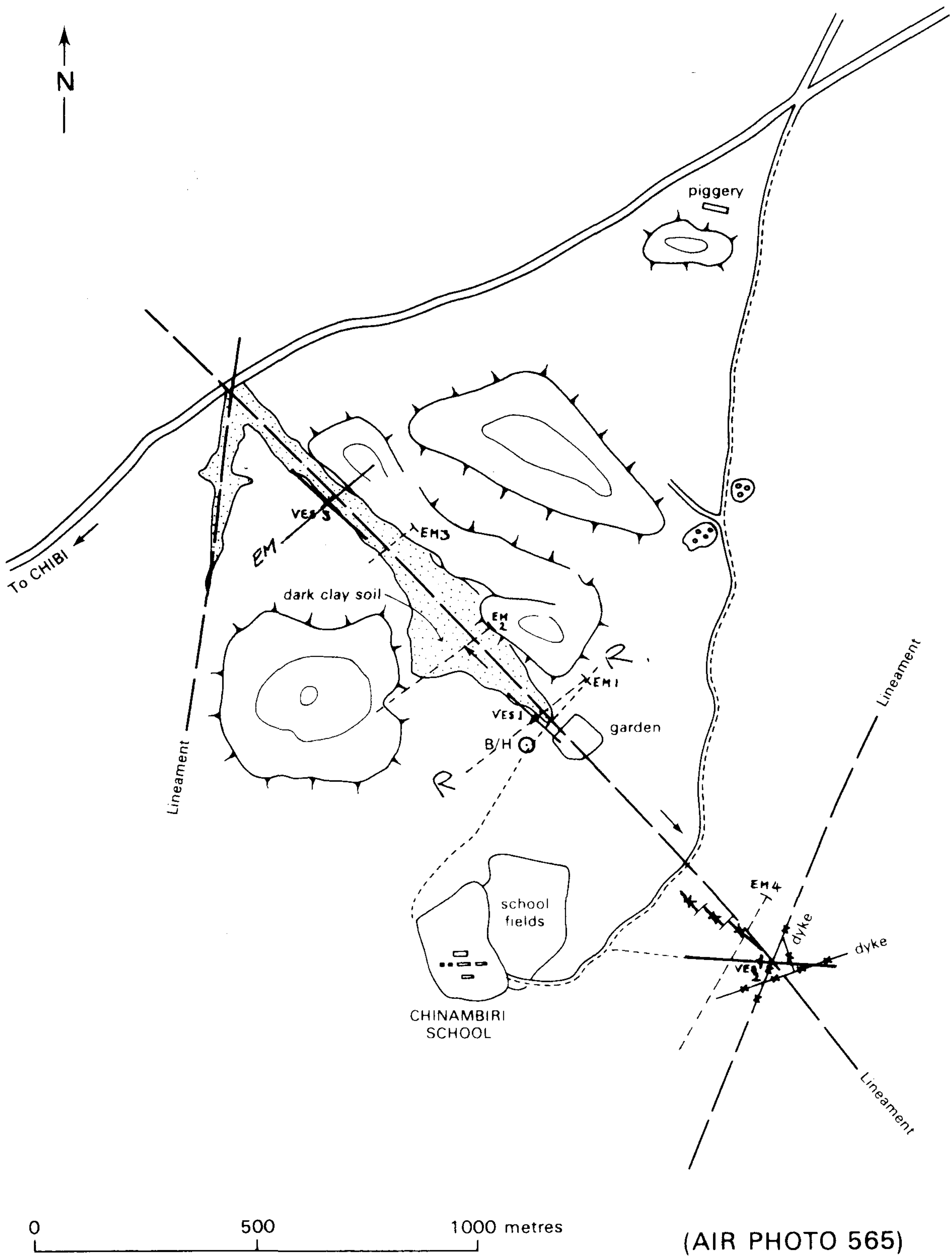

CHM NO 1
m/DD
Drawdown
Recovery
DRAWDOWN
T= 0.44 m²/day
R.W.L.
minutes
20m.

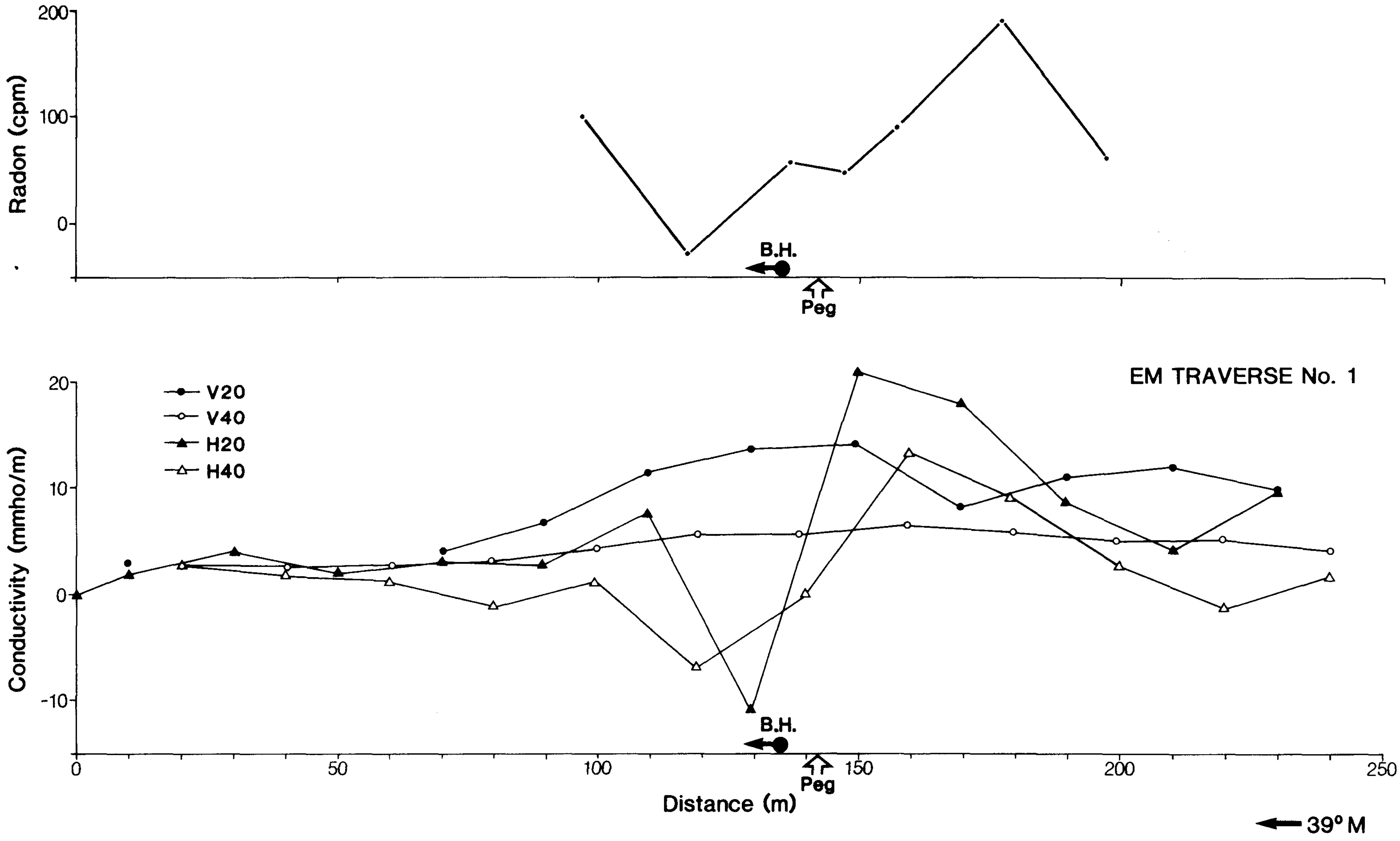
Figure 3.28

CHINAMBIRI SCHOOL: AREA F



(AIR PHOTO 565)

Figure 3.29



CHINAMBIRI SCHOOL SITE

Figure 3.30

VES by Borehole

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.30	560.00
2	5.00	8.50
Infinity		5000.00

Radon survey.

Background: 108 counts
Maximum anomaly: 187 counts

The radon counts were very small with the maximum anomaly less than double the initial background. There was no correspondence with the main EM anomaly. The maximum radon count was on the side of the traverse close to the existing borehole.

Drilling. (Figure 3.31) G.R. TN 459 553

The EM34 traverse and the AP interpretation indicated that the main lineament/structural feature occurred a short distance to the east of the existing borehole. Despite the minor anomaly, the poor VES and low radon, an experimental borehole was drilled at an angle of 20^o to the vertical and designed to intersect the main lineament zone as defined by the EM34 traverse. The drilling and lithological logs indicated regolith to 19 m transitional into medium-hard to hard rocks at 23 m and mainly composed of hornblende gneiss. The hole was effectively dry to 70 m and no significant fractures were encountered.

3.12.2 Alternative Site 2. Below Dam site (Figure 3.32)

This site showed a distinct vertical sided anomaly and the VES indicated a moderate thickness of regolith

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.80	600.00
2	20.00	50.00
Infinity		5000.00

Drilling. (Figure 3.33) G.R. TN 455 558

The log showed weathered material to 20 m transitional into fresher hornblende gneiss at 35 m and continuous to total depth. The drilling discharge was low and became apparent only near the bottom of the borehole.

Pumping test. (Figure 3.34)

Date: 13.11.87
Duration: 150 minutes; suction at 67 m
Discharge: 0.29/0.25 l/sec for 40 minutes reducing to 0.18 on reaching suction and then to 0.062 l/sec

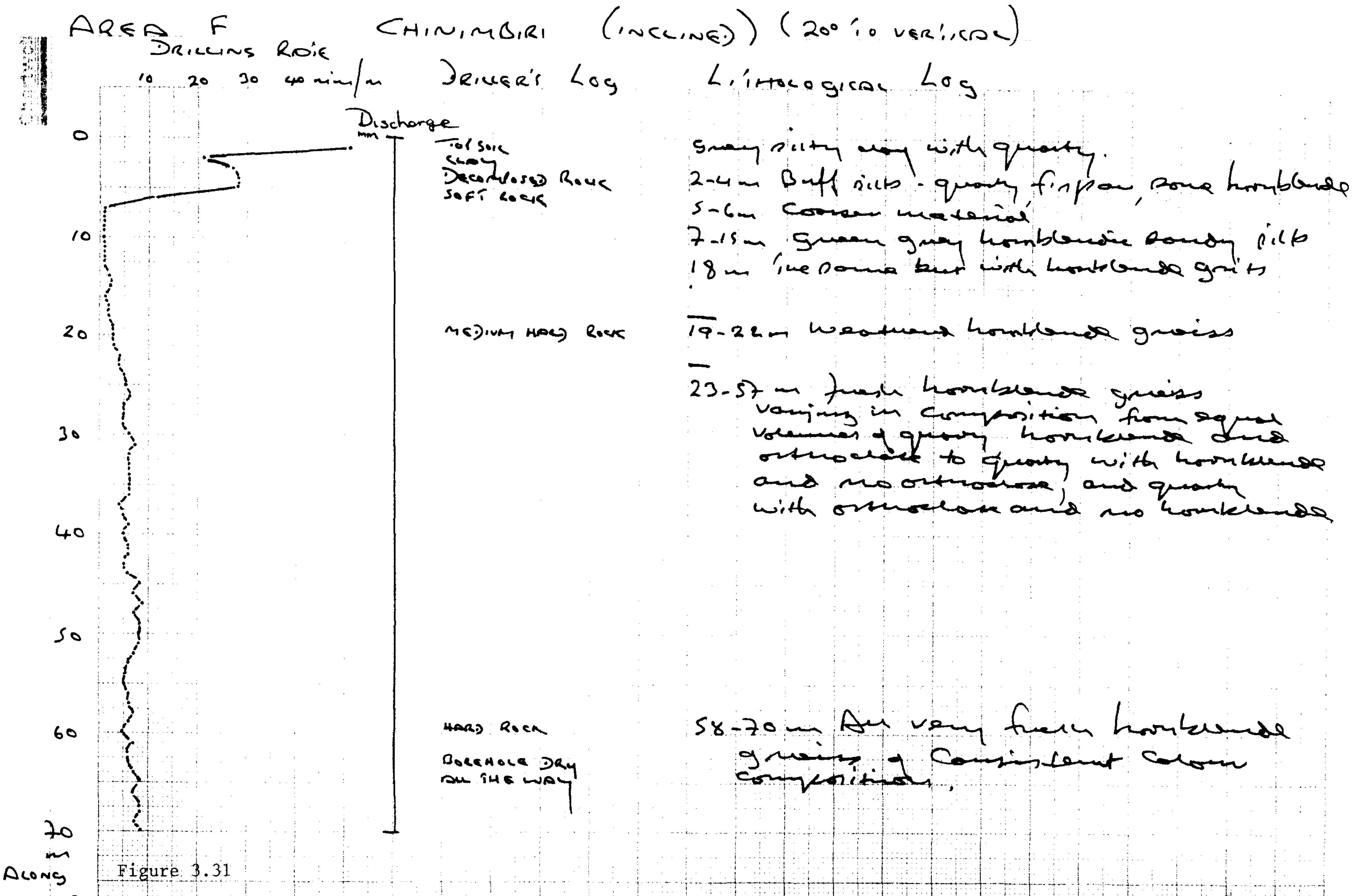
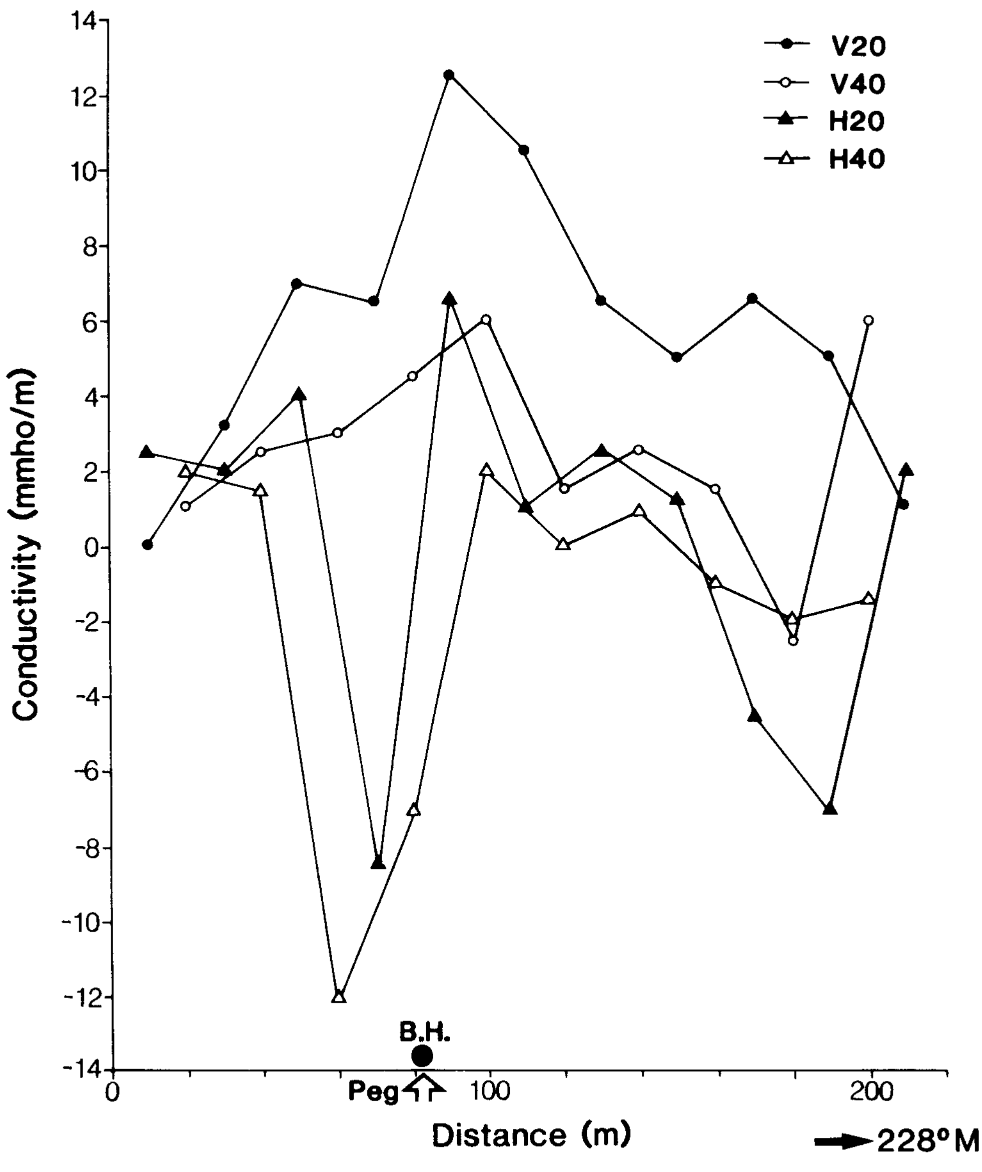

AREA F CHINIMBIRI (INCLINED) (20° to vertical)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm
0
10
20
30
40
50
60
70
m
ALONG
TOP SOIL
CLAY
DECOMPOSED ROCK
SOFT ROCK
MEDIUM HARD ROCK
HARD ROCK
BOREHOLE DRY
ALL THE WAY
Grey silty clay with quartz.
2-4m Buff silts - quartz, felspar, some hornblende
5-6m Coarser material
7-15m Green grey hornblendic sandy silts
18m The same but with hornblende grits
19-22m Weathered hornblende gneiss
23-57m fresh hornblende gneiss
varying in composition from equal
volumes of quartz, hornblende and
orthoclase to quartz with hornblende
and no orthoclase, and quartz
with orthoclase and no hornblende
58-70m All very fresh hornblende
gneiss of consistent colour
composition.

Figure 3.31



CHINAMBIRI
BELOW DAM BOREHOLE SITE

Figure 3.32

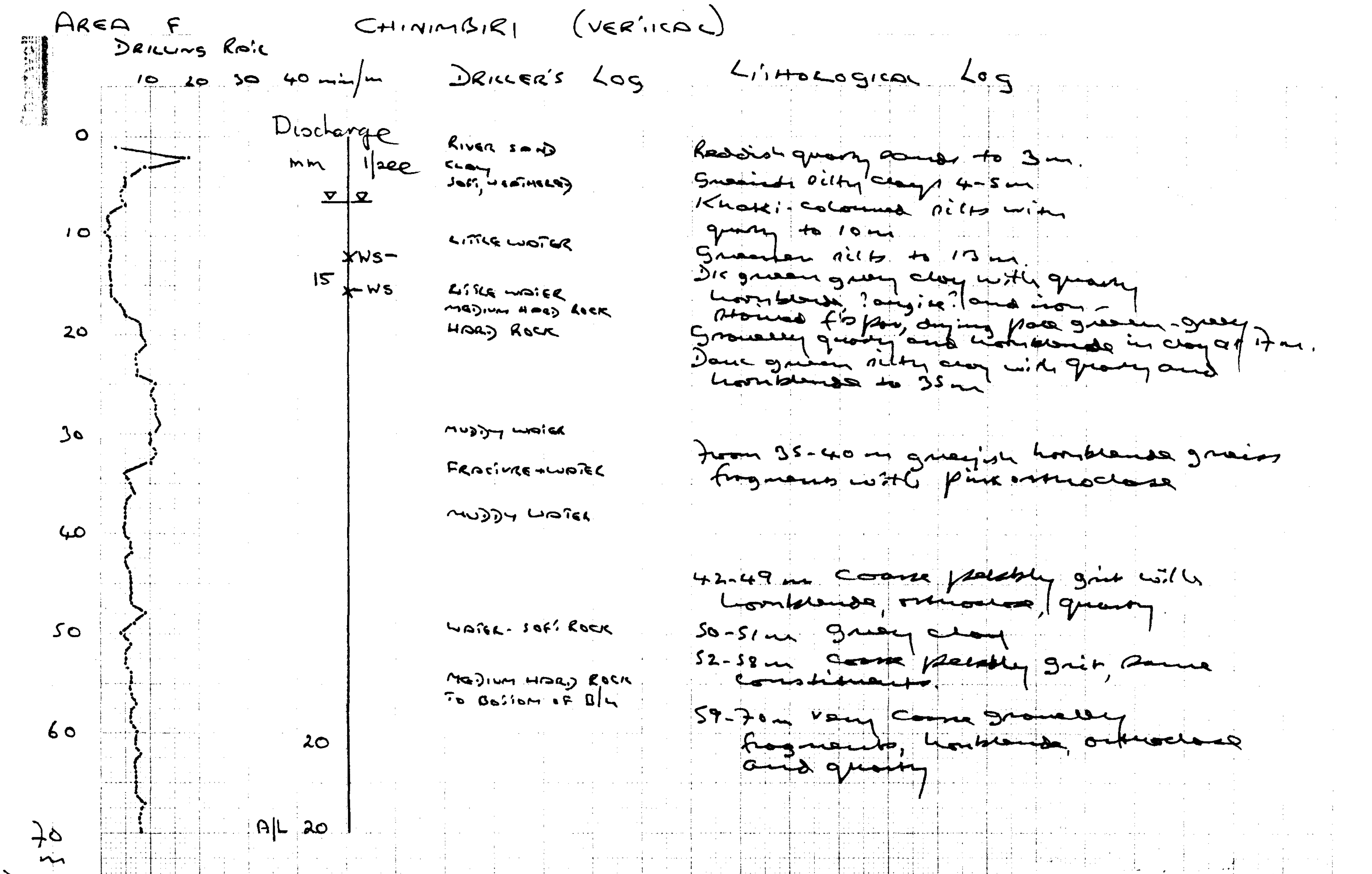
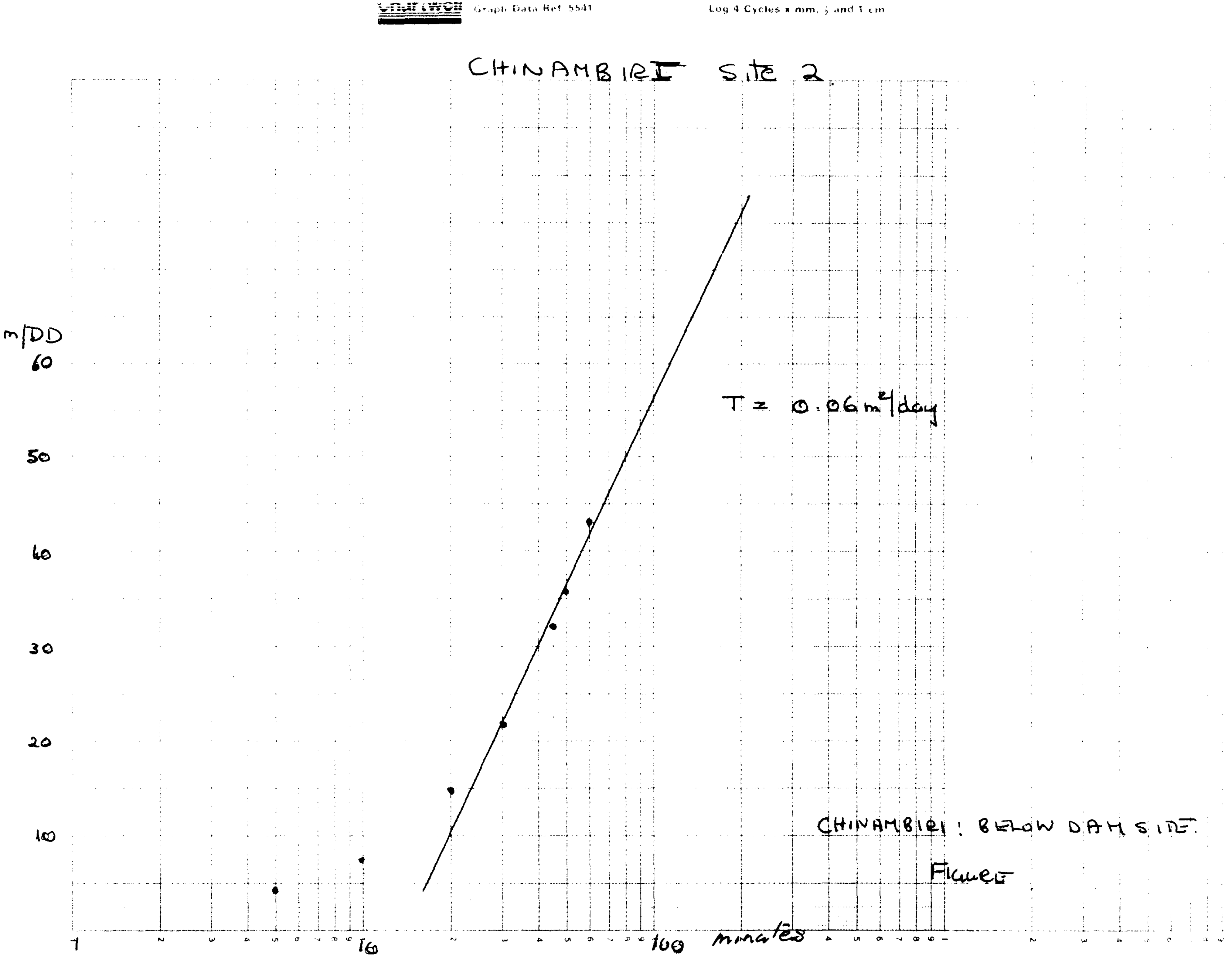

AREA F CHINIMBIRI (VERTICAL)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm 1/sec
0
10
20
30
40
50
60
70 m
15
20
A/L 20
WS
WS
RIVER SAND
CLAY
SOFT, WEATHERED
LITTLE WATER
LITTLE WATER
MEDIUM HARD ROCK
HARD ROCK
MUDDY WATER
FRACTURE + WATER
MUDDY WATER
WATER - SOFT ROCK
MEDIUM HARD ROCK
TO BOTTOM OF B/H
Reddish quartz sands to 3 m.
silty clays 4-5 m
Khaki-coloured silts with quartz to 10 m
Greenish silts to 13 m.
Dk green grey clay with quartz hornblende ?augite? and iron-stained f's
Gravelly quartz and hornblende in clay at 17 m.
Dark green silty clay with quartz and hornblende to 35 m
from 35-40 m greyish hornblende gneiss fragments with pink orthoclase
42-49 m coarse feldspathic grit with hornblende, orthoclase, quartz
50-51 m grey clay
52-58 m coarse feldspathic grit, same constituents.
59-70 m very coarse gravelly fragments, hornblende, orthoclase and quartz

Figure 3.33

Figure 3.34


Graph Data Ref 5541
Log 4 Cycles x mm, ½ and 1 cm
CHINAMBIRI Site 2
m/DD
60
50
40
30
20
10
T = 0.06 m²/day
CHINAMBIRI : BELOW DAM SITE
FIGURE
1
10
100
minutes

Quality: 1700 microsiemens but very muddy even by end of test
SWL: 7.79 m below datum (0.5 m agl)

The borehole yield is insufficient for a handpump and the borehole subsequently collapsed. A collector well could be considered on the site.

3.13 **Mhatiwa School** 2030 B3 (Figure 3.35)

Background.

Existing borehole: JP 5849 [2489/77474]
Total depth: 40.0 m
Saprolite: [40.0 m]
Rest water level: 8.0 m
Yield: 0.044 l/sec

The borehole has a very poor yield on test and is generally a poor producer which deteriorates in the dry season. The quality is also poor.

An alternative site is close to the existing borehole but located more precisely on the lineament. An angled hole could be considered. [Existing Borehole Site]

A second location for a borehole and/or dug well is in the vicinity of the dug wells down the valley close to the intersection of two strong lineament systems. [Valley Intersection Site]

A final site is in the valley which continues the same valley on which the borehole is located but downstream of the intersection above. The valley is floored by dark soils with green grass and phreatophytes apparent in the middle of the dry season. [East Valley Site]

3.13.1 Geophysical survey. (Existing Borehole Site)

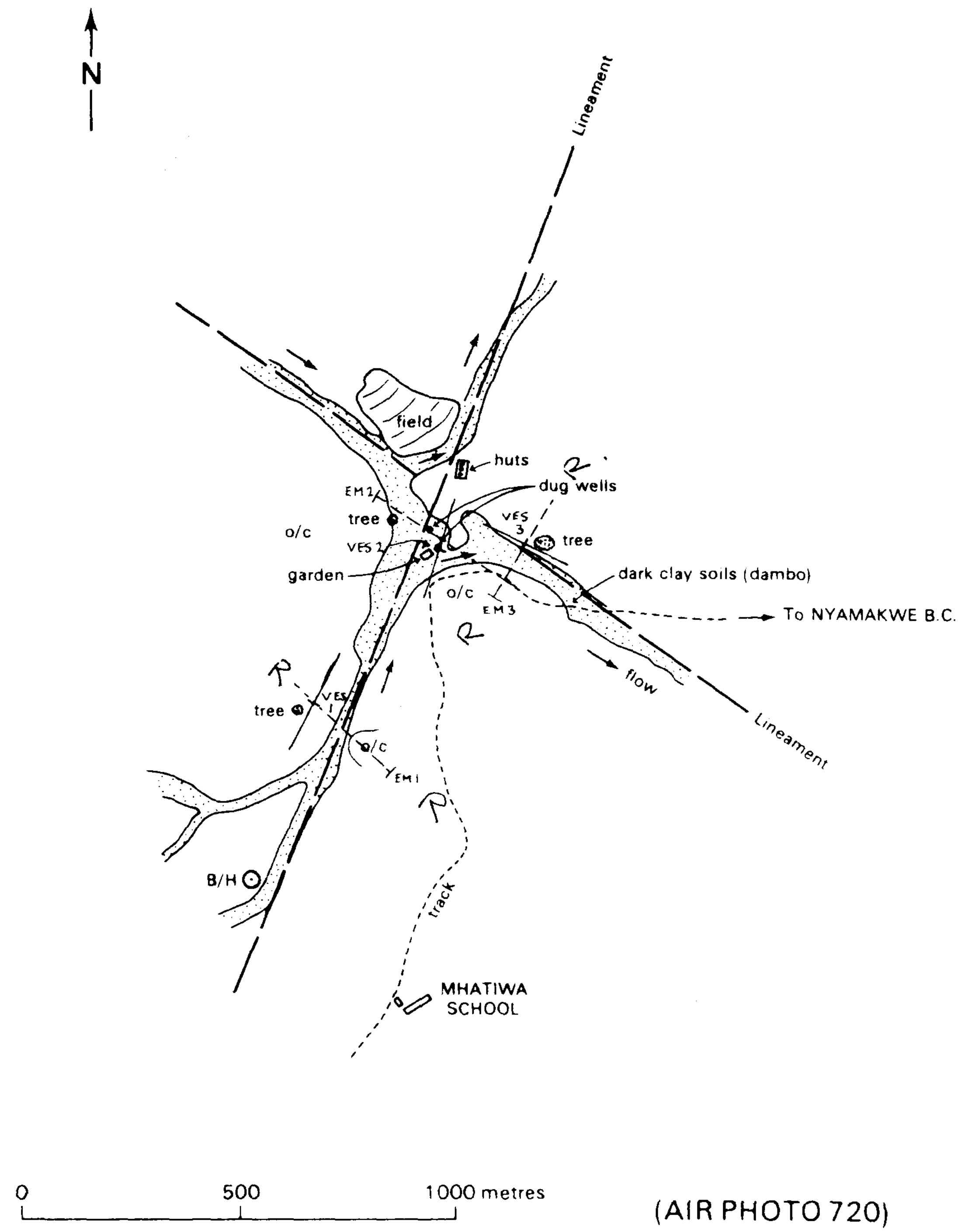
Seismic and EM34 traverses were carried out along a bearing of 134^{o} m from the borehole to the school across the valley which occurs on a marked lineament. This work was carried out in 1986 and the EM34 traverse is given in Figure 3.36. The seismic survey indicated a thin layer of soil or regolith with a maximum thickness of 6 m overlying hard bedrock. A sub-vertical conductive body some 40 m wide is suggested which occurs between the stream bed and the borehole. The feature is confirmed by the EM34 survey.

Radon survey.

Background: 5 cpm
Maximum anomaly: 808 cpm

Traverse: Values are generally well above background and the main anomaly corresponds fairly well with the EM peak. A repeat reading of the survey position close to the borehole (immediately to west)

MHATIWA SCHOOL: AREA F: MAP 2030 B3



(AIR PHOTO 720)

Figure 3.35

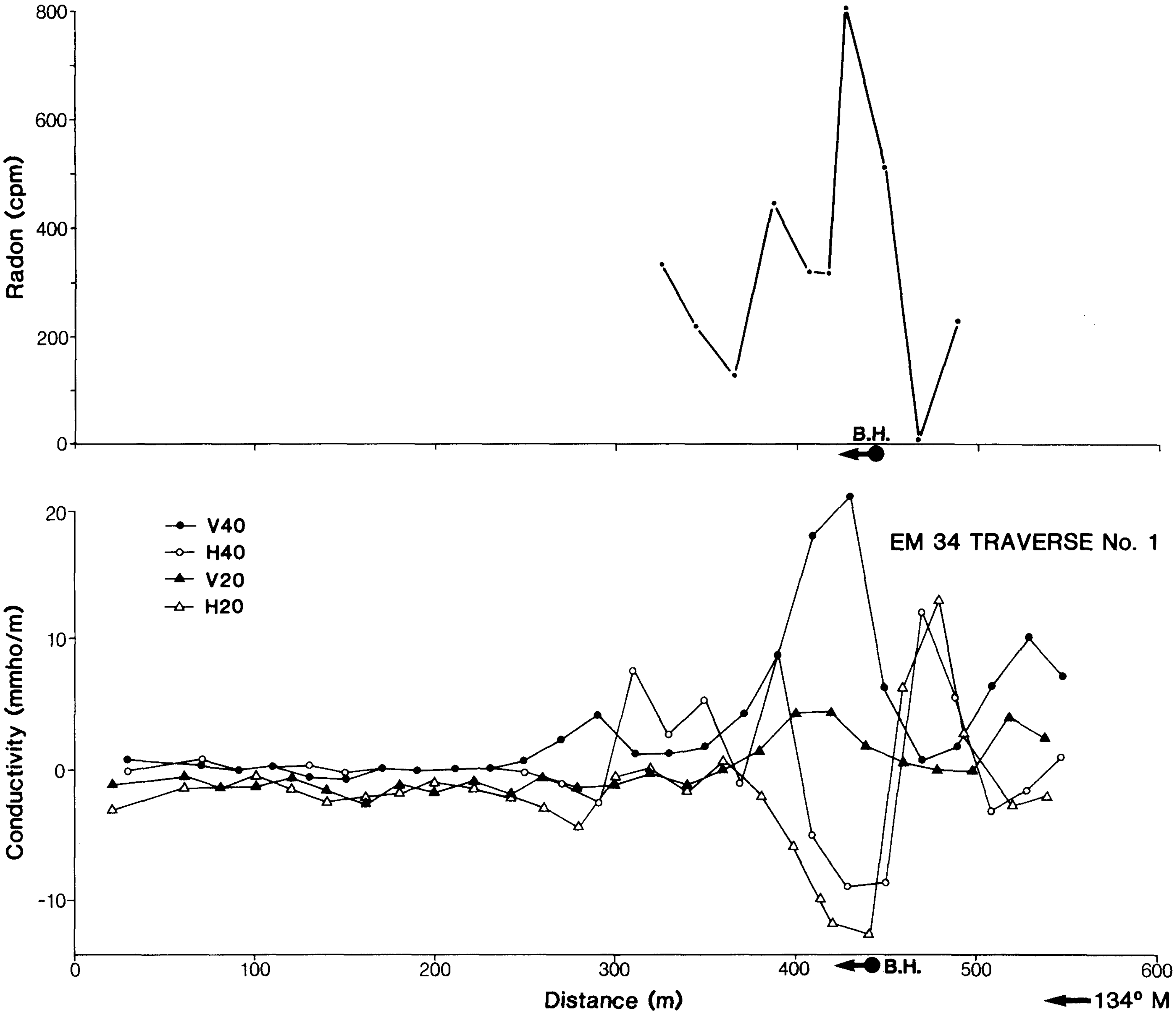


Figure 3.36

MHATIVA SCHOOL

gave a value of 371 as compared with 511 on the initial run. The rock outcrops on the traverse are of foliated fine to medium grained granite with pegmatite veins but few joints.

Drilling. (Figure 3.37) G.R. TN 489 474

The drilling rate did not vary greatly with depth but the drilling log indicated decomposed rock to 6 m (= 4 m vertical), corresponding roughly with the seismic data. The final drilling metrage was 49 m equivalent to 35 m vertical depth. The borehole encountered few fractures and could have been continued to greater depth but a deterioration of quality was noted, providing justification for stopping.

The lithological log showed stronger weathering to 9 m (= 6 m vertical) and increasing freshness of rock below. Some white material at 16 m could be carbonate or sulphate and could account for the poor water quality. The main rock is a fine grained foliated biotite granite.

Pumping test.

Date: 28 October 1987
RWL: 9.82 m along incline = 6.9 m vertical
Suction: 40 m = 28 m vertical
Discharge: 0.12 l/sec stabilised at 235 minutes
Quality: 7700 microsiemens (poor)
The dipper could not operate but a cutoff electrode at 26 m vertical position was not triggered during the above test.

3.13.2 East Valley Site. (Mhatiwa North)

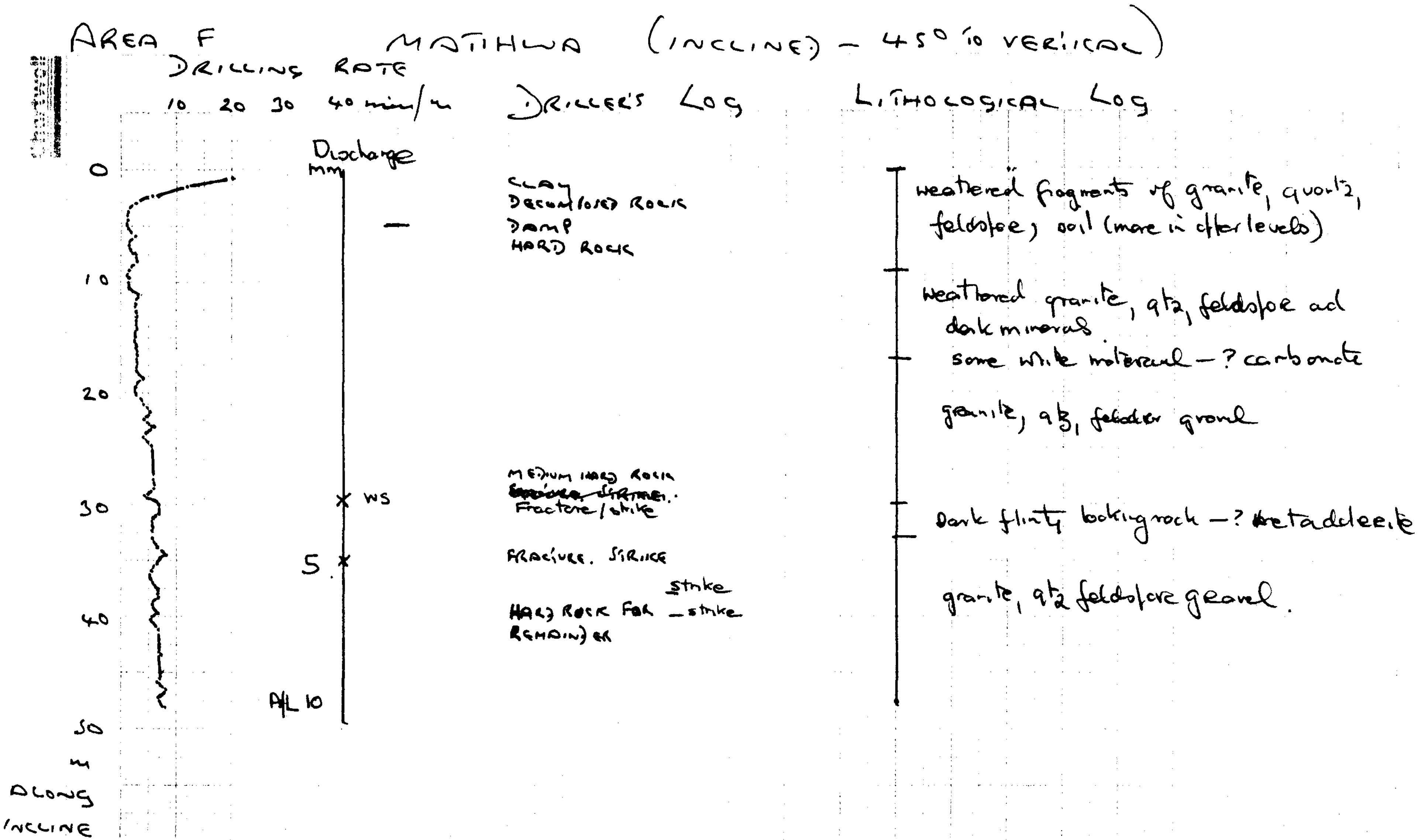
Geophysical survey. (Figure 3.38)

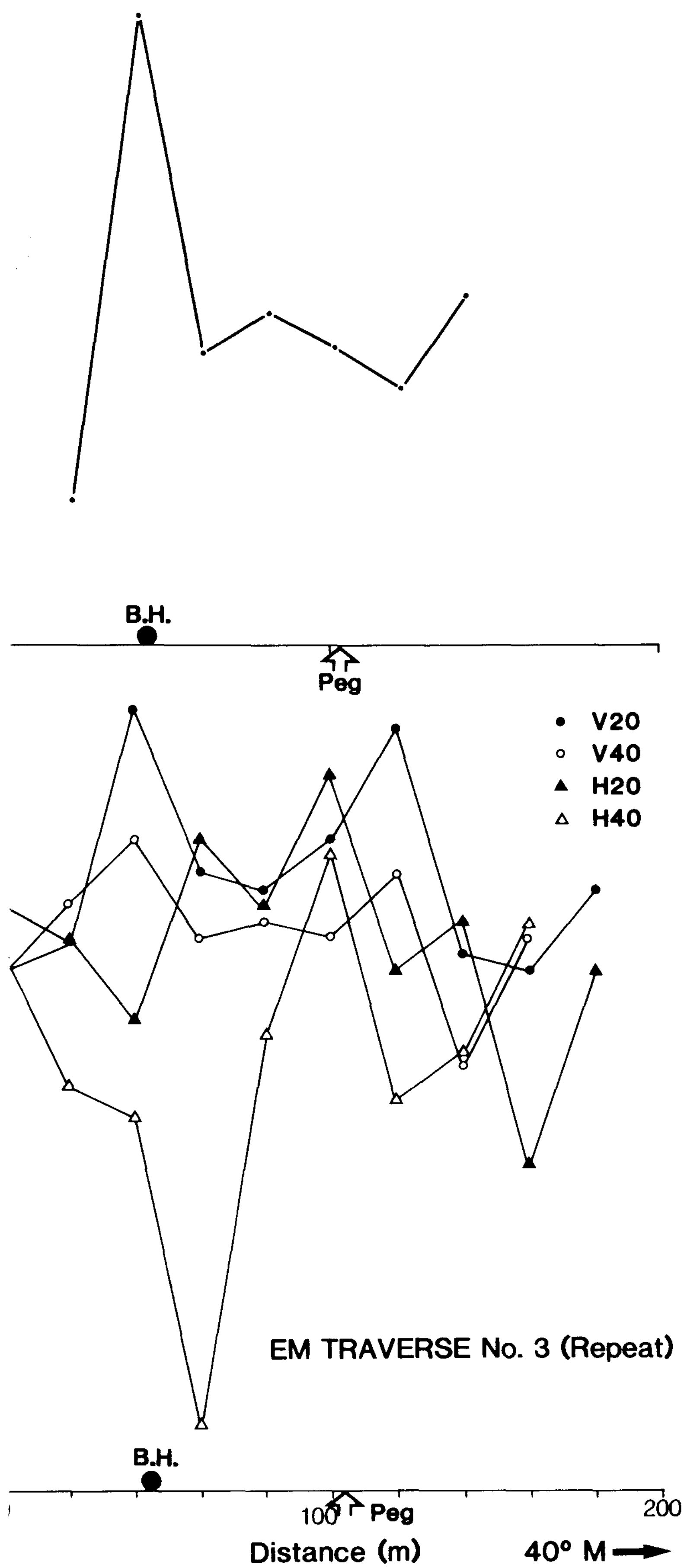
The second site is on the same valley after it turns to the east. The EM34 traverse showed a marked conductive anomaly on the south side. The VES on the site of the maximum anomaly and on a line parallel to the valley showed the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.75	800.00
2	3.75	40.00
3	3.4	400.00
Infinity		10,000.00

A VES on the north side of the valley adjacent to Smith's cairn gave the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.90	3,500.00
2	4.00	30.00
3	10.00	1,000.00
Infinity		5,000.00


AREA F MATIHWA (INCLINE) – 45° to VERTICAL)
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
0
10
20
30
40
50
m
ALONG
INCLINE
CLAY
DECOMPOSED ROCK
DAMP
HARD ROCK
MEDIUM HARD ROCK
Fracture / strike
WS
5
FRACTURE. STRIKE
strike
HARD ROCK FOR – strike
REMAINDER
AL 10
weathered fragments of granite, quartz, feldspar, soil (more in upper levels)
weathered granite, qtz, feldspar and dark minerals
some white material – ? carbonate
granite, qtz, feldspar gravel
Dark flinty looking rock – ? metadolerite
granite, qtz feldspar gravel.
Figure 3.37



MATIHWA NORTH SITE

Figure 3.38

The results of both VESs are comparable and neither is indicative of a favourable borehole site.

Radon survey.

The radon traverse data are shown in Figure 3.38 and exhibit a maximum anomaly to the immediate south of the EM conductive anomaly. The initial background reading was 60 and the maximum anomaly was 482 cpm.

Drilling. (Figure 3.39) G.R. TN 493 484

The site selected for drilling was on the main radon anomaly and close to the EM anomaly site. The drilling rate fluctuated considerably. Soft rock occurs down to 10 m transitional to harder rock progressively to 28 m, after which the drilling rate increases considerably. At these deeper levels, the rock fragments are mainly of hornblende gneiss with clayey material occuring at the levels of fractures.

Pump testing. (Figure 3.40)

Date: 10.11.87
RWL: 6.38 m below datum (0.51 m agl)
Suction: 61 m
Duration: 420 minutes
Discharge: (i) 0.29 to 100 minutes
(ii) 0.26 to 180 minutes
(iii) 0.22 to 230 minutes
(iv) 0.11 to 420 minutes
Mean 5 hour specific capacity: 0.007

The pumping yield of in excess of 0.22 l/sec for 4 hours could be considered a marginal borehole and may justify the fitting of a handpump. A collector well would be feasible if excavation is possible to at least 15 m. The water quality is only fair with the final discharge having a value of 1,000 microsiemens although it compares favourably with the Mhatiwa Existing Borehole Site.

AREA C

Area C is underlain largely by older gneisses with subordinate outcrops of younger granite and greenstone. Of the 43 boreholes drilled in Area C, 7 have no yield data and the failure rate is in the range 42-51% (depending on the actual status of the latter). The mean regolith thickness is 21.5 m of which 10.4 m is below the water table. Three sites were selected for experimental drilling-Chikore, Chikofa and Rungai.

3.14 Chikore School 2030 D1 (Figure 3.41)

Background.

Existing borehole: JP 5458 [2543/77296]
Total depth: 65 m
Saprolite: [11.5 m]

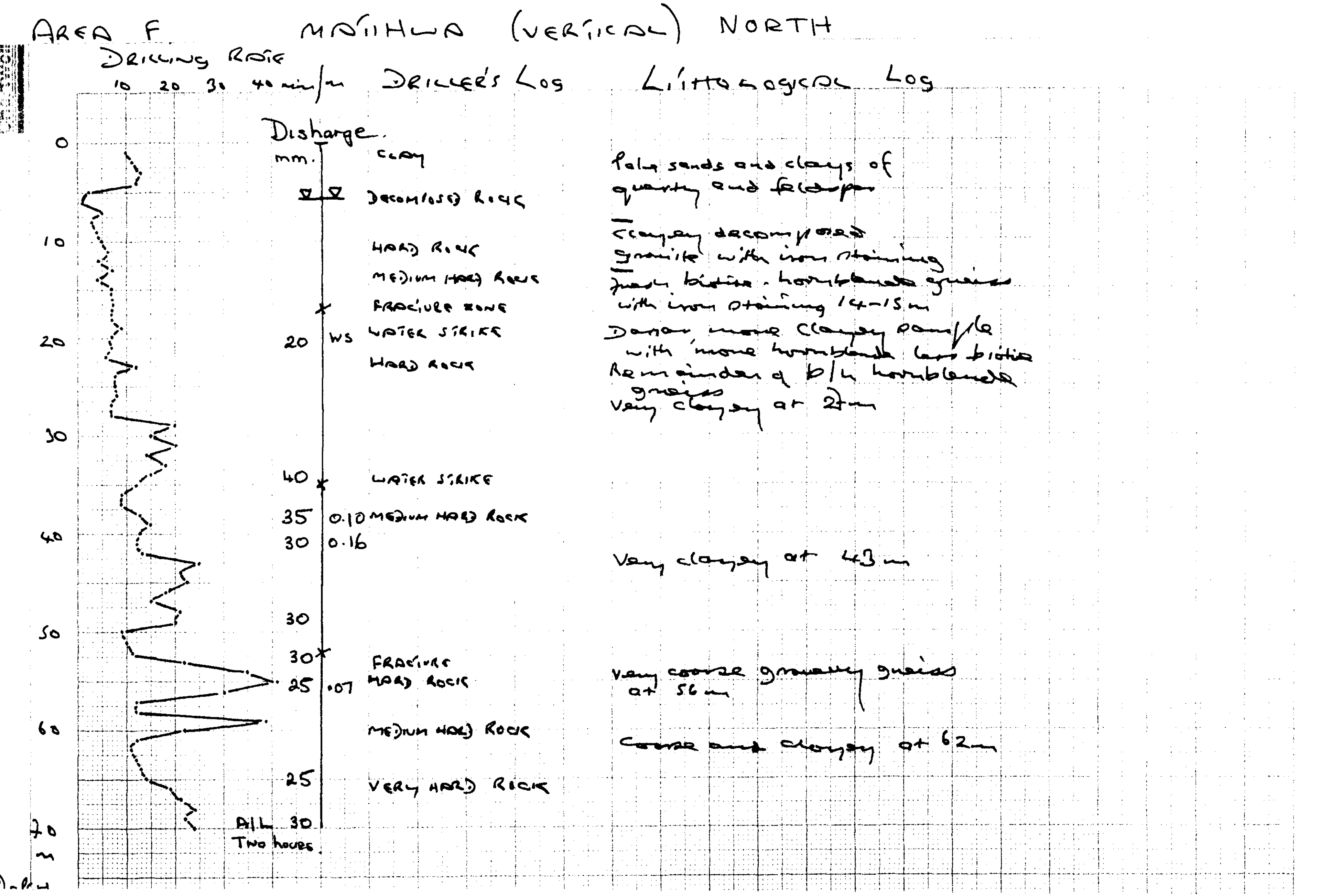
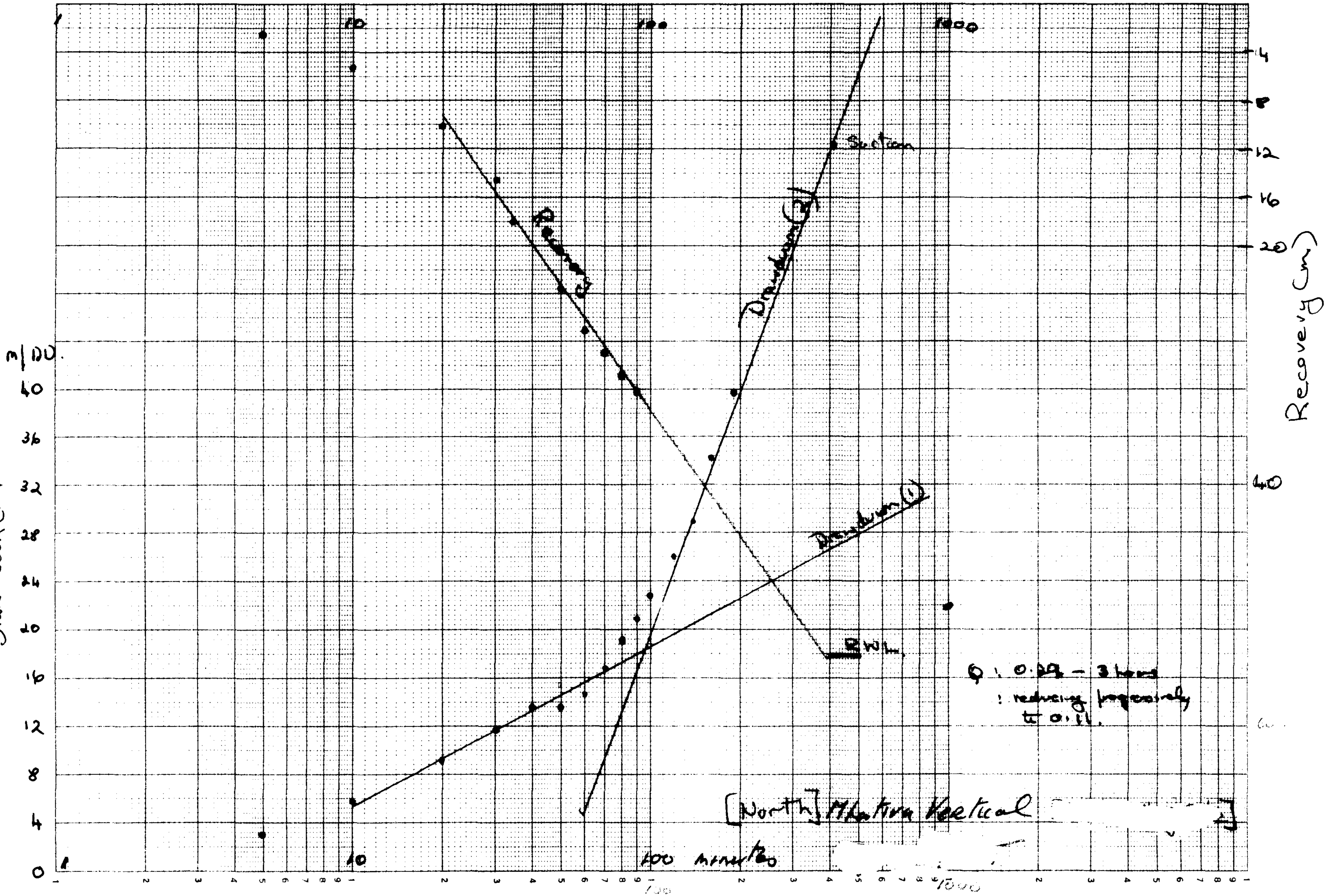

AREA F MAIIHWA (VERTICAL) NORTH
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Disharge.
mm.
CLAY
DECOMPOSED ROCK
HARD ROCK
MEDIUM HARD ROCK
FRACTURE ZONE
WATER STRIKE
HARD ROCK
WATER STRIKE
MEDIUM HARD ROCK
FRACTURE
HARD ROCK
MEDIUM HARD ROCK
VERY HARD ROCK
All 30
Two hours
20 WS
40
35 0.10
30 0.16
30
30
25 ·07
25
0
10
20
30
40
50
60
70
m
Pale sands and clays of quartz and feldspar
Clayey decomposed granite with iron staining
Fresh biotite - hornblende gneiss with iron staining 14-15 m
Darker, more clayey sample with more hornblende less biotite
Remainder of b/h hornblende gneiss
Very clayey at 27m
Very clayey at 43 m
Very coarse gravelly gneiss at 56 m
Coarse and clayey at 62m

Figure 3.39



Drawdown (m)
Recovery (m)
m/DD
Drawdown (1)
Drawdown (2)
Suction
RWL
100 minutes
[North] Mkatira Vertical

Figure 3.40

CHIKORE SCHOOL: AREA C: MAP 2030 D1

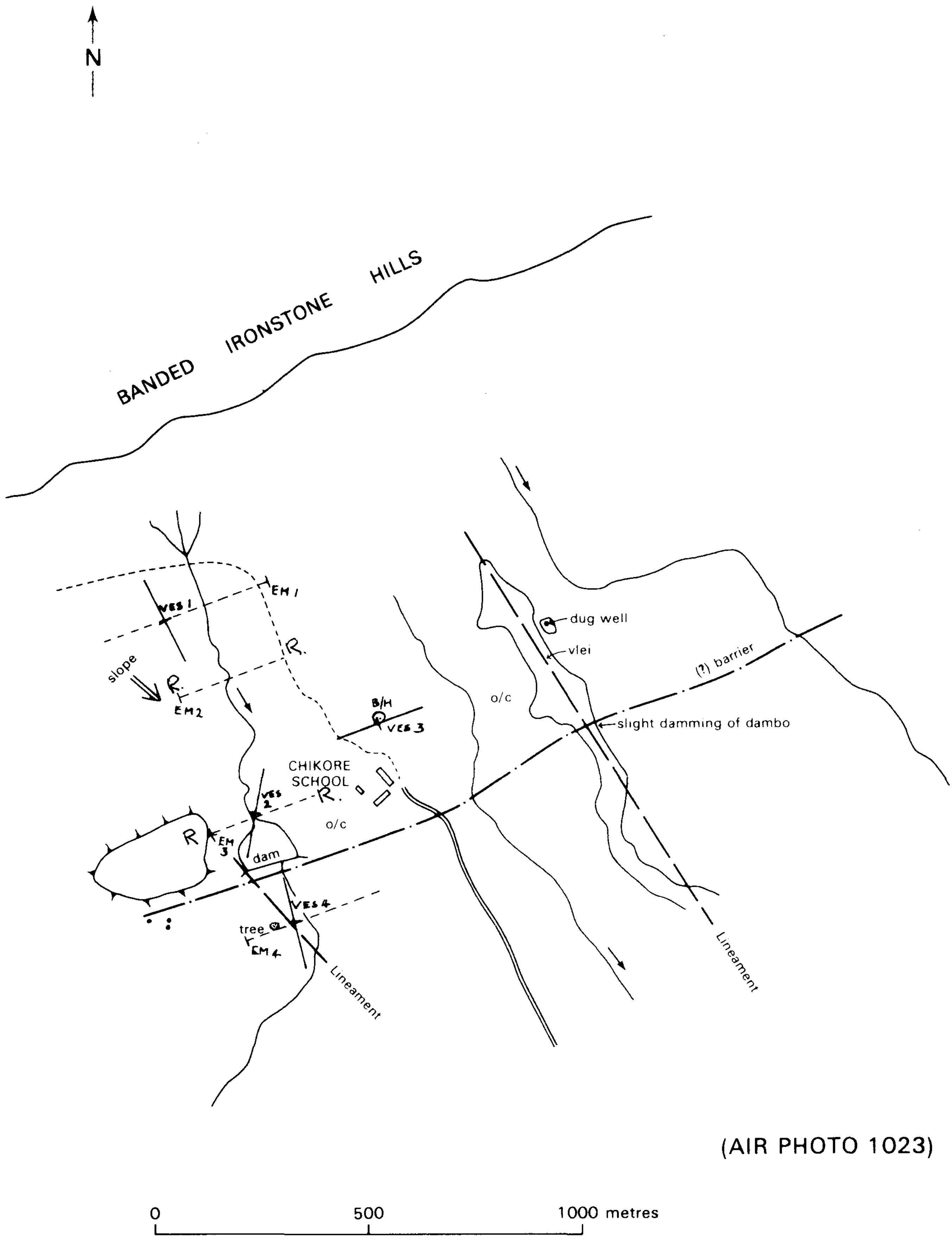


Figure 3.41

Rest water level: 6 m
Yield: 0.89 l/sec

The existing borehole is on a watershed between two parallel valleys and at the foot of an ironstone ridge. The test yield after drilling was recorded as high but the current yield is negligible. The DDF have visited the borehole 3 times in the last few years and have pulled the pump on at least one occasion. The Headmaster was informed verbally that there was 'no water'. The school community now obtains water from a very polluted reservoir close by. There have been various attempts to dig wells, both by the local people and the World Lutheran Digging Team but without success.

A few other possible borehole sites exist in the area but are not too favourable, mainly because shallow bedrock would be suspected and there are no strong lineaments. It is difficult to suggest an order of priority. The possible sites occur above and below the dam and in the valley to the east.

Site 1: In valley above the dam (Reservoir Site). There appears to be a rock barrier which extends below the dam abd a short distance upstream as indicated by the stream gradient which flattens out in this location. A lineament may exist parallel to the stream. There are calcrete nodules in the stream alluvium which may indicate rising water tables.

Site 2: The site below the dam could aim to intersect the junction of a possible lineament with the main stream valley. Both sites 1 and 2 could possibly induce recharge from the surface storage above the dam.

Site 3: This occurs in valley to east and once again saprolite could be thicker above a rock barrier.

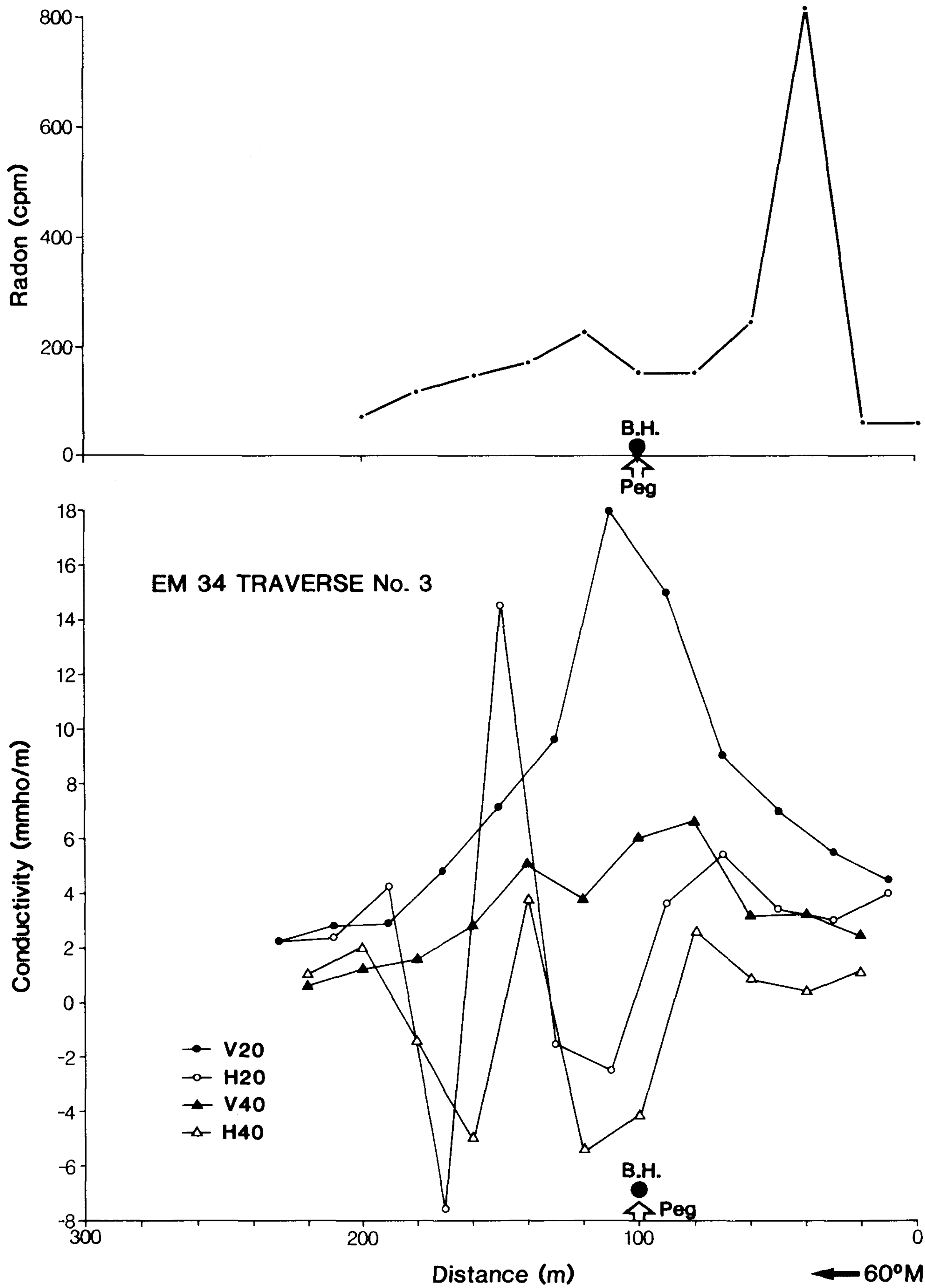
Geophysical survey was carried out in the Site 1 area and since the results appeared promising, neither of the other two sites were investigated. Two experimental boreholes were drilled in the Site 1 area and will be referred to as the Reservoir Site and Valley Site.

3.14.1 Reservoir Site.

Geophysical survey.

EM34 traverse 3 is above the dam and shows a vertical sided anomaly (Figure 3.42). A VES on the site and to the immediate west of the fracture system showed 32 m of regolith/saprock and was pegged. Details of the VES are as follows.

	Layer	Thickness (m)	Resistivity (ohm.m)
Solution 1	1	2.00	1100.00
	2	0.50	5.00
	3	25.00	150.00
	Infinity		5000.00



CHIKORE SCHOOL
RESERVOIR SITE

Figure 3.42

Solution 2	1	1.90	1100.00
	2	5.00	40.00
	3	25.00	200.00
	Infinity		5000.00

Such results would meet the Master Plan criteria for a borehole site and water levels could be assumed shallow. The overburden thickness is a little surprising since on the west bank of the same valley, the thickness is less than 4 metres.

Radon survey.

The survey is also shown in Figure 3.42. With an initial background count of 5 cpm, the maximum anomaly of 818 cpm is sited some 60 m to the west of the pegged site. An outcrop of migmatite gneiss occurs on the same traverse line and 56 m further to the west.

Drilling. (Figure 3.43) G.R. TN 539 295

The drilling log indicated decomposed rock to 5 m with variable drilling rate (high in clay) succeeded below by medium hard to hard rock to 55 m total depth. The lithological samples showed more sandy material to 12 m and rock gragments below. A fracture was encountered at only one location, 16-17 m. The inconsistency with the geophysical data is not easy to explain. It would have been of interest to drill on the radon high but there was insufficient time available in the programme to do this.

Drilling was completed on the 15.11.87. Water levels in the borehole measured on later occasions indicated a very slow inflow rate.

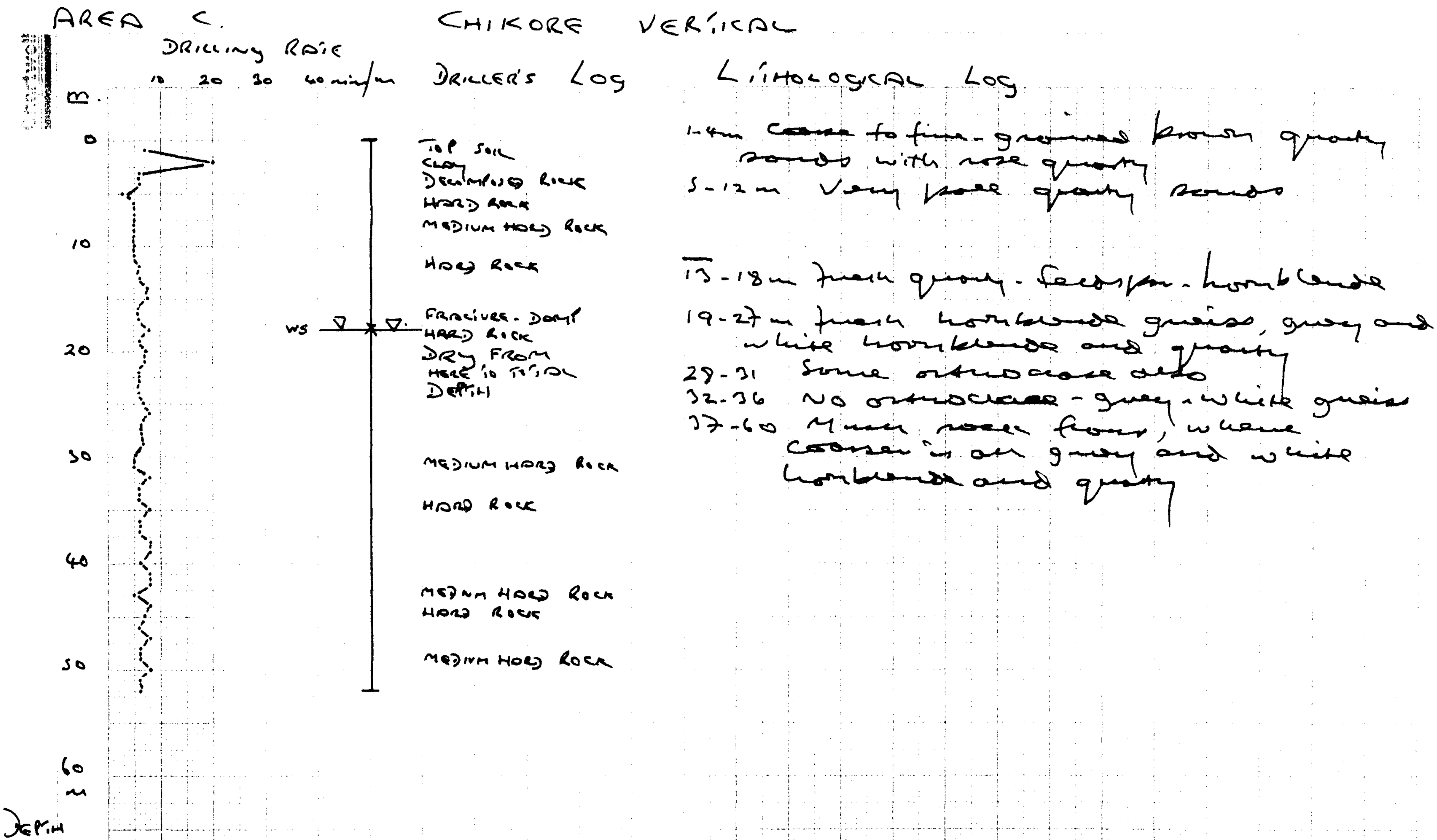
17.11	:	45.26 m below datum
19.11	:	39.88 m below datum
28.11	:	18.11 m below datum

3.14.2 Valley Site

Geophysical survey. (Figure 3.44)

EM34 traverse 2 showed a more marked vertical sided conductivity anomaly than on the previous site. A VES on the west bank gave the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.63	150.00
2	0.95	35.00
3	20.35	245.00
4	-	858.00
Infinity		



AREA C.
CHIKORE VERTICAL
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
m.
0
10
20
30
40
50
60 m
DEPTH
TOP SOIL
CLAY
DECOMPOSED ROCK
HARD ROCK
MEDIUM HARD ROCK
HARD ROCK
FRACTURE - DAMP
WS
HARD ROCK
DRY FROM HERE TO TOTAL DEPTH
MEDIUM HARD ROCK
HARD ROCK
MEDIUM HARD ROCK
HARD ROCK
MEDIUM HARD ROCK
1-4m Coarse to fine-grained brown quartz sands with rose quartz
5-12m Very pale quartz sands
13-18m fresh quartz - feldspar - hornblende
19-27m fresh hornblende gneiss, grey and white hornblende and quartz
28-31 Some orthoclase also
32-36 No orthoclase - grey - white gneiss
37-60 Much more fresh, where coarser is all grey and white hornblende and quartz

Figure 3.43

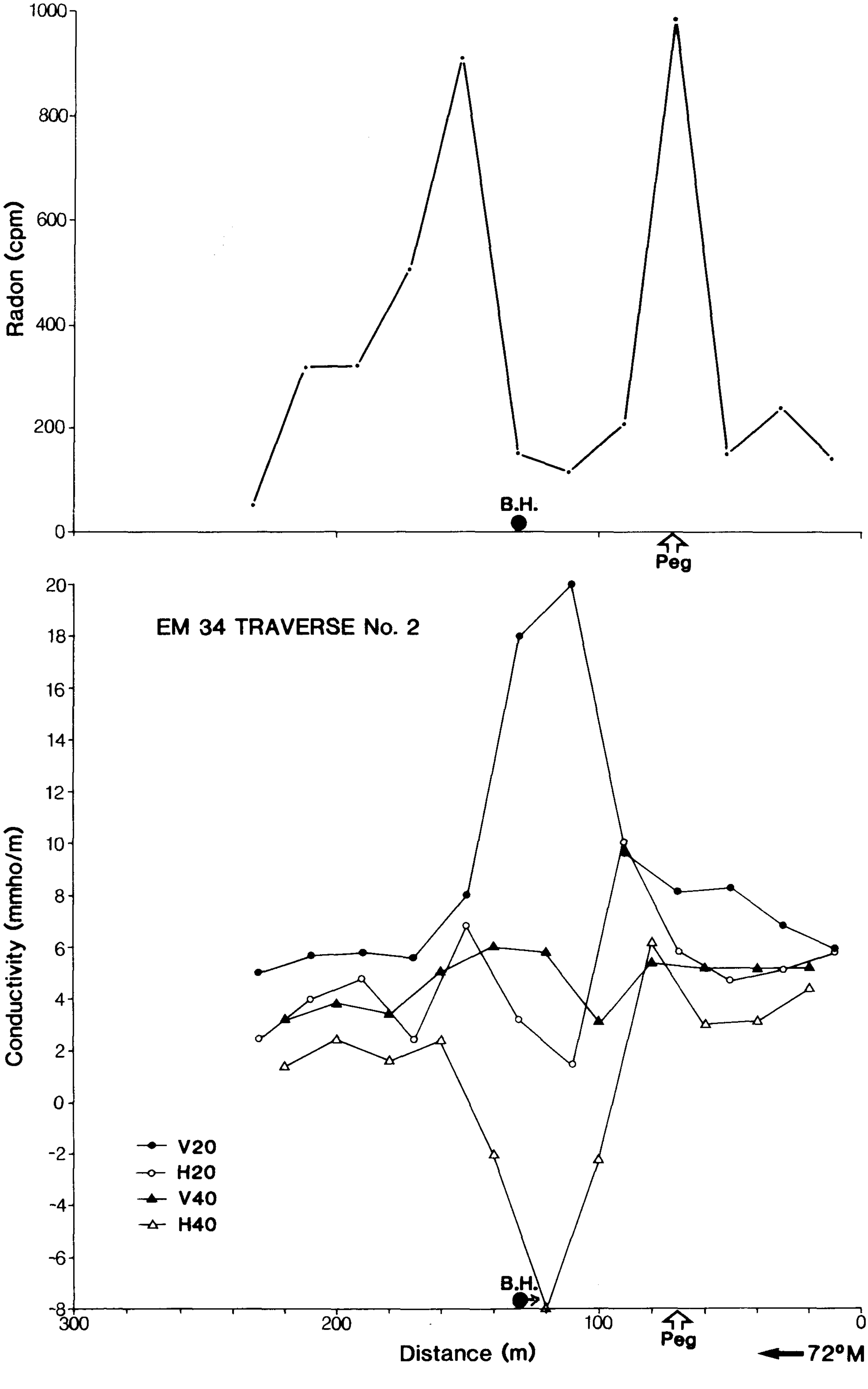


Figure 3.44

CHIKORE SCHOOL
VALLEY SITE

Radon survey.

The form of the measurements plot is unusual in that it shows two peaks which straddle the main EM34 anomaly. However, the central area of low counts correspond with a recent overland flow. It was decided to site the borehole on the east bank and to incline it at 35° to the vertical towards the NW since the migmatite banding strikes ENE-WSW. Thus the borehole should intersect both radon and EM anomalies and also cross the migmatite banding at an acute angle.

Drilling. (Figure 3.45) G.R. TN 538 298

The drilling log indicates an uppermost soft section to 5 m with clay followed by medium hard rock 'with boulders' to 15 m (12 m vertical) and medium hard to hard rock to total depth at 60 m (49 m vertical). The lithological log indicates more weathered material to 15 m (12 m vertical) and fresher rock below. The correspondence with the VES is not close. The main water strike was around 35 m but the water was extremely muddy.

Pump test.

No pump test was carried out because the yield was considered too low. Further development would have been merited, particularly in view of the need for water supply at this site. Drilling was completed on 16/17 November and the following water levels measured.

17.11	:	22.8 m below casing top
19.11	:	17.1 m below casing top
28.11	:	16.6 m below casing top
2.12	:	16.7 m below casing top

3.15 Rungai B.C. and Rungai School (Figure 3.46)

Background.

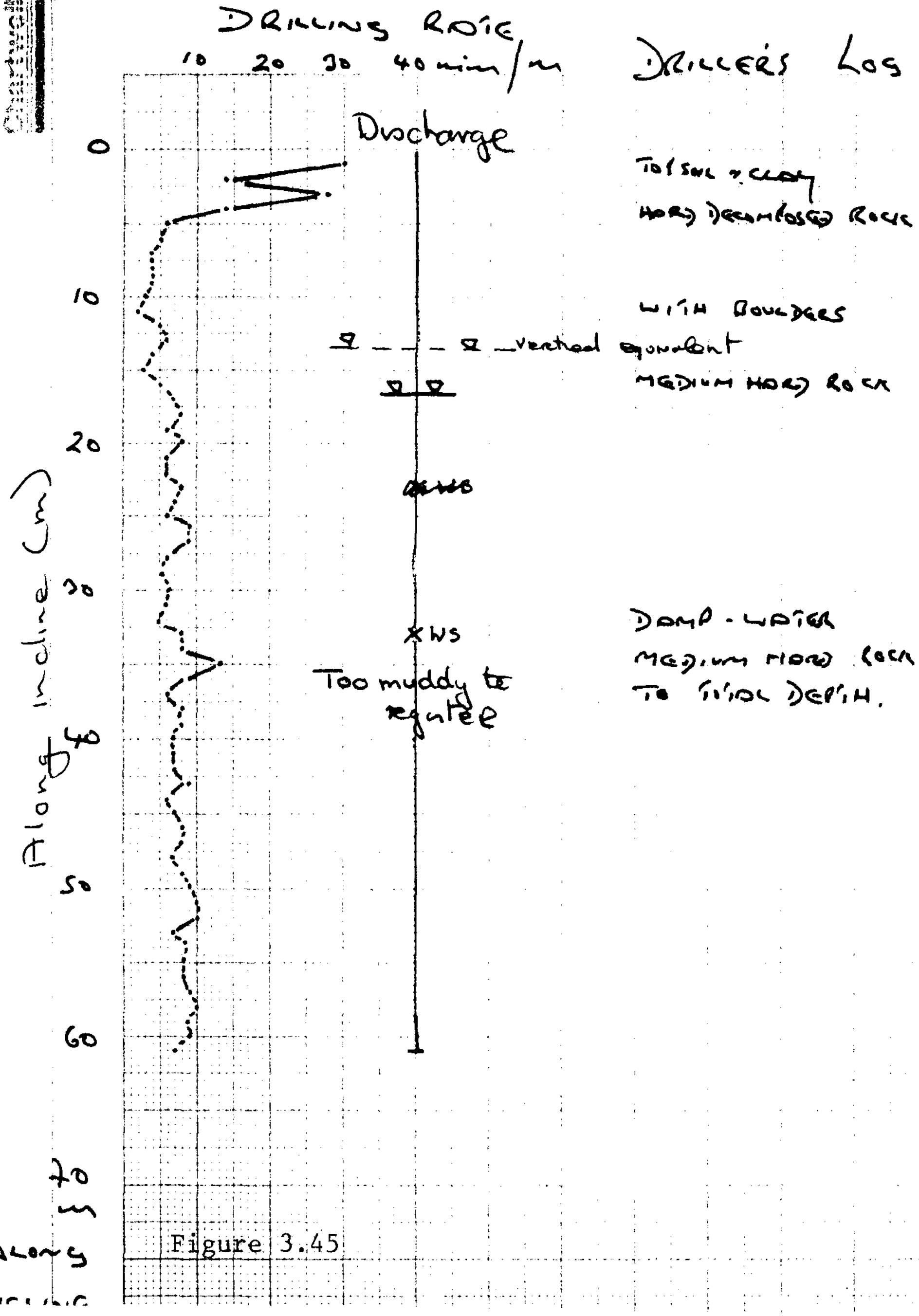
This area has been intensively investigated. The EEC drilled three dry holes. There is a private operating borehole with handpump at the Business Centre and a Lutheran well close by although at the time of a recent visit (3/7/87), the pump was broken down. The static water level at the same time was 8.60 m below the parapet and with a total depth in excess of 18 m.

The recommended site for another water supply point - borehole, dug well or collector well - is along the same valley on which the Lutheran well is sited and near the junction of a tributary valley which is along the line of a lineament. If yield is high, could provide water for both B.C. and school, preferably by pumping to storage.

Geophysical survey.

EM34 traverse 3 (Figure 3.47) shows vertical sided anomalies on the east bank and in the valley bottom. Both sites were pegged. VES1 in the valley bottom shows 13 m of overburden, the thickest layer of which has a low resistivity indicative of clay.

AREA C. CHIKORE INCLINE (35° to vertical)



LITHOLOGICAL LOG

1-2 m Brown silty sands and clays with quartz and hornblende

3 m Poor quartz sands, some iron staining

4 m Grey clayey sediments + quartz - feldspar

5-8 Cement-coloured silts with quartz hornblende and orthoclase fragments

9 m Weathered rock - much orthoclase, some quartz and hornblende

10-12 m Grey clayey silt with quartz, feldspar and hornblende.

13-14 m Pebbles of hornblende in green-grey silts

15 m Khaki silts

16-43 m Angular fragments of quartz feldspar and hornblende in rock flour. with increasing flour content to 43 m

44-56 Gritty quartz, feldspar and hornblende with some clay

57 m very floury

58-59 m Coarse fragments with flour

60-61 m very stony, like rock.

Figure 3.45

RUNGAI B.C.: AREA C: MAP 2030 D1

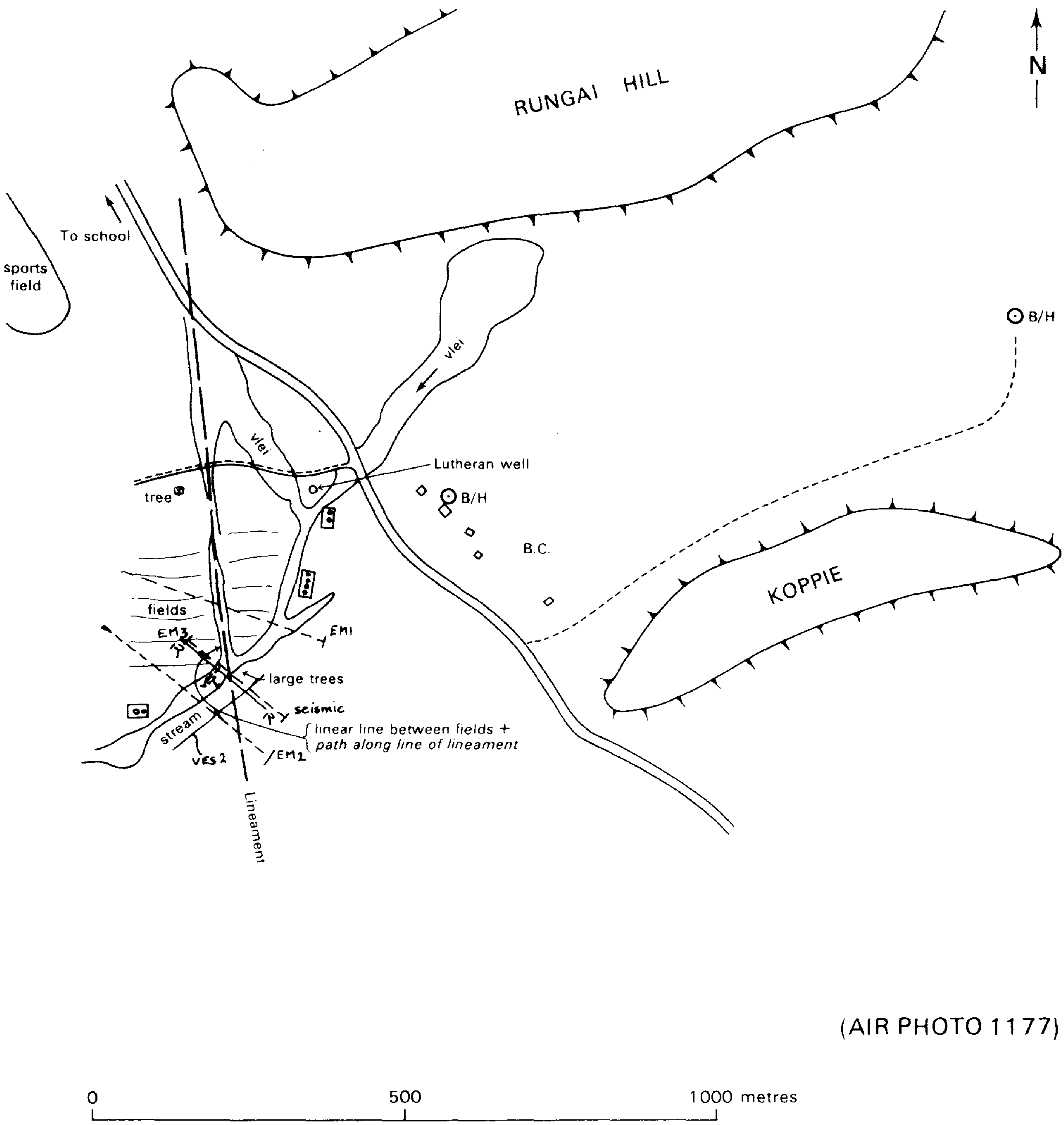
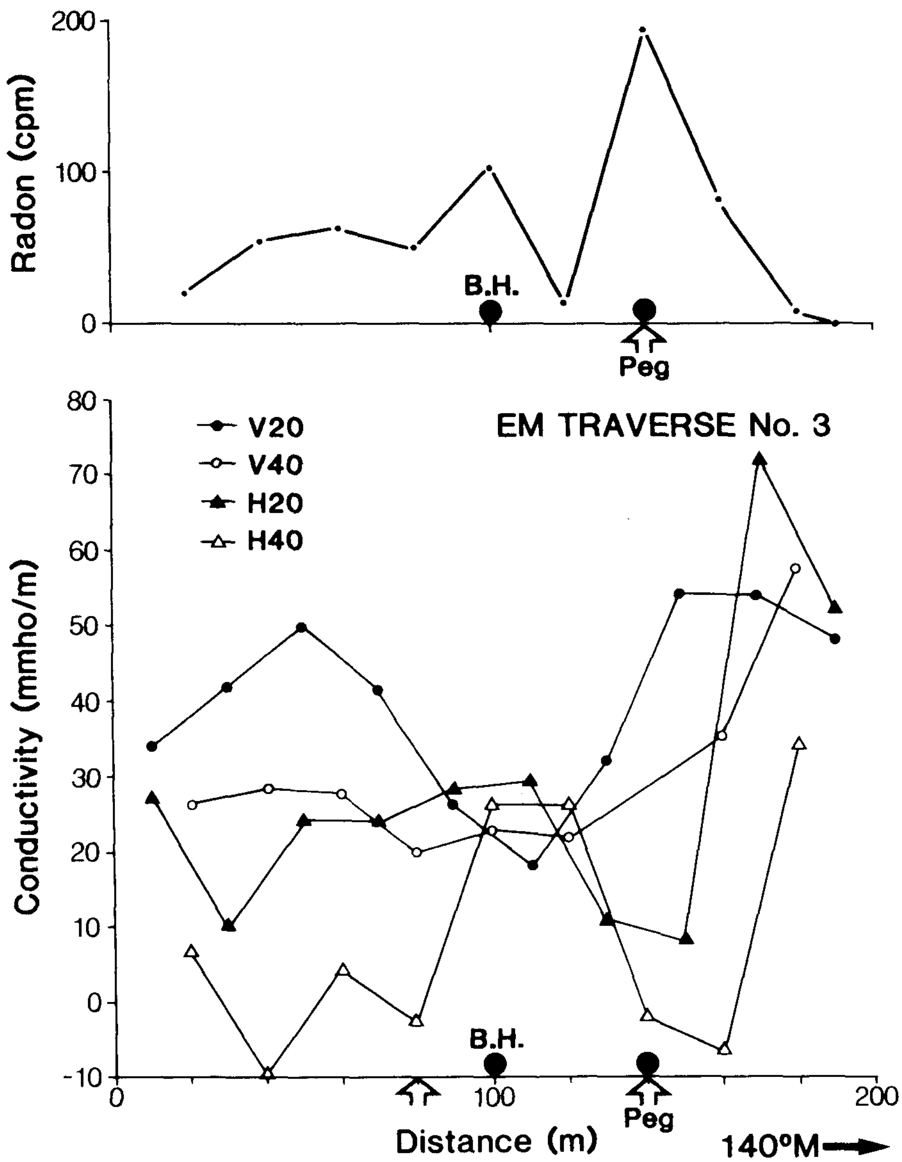


Figure 3.46



RUNGAI B.C.

Figure 3.47

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.50	1500.00
2	3.00	200.00
3	9.50	15.00

The VES on the bank a short distance to the south of the second pegged site has a smaller thickness of overburden (10 m). Neither site would meet the Master Plan criteria.

Layer	Thickness (m)	Resistivity (ohm.m)
1	2.00	14.00
2	8.00	5.00
Infinity		2000.00

Radon survey.

Anomalies correspond with both EM34 conductivity anomalies, the larger being on the east bank which was subsequently drilled. An ambiguity exists in relation to the precise position of the pegged sites which are separated by 40 m in the radon survey (by tape) and 60 m in the EM survey (by instrument).

Drilling. (Figure 3.48) G.R. 549 218

The drilling log indicated soft weathered material to 12 m with hard and medium rock to final depth of 43 m. Drilling ceased because of large flow of water at that depth. There was a reasonable correspondence with the bank VES.

The lithological samples include much clay to 4 m and 'silty' material with variable amounts of quartz, hornblende biotite and occasional 'clay' below. The junction at 12 m is not apparent.

Pump testing. (Figure 3.49)

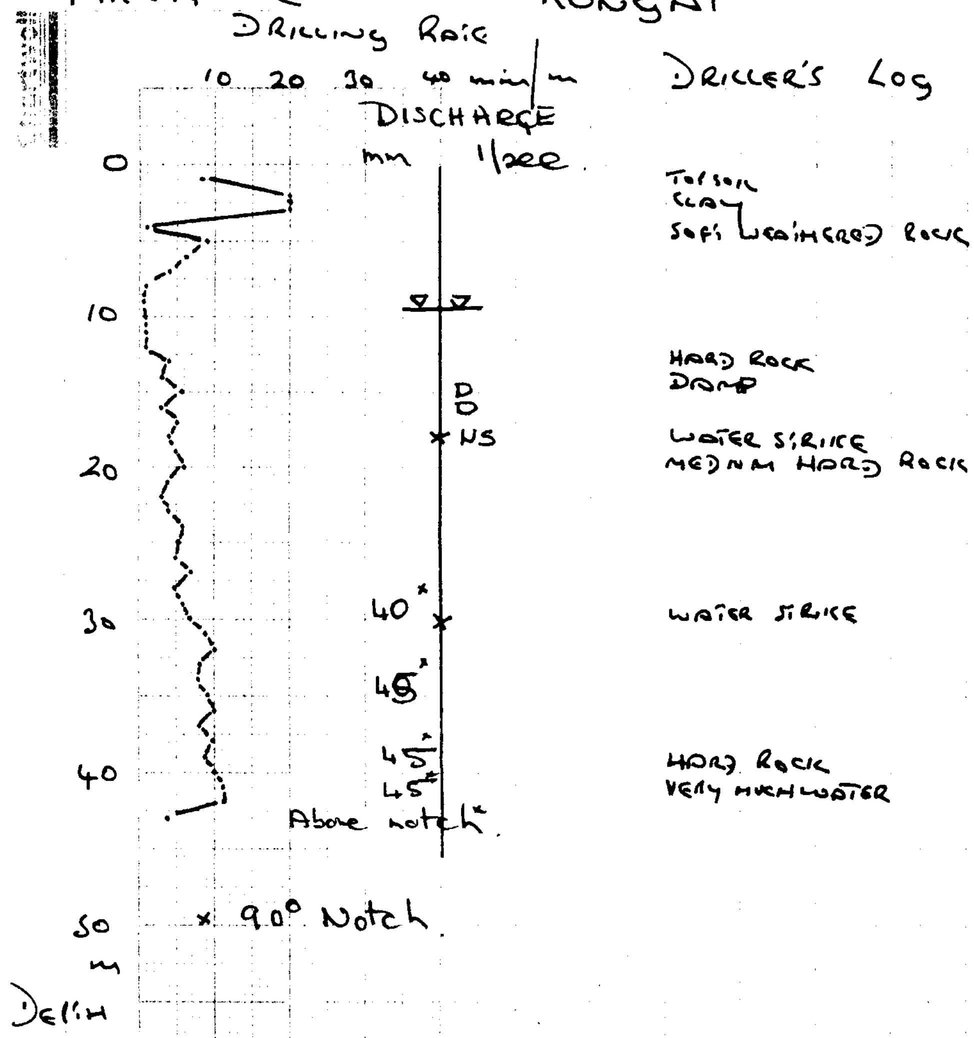
RWL: 10.12 m from 0.55 m agl
Date: 14.11.87
Suction: 40 m
Duration: 8 hours
Discharge: 4 hours at 1.6 l/sec, 4 hours at 2.2 l/sec
Maximum drawdown: 1.99 m at 4 hours, 2.9 m at 8 hours
Quality: good (400 microsiemens)
Five hour specific capacity: 0.76 l/sec/m

This borehole can be fitted with a motorised pump and a higher yield test is recommended.

Lutheran well.

TD: 18 m below concrete sill
Diameter: 1.26 m
Pumping test: 0.25 l/sec for 80 minutes

AREA C RUNGAI



LITHOLOGICAL LOG

0-1m Reddish quartzose clayey sands
2-4m Greyish white clays with much less quartz at 2m more below.
5-7m Pale 'khaki' silts with quartz, hornblende and ironstained mineral
8-14m Pale greenish-grey silts with quartz and hornblende
15-16 More clayey sand plus white zeolite-looking mineral (waxy)
17 Same but also brassy mica
18 Pale brown micaceous clays with aggregates of soft hornblende 'lumps'
19-27 Pale sandy-brown clayey silts with much quartz
28 More grey - due to account of hornblende
29 Very coarse grey-brown sand with Q + H.
30 The same plus patches of grey varved clay
31 Dark green-grey sand to clay silt with patches of varved clay
32-34 The same but patchy - quartz and hornblende.
35-36 Coarse quartz granules with some of hornblende and quartz
37 Coarse granules with well weathered "aggregates" of quartz and hornblende.
38 Patchy sands of gneiss mostly quartz
39-41 Granules to clayey silts
42 Very coarse gravel large pebbles in coarse sands.

Figure 3.48

Graph Data Ref. 5541 Log 4 Cycles x mm, ½ and 1 cm

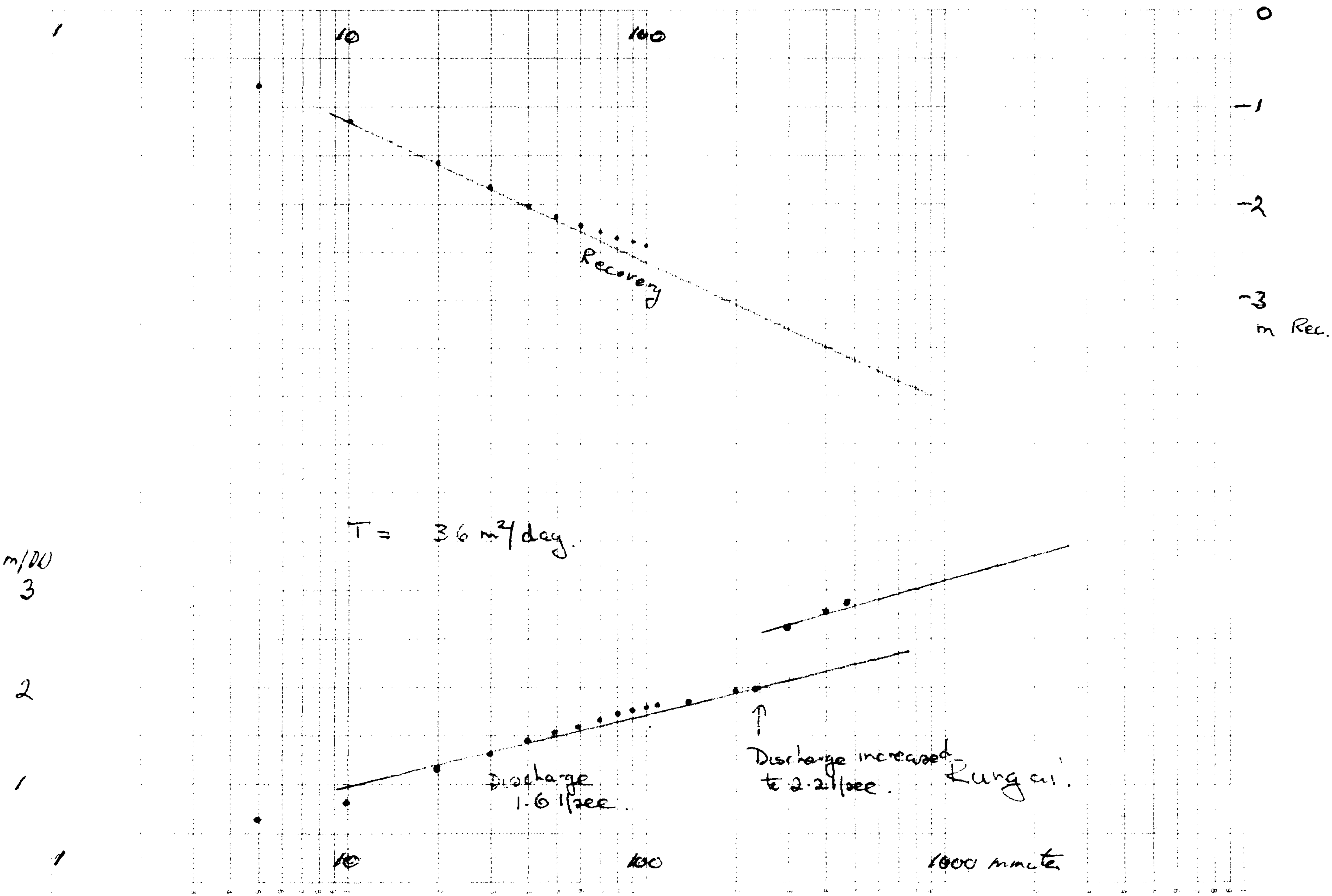


Figure 3.49

Drawdown: 0.867 m
25% recovery: 700 minutes

3.16 Chikofa School 2030 D1 (Figure 3.50)

Background.

Existing borehole: EEC 86 [2446/77216]
Total depth: 30.5 m
Saprolite: 1.8 m
Rest water level: 7.9 m below ground level
Test yield: 0.28 l/sec

Current situation: Borehole now extremely low yielding. Intermittent pumping demonstrates that problem relates to borehole and not to handpump. No other feasible borehole sites in area which would justify geophysical survey. The thin regolith probably makes the borehole yield very sensitive to seasonal water level change.

Rocky outcrops have a widespread occurrence. The rock consists of a hard, weakly-fractured gneissose granite. Potential sites for dug wells or possibly a combination of borehole and well occur in watershed areas to north of school between the two inselbergs or along the valley which trends to the SE and E of the school. The existing dug well on the watershed has 1-2 m of dark clay (dambo clay) with at least 2 m of saprolite below. The saprolite is brown-stained, indicative of fluid movement. Rock outcrops are rare in the vicinity of well and in the tributary valley which joins from the NE and along which there are tall trees clearly drawing on shallow groundwater. Below the intersection, rock outcrops become more common and may constitute a barrier across the main valley.

Geophysical survey. (Figure 3.51)

The pegged site occurs on EM34 traverse 3 which is transverse to the SE trending valley, referred to above, and on a marked vertical sided anomaly. A VES close by showed the following results, with 17 m of overburden which would not meet the Master Plan criteria.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.30	3000.00
2	4.00	32.00
3	3.00	15.00
4	10.00	100.00
Infinity		5000.00

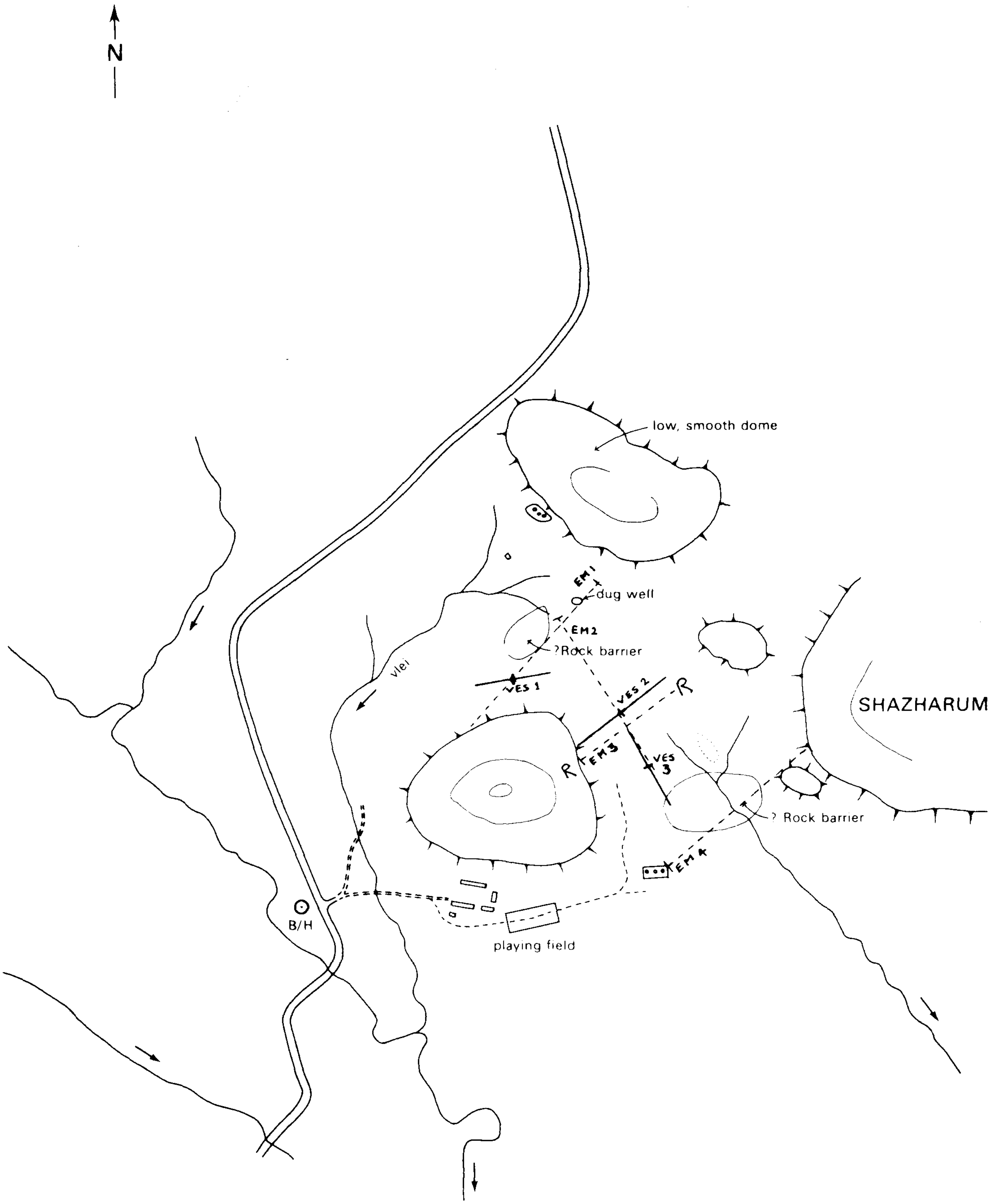
Radon survey.

A radon anomaly corresponds with the EM anomaly. The central dip between the two peaks almost certainly relates to recent runoff.

Drilling. TN 453 221 (Figure 3.52)

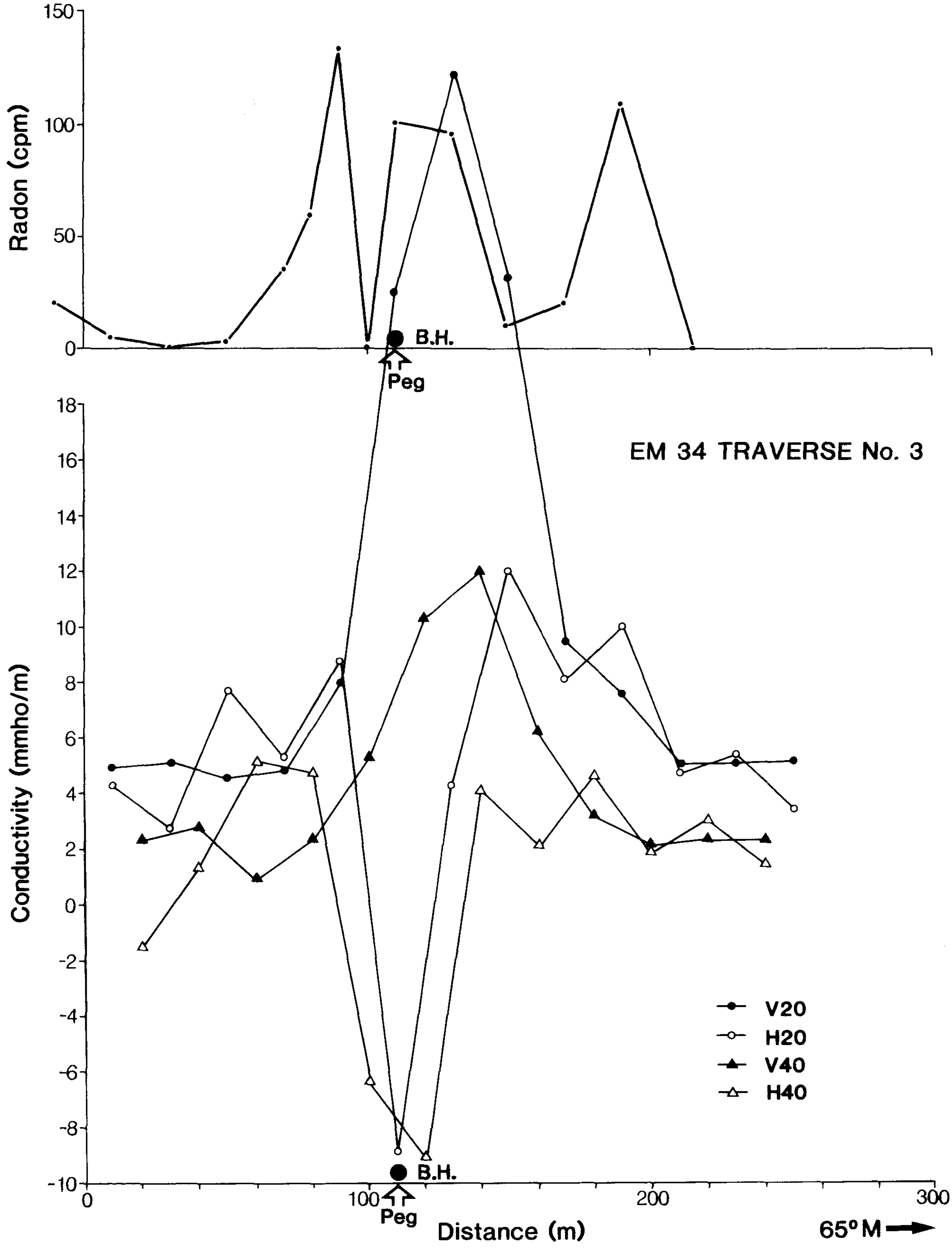
The drilling log indicated weathered material to 6 m but the drilling rate suggests that the transitional zone to hard rock could

CHIKOFA SCHOOL: AREA C: MAP 2030 D1



(AIR PHOTO 1172)

Figure 3.50



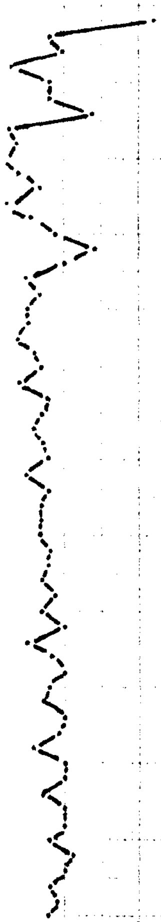
CHIKOFA SCHOOL

Figure 3.51

A C CHIKOFA

DRILLING RATE

10 20 30 40 min/m DRILLER'S LOG LITHOLOGICAL LOG



Discharge mm l/sec

BOULDERS
DAMP CLAY
WEATHERED ROCK
HARD BROWN SOIL
HARD
WEATHERED ROCK
HARD
MEDIUM HARD ROCK

45° Notch FRACTURE.
X WS FIRST WATER
25
"
"
90° Notch
45 X WS SECOND WATER
50
"
55
X WS THIRD WATER

75 X FOURTH WATER
70
65 MEDIUM HARD ROCK TO TOTAL DEPTH.

65

3 hours at 60 mm over 90° notch

1-2 m Coarse quartz gravel and
3-5 Buff silty sand, quartz, feldspar, hornblende.

6-8 Coarse to fine white quartz-feldspar sand
9 More silty quartz-feldspar sand
10-11 More greenish some brown & hornblende
12 Pinkish-grey quartz feldspar gravel with hornblende flakes.
13-22 Pinkish quartz-feldspar gravels to fine sand with hornblende fine-grained only
24 Clayey sand
25 Very fresh fragments
27-30 Very fine-grained rock fragments
31 m very coarse fragments quartz-feldspar. hornblende
33 Much hornblende in sample
34 Very large fragments quartz feldspar, hornblende
35-50 Rock fragments varying from coarse sand to silt in size.
50-60 m Some very fine rock flour in samples giving ashy appearance.

Figure 3.52

be around 14 m which corresponds with the VES. The lithological samples suggests rock, possibly saprock, from 6-13 m, although the first water strike is below this level at 24 m.

Pump testing. (Figure 3.53)

RWL: 17.15 m from 0.52 agl
Date: 17.11.87
Suction: 58 m
Duration: 5 hours
Discharge: 0.75 l/sec
Final drawdown: 13.2 m
Five hour specific capacity: 0.57 l/sec/m
Quality: good (740 microsiemens)

The borehole is capable of operating with a small motorised pump.

AREA J

Area J is floored by high grade gneisses and schists of the mobile belt. Of the 37 boreholes in this area, 3 have no yield data. The failure rate is 26-30% depending on the status of the boreholes without yield data. The mean regolith thickness is 22.6 m and the mean saturated thickness is 15.3 m, which are comparatively high and presumably accocunts for the relatively low failure rate. Two experimental sites were drilled in Area J, at Sarahuru and Chikadze.

3.17 Sarahuru Siding 2030 D3 (Figure 3.54)

Existing boreholes: (Records) (i) V 0948 [2467/76780]; Tshumele
Total depth: 29 m
Saprolite: 23.2 m
Rest water level: 7.6 m
Yield: 2.525 l/sec

V 0948 occurs on a marked lineament but the high yield must be suspect. The original records showed the depth to be 44 m with no data on RWL or yield. Following a clean-out the borehole was said to have a depth of 29 m, a RWL of 7.6 m and a yield of 2.525 l/sec. It is fitted with a handpump. During the recent project work, an attempt was made to test the yield and when the pump was removed, the depth was found to be 24.5 m and RWL at 20.5 m, comparable with that of the disused borehole, V2385. The yield was comparatively small and may indicate that the test yield was 0.25 rather than 2.5 l/sec.

Existing boreholes: (Records) (ii) V 2385 [2465/76777]
Total depth: 48 m
Overburden: 40 m
RWL: 34 m
Yield: 0.250 l/sec

V 2385 occurs at a short distance to the west of V 0948 and is apparently abandoned. The deep RWL appears anomalous in relation to the figures quoted for V 0948. The borehole was opened up and depth

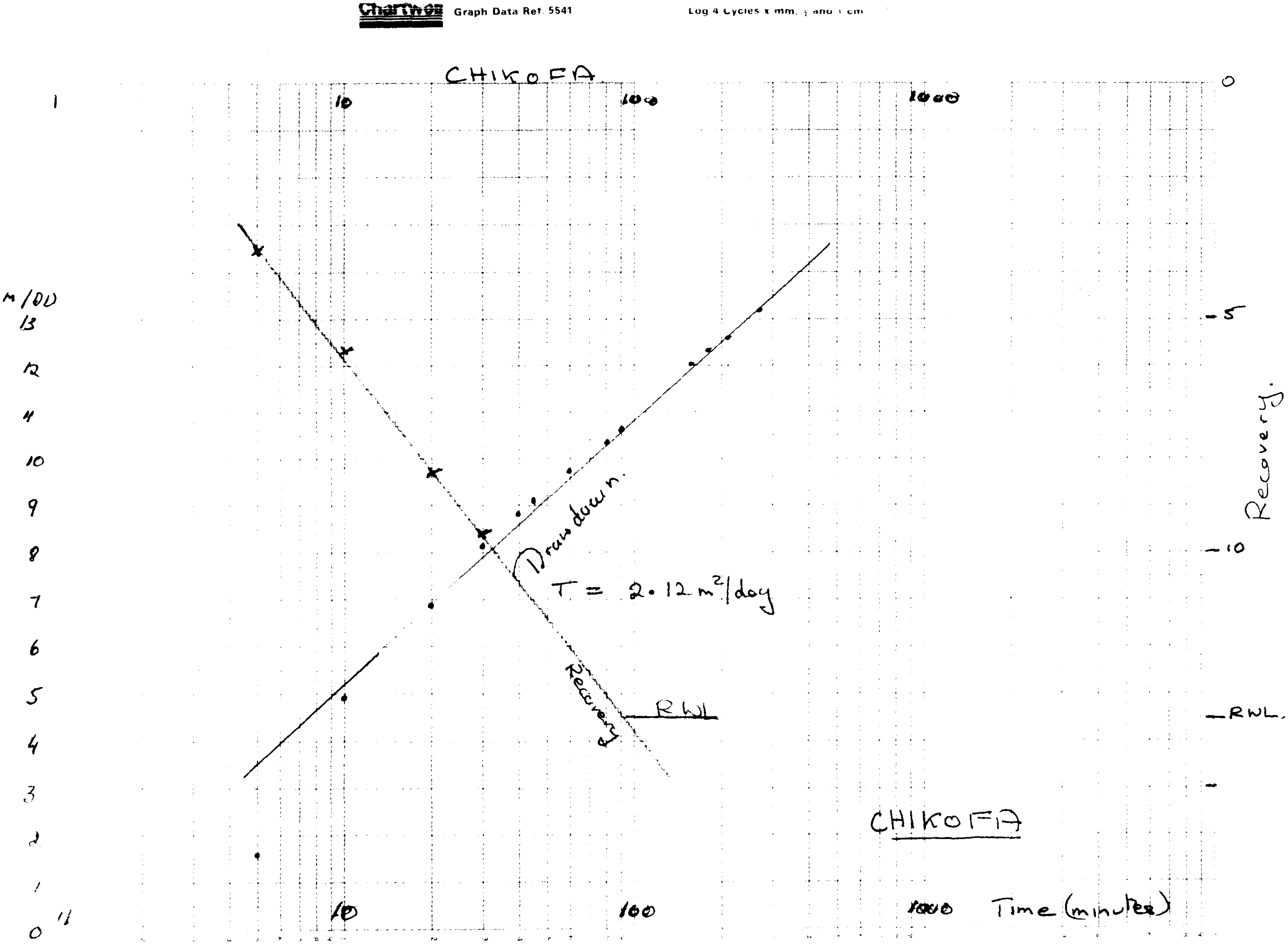
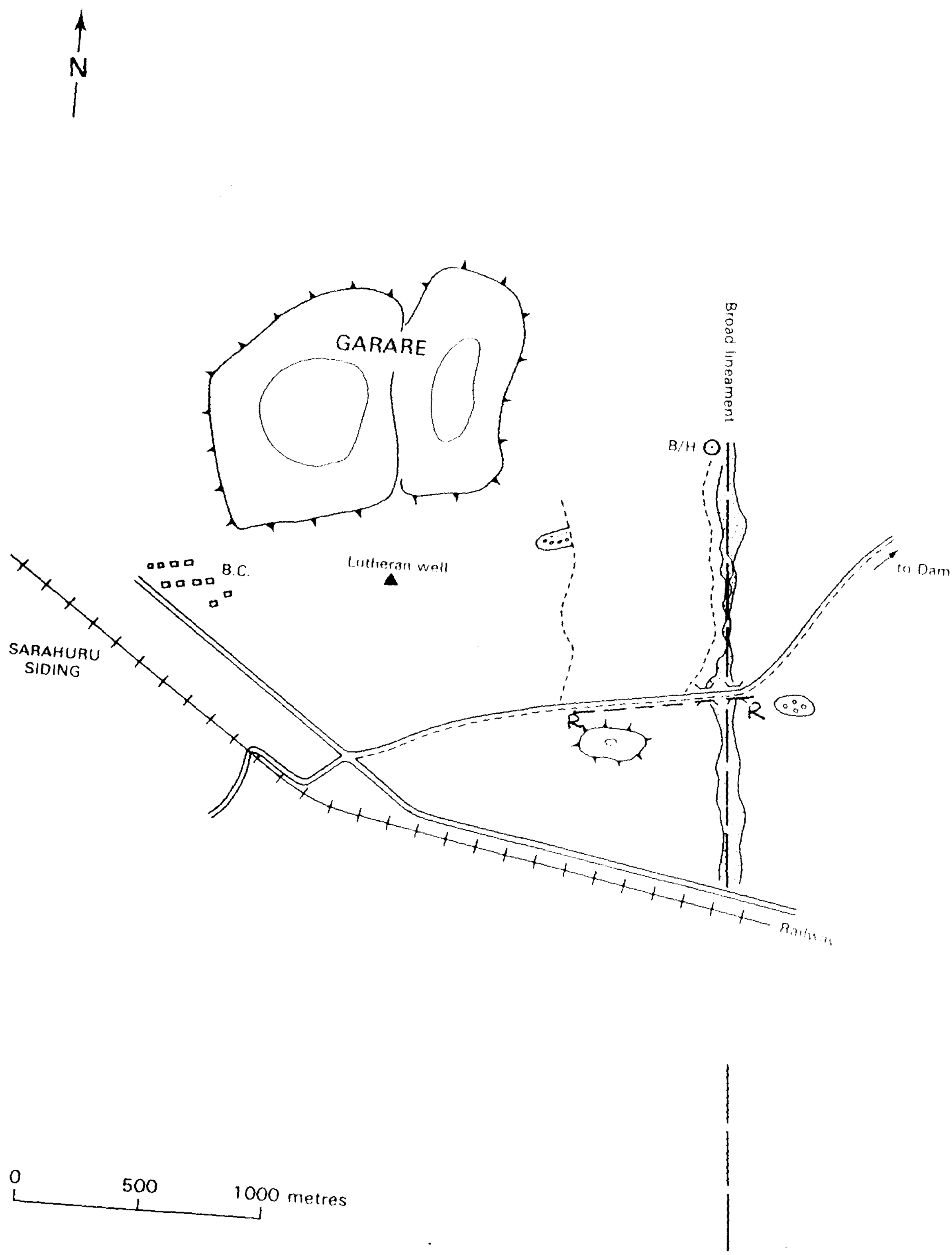

Chartwell Graph Data Ref. 5541
Log 4 Cycles x mm, ½ and 1 cm
CHIKOFA
m/OD
Drawdown.
Recovery
T = 2.12 m²/day
RWL
Recovery.
RWL.
CHIKOFA
10
100
1000
Time (minutes)

Figure 3.53

SARAHURU B.C.: AREA J: MAP 2030 D3



(AIR PHOTO 2025)

Figure 3.54

and water levels measured during the recent programme. Current depth is 21.7 m and the current water level is 20.7 m.

V 0948 occurs on a marked lineament. If a high yielding borehole/collector well could be sited on this lineament, the discharge could be pumped to storage on the top of a low hill to the south of the road and gravity fed to Sarahuru. The purpose of the subsequent survey had this aspect in mind.

Geophysical survey. (Figure 3.55)

A site close to the road and in the vicinity of the main orthogonal lineament was proposed. An EM34 traverse was carried out along the road which demonstrated a steady increase in overburden thickness from the low hill eastwards to the bridge where the anomaly takes on the characteristics of a moderate, vertical sided anomaly. Beyond the bridge, the thickness decreases again. A VES parallel to the lineament and 60 m away on the west side indicated a thick zone at depth of intermediate resistivity, indicative of regolith or saprock.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.50	180.00
2	7.50	12.60
Infinity		126.00

A second VES was carried out on the same trend but closer to the lineament and gave the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.22	450.00
2	4.40	10.00
3	22.00	25.00
Infinity		

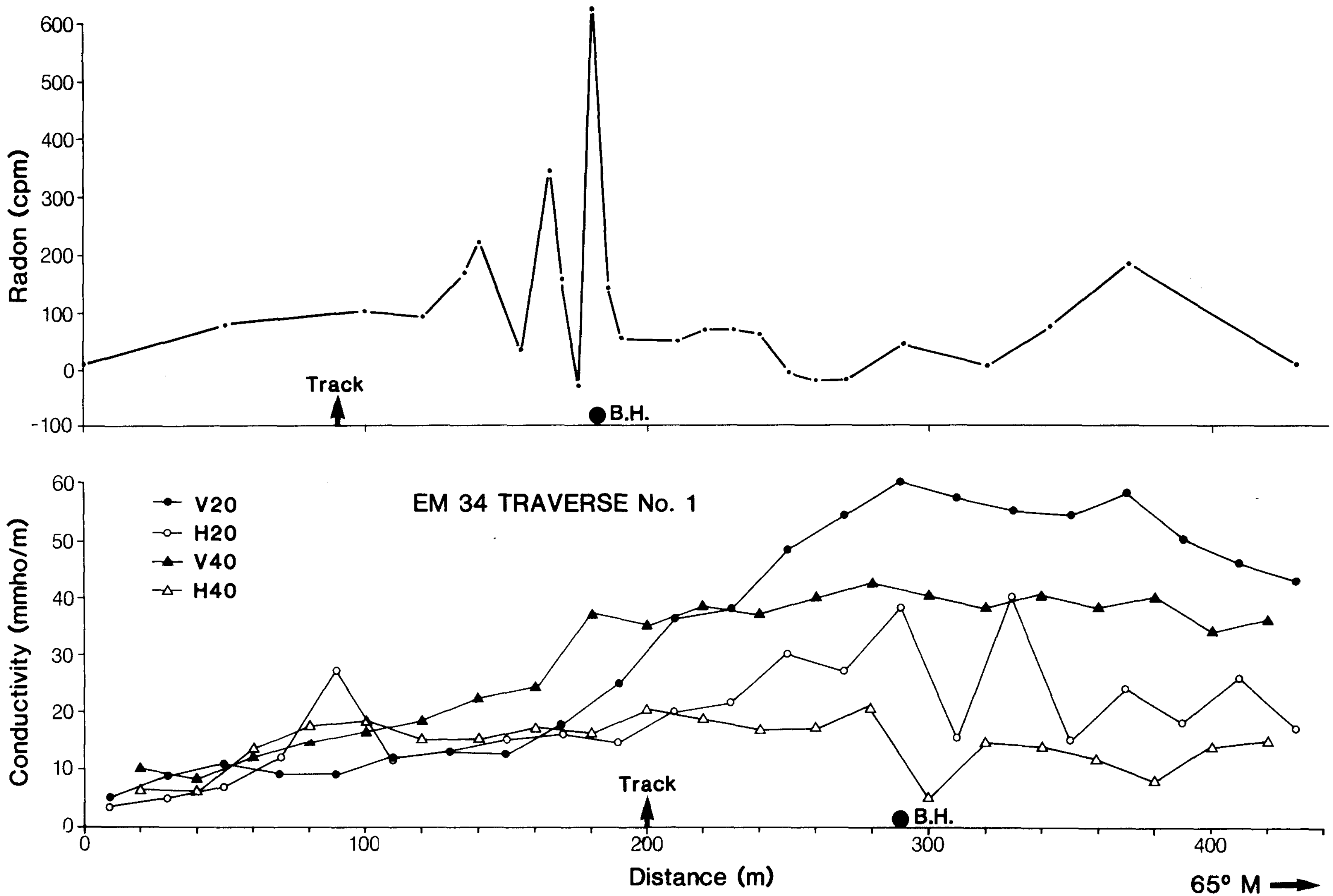
Although the thickness favours a borehole site, the resistivity is indicative of low permeability clayey material.

Radon survey.

A traverse along the EM line shows a marked, although fluctuating anomaly to the immediate west of the bridge, and coincident with the lineament and general position of a possible conductive anomaly. The fluctuating character in this case is unlikely to relate to surface runoff effects but may relate more to the variability in the fissured bedrock or the variable 'damping' of clayey overburden.

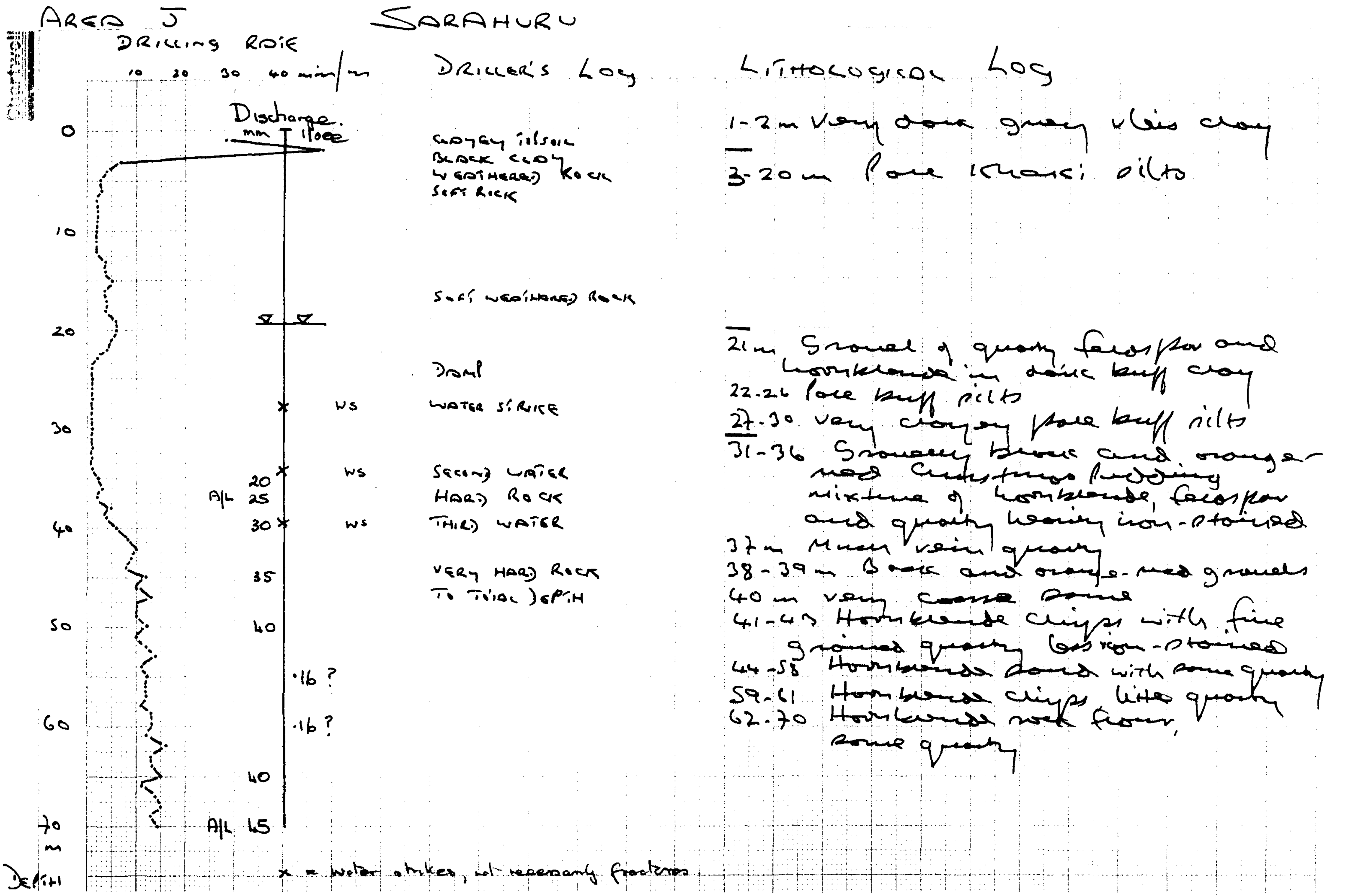
Drilling. (Figure 3.56) G.R. TM 468 774 (on radon high)

The drilling rate and drillers notes clearly demonstrate that soft and weathered rock persist to 37 m, deeper than the level assessed in the second VES. The lithological sample descriptions refer to clayey material to 30 m weathered rock material to 36 m and fresher



SARAHURU

Figure 3.55



Area J
Sarahuru
Drilling rate
10 20 30 40 min/m
Discharge.
Driller's Log
Clayey topsoil
Black clay
Weathered rock
Soft rock
Soft weathered rock
Water strike
Second water
Hard rock
Third water
Very hard rock
To total depth
WS
WS
WS
20
A/L 25
30
35
40
·16 ?
·16 ?
40
A/L 45
Lithological Log
1-2m Very dark grey vleis clay
3-20m Pale khaki silts
21m Gravel of quartz felspar and hornblende in dark buff clay
22-26 Pale buff silts
27-30 Very clayey pale buff silts
31-36 Gravelly black and orange-red cuttings
mixture of hornblende, felspar and quartz heavily iron-stained
37m Milky vein quartz
38-39m Black and orange-red gravels
40m very coarse sand
41-43 Hornblende chips with fine grained quartz less iron-stained
44-58 Hornblende sand with some quartz
59-61 Hornblende chips little quartz
62-70 Hornblende rock flour, some quartz
0
10
20
30
40
50
60
70
m
Depth
x = water strikes, not necessarily fractures.

Figure 3.56

hornblende 'rock' below. This well should be gravel packed for eventual use since all the wells in the area have silted up to the top of the screen. The water level corresponds with that in the other borehole on the same lineament and confirms the suspicions on the validity of the post clean-out records.

Pumping test. (Figure 3.57)

Date: 21.11.87
Pump suction at 61 m bgl = 41 m below water level
RWL: 20.84 m from 0.5 m agl
Discharge: (i) 0.29 l/sec - 130 minutes
(ii) 0.44 l/sec - 130-240 minutes
(iii) 0.67 l/sec - 240-360 minutes
Specific capacity at 5 hours assuming initial rate: 0.060 l/sec/m
Water quality: good (880 microsiemens)

The borehole gives a very adequate performance for a handpump and could possibly be used with a small motor pump at 0.5 l/sec for possibly intermittent pumping. A test would need to be carried out and the borehole should be gravel packed. Water levels are too deep for a collector well.

3.18 Chikadze School 2030 D3 (Figure 3.58)

Background.

Existing borehole: JP 6260 [2527/76777]
Total depth: 45.0 m
Saprolite: [13.0 m]
Rest water level: 15 m
Yield: 0.278 l/sec

The test yield was quite high but the current yield is very low and the community have to wait lengthy periods between pumping to allow the water levels to recover. The trouble clearly lies with the aquifer water levels.

Alternative sites include one (1) fairly close to the road and to the east-south-east from the existing well. It occurs on a possible junction of lineaments and the presence of grass which is green abd phreatophyte trees suggest shallow groundwater.

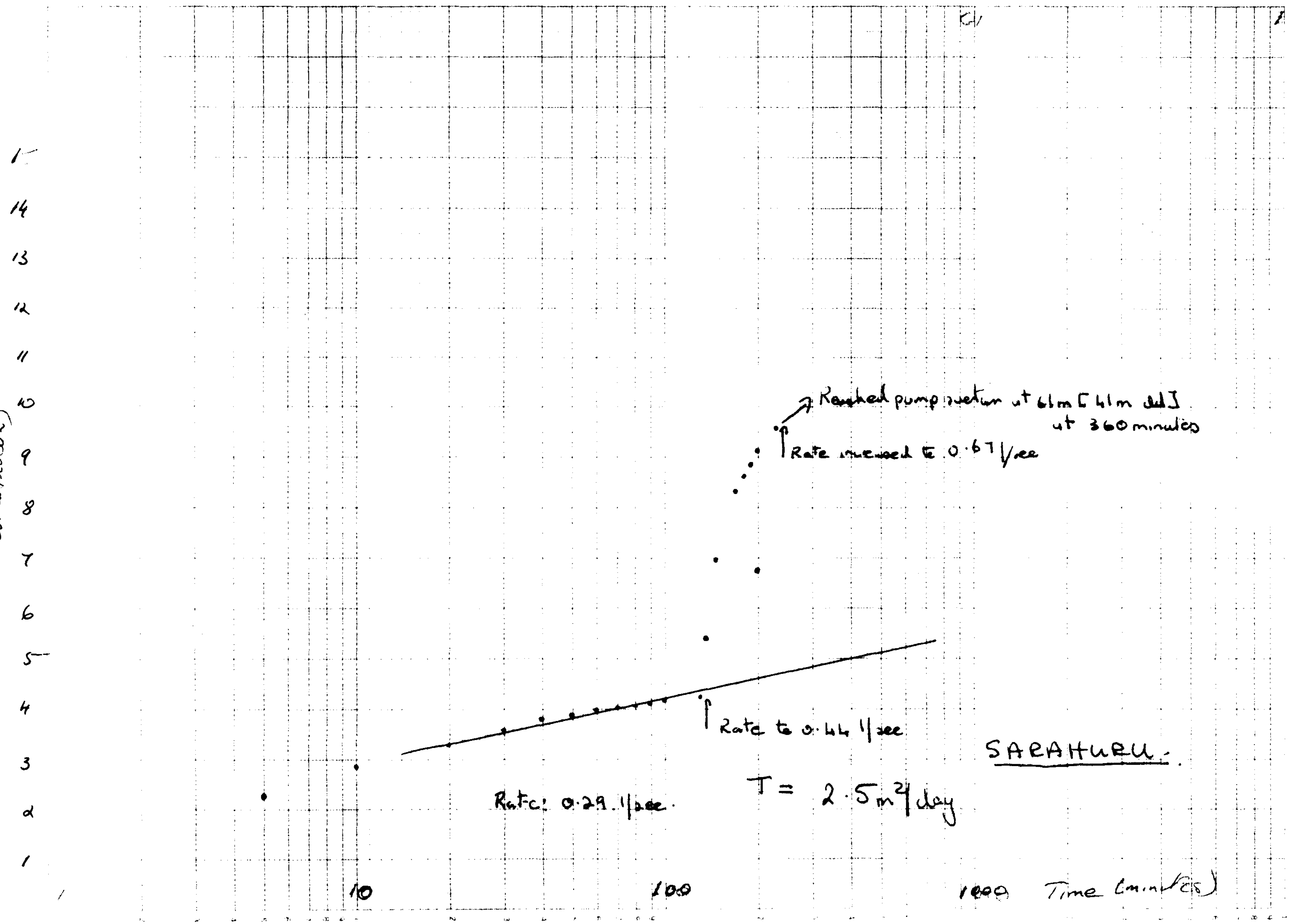
A more favourable looking site is in the valley further to the east beyond the dry hole. There is a dug well which occurs close to an intersection of a tributary valley from the north east, which apparently never dries up. A second dug well occurs in the tributary valley and has a good sustained yield. A borehole or a protected dug well could be considered in this location although it is rather far from the school. It might be given consideration if the recommended borehole site proves to be poor on survey.

Geophysical surveys. (Figure 3.59)

These surveys were carried out during the October-November 1987 field visit. One EM34 traverse only will be reproduced here, the

Chartwell Graph Data Ref. 5541 Log 4 Cycles x mm, ½ and 1 cm

Figure 3.57



CHIKADZI SCHOOL: AREA J: MAP 2030 D3 GR253000/767800

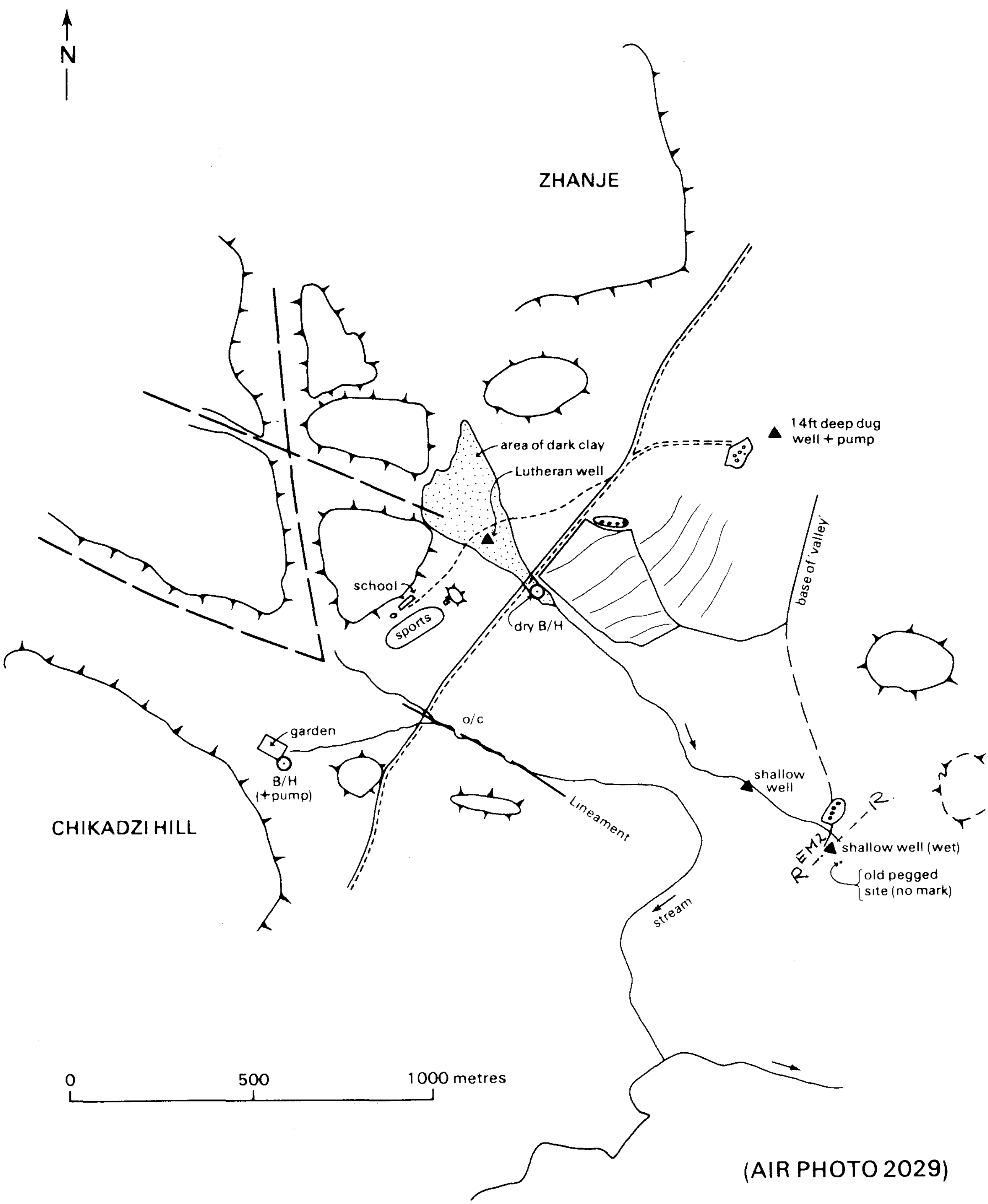


Figure 3.58

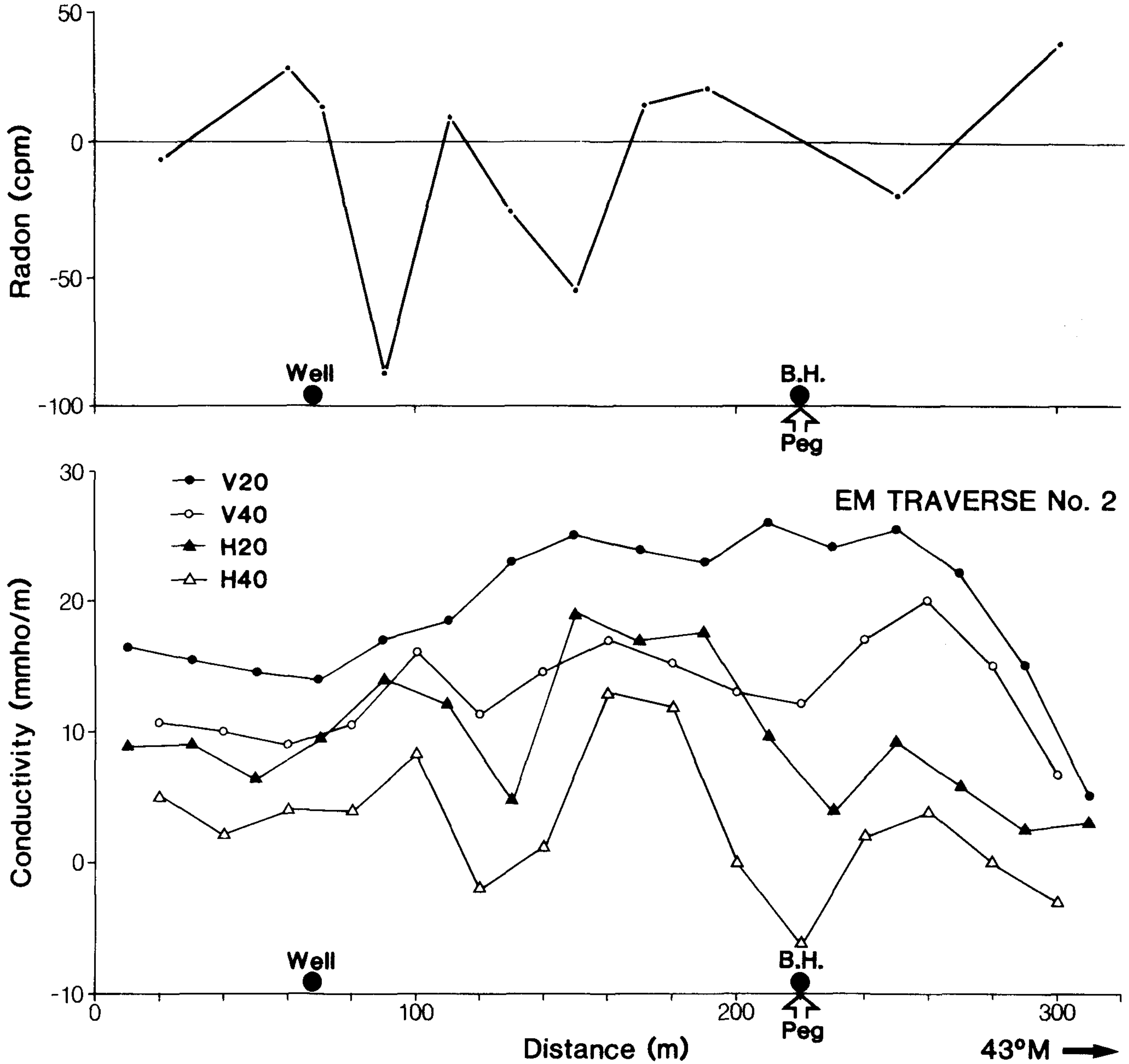


Figure 3.59

CHIKADZI SCHOOL

traverse on which a test borehole was drilled. The others will be reproduced elsewhere but brief descriptions will be included.

EM34-T1 : 45°m at alternative site (1) at junction of lineaments. No conductive anomaly is apparent and the overburden appears thin.

EM34-T2 : 48°m across site of dug well. The overburden appears generally thicker and two conductive anomalies are apparent. The more important one was surveyed by VES and in the event became the drilling site.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.50	900.00
2	3.25	9.00
3	8.40	90.00
Infinity		

The site is not particularly favourable but appears to be the only possible one of the areas surveyed.

EM34-T3 : 50°m. Through borehole to school fence. The measurements are very variable and irregular although with a possibility of a vertical anomaly across the gully near the school. The catchment seems likely to be very small since the site abuts closely on rocky outcrops on the adjacent high hill masses. The VES on the site of the EM anomaly indicates 3 m of very conductive (5 ohm.m) overburden. The VES surveys by the borehole and west of the borehole indicate overburden thicknesses of 15 and 40 m!, although in the latter case the high value of the resistivity (420 ohm.m) is approaching massive bedrock.

Radon surveys.

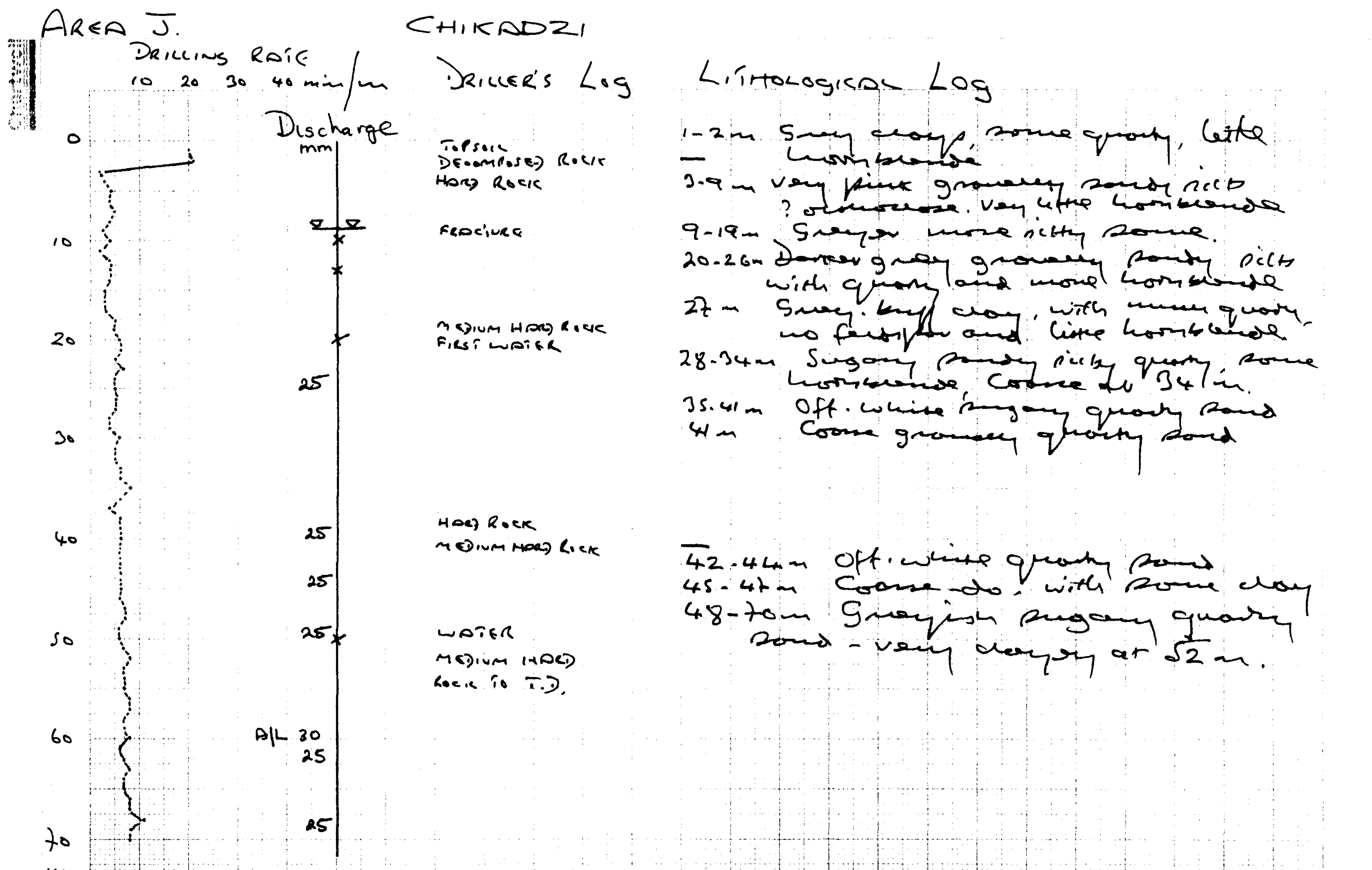
Radon surveys were carried out parallel to all three EM traverses. None appear favourable for a borehole site and the decision to drill was based on the EM data alone and because of the urgent need for an improved water supply.

Drilling. TM 533 778 (Figure 3.60)

The drillers log indicated decomposed rock to 2 m with hard or medium hard rock below although the relatively fast drilling rate would indicate that the latter is a better description, at least to 17 metres. The samples indicated relatively fresh rock below 2 m but with occasional 'clay' at the sites of fractures.

Yield.

Small drilling yields were recorded over the V-notch but the very poor water quality precluded testing (11,000-12,000 microsiemens-saline).



AREA J.
CHIKADZI
DRILLING RATE
10 20 30 40 min/m
DRILLER'S LOG
LITHOLOGICAL LOG
Discharge
mm
0
10
20
30
40
50
60
70
m
25
25
25
25
A/L 30
25
25
TOPSOIL
DECOMPOSED ROCK
HARD ROCK
FRACTURE
MEDIUM HARD ROCK
FIRST WATER
HARD ROCK
MEDIUM HARD ROCK
WATER
MEDIUM HARD
ROCK TO T.D.
1-2m Grey clay, some quartz, little hornblende
3-9m Very pink gravelly sandy silt ? orthoclase. Very little hornblende
9-19m Greyer more silty same.
20-26m Darker grey gravelly sandy silt with quartz and more hornblende
27m Grey. buff clay, with minor quartz, no feldspar and little hornblende
28-34m Sugary sandy silty quartz, some hornblende, Coarse to 34m.
35-41m Off-white sugary quartz sand
41m Coarse gravelly quartz sand
42-44m Off-white quartz sand
45-47m Coarse do. with some clay
48-70m Greyish sugary quartz sand - very clayey at 52m.

Figure 3.60

There was no significant increase in drilling yield below 25 m and no samples were collected at this level to compare with the final discharge. If the 'planned' borehole log shows that water quality is better near the top of the aquifer, a dug well or collector well could be given consideration. In any event, a rainwater catchment system constructed on the nearby hills is strongly to be recommended.

AREA E

Area E is underlain by the older gneiss complex and there are substantial numbers of basic dykes of varying age. Of the 58 boreholes drilled in Area E, 7 have no yield data and the failure rate is between 57-62% depending on the true status of the boreholes without yield data. The mean thickness of the regolith is 22.9 m and the mean saturated thickness is 10.9 m. Two sites were experimentally drilled, at Madangombe and Maramba.

3.19 Madangombe School 2030 A2 (Figure 3.61)

Background.

Existing borehole: EEC 77 [2193/77788]
Total depth: 61.0 m
Saprolite: 45.0 m
Rest water level: 10 m
Yield: 0.270 l/sec

The existing borehole is on a watershed surrounded by low koppies of equigranular granite (Younger Granite). The current yield is quite good although abstraction rates tend to drop off in the afternoon with intensive use. There is a substantial demand for the combined populations of the school, a military post and the local community. This is the origin of a request for a second water point.

A recommended site for survey is in the valley to the north east of the school and in the vicinity of the contact of the granite with migmatic older gneiss. The gneissic foliation strikes about 200^{o}m which is orthogonal to the stream and harder bands could create a barrier which may backup the water level in the granite saprolite. The site could be feasible for a borehole and/or a protected dug well. The site should avoid the lowest part of the valley where periodic flooding and still stand occurs. A site in the central valley could also lie on a lineament parallel to the valley. A likely site is on the intersection of a tributary valley which seems to follow the contact of granite and gneiss and where there is a pool which remains wet for a lengthy period of the dry season. There could be constraints on a dug well if the main aquifer is in weathered saprock rather than saprolite. Wire fences might constrain the use of EM.

Geophysical survey. (Figure 3.62)

Three EM34 traverses and two VES surveys were carried out in the initial programme in mid-1987. EM34 traverse 2 was repeated in late 1987 in addition to two VES on traverse 2 in the vicinity of the peg

MADANGOMBE SCHOOL: AREA E: MAP 2030 A2 GR 219000/777900

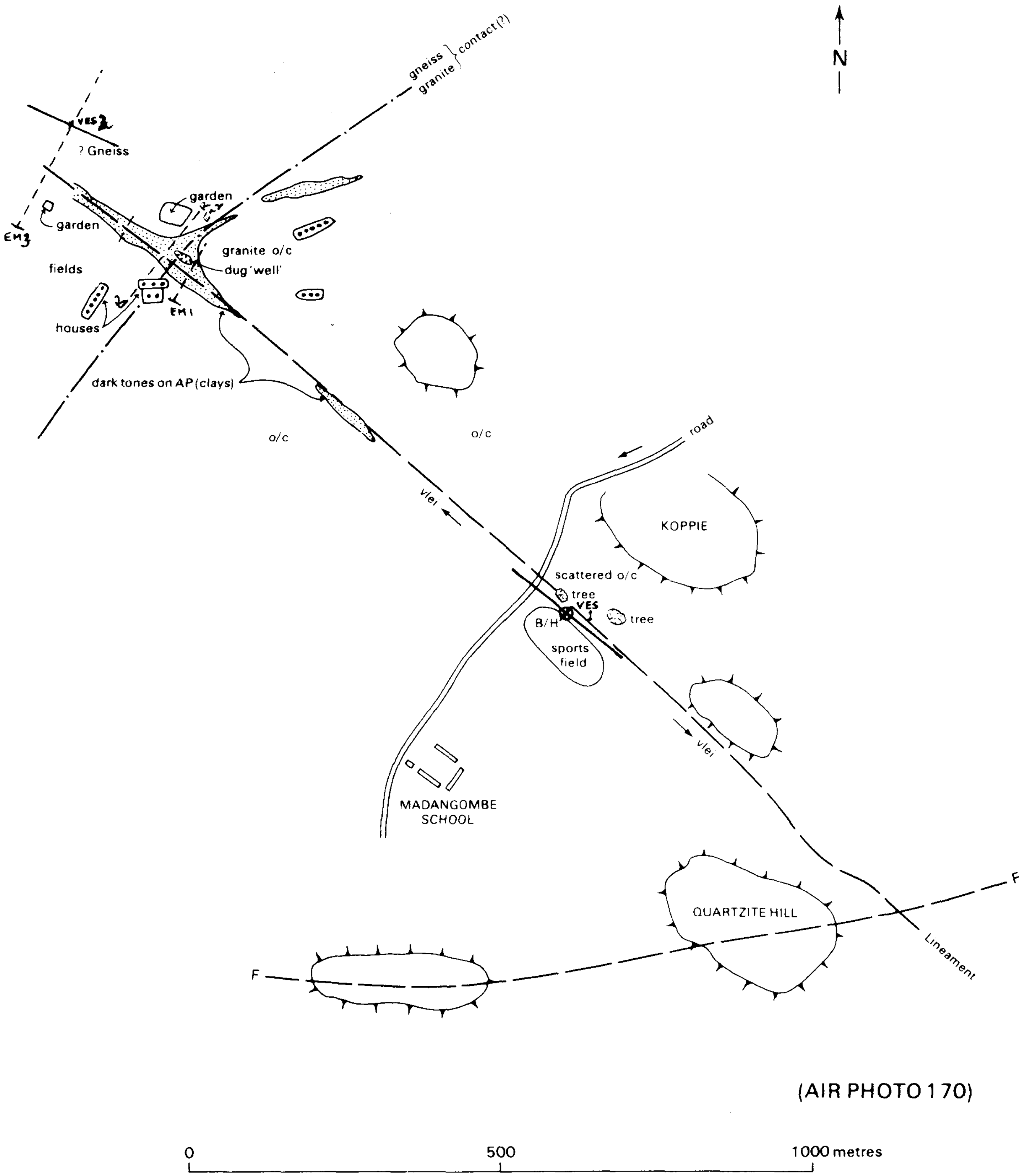
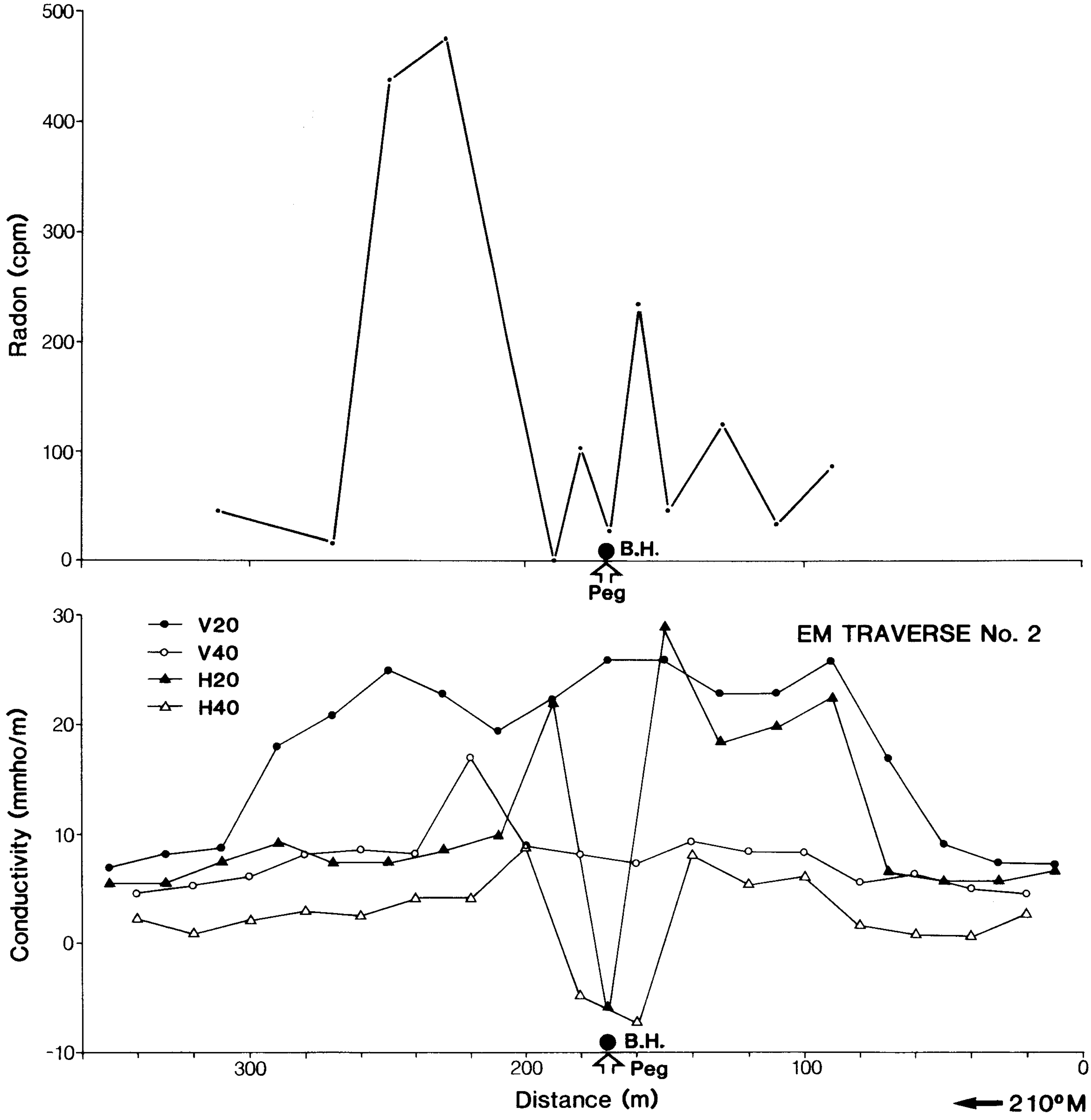


Figure 3.61



MADANGOMBE SCHOOL

Figure 3.62

and the main radon anomaly. EM34-T2 shows a marked vertical sided anomaly which is pegged in the centre. The VES on the pegged site gives the following prediction.

Layer	Thickness (m)	Resistivity (ohm-m)
1	1.1	11.00
2	6.6	22.00
Infinity		

The VES on the radon anomaly further to the west gives a similar order of results.

Radon survey.

Initial background: 11 cpm
Maximum anomaly: 474 cpm

The radon survey showed a small anomaly at 10 m to the east of the peg and a much larger anomaly at 50 m to the west of the peg. The latter position corresponds closely with the position estimated for the lineament trend based on the air photograph.

Drilling. (Figure 3.63)

The pegged site was drilled and proved effectively dry. It would obviously have been interesting to have drilled on the radon anomaly but time did not permit this to be done.

The drilling log and samples indicated relatively soft and weathered material to total depth which certainly does not accord with the geophysical survey. Four (4) small strikes with water inflow occurred between 12 and 42 metres bgl.

Recommendations.

A redrill on the radon anomaly. A collector well is a possibility and a short pumping test after 20 m drilling should be carried out.

3.20 **Maramba School** 2030 A2 (Figure 3.64)

Background.

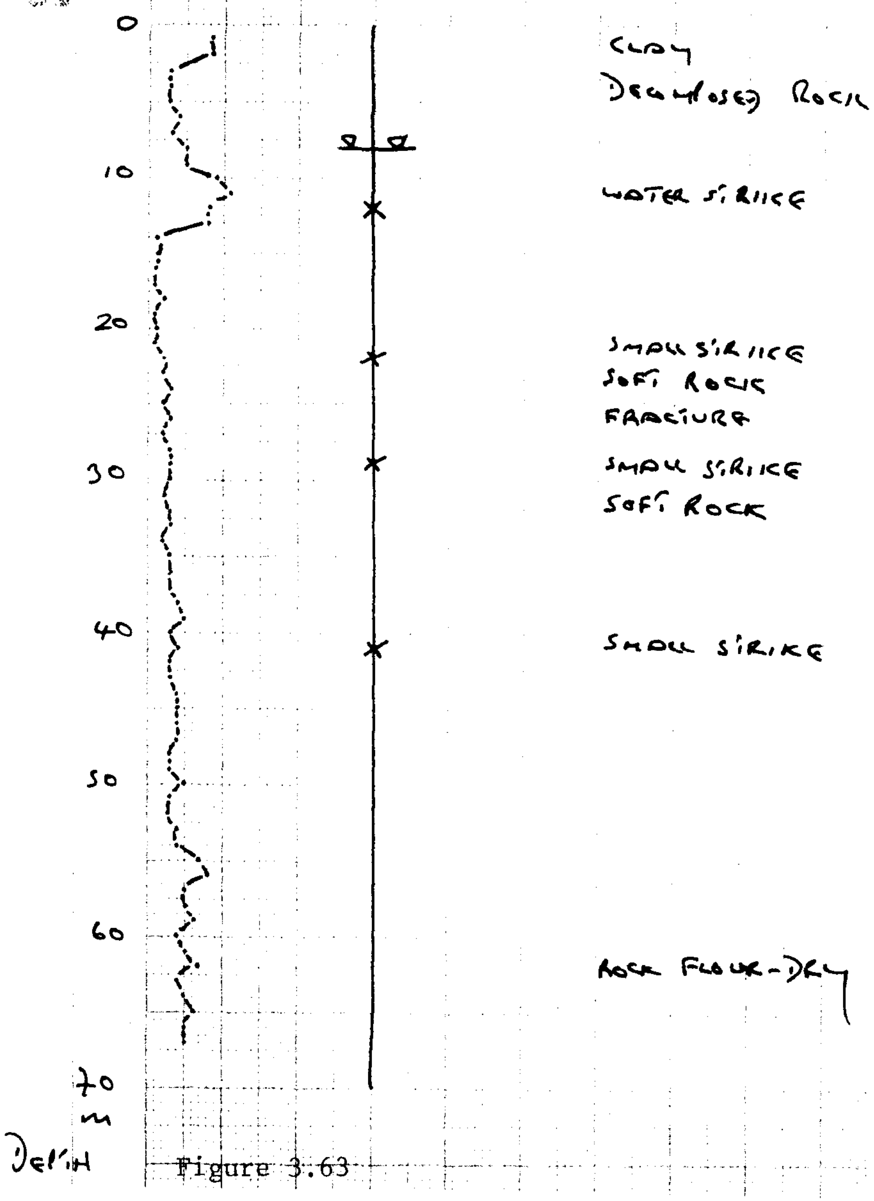
Existing borehole: V 2667 [2220/77680]
Total depth: 42 m
Saprolite: [20.6 m]
Rest water level: 8.0 m
Yield: 3.41 l/sec

The water quality was said in the drilling report to be fresh but is currently quite saline with an electrical conductivity of c. 4000 microsiemens which is equivalent to about 3000 ppm total dissolved solids. The yield is adequate for a handpump. Both quantity and quality of output is said to be constant throughout the year. The borehole is quite far from the school.

AREA E MADANGOMBE

DRILLING RATE

10 20 30 40 min/m DRILLER'S LOG LITHOLOGICAL LOG



1-2 m Dark grey v less clays

3-11 m Khaki silty sands with hornblende and quartz

12-16 m Damp, clayey khaki silty sands with hornblende and quartz

17-23 m Dry khaki silt with hornblende and quartz

24-55 m Very dark blue-grey weathered hornblende, clayey at 26, 29, 35, 41 and 42 m

56 m Pinkish-grey silty sediment, much rose quartz, some hornblende and a shiny-clearing glossy translucent mineral

57 m Dark khaki silty clay nodules with glossy mineral

58 m Transition to

59-67 m Pink-grey melange of green, grey clay nodules, pink quartz, white quartz, muscovite and a glassy mineral

Figure 3.63

MARAMBA SCHOOL: AREA E: MAP 2030 A2 GR22270/776820

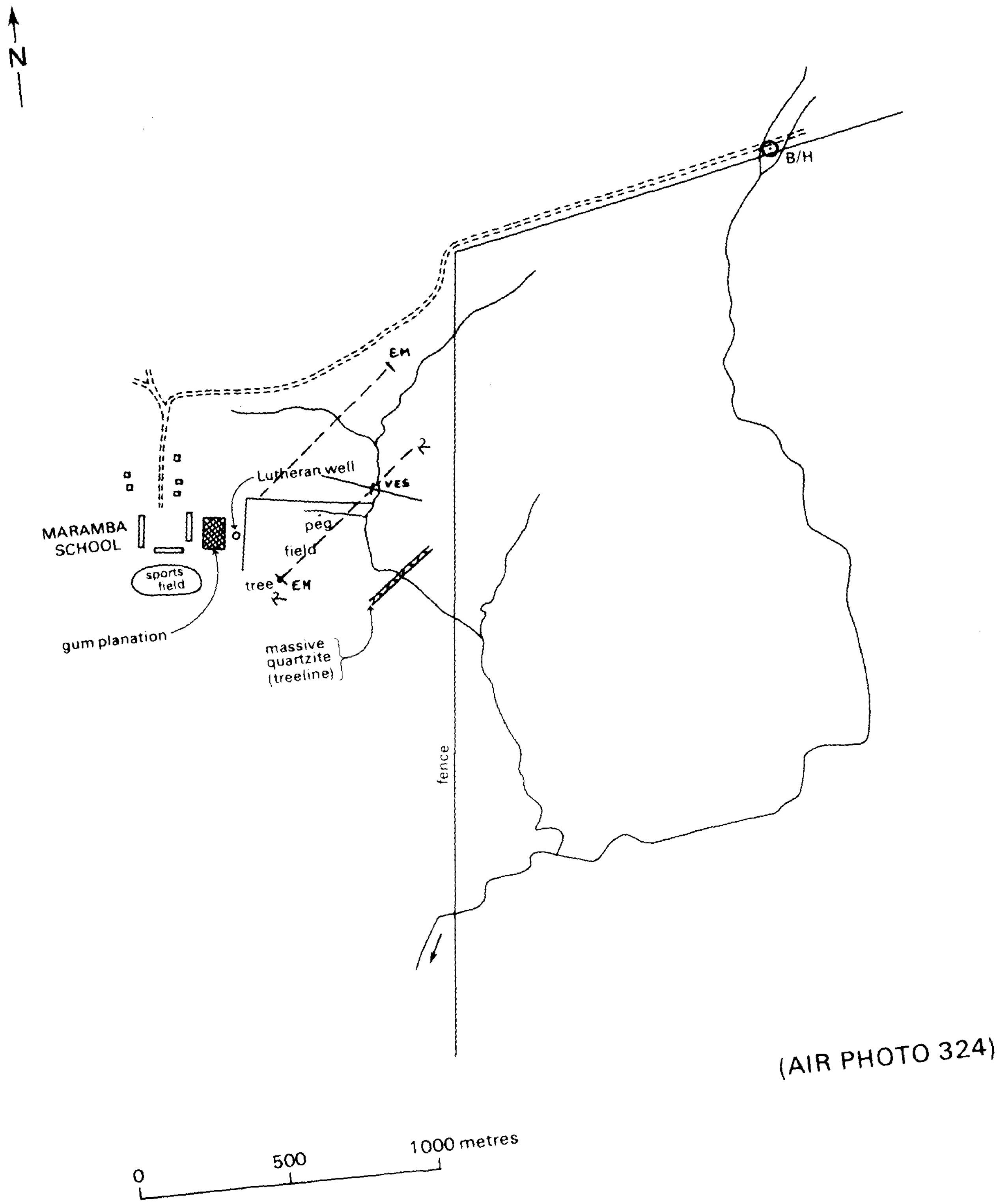


Figure 3.64

There are two pegged sites quite close to the school and almost at the same elevation. The locations do not appear to have been geophysically surveyed. A Lutheran well is in course of construction in the same area as one of the pegs. It is currently at c. 10 m depth without reaching water and is in fresh granite. The second peg has a bearing of 165^{0} magnetic from the school and about 150 m away from the edge of the school building.

The problem appears to be one of both quantity and quality and hence the need to seek sites with good localised recharge. Fresh water could overlie saline water and may constitute difficulties in the use of a deep borehole. In such circumstances, a well which'skims' the surface aquifer might be more effective. The recommended site for investigation is on the edge of an incised valley upstream of a quartzite dyke (2/3 metres) which is orthogonal to the stream and could act either as a barrier which will build up the water levels or as a good fracture zone. A borehole/well site on the school side of the stream would be more convenient. The investigation should seek to ascertain deep saprock or saprolite with good recharge.

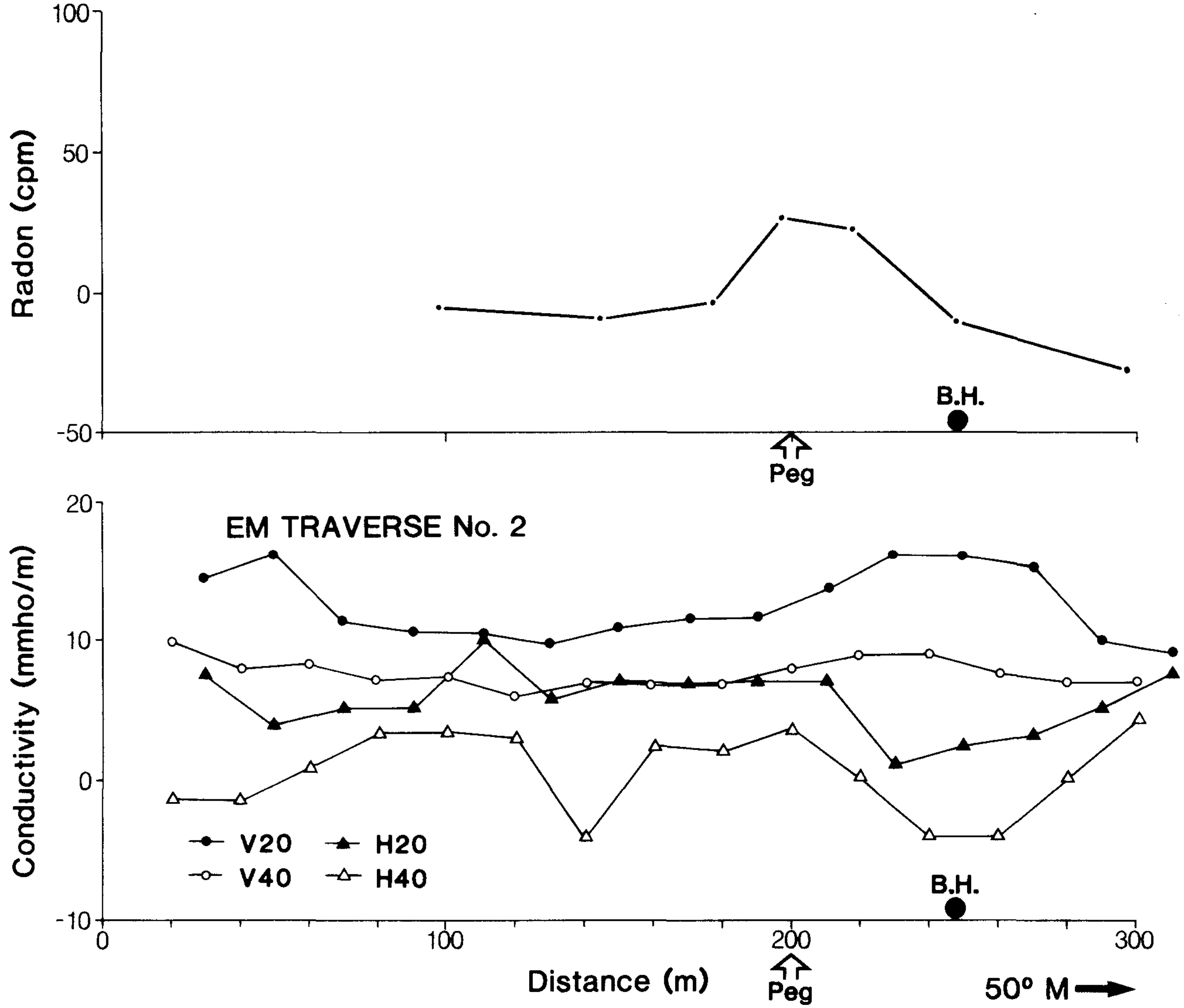
If this site proves unacceptable, a feasible location for a protected dug well occurs close to the main river valley about 2 km from the school. There are tall phreatophyte trees in the area and an existing dug well apparently never dries. Although the site is too far from the school for general use, it might be considered as a supplementary supply for better quality drinking use to augment the saline water from the borehole. Roof catchments could also be added.

Geophysical survey. (Figure 3.65)

The recommended survey site was not identified by the survey team which carried out two EM34 traverses further upstream, on one of which (T2) a site was pegged on a relatively minor conductive anomaly. Two VES surveys were also carried out, one at the borehole which indicated 28 m of low resistive overburden (27/50 ohm.m). The VES in the valley close to the pegged site indicated only 10 m of overburden.

Subsequent surveys immediately prior to drilling indicated an EM34 traverse along the initially recommended line by the quartz vein. The results showed a modest thickness of overburden but no marked vertical anomaly. A repeat EM34 traverse along the pegged line was also carried out and a preferred site for a borehole identified, although again the anomaly was relatively minor. A VES on the site gave the following results.

Layer	Thickness (m)	Resistivity (ohm.m)
1	0.30	125.00
2	2.25	18.75
3	8.75	65.60
Infinity		



MARAMBA SCHOOL SITE

Figure 3.65

Radon survey.

Background: 40 cpm
Maximum anomalies: 111 and 29

Both EM34 traverses (the more recent survey) were also traversed with the Radon probe. Neither showed significant anomalies and the surveys showed frequent negative readings and poor repeatability (111 and 15 on same site).

Drilling. (Figure 3.66)

Although in normal circumstances, no site on the surveyed line would have been pegged, the need for a water supply justified drilling as part of an experimental programme.
The drilling log and samples indicated no clear overburden but the drilling rate reduced after 10 m which is perhaps indicative and corresponds with the survey. Two minor fractures/water strikes were encountered and the log referred to muddy water over the V-notch which prevented a reading. The yield was referred to as low. This is perhaps an example of a site which could be used for experimental 'hydrofracturing'.

3.21 Discussion of Results.

3.21.1 General assessment.

Seventeen locations were drilled during the current programme, the majority of which had been drilled on previous occasions and had produced dry or low yielding boreholes. The results are tabulated in Tables 3.3, 3.4 and 3.5. The yield data are classified as high when exceeding 0.25 l/sec for 5 hours or more test pumping; marginal for equivalent yields of 0.2 to 0.25, low for 0.1 to 0.2 and below 0.1 l/sec, 'dry'. Since these tests were carried out at the end of the dry season the marginal yields can be considered as probably adequate for hand pumps. Of the locations drilled, seven (7) produced high yields, three (3) marginal although one (1) with saline water, one (1) low yielding and six (6) dry. In the circumstances, the 10 successful boreholes demonstrate the feasibility of borehole construction at difficult sites which do not meet the Master Plan criteria. With greater attention to the dip of the conductive fracture zones and improved borehole development techniques, the success rate could have been higher. It is also significant that 5 of the 7 high yielding boreholes could probably have been pump tested at higher rates than 1 l/sec which is statistically higher than average percentages of high yielding boreholes (Figure 3.67).

Only two of the sites exhibited VES surveys which met the Master Plan criteria (sites 5 and 14) and an adequate thickness of saturated overburden by the same criteria was exhibited by two other (different) sites (sites 3 and 6). The overburden thickness obtained by drilling did not in general correspond closely with the predicted thicknesses from the VES surveys; in only six cases did a fairly close correspondence exist. There was no particular

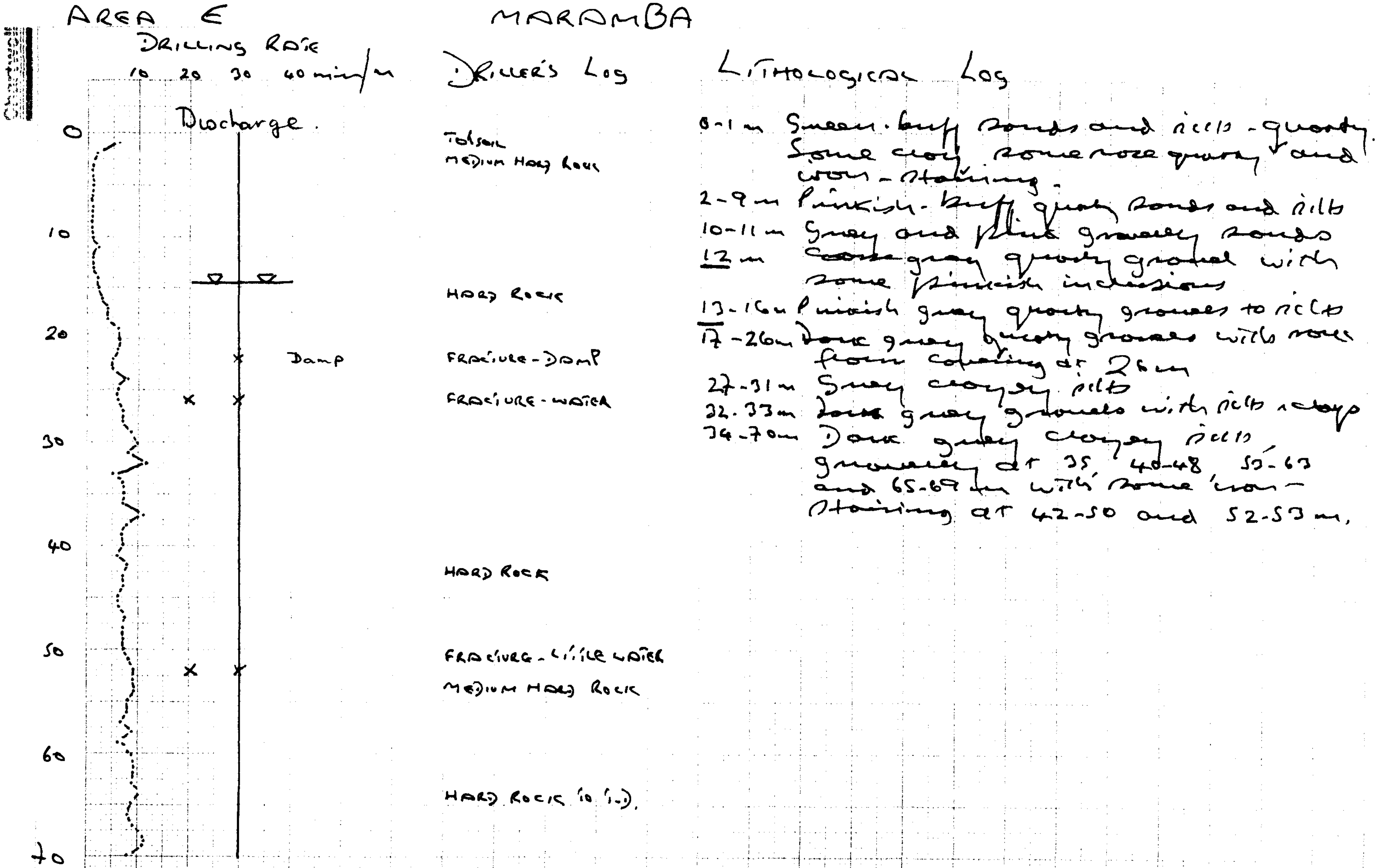

AREA E
MARAMBA
DRILLING RATE
10 20 30 40 min/m
Discharge
Damp
0
10
20
30
40
50
60
70 m
DRILLER'S LOG
TOPSOIL
MEDIUM HARD ROCK
HARD ROCK
FRACTURE - DAMP
FRACTURE - WATER
HARD ROCK
FRACTURE - LITTLE WATER
MEDIUM HARD ROCK
HARD ROCK (to T.D.)
LITHOLOGICAL LOG
0-1 m Green-buff sands and silts - quartz. Some clay, some rose quartz and iron-staining.
2-9 m Pinkish-buff quartz sands and silts
10-11 m Grey and pink gravelly sands
12 m grey quartz gravel with some pinkish inclusions
13-16 m Pinkish grey quartz gravels to silts
17-26 m grey quartz gravels with water from fracture at 26 m
27-31 m Grey clayey silts
32-33 m grey gravels with silts & clays
34-70 m Dark grey clayey silts, gravelly at 35, 40-48, 53-63 and 65-69 m with some iron-staining at 42-50 and 52-53 m.

Figure 3.66

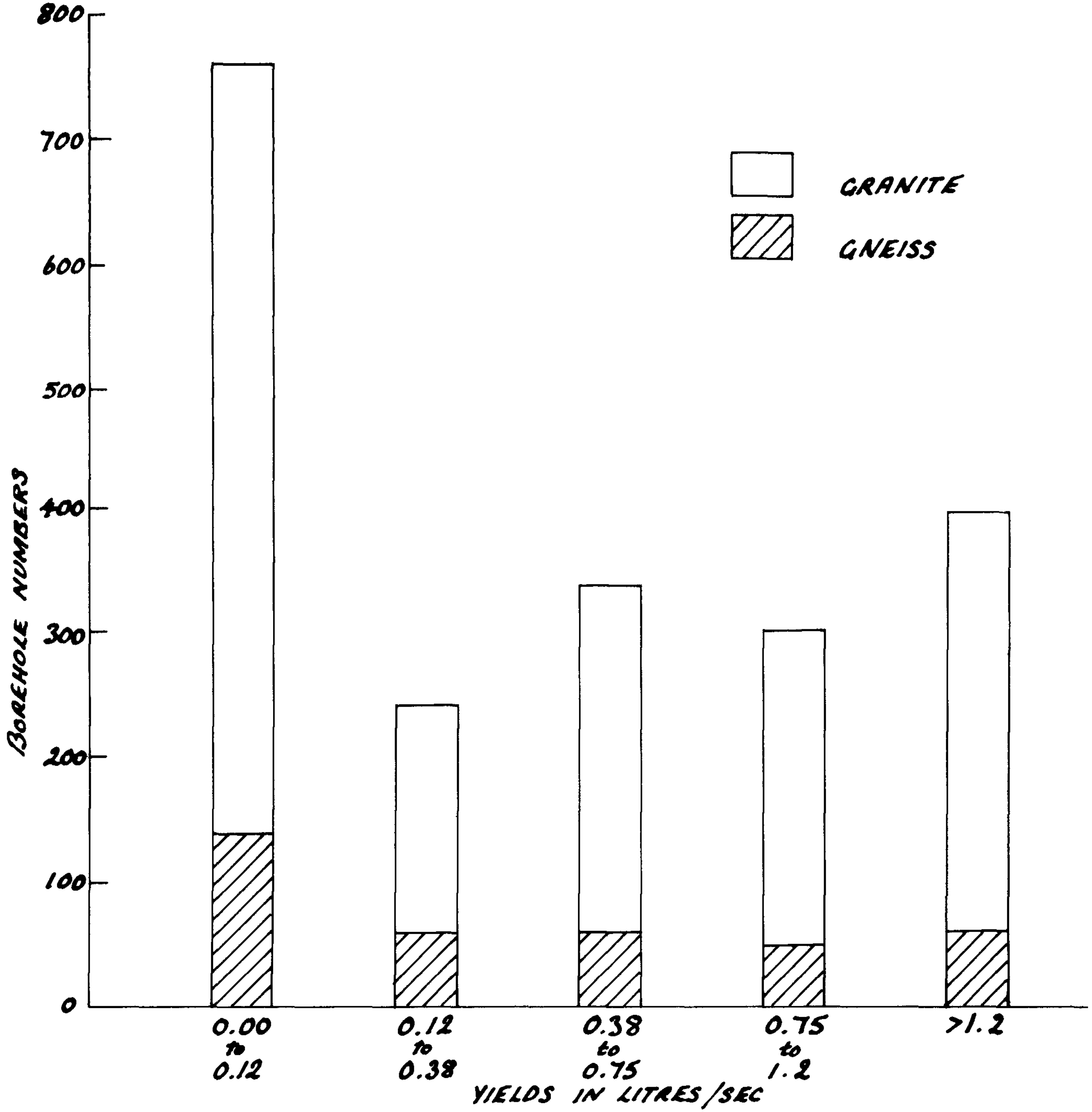


Figure 3.67 FREQUENCY DISTRIBUTION OF SHORT DURATION TEST YIELDS IN BOREHOLES IN ZIMBABWE

consistency in the discrepancies which may be ascribed perhaps to the transitional nature of the weathered bedrock (saprock) into the fresher bedrock.

Marginal yields were obtained at sites 3, 10 and 15. In the case of site 3 (Matatire), there is a good likelihood that with further development, and if possible the emplacement of a gravel pack, this borehole could provide an improved yield. Site 10 (Mhatiwa North) could possibly be developed further and both these sites are suitable for collector wells. The third site, No. 15 (Chikadze) had saline water. It is possible that the upper levels of the aquifer are fresh and a collector well could act as a skimming well.

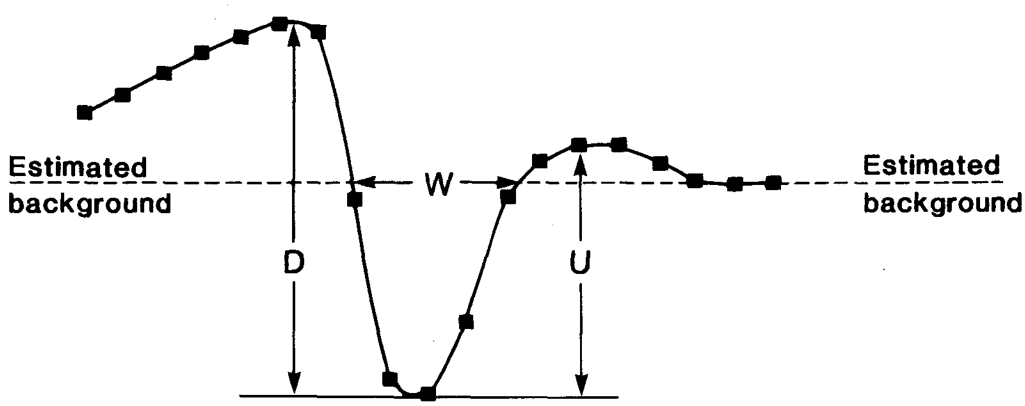
3.21.2 Radon anomalies and inclination of the 'conductive' zone.

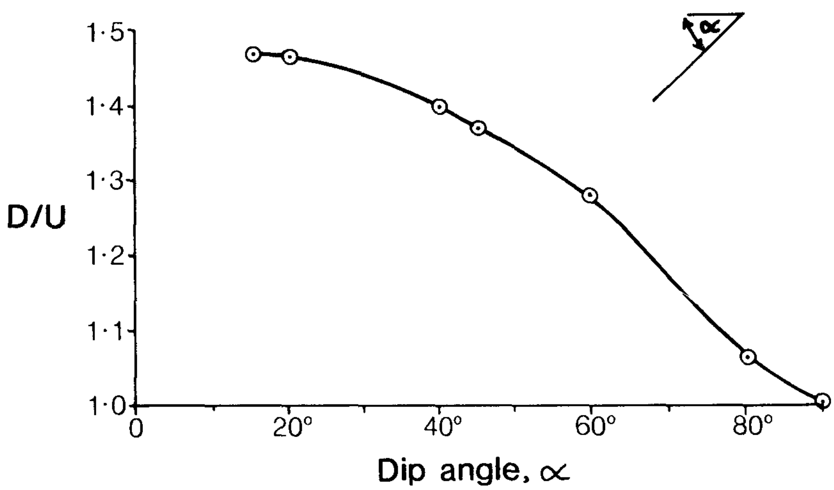
The pegged sites were mainly selected on the basis of EM traverse results since, as has been described, the VES site surveys rarely met with the Master Plan criteria. The emphasis lay in the identification of a narrow anomaly which was assumed to be steep sided. This assumption may not always have been correct. Figure 3.68 has been provided by Mr R Cratchley, formerly of BGS, and demonstrates how the dip of a conductive zone can be calculated from the form of an EM survey. More accurate data can be obtained if the traverse spacings are made smaller. In the present surveys these were at 20 metres and a closer spacing would have been desirable. With a dipping conductive zone, the borehole site will need to take account of the angle of dip and the probable depth of the water table if it is planned to intersect the zone at a down-dip position. For thin and shallow dipping zones, an angled borehole down the dip could prove the only method to obtain adequate intersection of the zone and precise knowledge of the zones' geometry is needed. A collector well is likely to be more effective in such circumstances with the radial boreholes being directed either along the intersection of the saprolite-saprock and also down the dip of the conductive zone.

Radon traverses were carried out over the EM traverses following the initial EM interpretations. The radon anomaly is likely to coincide with the EM anomaly when the latter is vertical or steeply dipping. Where the conductive zone is dipping at a significant angle, the radon anomaly seems likely to be offset down the dip and corresponding also with the depth of the water table since the gas will tend to migrate vertically upwards from this level. The anomaly therefore not only provides information on degree of fluid movement but also on the geometry of the conductive zone and the water table.

The results of a preliminary interpretation of the radon and EM surveys in relation to possible inclination are shown in Table 3.5. At a substantial number of sites (8), the radon anomaly corresponded fairly closely with the EM anomaly. Seven (7) sites show vertical anomalies and it is significant that the others appear to show significant angles of dip which could well have affected the borehole yield. In most cases, the maximum radon anomaly is in a down dip direction with one or two notable exceptions, e.g. Nemarundwe (site 2). A feature that should be noted is that EM and

ESTIMATION OF DIP ANGLE FOR DIPPING SHEET CONDUCTOR





D = Amplitude, downdip side
U = Amplitude, updip side

Anomaly width, W (measured at background level, which is best estimated from "U" side of anomaly)

W = Coil spacing S for single narrow conductor
= (s + d) for conductive zone of width d

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Figure 3.68

radon anomalies sometimes exhibit double features suggestive of a double fracture zone. Rungai is a case in point. The borehole may well have been effective by striking both dipping zones. In such a case a vertical hole down dip and able to intersect both zones would have advantages.

Although the angle of dip may well have been of significance for the successful boreholes, it is more pertinent to ask whether it was of significance for the failed boreholes.

Site 2 - Nemarundwe: Three boreholes were drilled on this site, one on the surface expression of an EM anomaly, one on the observed maximum radon anomaly and a third angled to the NE from one to the other. The first hole on the original pegged site produced a modest yield, although inadequate for a handpump, as also did the inclined hole. It is anomalous that the radon high occurs on the updip side. If the dip of the conductive zone is as indicated by the survey, the pegged site would be wrongly placed and the inclined hole should have been drilled to the SW. The site is suitable for a collector well.

Site 7 - Chinambiri School: This site is in the vicinity of an existing borehole which was thought to have been placed 'off' the lineament. The EM survey shows a low angle of dip to the SW. The inclined borehole to the NE is therefore incorrectly sited and should have been drilled in the opposite direction which would also have correlated with the radon anomaly.

Site 8 - Chinambiri Dam: The test yields ranged from 0.29 l/sec to 0.062 l/sec towards the end of the test. The discharge remained muddy throughout. Further development might possibly have converted this into a successful borehole. There is some uncertainty on the inclination of the conductive zone which may be dipping fairly steeply to the SW and if correct would have merited a shift in the pegged site.

Site 9 - Mhatiwa School: This produced a marginal yield of low quality water. The inclined borehole was drilled towards the SE to intersect the lineament. However the EM results demonstrate a possible low dip to the NW and the inclined borehole is not appropriately located to obtain an optimum intersection.

Site 11 - Chikore: Two boreholes were drilled at this site and both proved to be dry, although further development of the second inclined hole would have been merited since it produced muddy water. The reservoir survey site has an anomalous relation with the radon anomaly which it would be valuable to reconfirm. The valley site anomaly dips to the west and the angled borehole should have intersected the zone. An alternative position would have been a vertical borehole on the 'peg' location.

Site 16 - Madangombe: The pegged site has an anomalous relation with the radon anomaly which it would be valuable to reconfirm. A dip to the SW might be anticipated from the radon anomaly which could significantly affect the preferred location of the borehole.

Site 17 - Maramba: This is a poor site from both the geophysical survey and radon results. It would not have merited drilling but for the importance of the demand for the local school.

It is recommended that 5 of the 6 failed sites could be re-examined with more detailed geophysical and radon surveys to determine whether more appropriate drill sites could be located. Further development of the boreholes on two of these sites are merited (sites 2 and 11(ii)).

4. CONCLUSIONS

The main emphasis during 1987-88 has been on the Masvingo Borehole Project in Zimbabwe and to a lesser extent the Chimimbe dambo studies in Malawi. The catchment database and the Chisengeni satellite imagery study have all progressed to some extent but fuller consideration will be given to them in the final year of the project (1988-9).

Although no further field work on the Masvingo Borehole Project is planned, other than to complete the borehole geophysical logging, it would be of considerable value if the Zimbabwe Government could follow up the recommendations for further, more detailed, geophysical work on the 5 failed borehole sites with a view either to redrilling or in two cases redevelopment of the existing boreholes. In any event, some further development of several of the boreholes could be merited on the occasion when pumps are installed.

Table 3.3(i)

SITE DETAILS			GEOPHYSICAL SURVEY*		RADON SURVEY			DRILLING				TESTING					
No.	Location	Borehole	Overburden Thickness	Overburden Resistivity	Background (cpm)	Borehole Site Anomaly	Maximum Anomaly	Predicted Overburden Thickness (m)	Observed Thickness (m)	Fracture Depths (mogl)	First Main Water Strike (mogl)	Test Yield (1/sec)	5-Hour Drawdown (m)	5-Hour Specific Capacity	Discharge Electrical Conductivity (microsiemens)	Static Water Level (mogl)	STATUS†
1.	Nanwi	I	x	x	0	250	394	0	0	[3,5, 8, 10, 11, 13-17, 22, 27, 32, 34]	17				370		H
		II								[13, 14, 16, 24]	14.	0.275	14.4	0.019	370	2.03	H
2.	Nemarundwe	I	x	xxxx	101	48	1628	5	10-13	[None]	12	0.015	22	–	–	3.0	D.
		II			101	1628	1628	–	6	[12, 35, 39, 52]	11	–	–	–	–	–	D
		III			–	–	–	–	–	[12, 18, 23, 44] Incl	12	–	–	–	–	–	D
3	Matatire		xxx	xx	30	675	758	23	33	[45, 52, 45]	45	0.25	50.	0.005	150	3.1	M
4.	Zimuto Blind School.		xxx	xxxx	66	287?	785	22	13	[30, 39, 40]	30	0.32	4.2	0.076	580	4.3	H
5	Zimuto Siding		xxxx	xxxx	13	67	67	28	20	[24, 26, 34, 36]	24	0.55	0.36	1.528	600	20.	H
6	Chibi B.C.	I	xxxx	xxx	41	578	578	48	28	[25]	16	0.57/0.27	23.	0.018	550	7.	H
		II			41	202	578	–	–	–	4	–	–	–	–	–	
7.	Chinambiri Borehole Site		x	x	108	Angle hole	187	5	18-22	[None]	–	–	–	–	–	–	D.
8	Chinambiei Valley Site		xxx	xxxx	–	–	–	21	20	[None]	12	0.29/0.062	59	–	–	7.4	D.
9	Mhatiwa School.		–	–	5	[371 511]	808	6	4	[29, 35]	29	0.12	?	>0.005	8,200	?	M.
10	Mhatiwa North		x	x	60	482	482	8	10	[17, 20, 35, 52]	20	0.29 [180 min]	36	0.007	1,100	5.9	M
11	Chikore Reservoir		xxxx	xx	5	178	818	28/32	5	[17]	17	–	–	–	1000	18.1	D
	Chikore Valley		xxx	xx	5	Angle	988	22	5/15	[33 online]	33	–	–	–	1100/400	13.6	D.
12	Rungai.		x	x	17	192	192	10	12	[18, 30]	18	1.6/2.2	2.1 [for 1.6]	0.76	400	9.5	H

* Notes on Geophysical Survey

Overburden thickness (m) :

> 25	xxxx
20 < 25	xxx
15 < 20	xx
< 15	x

Overburden resistivity (ohm-m) :

20 - 100	xxxxx
101 - 150	xxxx
151 - 250	xxx
> 250	xx
< 20	x

† H : high yield > 0.25 1/sec
M : medium yield 0.2-< 0.25 1/sec
L : low yield 0.1-< 0.2 1/sec
D : < 0.1 1/sec

Table 3.3(ii)

SITE DETAILS No.	SITE DETAILS Location	SITE DETAILS Borehole	GEOPHYSICAL SURVEY* Overburden Thickness	GEOPHYSICAL SURVEY* Overburden Resistivity	RADON SURVEY Background (cpm)	RADON SURVEY Borehole Site Anomaly	RADON SURVEY Maximum Anomaly	DRILLING Predicted Overburden Thickness (m)	DRILLING Observed Thickness (m)	DRILLING Fracture Depths (mbgl)	DRILLING First Main Water Strike (mbgl)	TESTING Test Yield (l/sec)	TESTING 5-Hour Drawdown (m)	TESTING 5-Hour Specific Capacity	TESTING Discharge Electrical Conductivity (microsiemens)	TESTING Static Water Level (mbgl)	STATUS†
13	Chikofa		xx	xxxx	10	101	134	17	6-14	[23, 34, 41, 49]	23	0.75	12.5	0.06	740	16.5	H
14	Sarahuru		xxxx	xxxx	11	620	620	26	30-36	[28, 35, 40]	28	0.29-0.67	4.8 [0.29]	0.06	880	20.3	H
15	Chikadze		x	xxxx	46	0	38	12	2-17	[9, 13, 20, 25]	20	Not tested.			11,000/12,000	8.8	[M] Saline
16	Madangombe		x	x	11	28	474	8	20	[11, 22, 29, 41]	11					8.4	D
17	Maramba		x	xxxx	40	0	110	11	10	[22, 26, 52]	26	Not tested : hole collapsed.				14.5	D

* Notes on Geophysical Survey

Overburden thickness (m) :

> 25	xxxx
20 < 25	xxx
15 < 20	xx
< 15	x

Overburden resistivity (ohm-m) :

20 - 100	xxxxx
101 - 150	xxxx
151 - 250	xxx
> 250	xx
< 20	x

† H : high yield > 0.25 l/sec
M : medium yield 0.2-< 0.25 l/sec
L : low yield 0.1-< 0.2 l/sec
D : < 0.1 l/sec

Table 3.4

SITE No.	Location	Borehole No.	Total Depth (m)	Inclination*	Diameter (mm)	Casing Depth (m)	Headworks
1	Nanwi	I	34.5	30^o	95	0	Boulder
	Nanwi	II	37.5	V	150	25	Screw cap
2	Nemarundwe	I	30	V	150	7	Screw cap
	Nemarundwe	II	59	V	150	6	Screw cap
	Nemarundwe	III	45	49^o	95	6	Boulder
3	Matatire	-	60	V	150	5 [PVC-TD]	Welded plate
4	Zimuto Blind School	-	60	V	150	8	Screw cap
5	Zimuto Siding	-	40	V	150	9	Screw cap
6	Chibi B.C.	I	67	V	150	7.5	Screw cap
	Chibi B.C.	II	31	V	150	9	Screw cap
7	Chinambiri Borehole Site	I	70	20^o	150	5	Casing pulled
8	Chinambiri Valley Site	II	70	V	150	-	Casing pulled
9	Mhatiwa School	-	48.8	45^o	95	3	Boulder
10	Mhatiwa North	-	70	V	150	1.5	Hammered over
11	Chikore S.	I	52	V	150	3	Boulder
	Chikore N.	II	61	35^o	150	3	Boulder
12	Rungai	-	42	V	150	12	Hammered over
13	Chikofa	-	60	V	150	6	Hammered over
14	Sarahuru	-	70	V	150	16 [PVC-TD]	Welded cap
15	Chikadze	-	70	V	150	3	Boulder (Blocked at 27 m)
16	Madangombe	-	67	V	150	-	Casing pulled
17	Maramba	-	70	V	150	16	Boulder (Blocked at 16 m)

* Angle to vertical

Table 3.5

No.	SITE Location	Borehole	Saturated Overburden Thickness (m)	Radon Anomaly*	H40 Inclination to Horizontal and (direction)	Width (m)	H20 Inclination to Horizontal and (direction)	Width (m)
1	Nanwi	II	0	C	V	0	65 (W)	12
2	Nemarundwe	I	7-10	E	low (SW)	25	50 (SW)	20
3	Matatire		30	C	70 (NE)	14	45 (SW)	18
4	Zimuto Blind School		9	(NE)	low (NE)	40	low (NE)	?
5	Zimuto Siding		0	NW	65 (NW)	wide	?	?
6	Chibi Business Centre		21	(E)	?	?	?	?
7	Chinambiri Borehole Site		0	(SW)	<20 (SW)	5	low (SW)	12
8	Chinambiri Dam Site		12	-	V	8	55 (SW)	8
9	Mhatiwa School		0	C	68 (NW)	5	low (NW)	38
10	Mhatiwa North		4					
11	Chikore							
	(i) Reservoir		0	SW	?V	wide	?V	wide
	(ii) Valley Site		<2	C	40 (W)	30	<20 (W)	?
12	Rungai		3	C	<20 (SW)	10	<20 (SW)	14
13	Chikofa		0-11	C	V	8	85 (NE)	8
14	Sarahuru		10-16	(W)	40 (W)	<10	?	?
15	Chikadze		0-8	-	<20 (SW)	4	<20 (SW)	0
16	Madangombe		12	SW	V	4	70 (NE)	0
17	Maramba		0	SW	V	wide	V	wide

* C = coincidental with EM anomaly;
(XY)/XY : (slight offset)/significant offset in the direction indicated