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Some remarks on ground water conditions and use of geophysical instruments in hard rock (Crystalline Rock) areas based on findings from the WHO/UNICEF sponsored Village Water Supply Programme in India.

Only on crystalline rocks

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HYDROGEOLOGIST

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Corrigenda

1. On the cover and the fly leaf the words "...WHO/UNICEF assisted Village Water Supply Programme in India" should replace the present wording.

2. The first paragraph on page one should be deleted and the following substituted:

   "In 1970 the Government of India with the assistance of UNICEF and WHO initiated a joint programme for the provision of potable water to 12,000 villages in water scarcity areas of the country. Some 18,000 wells will be drilled in this programme of which the majority will be fitted with handpumps."

3. On page one, paragraph three, the word "are" should replace "is" at the end of the second line.

Some remarks on ground-water conditions and the use of geophysical instruments in hard rock (crystalline rock)areas based on findings from the WHO/UNICEF sponsored Village Water Supply Programme in India.

WATER SUPPLY SECTION
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1. General

In 1971 the Government of India with the help of WHO and UNICEF started a joint water supply programme for the supply of potable water to about 8,000 villages in drought or famine affected areas. Some 14,000 wells will be drilled in this programme and most wells are to be fitted with hand pumps.

The selected villages are mainly located in hard rock areas, i.e. areas where the bedrock consists of basalt, granite, gneiss, hard compact sandstone, crystallized limestone etc. States in India with this kind of bed rock and where the drilling is most intensive are Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Mysore and Tamil Nadu.

In this paper some of the findings and conclusions regarding the use and usefulness of the geophysical surveying equipment provided by UNICEF is discussed as well as some of the various groundwater conditions found during the drilling activities. It is however not the intention of this report to give a detailed description of geological, meteorological conditions etc. in various areas; such data can be found elsewhere.

The views and comments given are entirely the writer's and the report is only intended to be distributed to the geologists and engineers working in this programme. The reader is supposed to have a sound knowledge of hydrogeology and the geology of India.

The drill rigs supplied for this programme are air rigs for down-the-hole or top hammer drilling. The rigs are capable of drilling 4" to 6" diameter wells to a depth of approximately 200 to 250 ft. (4 inch) and 500 to 600 ft. (6 inch).

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The rigs used for 4 to 4½ inch wells are:

(a) Halco Tiger, model F10HR and A71 HR down-the-hole hammer

(b) Halco Minor, model 14 HR and 29 HR down-the-hole hammer

(c) Atlas Copco COP-4 down-the-hole hammer

(d) Atlas Copco BBE-57 top hammer

The rig used for 6 inch wells is:

(e) Ingersoll-Rand model TRUCM-3, down-the-hole hammer

The following number of rigs have been delivered (September 1972) by UNICEF:

Rig	Quantity
(a)	11 nos. G 10 HR
	9 nos. A 71 HR
(b)	7 nos. 14 HR
	1 no. 29 HR
(c)	29 nos.
(d)	7 nos.
(e)	9 nos.

So far (January 1973) about 9,000 wells have been drilled. The average depth varies from state to state (or rather from one geological area to another) but is about 100 to 150 ft. for the 4 inch wells and 150 to 170 ft. for 6 inch wells. The failure rate is normally around 20 per cent but varies often to a great extent depending on the type of geological formation etc. (The matter is discussed in detail in section 4.)

A well yielding less than 100 GPH is normally considered as unsuccessful although in some states, a well yielding as little as 20 GPH is listed as successful. This difference makes it sometimes difficult to compare hydro-geological data from various states.

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2. The Use of Geophysical Instruments

UNICEF has supplied a total of fifteen resistivity meters, fifteen magnetometers, four seismic timers and five well loggers. (January 1973)

2.1 Resistivity Methods and Instruments

The resistivity instruments supplied are:

"Terrameter" manufactured by Atlas Copco ABEM AB, Sweden. The output is 6W at 100, 200 or 400 volt using low frequency square waves.

Without doubt, the most useful geophysical instrument for locating good well sites in this programme is the resistivity meter. The surveying method used is normally the "sounding" method in which a number of various proposed well sites are evaluated. The result will however be only a study of the relative value of the various sites; it will not give the overall best location. To do this, the method of "profiling" has to be applied. This method is however sometimes difficult or even impossible to use because the villagers frequently want the well to be drilled on a very particular spot or area such as in the middle of the village where no measurements for practical reasons can be done. Also the requirement that the well normally should be located on government-owned land sometimes limits the use of the instrument. It must however be pointed out that the profiling method is by far the better one for selection of the best well site.

Attached are some resistivity profiles from Mysore -- figures 1A& B. In both figures are shown resistivity profiles using an electrode spacing of fifty feet. The areas with the lowest apparent resistivity has been selected for well sites. The method is however not "foolproof" as usually also the tectonic structure has to be taken into consideration. Perhaps the well location shown in Figure 1A could have been better if the well was drilled some twenty to thirty feet WSW of the actual location. This because the steady increase in resistivity ENE of the well indicates a more solid rock in this direction. Which interpretation is best can only be solved through experience and if possible, test drilling.

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It is a common belief that by using the "sounding" method the depth of a well in crystalline rock can be calculated or estimated. It is the writer's opinion that this is not quite so. The reason is that in most cases the measured resistivity data to a too great extent depends on the thickness and moisture content in the overburden and the weathered zone of the rock. As however most ground water to be extracted from the well moves in the fracturesor open fault zones below the weathered zone, it is necessary to drill deep enough below this zone to find and penetrate as many open cracks, fractures etc. as possible. The amount and location of such water transporting fractures cannot possibly be accurately detected with the sounding method. What the sounding method can give (if properly analysed by means of Standard Curves) is a fairly good idea of moisture content and of the thickness of the overburden and the weathered zone but nothing else. It is another matter, of course, that the thicker the weathered zone is the higher the long term yield can be expected to be. The matter is further discussed in paragraph 2.8.

2.2 Magnetometer Methods and Instruments

The magnetometers given by UNICEF is the "Minimag", a suspension-wire magnetometer that measures vertical and horizontal field components. The accuracy is ± 20 gammas if tripod is used. The instrument is sold by Atlas Copco, ABEM, AB, Sweden.

The use of magnetometer has proved to be more successful in some areas than others depending mainly on the geological conditions. They are of good use in granite areas where vertical (or nearly vertical) dykes are frequent. In basaltic areas, they are of no or little use. As dykes normally have another mineral composition than the surrounding rock, an anomaly in the magnetic field can be observed. The dykes sometimes also serves as underground barriers for the groundwater, therefore in case of undulating topography, a difference in the depth to ground-water can sometimes be found on the two sides of the dyke.

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If therefore the geologist can determine in what direction the groundwater moves he can also locate the most successful well site by determining the location of the dyke with the magnetometer. (This can of course also be done by using a resistivity meter and the profiling method, but this procedure will take considerably longer time.)

As a conclusion it can be said that the instrument is useful in areas where the topography is undulating and where some groundwater movement can be expected (and not stagnant or nearly stagnant conditions exist) and where dykes of more than approximately half to one meter width and several hundred meters length are frequent. Under other conditions, as well as in the basaltic areas of the Deccan Trap, the instrument is of little use.

In Figure 2A & B are given some examples on profiles across a dyke and how the data was interpreted.

2.3 Seismic Methods and Instruments

The seismic timers delivered are of the following make:

Porta Seis model ER-75-12 using Polaroid film casettes.

The seismic timers have so far not been extensively used. Only in one of the states has the instrument been tested, the reason is that the existing geological cells created for the location of well sites are not staffed with geologists trained in the use of such instruments. Also, as mentioned earlier, there are often several practical limitations to its use due to topographical and land ownership problems as well as problems with procurement, transportation and storage of explosives. The method is also rather time-consuming and due to the small yield that is normally needed, the instrument is often regarded to be too costly to use.

The instrument may, however, be of great help in locating larger fracture zones or other favourable geological structures, where high yielding wells are needed but this requires that the site can be selected within a fairly large area and that few limitations are put on its use. In this particular project, where the wells have to be located either in or very close to the village, the use of a seismic timer is almost nil.

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2.4 Electrical Well Loggers

An electric well logger is, when properly utilized, a most versatile instrument for the evaluation of geological and hydrogeological parameters, particularly in alluvial formations. The use of it in crystallized rock areas may be more limited, good use could however probably be obtained using the following probes:

(a) single point resistivity

(b) caliper

(c) flowmeter and

(d) temperature.

The loggers given by UNICEF are:

3 nos. of Neltronic Well Logger, model KLD, supplied with (a) single point resistivity and self potential (b) multi-point resistivity (16" short normal and 64" long normal) and (c) gamma ray.

1 no. of Log Master Model LMH-15. The probes are the same type as for the Neltronic loggers.

(Note: One more Log Master has been delivered to Rajasthan Groundwater Board, as this logger is not intended to be used in hard rock formations, it is not further discussed here.)

The self potential will nearly always give a straight line on the recorder as no drill mud is used during the drilling. As it however normally is recorded simultaneously with the resistivity, it may be of some use sometimes.

The use of single point resistivity probe has proved useful as pronounced and sharp breaks seem to indicate open (and probably) water transporting cracks or fissures. This has to be further checked but for this reason, a caliper (and perhaps also a flowmeter) is needed.

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The use in this project of the multipoint resistivity probes (16" short normal and 64" long normal) as compared with the single point probe has been very limited for mainly two reasons:

(a) such probes are normally intended to be used for a detailed identification, separation and the geophysical evaluation of various strata or formations and

(b) the probe is too long and the well depth below the water table normally is not more than 75-100 ft. so that there is not much formation that can be logged.

The gamma (natural) ray probe is designed to be used for differentiating between clay or slate in sedimentary formations. The use of this tool in crystalline rocks is therefore very doubtful, because the recorded graph will mainly show the distribution of radioactive minerals in the granite or gneiss. This is of no interest in water well drilling as the radio-activity as such is very low and has nothing to do with the success or failure of a well. Perhaps some application and use of it may be found after some experience has been gained; this is however very doubtful.

In Figure 3 A & B, are given some examples on various logging curves obtained from Department of Mines and Geology in Bangalore.

2.5 Resistivity and Lithology

One of the most interesting and possibly also the most valuable contribution to geophysical groundwater exploration in hard rock areas is the use of surface resistivity methods. Too little emphasis has however been laid by the geologists employed in this programme on how valuable and accurate the sounding method is although most geologists use it. What is needed is a careful collection and evaluation of resistivity data with reference to various geological situations and particularly to variation in the yield of the wells. Here, of course, not only data from highly successful wells should be analysed but also, and this is equally important, data from unsuccessful or very low yielding wells.

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Some work in this field has been done by the Department of Mines and Geology in Mysore from where the following data has been collected:

Lithological character	Resistivity in ohm metre
1) Soil, dry	15-90
2) Soil, saturated	15
3) Weathered gneiss, dry	170
4) Weathered gneiss, saturated	15-170
5) Highly weathered gneiss, saturated	14-38
6) Unweathered granite/gneiss with water filled joints	200/400
7) Massive granite/gneiss	400-900

The data can be summarised:

Rock type	Resistivity in ohm metre
1) Highly weathered and saturated gneiss/granite	less than 40
2) Weathered and saturated gneiss/granite	40-80
3) Weathered but less saturated	80-170
4) Unweathered granite/gneiss with water filled joints	170-400
5) Massive rock	400 or more

These data can however only be regarded as a first step toward a better understanding of the resistivity in various geological formations and further studies must be done to find out how the resistivity changes with other hydrogeological parameters such as depth to groundwater, various soil types, the influence of rain (before and after the monsoon) etc. With the increasing number of geologists employed in this programme and with the improved use of the instrument such studies should be encouraged and initiated in each state. The result will be a vastly improved knowledge of where to locate successful well sites.

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In Figure 4 are given some data about the resistivity from various rocks and soils. The data are from ABEM Geophysical Memorandum 5/72. The data should not, however, be taken too rigidily, they serve mainly to indicate the large variation in the resistivity that exists in various formations.

The always debated question to what depth a well should be drilled can however seldom be accurately solved by surface resistivity measurements. This because even in hard or massive rocks, with high resistivities, water transporting cracks may be encountered at large depth. A carefully executed and analysed sounding survey can however indicate the thickness of the overburden, the approximate thickness of the weathered zone, and this is the most important, it can give some idea of the water content in this zone. And normally, if the weathered zone is highly saturated (low resistivity) a good well should be found although it may be necessary to drill to some 50 to 100 (or sometimes even 200 or more feet) below this zone in order to find the water transporting cracks or joints which drains the weathered zone.

3. Ground-water Conditions

In this section some comments about ground-water hydrogeology are made based on findings from the drilling activities and data collected by the writer during various field trips.

3.1 The Effect of the Weathered Zone

In many hydrogeological reports dealing with hydrogeology in hard rock areas (crystalline rocks) a commonly found statement is that the weathered zone is the one and onlyzone for extraction of ground water and drilling should, therefore, as a principle, not go beyond the weathered zone more than a few feet.

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Such a statement involves, in the writer's opinion, some mixing of two basic hydrogeological parameters i.e. permeability and storage. There is no doubt that the weathered zone has a much higher porosity than the unweathered (or fresh) rock, but in most cases the permeability in the weathered zone is very low due to the formation of clay minerals etc. during the weathering process. If the topography is flat or only slightly undulating, the movement of the groundwater is extremely slow and no transportation or removal of these clay minerals takes place; the result is a porous formation but with normally low, even very low, permeability. The extraction of groundwater which is stored in such formations must therefore be limited if a well, and particularly a small diameter well is sunk into such a formation. If however the well penetrates through the weathered zone and hits fractures in the massive (or fresh) rock below this zone these fractures will act as drains for the water stored in the weathered zone alone. When pumping occurs, the water will then move along the fractures towards the well. A deep, small diameter well will therefore be able to utilise the groundwater stored in the weathered zone within a much larger area than the ordinary open dug well can do.

The best location for high yielding wells in crystalline rock is normally in areas with a thick weathered and water saturated zone and where open cracks or fractures exist below this zone. The deeper the fractures are located the better as normally the area of influence increases with increasing depth or draw-down in the well. Because of the difficulty of indicating or knowing at what depth such fractures will be found, it is not possible to give an overall or general figure for the maximum depth for a well. To solve this problem only hydrogeological knowledge and experience (including sometimes test drilling) will help. If therefore a close follow up of the present drilling programme is done including particularly measurements of the depth at which water is struck and its amount, valuable knowledge will be obtained about the hydrogeological conditions at greater depths.

The low permeability in the weathered zone is further demonstrated by the fact that it is commonly found during the drilling that no or very little water is found in the weathered zone. It is only after the drilling has gone through this zone that water is struck. The water level then normally rises to a higher level. This is illustrated on Figure 5 where data from 97 wells in a

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granitic area in Bihar are plotted showing the depth at which water was first struck and the final water level. There is in this particular area a tendency for the water to rise to approximately half the depth as it was struck. The geological formation in the area normally consists of five to ten feet of soil, fifteen to twenty feet of weathered granite followed by massive granite.

The fact that the groundwater is seldom found to flow into the drilled well within the weathered zone and that the groundwater, after being struck, normally rises several feet indicates confined or semi-confined conditions. Some confined effect may however be attributed to the soil layer which normally covers the rock but as the thickness of this layer in most cases is only a few feet, a tight soil cannot be the main reason for the confining effect. This must instead depend on the low permeability of the weathered rock.

3.2 Revitalization of Open Wells

The so-called revitalization of dug wells in crystalline rock areas in which a number of small diameter (1 to 2 inch) holes are drilled some fifteen to twentyfive feet vertically in the bottom of the well is usually undertaken because the water level in the open as well has sunk to or below the bottom of the well and it is difficult to deepen it further. When the drilling is finished, e.g. when the drill bit has reached deep enough to hit some water transporting fractures, water normally flows out of the hole and the water level rises to some feet above the previously dry bottom of the well. This is also an indication of the confining effect of the weathered zone as this. would not happen if the weathered zone had been permeable.

Another way of revitalizing open wells and which method is widely used, is to drill small diameter holes in the weathered zone horizontally from the bottom of the well. This method has also proved successful but there is a tendency for the yield to decrease more rapidly than is the case in vertical revitalization drilling. This is natural and the reason is that with this method no increase in the drawdown is obtained, the horizontal holes only drains the overlying formation and when that water is drained, the yield will drop to nearly the same as before the revitalization.

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By the vertical drilling perhaps notso much water is obtained, as a total per day, but the increased flow will normally last longer.

4. Yield of Wells

A question which is commonly met (with respect to the situation in hard rock areas) is whether a drilled well is better than an open dug well or vice versa. It is, of course, not possible to give a definite answer to such a question as many variable factors are involved. In such a problem the question of storage also comes into the picture as the main use of large dug wells is for irrigation where it is necessary to pump a considerable amount of water for short periods to maximise irrigation efficiency and reduce evaporation losses. Intermittant use of the well however does not favour maximum utilization of the well -- for this purpose, a constant, and as high drawdown in the well as possible, is better. If therefore, a surface storage tank is used which could be tapped when enough water had been pumped to it, a pump with a capacity equal to the groundwater inflow to the well could be run continusouly and often between twice to four times as much water could be withdrawn. This is further discussed in the following paragraph no.4.2.

4.1 Open Wells

It is very difficult to give a clear picture of the yield of open dug wells as very little data based on reliable pump tests is available. The normal procedure when testing such wells is to pump it for a few hours and then calculate the capacity on the recuperation rate. This procedure is not suitable for an accurate evaluation of the inflow to the well. What however can be estimated from such a test is the change in the amount of extractable water when using either the intermittant or longer term pumping methods.

In Figure 6 the drawdown from a typical pump test is given. The pump capacity was 6000GPH and the well was pumped for two hours. The normal procedure in estimating the withdrawable amount of water per day (or 24 hours) is to add the time for pumping with that of recuperation and then calculate the pumping time available within the 24-hour period. In this case, the daily (24-hour period) yield would be approximately 24,000 gallons.

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If however as shown in Figure 7, the pumping is done between for example 3 to 5 metre depth (and not wasting time for a full recuperation cycle) the total amount of water that can be withdrawn (per 24 hour) is instead about 45,000 gallons or nearly twice as much as by the other method. It must however be mentioned that in this calculation no attention has been given to the long time decline of the water level and the following decline in inflow to the well. The well will however be affected in this respect also if pumping with a full recuperation cycle is used. The calculation is also valid only for this particular water level. The examples however underline the idea that by utilizing a larger drawdown the well efficiency is increased.

4.2 Bore Wells (tube wells)

The yield from bore wells (tube wells) in hard rock areas varies from zero to several thousand gallons per hour. This is of course due to the inhomogenic nature of the aquifer and is nothing new to a hydrogeologist. During the UNICEF drilling programme some interesting data regarding well capacity and its relation to type of rock, depth etc has been found and will consequently be discussed in the following.

4.3 Variation of Yield with Depth

No mathematical formula has yet been developed which explains or predicts the changes of the capacity of a well with depth in fractured crystalline rock. For homogenous formations this is no problem, but as it is not possible to predict if, or how many water carrying fractures there are within a certain depth, only practical experience will tell what the yield normally will be at various depths within various geological formations.

In Figure 8 is shown a typical analysis in which an attempt is made to correlate yield with depth. Such a correlation or analysis, the way it is done here, is however nonsense as it only shows that some wells have a high yield at shallow depth and some wells a very poor yield at larger depth. What would, for example, the yield have been, if a shallow high-yielding well had been drilled to a greater depth?

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Perhaps no increase at all, which depth figure should in this case have been used? With other words, the problem have to be tackled in another way.

As the yield in drilled wells entirely depends on the size and number of fractures encountered, the best approach is by an analysis in which reliable data about the depth to the water transporting fractures and the amount of water extractable from each of them is used.

In the absence of detailed geological data, a useful way of finding out how the yield varies with depth is to produce a simple statistical frequency in which the number of wells and the variations in yield and depth is correlated.

In Figure 9 is shown such an analysis where four and six inch diameter wells are compared. The wells are drilled within the same geographical/geological area -- the main difference between the wells being that the six inch wells normally are drilled to a greater depth than the four inch wells. If we look for the percentage of wells yielding more than 7500 LPH, the figure is 23.9 per cent for six inch wells as compared to 7.1 per cent for four inch wells. As an increase in yield has very little to do with an increase in diameter the main reason for the obvious variation in yield must be the difference in total depth. As no mathematical formula can be developed to express this situation, it can only be done by empirical studies, in which wells drilled in the same geological formations are grouped together, and then compared with other geological units.

If such studies are done by the geologists in areas or districts where the WHO-UNICEF programme is active, it would be possible to outline areas where an increase in average total drilled depth is justified. This can be expressed or evaluated in percentage figures in relation to the needed yield.

4.4 Variation in Yield with Type of Rock

How the yield varies with various types of rocks is demonstrated in Figures 10 to 13. The best yielding rock is clearly the limestone, in this case the Cuddapah district of Andhra Pradesh, followed in general by granite and gneissic areas (although even here, there is considerable variation), the least yielding formation being the basalt (in Maharashtra and Gujarat).

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In the given figures and graphs a well which yields less than 100 GPH or about 500 LPH has been used as a definition for an unsuccessful well, in some cases also the rate of totally dry bores are given. In these studies the accuracy of the data may sometimes be questionable and the results not comparable, as the time and effort spent on doing proper yield tests varies from state to state, and even between different rigs within the same state. The given data should therefore be used as guidelines or trends, and not as absolute or definite values. The reason for the variation in yield is easily explained by the variation in the physical characteristics of the rocks and there is no need to go further into this matter here. What however is of more interest is to point out the use of a statistical approach by which is it is possible to express changes in water yielding capacities in comparable figures.

With this method, it is thus possible to compare various districts or different geological areas and define good or bad areas (from the possibility of getting water or not). In doing this, differences in topography, amount of rain, etc. will have to be taken into account, as well as the fact that the tests must be done in the same way and the data collected be comparable. This means that the length of the test, the method and accuracy of measuring the yield etc. have to be the same, not only between the rigs in one state but within all states engaged in this sprogramme. It is therefore suggested that the criterion for a successful well should be a well which yields more than 500 LPH (or approximately 100 GPH, although it is preferable to use the metric system). The pumping time should not be less than two hours and the drawdown should, if possible, be measured. It is preferable that a proper airlift pump be used rather than the well tested by blowing air through the drill string. By this latter method, there will always be a considerable difference between the measured yield and the true well capacity. As this difference depends on the geological conditions, the testing time etc. the measured yield may be larger than the true in some cases, and lower in other cases, the latter being the most common. It is unfortunately therefore not possible to use a commonly acceptable 'rule of thumb'. Perhaps in some local areas some relationship may be found, but it is not possible to obtain any mathematical expression or formula to solve

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this problem. The true capacity of the well (and the aquifer) can only be found through a proper pumping test in which reliable drawdown and capacity data are collected and analysed.

4.5 Optimum Well Yield

A common mistake in well testing is the confusion of the yield of the well with the total extractable amount of water from the aquifer. Normally the well yield has very little to do with how much water can be withdrawn totally over a longer period. This is instead determined by the infiltration or recharge conditions of the aquifer, the permeability, the porosity etc. The yield of a well is instead only an expression of the availability of water withdrawable through this particular well, and nothing else.

In hard rock areas, where the water usually is stored in and moves through fractures, a well which penetrates one or several large fractures may momentarily yield large quantities of water. In this respect the well is high yielding. If, however, the fractures are of limited extent and the recharge poor, within a short time the yield will go down drastically as the water magazine is being depleted. A proper pump test must therefore be of such a duration that the true yield can be calculated. The time required for such a test may vary from some hours to several weeks.

Calculation of permeability and storage is of little use as regards fractured rocks as the present formulae available are not usable for such conditions. Here, the best and probably only method is the empirical method.

To estimate the maximum well yield (not the potential of the aquifer!) it is not necessary to pump the well with its maximum capacity which is commonly believed. If instead the well can be pumped with two various capacities for such a duration that the drawdown has more or less stabilized the maximum yield can be easily estimated. This is shown on Figure 14 -- note that the aquifer is unconfined and that the specific capacity varies with depth. The maximum economical yield is about 620 LPH as any further increase in the drawdown only will yield a very small amount of water.

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The method will be more accurate the longer each test is done and if several various capacities are used. Using only one capacity, and thus only one drawdown figure, is not advisable.

5. Drill Bit Penetration Rate and Total Life

Within the scope of the WHO/UNICEF well drilling project should be an evaluation of the efficiency of the various drill rigs used. Unfortunately not much has been done so far. If however a systematic approach is made, efficiency parameters such as penetration rate of various drill bits and hammers contra various rock materials, running costs per depth drilled etc. could easily be established. In the following some studies of this kind are shown, using some of the present available data - Figures 15-21.

5.1 Penetration Rate

Time for changing drill bits or adding drill rods is not included in the graphs given. Only the actual drilling time has been used as in this way, it is possible to get some information about the efficiency of the various hammers and bits. If total drilling time is used more emphasis would be on crew efficiency than on the actual drilling efficiency.

In Figure 15 is shown the penetration rate for one x-bit and one button-bit using a Halco Tiger rig with an ASS-100 hammer. A new or re-ground bit was used every ten feet. The graph shows that the button-bit has a somewhat higher penetration rate compared to the x-bit. In Figure 16, an ASS-100 hammer is compared with the newer DF-400 hammer. The DF-400 hammer is slightly faster.

In Figure 17, the penetration rate in hard,abrasive sand stone is shown. The data available are more detailed than in the previous examples. The average drilling velocity is here about 0.18 ft./minute as compared to about 0.21 in the massive granite (Figures 15 and 16). In Figures 18 and 19, are shown some penetration rates for the Atlas Copco COP-4 rig drilling in basalt and Ingersoll-Rand TRUCM-3 drilling in hard sand-stone and hard crystalline limestone. The penetration rate for the COP-4 rig was about 0.17 ft./minute and 0.20 for the Ingersoll-Rand in sandstone and 0.17 ft./minute in crystalline limestone.

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In Figures 20 and 21 are shown some more penetration rates data for the Ingersoll-Rand and Cop-4 rigs in various rock types.

The graphs and data shown cannot be regarded as anything other than an introduction to what can be done, and before any particular conclusion can be drawn, much more data are needed as otherwise no clear trend will be observed. Regarding penetration rate, factors such as the depth at which water was met, the amount of water coming into the well, intervals between regrinding of the bit, feeding pressure etc. also have to be accounted for.

5.3 Total Life

It is difficult to get a clear picture of the average maximum penetration or drilling depth that can be achieved by the various drill bits used. This because the total depths varies with how frequently the bit is reground, the rock in which it is drilling, the efficiency of the flushing out of the drill cuttings etc.

In the following table data from two states (Andhra Pradesh and Madhya Pradesh) are given:

Bit type	Size, inches	Rock type	Total Depth, feet (A.P.)	Total Depth, feet (M.P.)
Halco x-bit	4-4½	Granite	325	150
		Basalt	300	-
		Sand-stone	475	-
Halco button-bit	4-4½	Granite	-	-
		Basalt	-	-
		Sand-stone	-	-
Atlas Copco COP-4 x-bit	4-4½	Granite	350	600
		Basalt	290	-
		Sand-stone	450	-
Atlas Copco BBE-57 x-bit	4-4½	Granite	450	600
		Basalt	400	-
		Sand-stone	450	-

/...

Bit type	Size, inches	Rock type	Total Depth, feet (A.P.)	(M.P.)
Ingersoll-Rand x-bit	6½-6	Granite	-	-
		Basalt	-	-
		Sand-stone	-	-
Ingersoll-Rand button-bit	6½-6	Granite	2,000	1,500
		Basalt	-	-
		Sandstone	3,000	-

The total depth values given must be considered to be crude and not fully reliable. The BBE-57, for example, usually gives about two times the footage compared to COP-4 and a common value is about 1,200 feet in granite. This makes the values for COP-4 from Andhra Pradesh to look too small. The values for Ingersoll-Rand on the other hand seems a little bit high. The data given is unfortunately all that at present is available and they clearly show that much more must be done in this field for a better evaluation of the bit and hammer performance.

-:oOo:-

APPARENT RESISTIVITY PROFILE

LOCALITY: LISHA FARM BANGALORE
MYSORE STATE

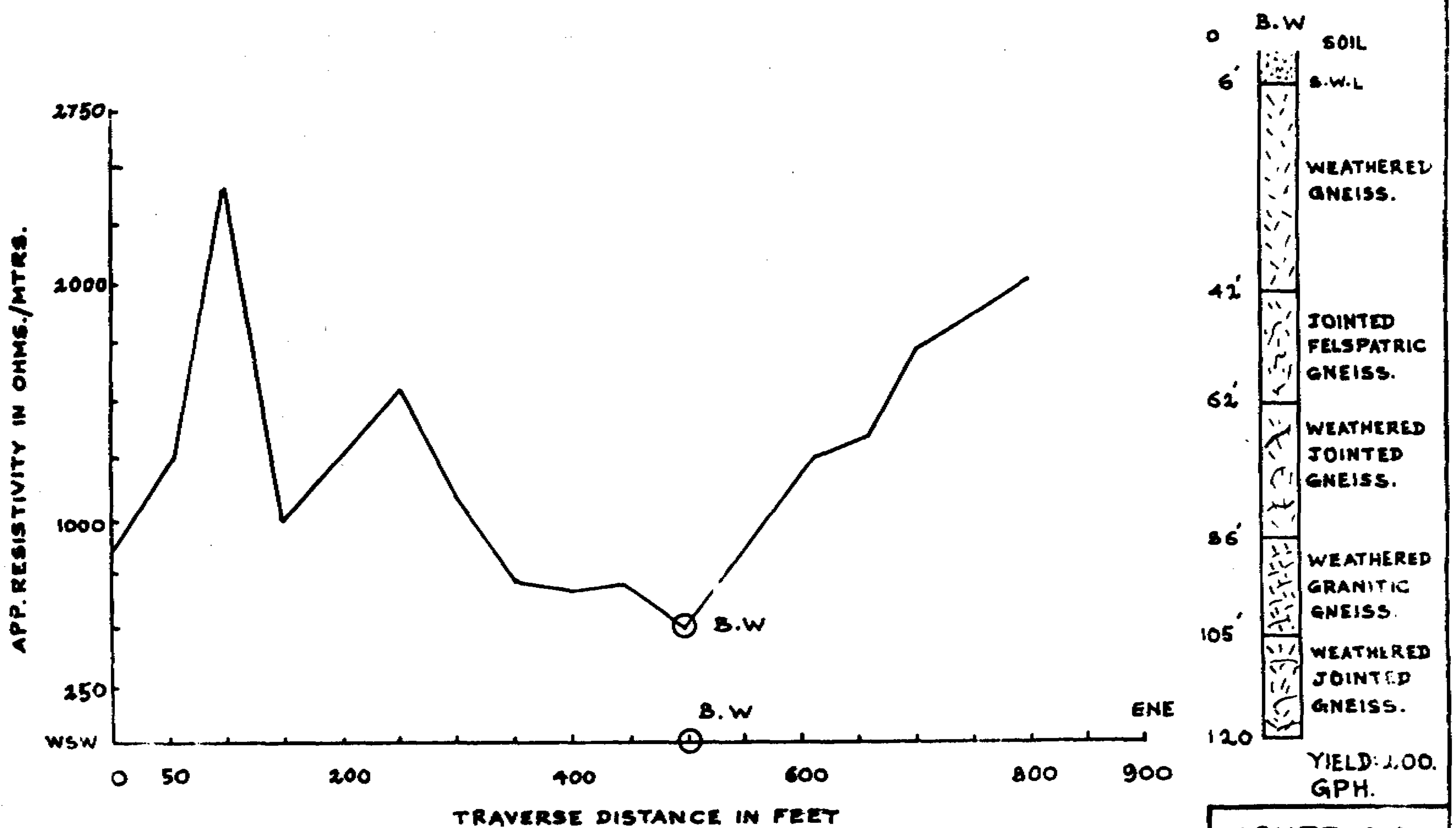


FIGURE 1 A

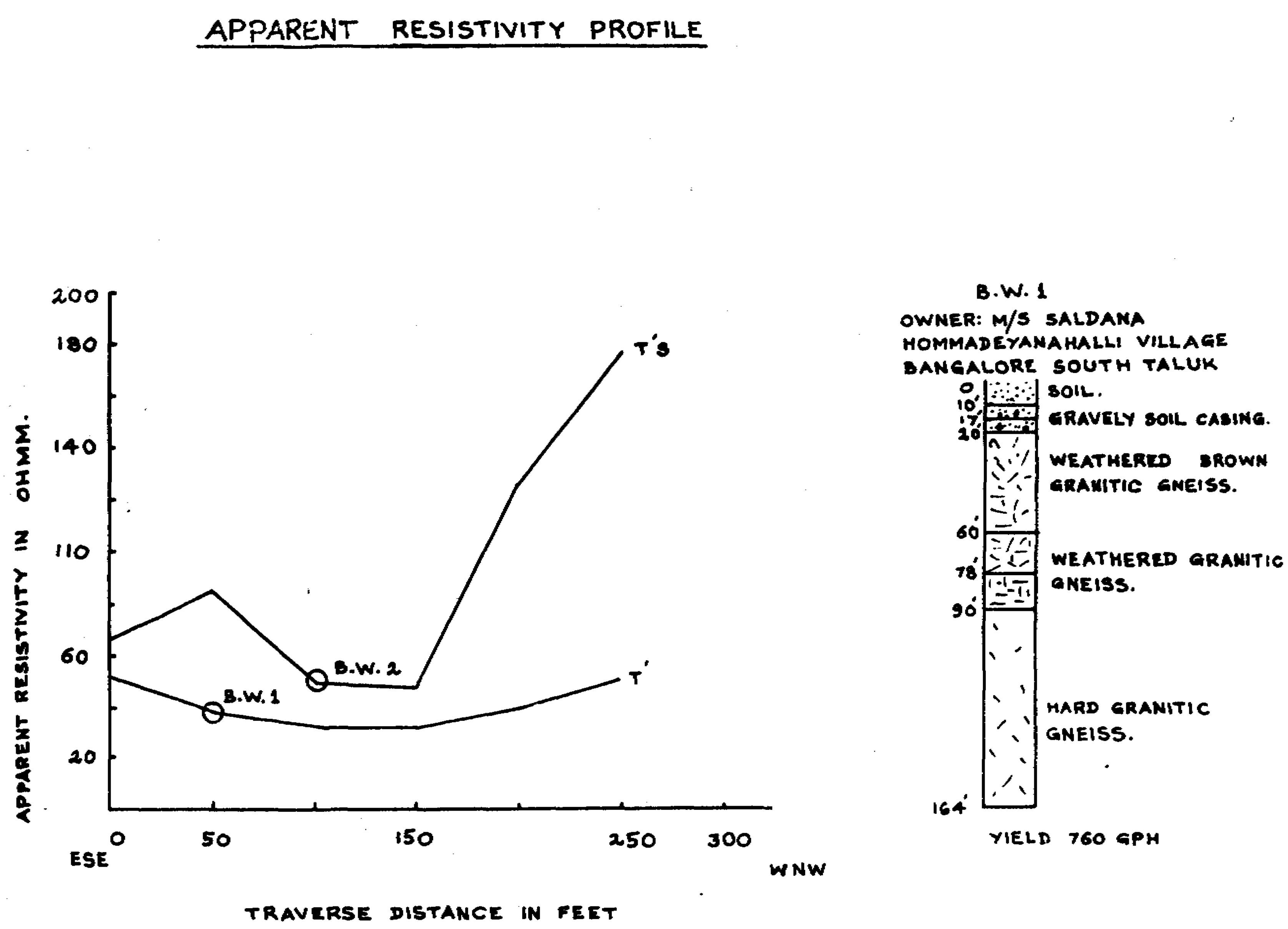
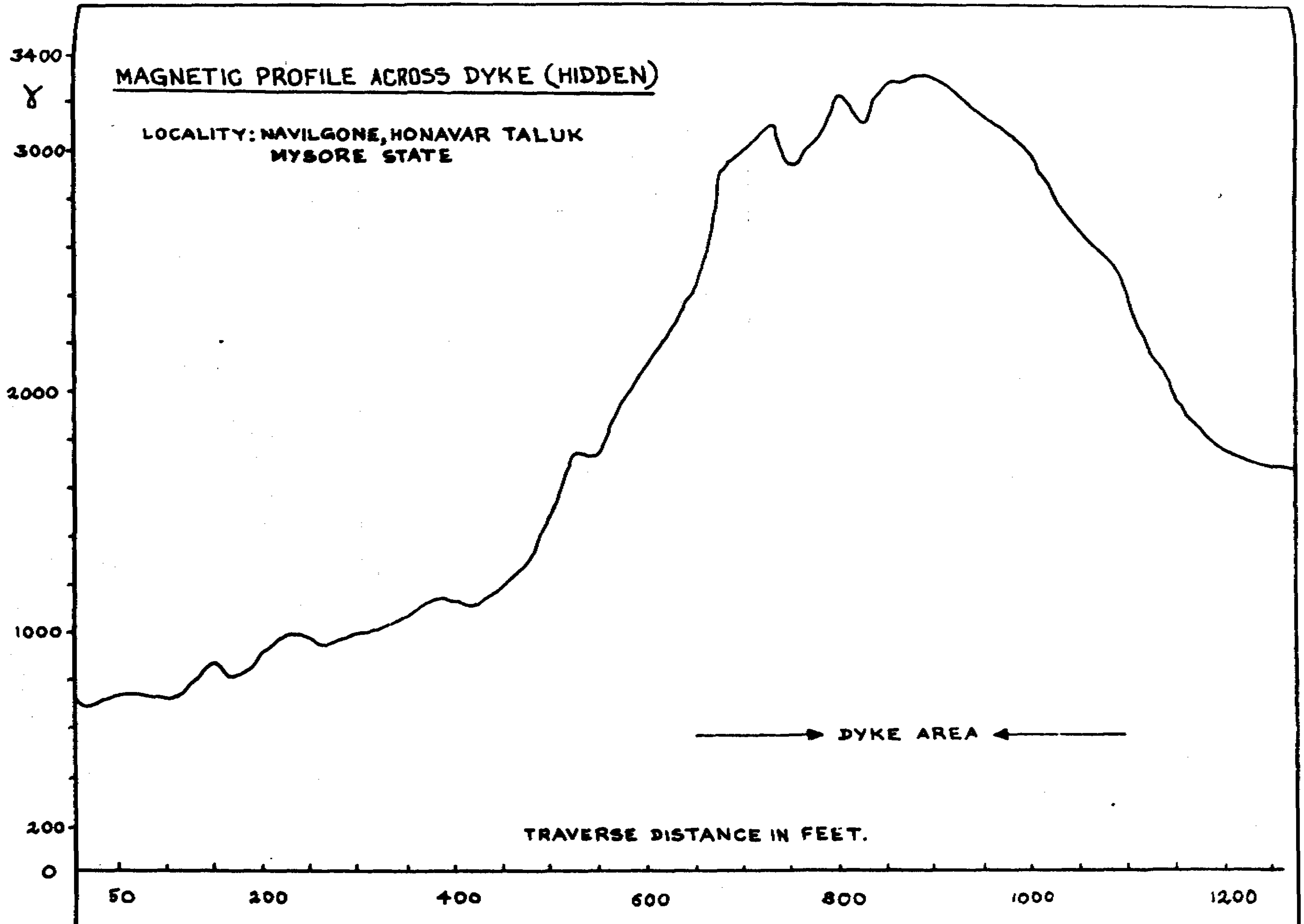
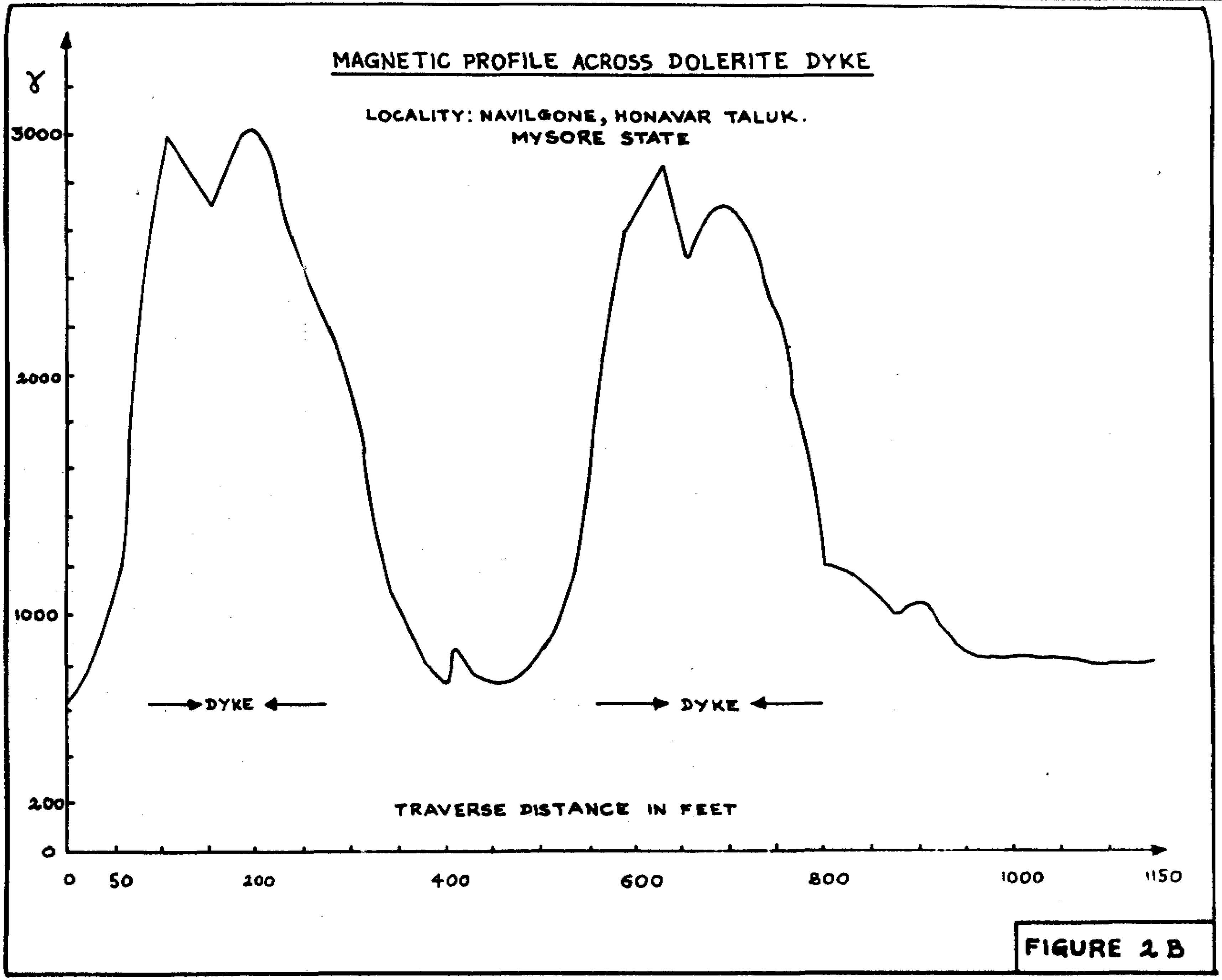

APPARENT RESISTIVITY PROFILE
APPARENT RESISTIVITY IN OHMM.
200
180
140
110
60
20
T'S
T'
B.W. 2
B.W. 1
0
50
150
250
300
ESE
WNW
TRAVERSE DISTANCE IN FEET
B.W. 1
OWNER: M/S SALDANA
HOMMADEYANAHALLI VILLAGE
BANGALORE SOUTH TALUK
0'
10'
17'
20'
60'
78'
90'
164'
SOIL.
GRAVELY SOIL CASING.
WEATHERED BROWN GRANITIC GNEISS.
WEATHERED GRANITIC GNEISS.
HARD GRANITIC GNEISS.
YIELD 760 GPH

FIGURE 1 B



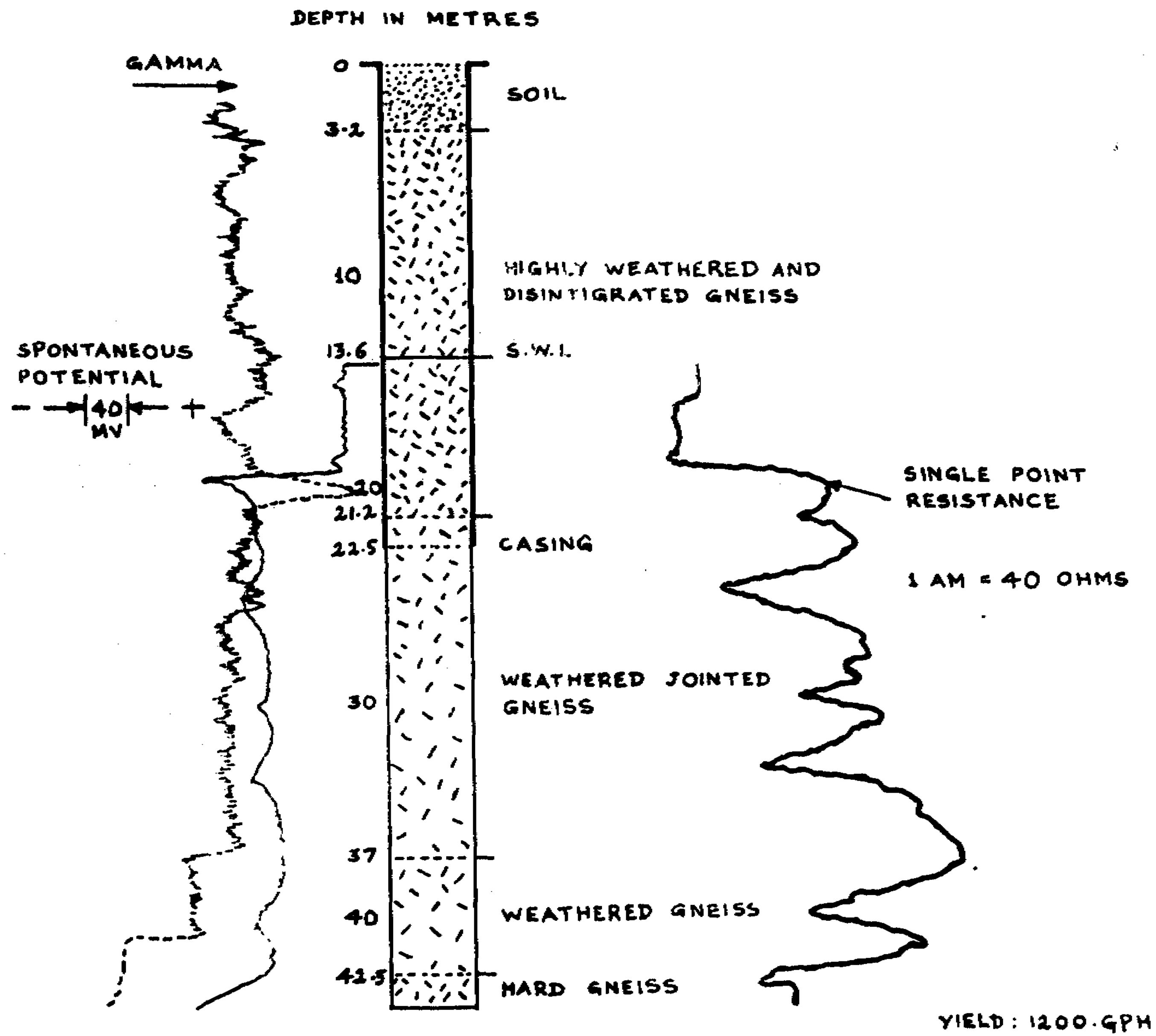
MAGNETIC PROFILE ACROSS DYKE (HIDDEN)
LOCALITY: NAVILGONE, HONAVAR TALUK
MYSORE STATE
3400
γ
3000
2000
1000
200
0
DYKE AREA
TRAVERSE DISTANCE IN FEET.
50
200
400
600
800
1000
1200

FIGURE 2 A



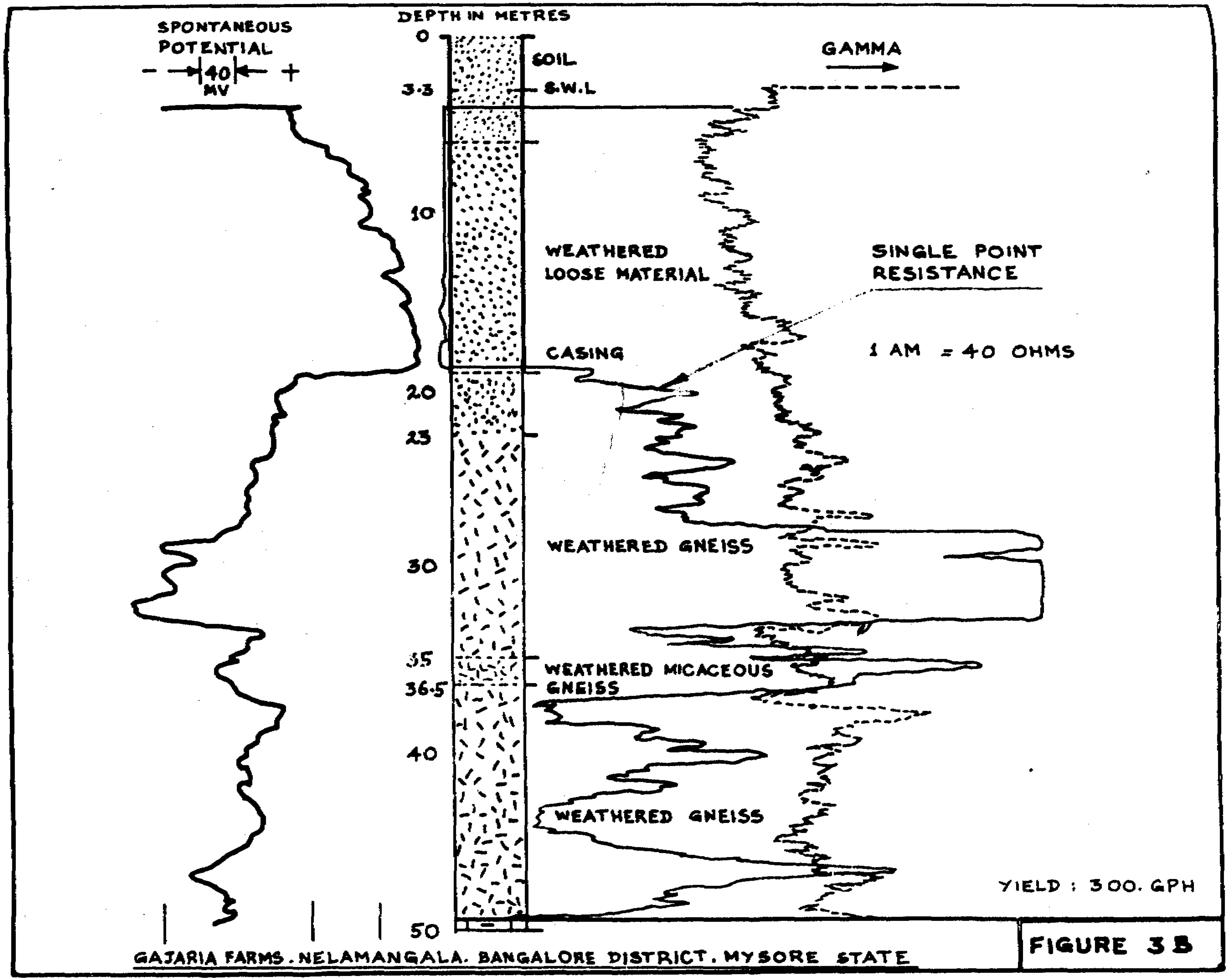
MAGNETIC PROFILE ACROSS DOLERITE DYKE
LOCALITY: NAVILGONE, HONAVAR TALUK.
MYSORE STATE
γ
3000
2000
1000
200
0
DYKE
DYKE
TRAVERSE DISTANCE IN FEET
0
50
200
400
600
800
1000
1150

FIGURE 2 B



GOLF GROUNDS BANGALORE, MYSORE STATE

FIGURE 3 A


SPONTANEOUS POTENTIAL
40 MV
DEPTH IN METRES
0
3.3
10
20
25
30
35
36.5
40
50
SOIL
S.W.L
WEATHERED LOOSE MATERIAL
CASING
WEATHERED GNEISS
WEATHERED MICACEOUS GNEISS
WEATHERED GNEISS
GAMMA
SINGLE POINT RESISTANCE
1 AM = 40 OHMS
YIELD : 300. GPH
GAJARIA FARMS. NELAMANGALA. BANGALORE DISTRICT. MYSORE STATE
FIGURE 3B

RESISTIVITY OF VARIOUS ROCKS AND SOILS

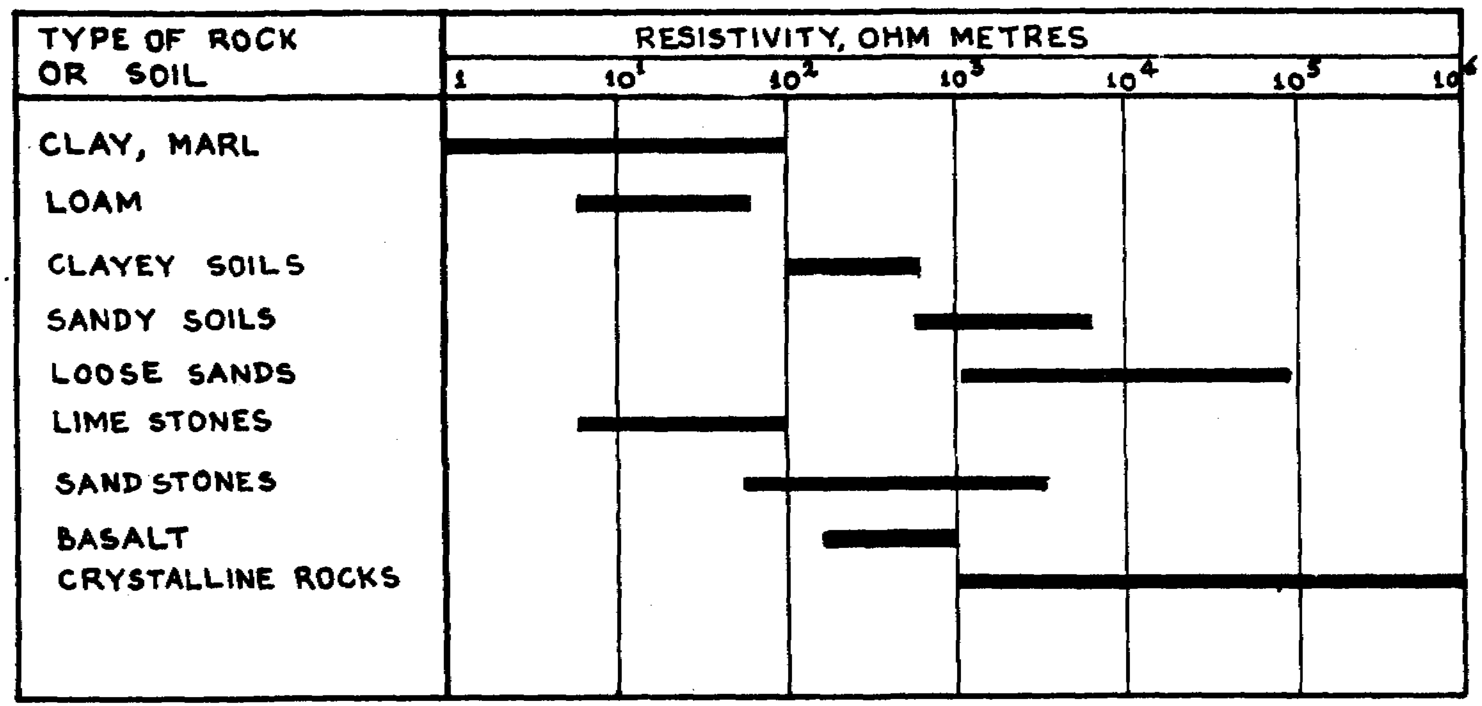
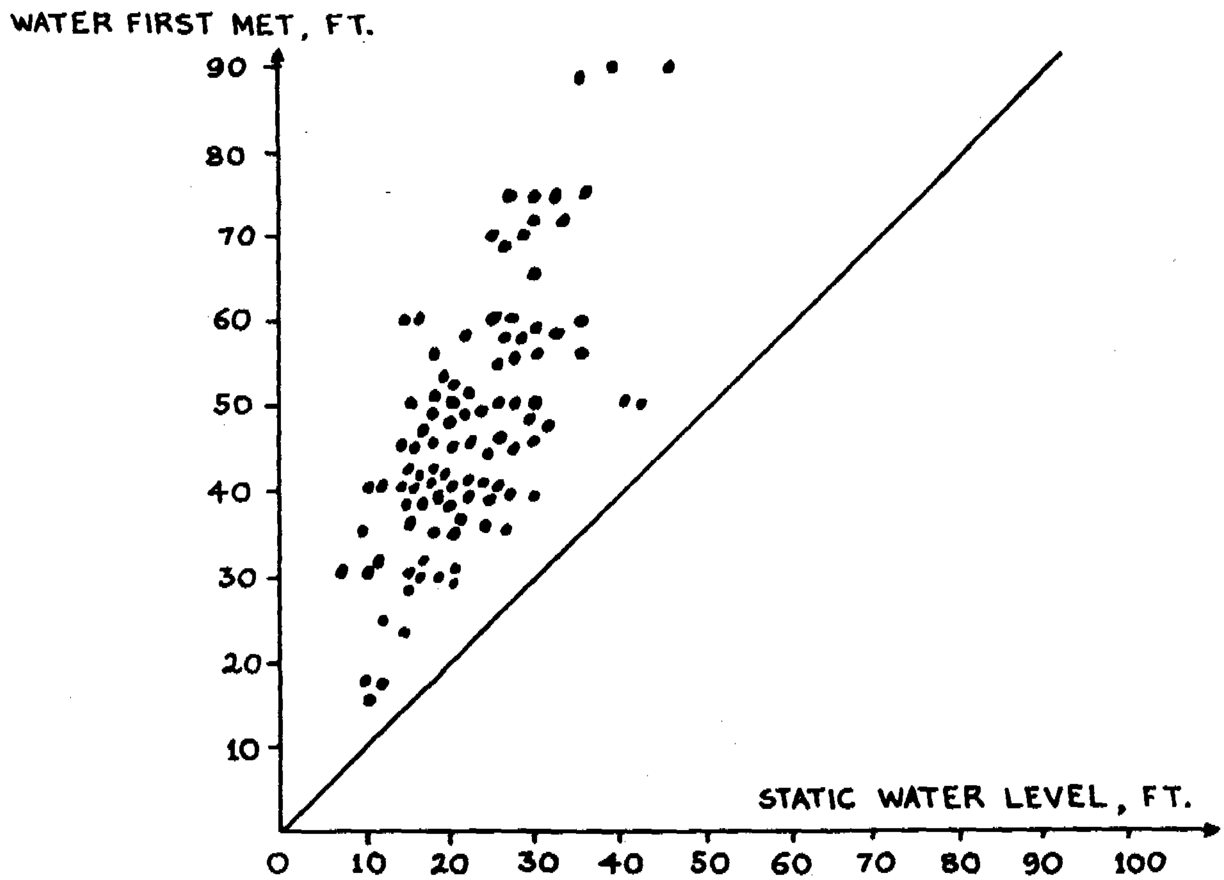


FIGURE 4

RELATION BETWEEN DEPTH AT WHICH WATER WAS FIRST MET AND THE FINAL STATIC WATER LEVEL.

BIHAR, GRANITE, 97 WELLS



CONCLUSIONS: 1. WATER LEVEL IS SELDOM BELOW 50 FEET.

2. ON THE AVERAGE THE WATER IS FIRST MET AT ABOUT TWICE THE DEPTH OF THE FINAL STATIC WATER LEVEL.

NOTE : THE THICKNESS OF THE WEATHERED ZONE INCLUDING THE OVERBURDEN IS NORMALLY 15 TO 25 FEET.

FIGURE 5

WATER LEVEL FLUCTUATIONS WHEN USING VARIOUS PUMPING TIMES OR INTERVALS.

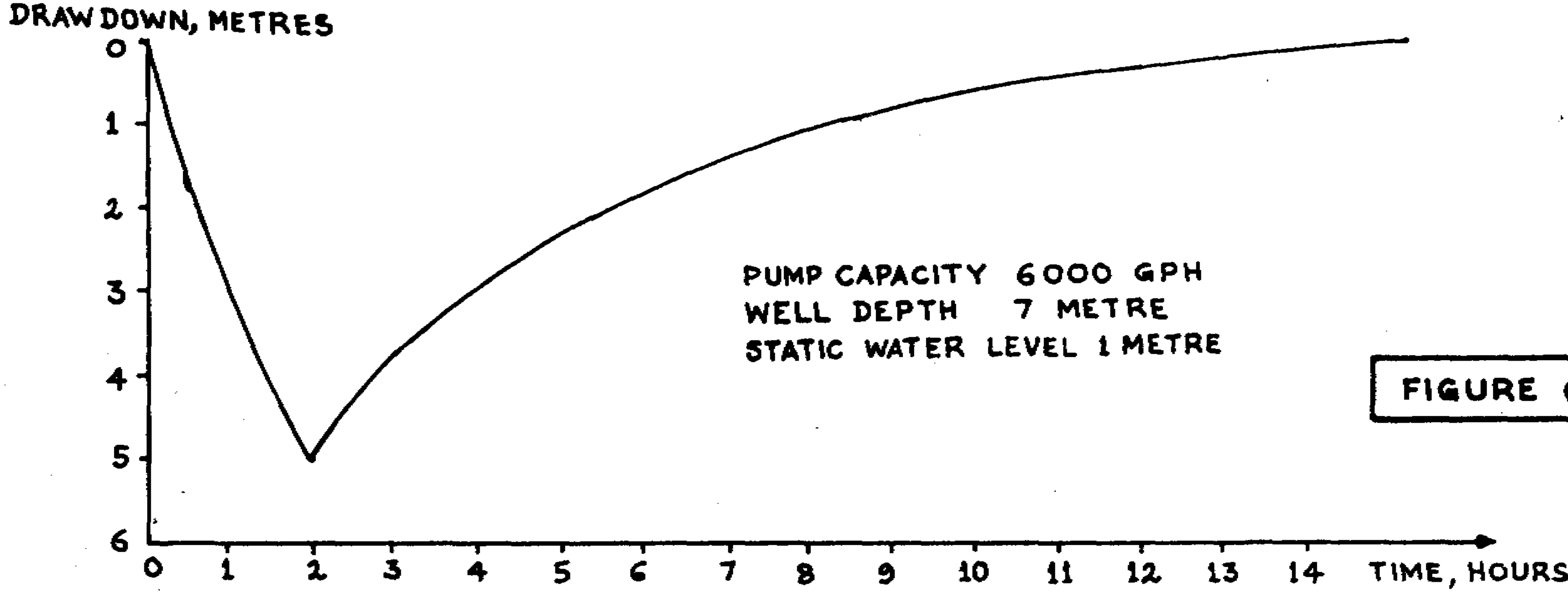


FIGURE 6

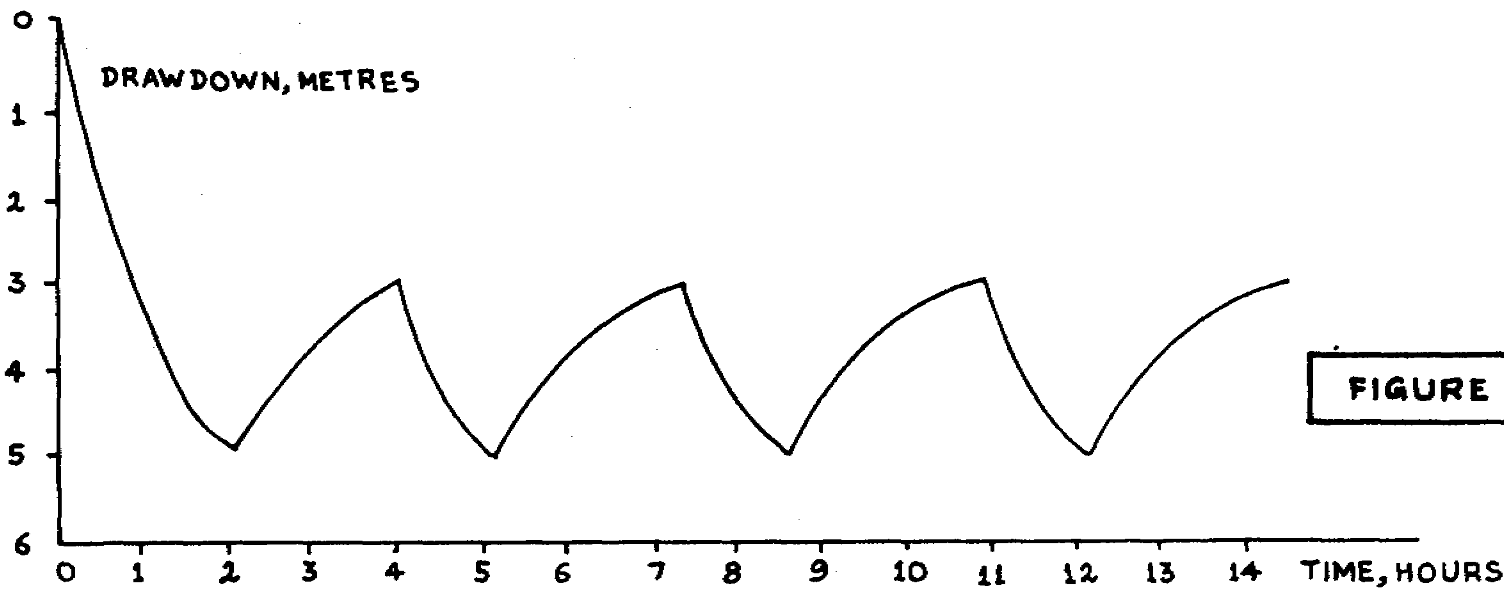


FIGURE 7

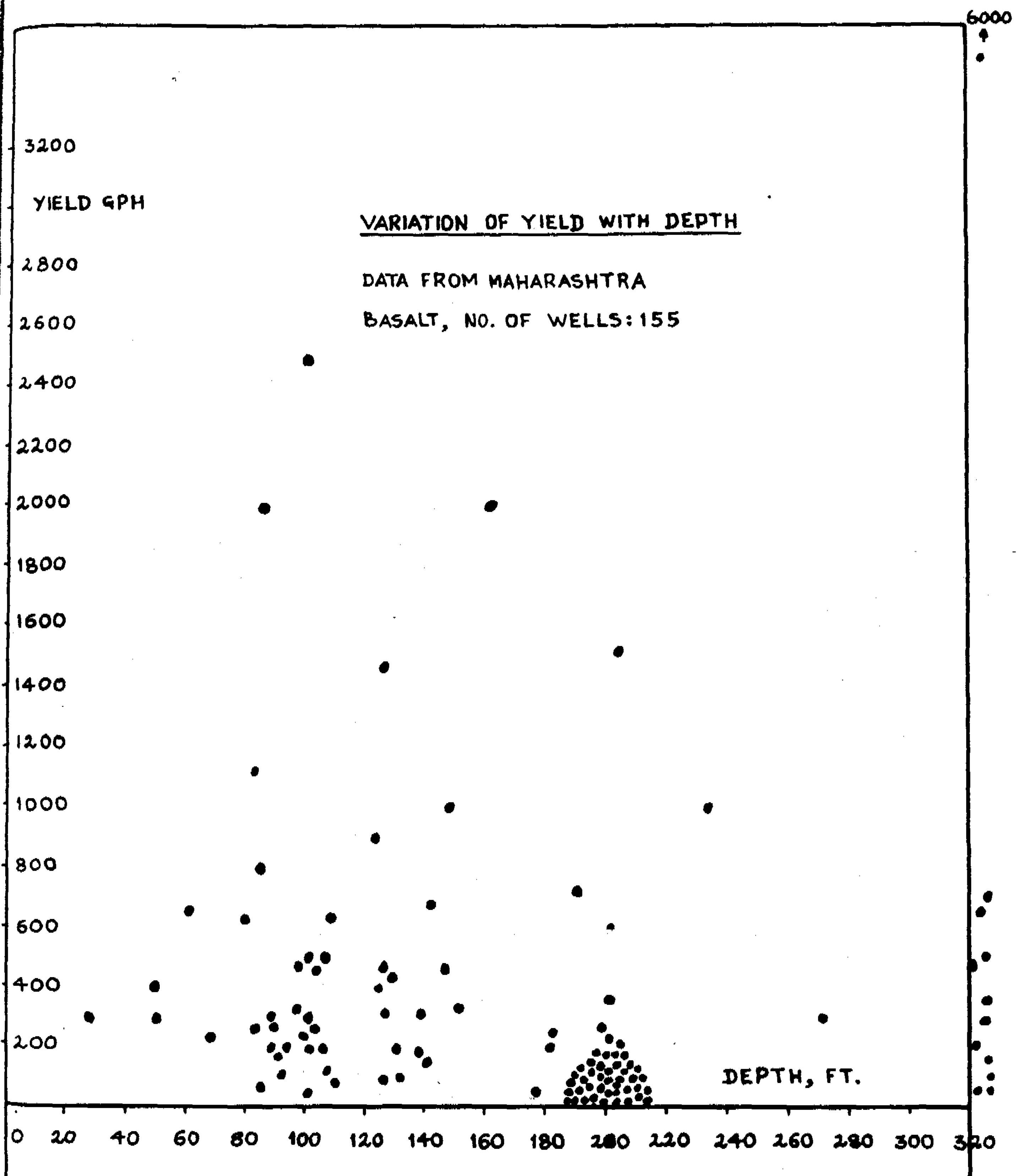

6000
3200
YIELD GPH
VARIATION OF YIELD WITH DEPTH
DATA FROM MAHARASHTRA
BASALT, NO. OF WELLS: 155
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
DEPTH, FT.
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320

FIGURE 8

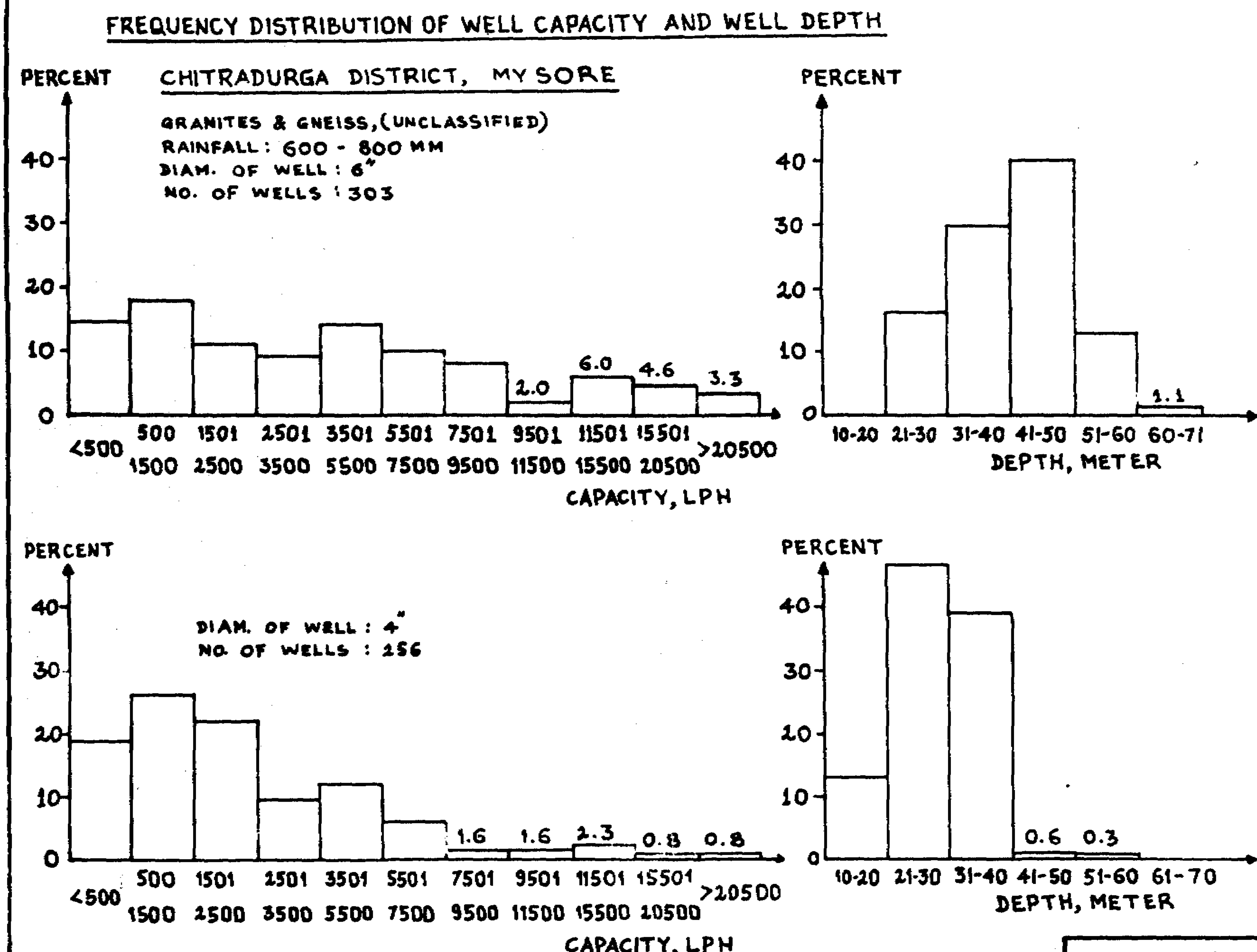

FREQUENCY DISTRIBUTION OF WELL CAPACITY AND WELL DEPTH
CHITRADURGA DISTRICT, MYSORE
PERCENT
GRANITES & GNEISS, (UNCLASSIFIED)
RAINFALL : 600 - 800 MM
DIAM. OF WELL : 6"
NO. OF WELLS : 303
40
30
20
10
0
2.0
6.0
4.6
3.3
<500
500 1500
1501 2500
2501 3500
3501 5500
5501 7500
7501 9500
9501 11500
11501 15500
15501 20500
>20500
CAPACITY, LPH
PERCENT
1.1
10-20 21-30 31-40 41-50 51-60 60-71
DEPTH, METER
PERCENT
DIAM. OF WELL : 4"
NO. OF WELLS : 256
1.6
1.6
2.3
0.8
0.8
CAPACITY, LPH
PERCENT
0.6
0.3
10-20 21-30 31-40 41-50 51-60 61-70
DEPTH, METER

FIGURE 9

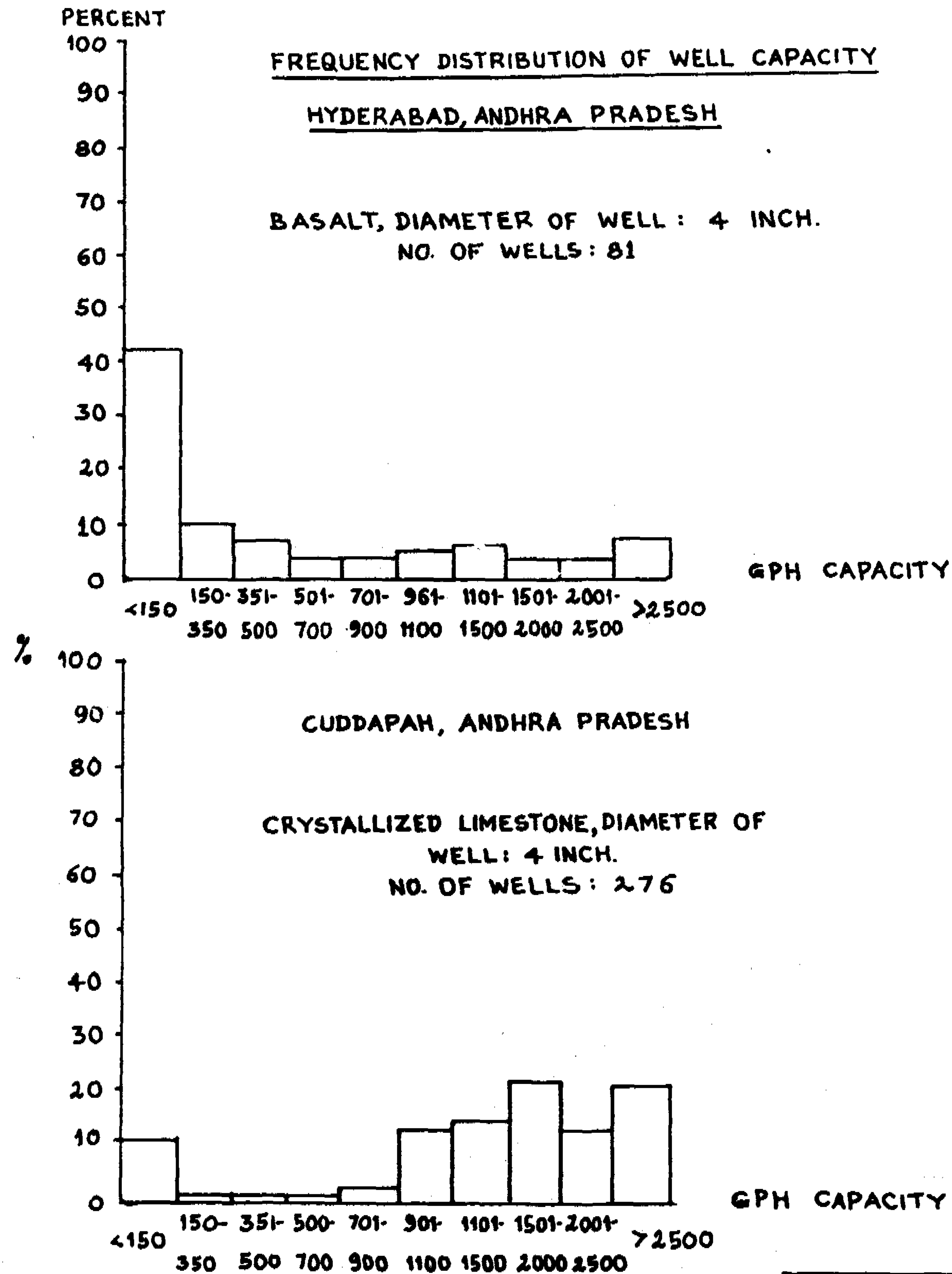
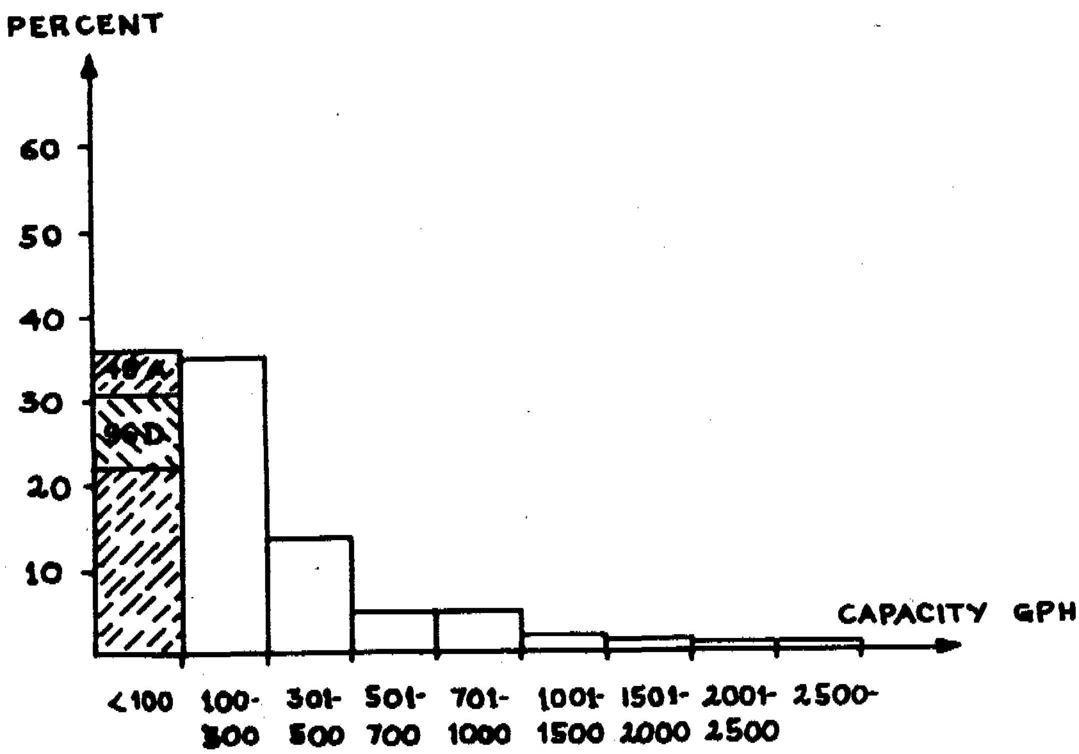

PERCENT
FREQUENCY DISTRIBUTION OF WELL CAPACITY
HYDERABAD, ANDHRA PRADESH
BASALT, DIAMETER OF WELL : 4 INCH.
NO. OF WELLS : 81
100
90
80
70
60
50
40
30
20
10
0
GPH CAPACITY
<150
150-350
351-500
501-700
701-900
961-1100
1101-1500
1501-2000
2001-2500
>2500
%
CUDDAPAH, ANDHRA PRADESH
CRYSTALLIZED LIMESTONE, DIAMETER OF WELL: 4 INCH.
NO. OF WELLS : 276
GPH CAPACITY
<150
150-350
351-500
500-700
701-900
901-1100
1101-1500
1501-2000
2001-2500
>2500

FIGURE 10

FREQUENCY DISTRIBUTION OF WELL CAPACITY

MAHARASTHRA

BASALT, NO. OF WELLS : 156



A = ABANDONED WELL.

D = DRY WELL.

FIGURE 11

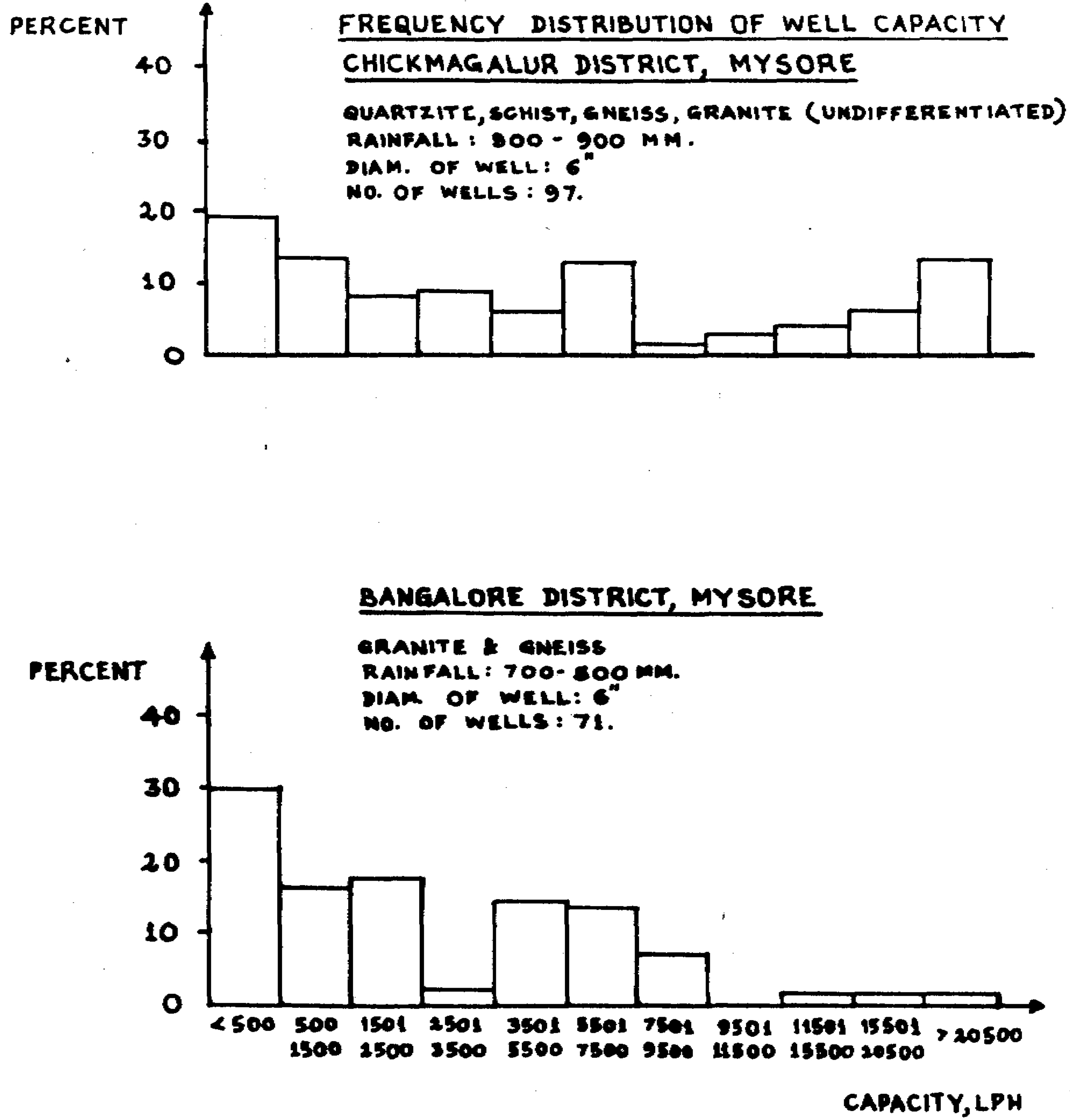
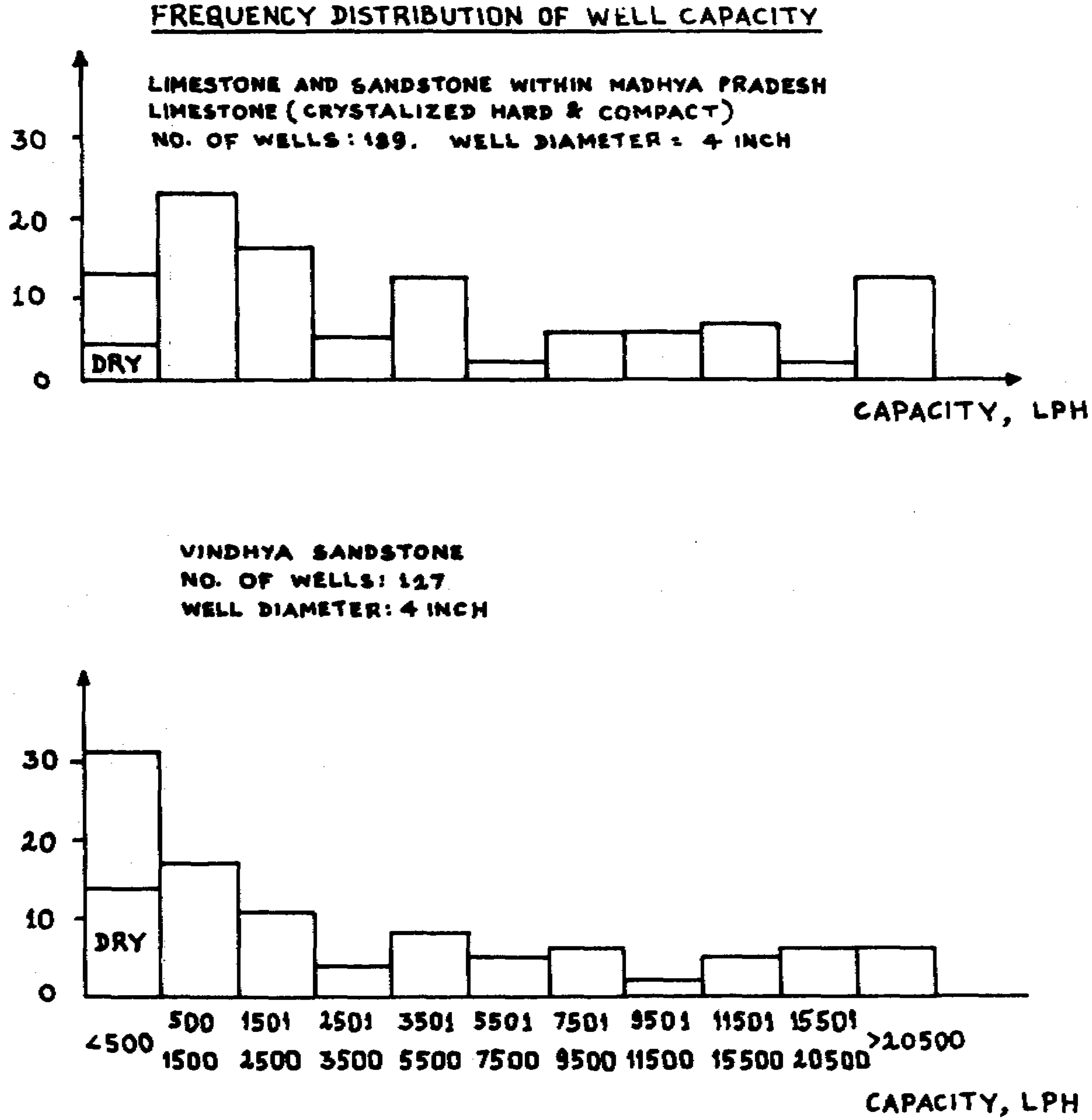
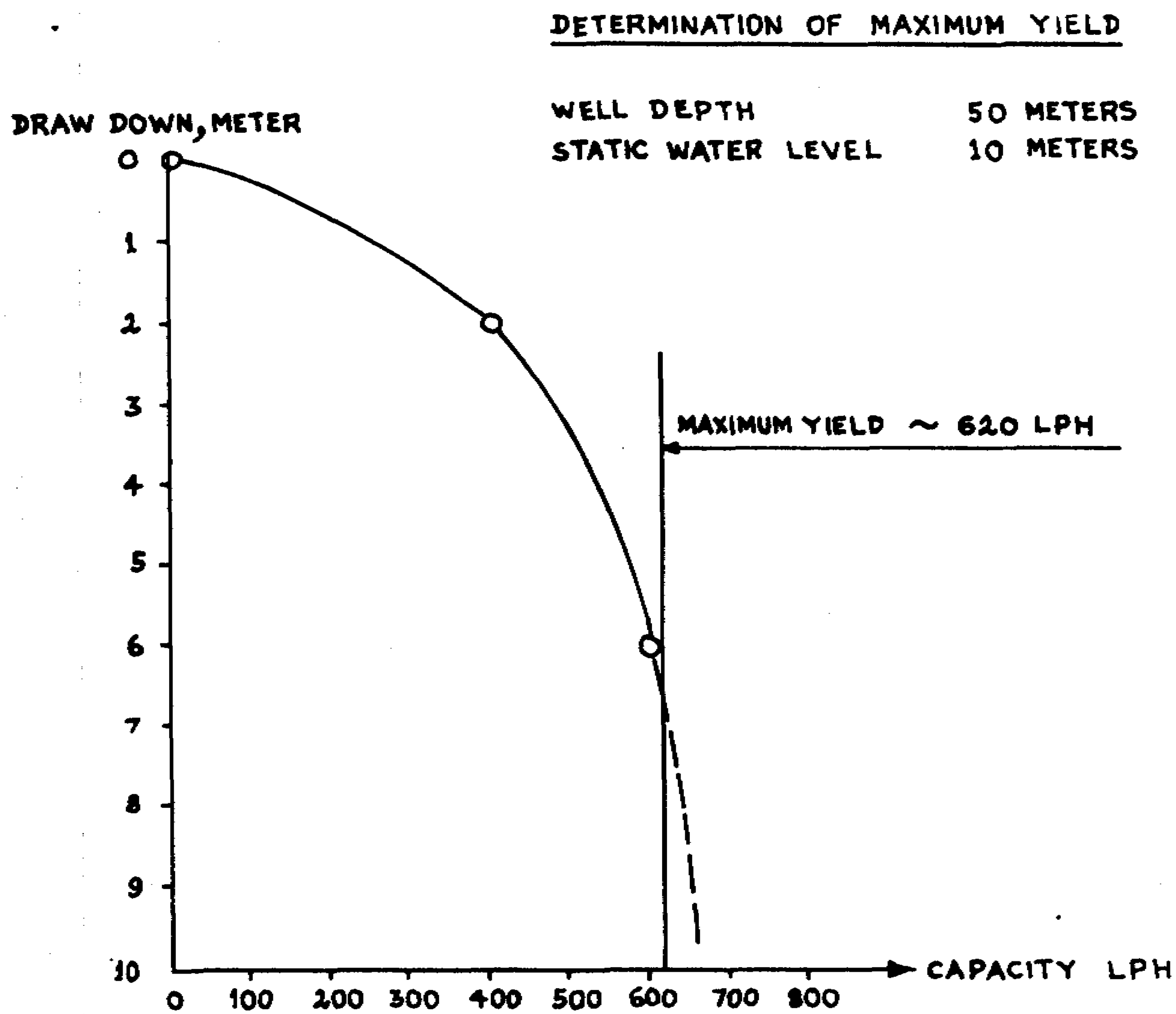

FREQUENCY DISTRIBUTION OF WELL CAPACITY
CHICKMAGALUR DISTRICT, MYSORE
QUARTZITE, SCHIST, GNEISS, GRANITE (UNDIFFERENTIATED)
RAINFALL : 800 - 900 MM.
DIAM. OF WELL: 6"
NO. OF WELLS : 97.
PERCENT
40
30
20
10
0
BANGALORE DISTRICT, MYSORE
GRANITE & GNEISS
RAINFALL: 700-800 MM.
DIAM. OF WELL: 6"
NO. OF WELLS: 71.
PERCENT
40
30
20
10
0
<500
500 1500
1501 2500
2501 3500
3501 5500
5501 7500
7501 9500
9501 11500
11501 15500
15501 20500
>20500
CAPACITY, LPH

FIGURE 12



FREQUENCY DISTRIBUTION OF WELL CAPACITY
LIMESTONE AND SANDSTONE WITHIN MADHYA PRADESH
LIMESTONE (CRYSTALIZED HARD & COMPACT)
NO. OF WELLS: 139. WELL DIAMETER: 4 INCH
30
20
10
0
DRY
CAPACITY, LPH
VINDHYA SANDSTONE
NO. OF WELLS: 127
WELL DIAMETER: 4 INCH
30
20
10
0
DRY
<500
500 1500
1501 2500
2501 3500
3501 5500
5501 7500
7501 9500
9501 11500
11501 15500
15501 20500
>20500
CAPACITY, LPH

FIGURE 13



DETERMINATION OF MAXIMUM YIELD
WELL DEPTH 50 METERS
STATIC WATER LEVEL 10 METERS
DRAW DOWN, METER
0
1
2
3
4
5
6
7
8
9
10
MAXIMUM YIELD ~ 620 LPH
0
100
200
300
400
500
600
700
800
CAPACITY LPH

FIGURE 14

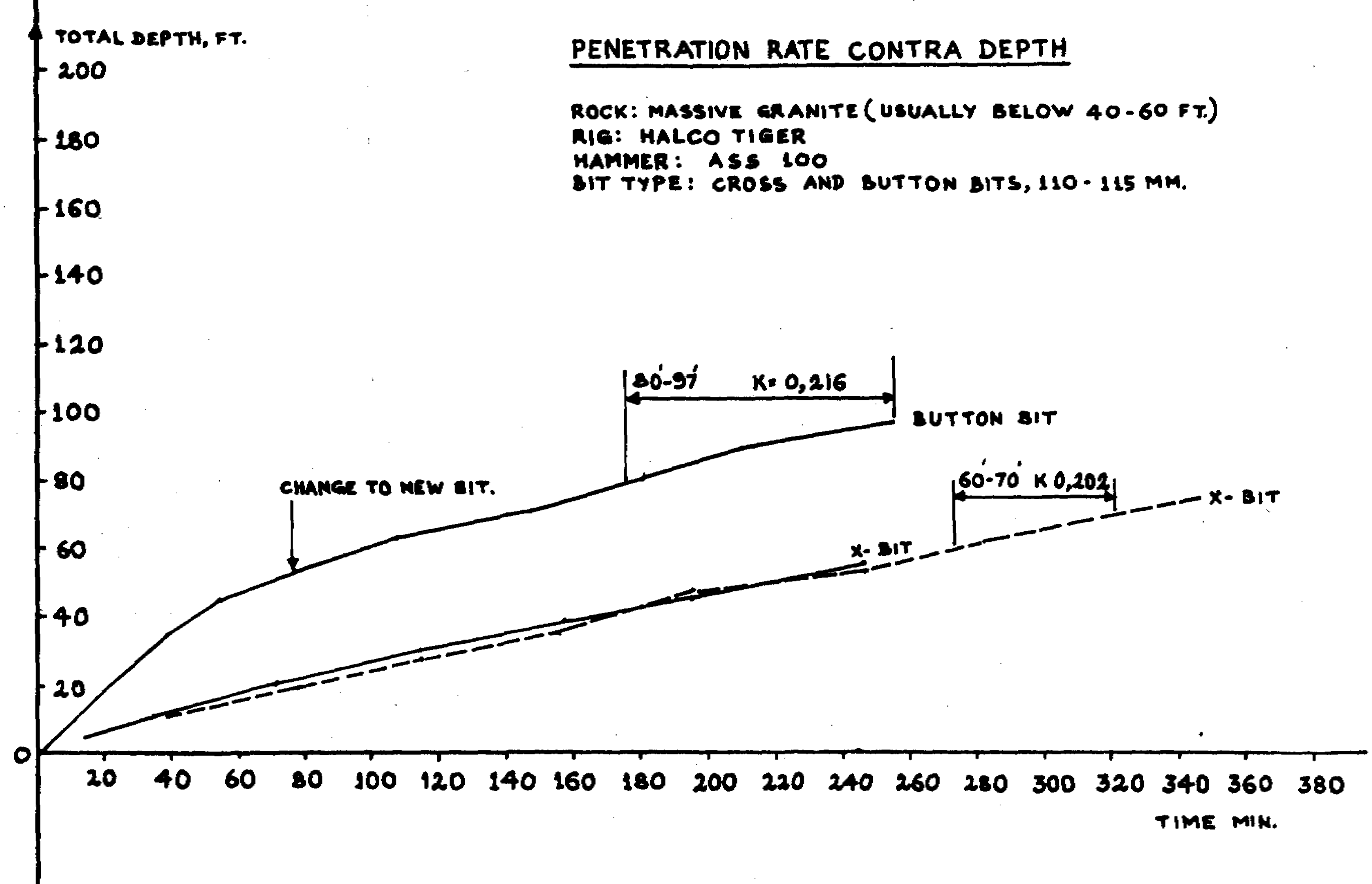

PENETRATION RATE CONTRA DEPTH
ROCK: MASSIVE GRANITE (USUALLY BELOW 40-60 FT.)
RIG: HALCO TIGER
HAMMER: ASS 100
BIT TYPE: CROSS AND BUTTON BITS, 110-115 MM.
TOTAL DEPTH, FT.
0
20
40
60
80
100
120
140
160
180
200
TIME MIN.
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
CHANGE TO NEW BIT.
80'-97'
K= 0,216
BUTTON BIT
60'-70'
K 0,202
X- BIT
X- BIT

FIGURE 15

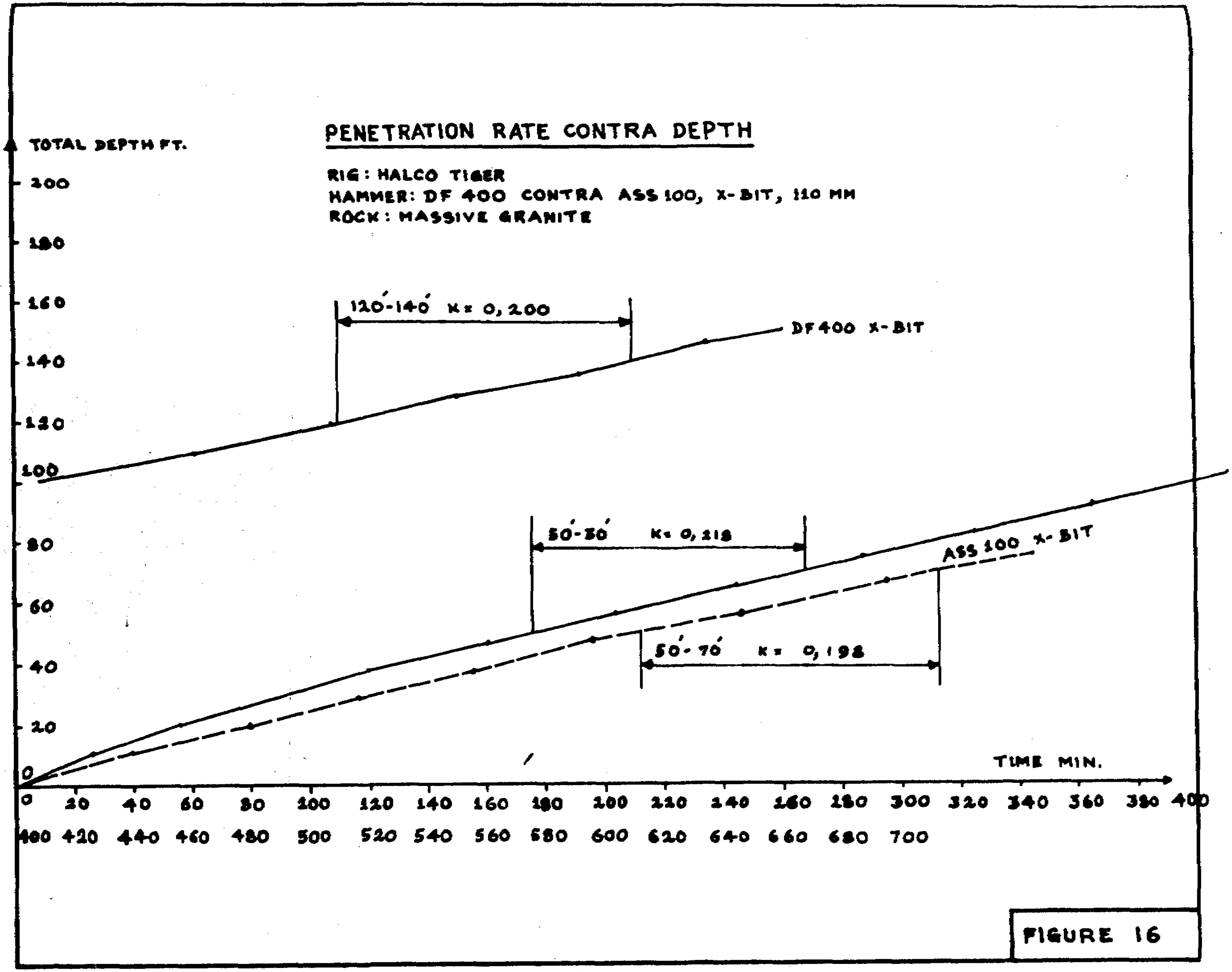
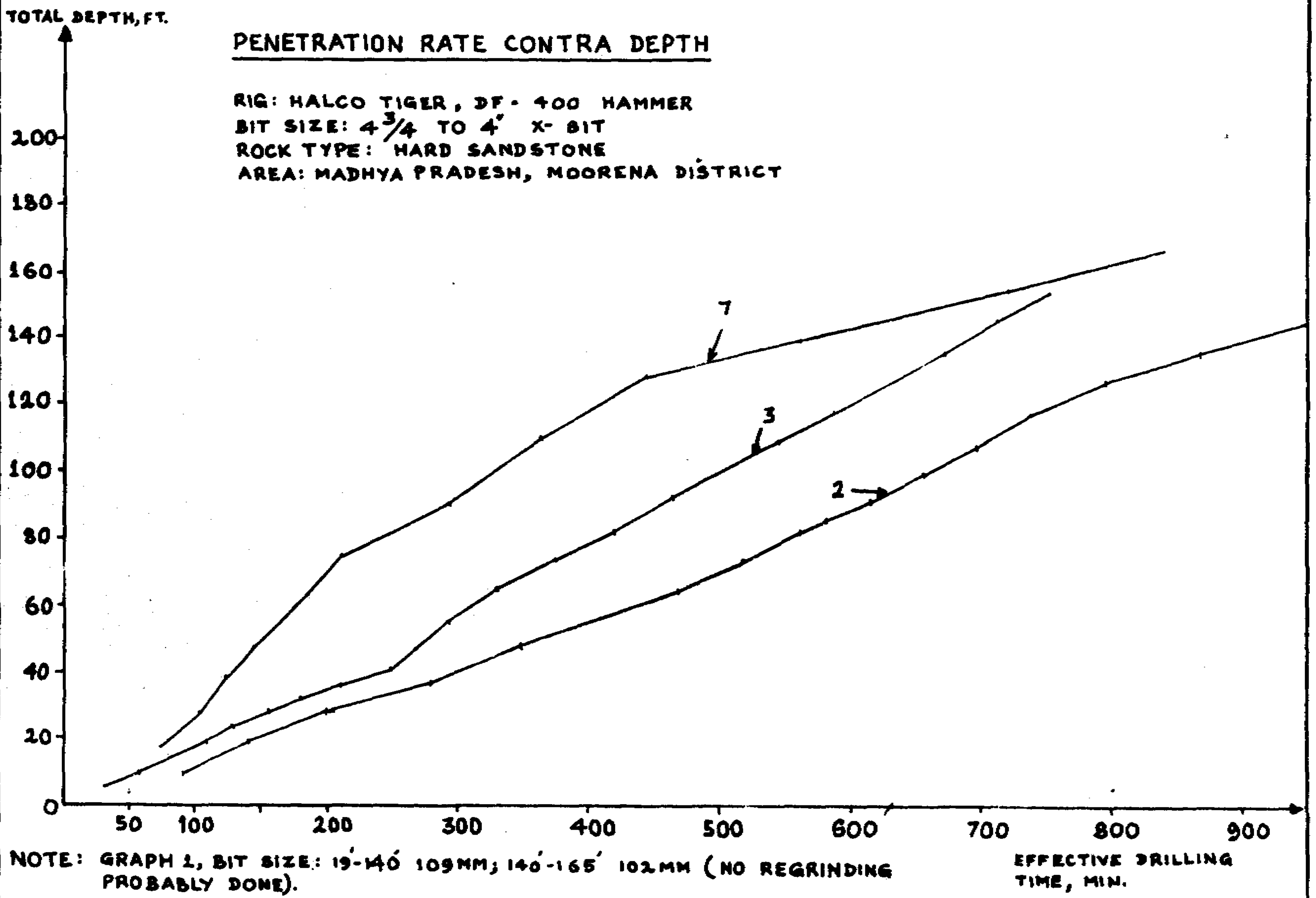

PENETRATION RATE CONTRA DEPTH
RIG: HALCO TIGER
HAMMER: DF 400 CONTRA ASS 100, X-BIT, 110 MM
ROCK: MASSIVE GRANITE
TOTAL DEPTH FT.
0
20
40
60
80
100
120
140
160
180
200
120'-140' K = 0,200
DF400 X-BIT
50'-80' K= 0,218
ASS 100 X-BIT
50'-70' K= 0,198
TIME MIN.
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700

FIGURE 16

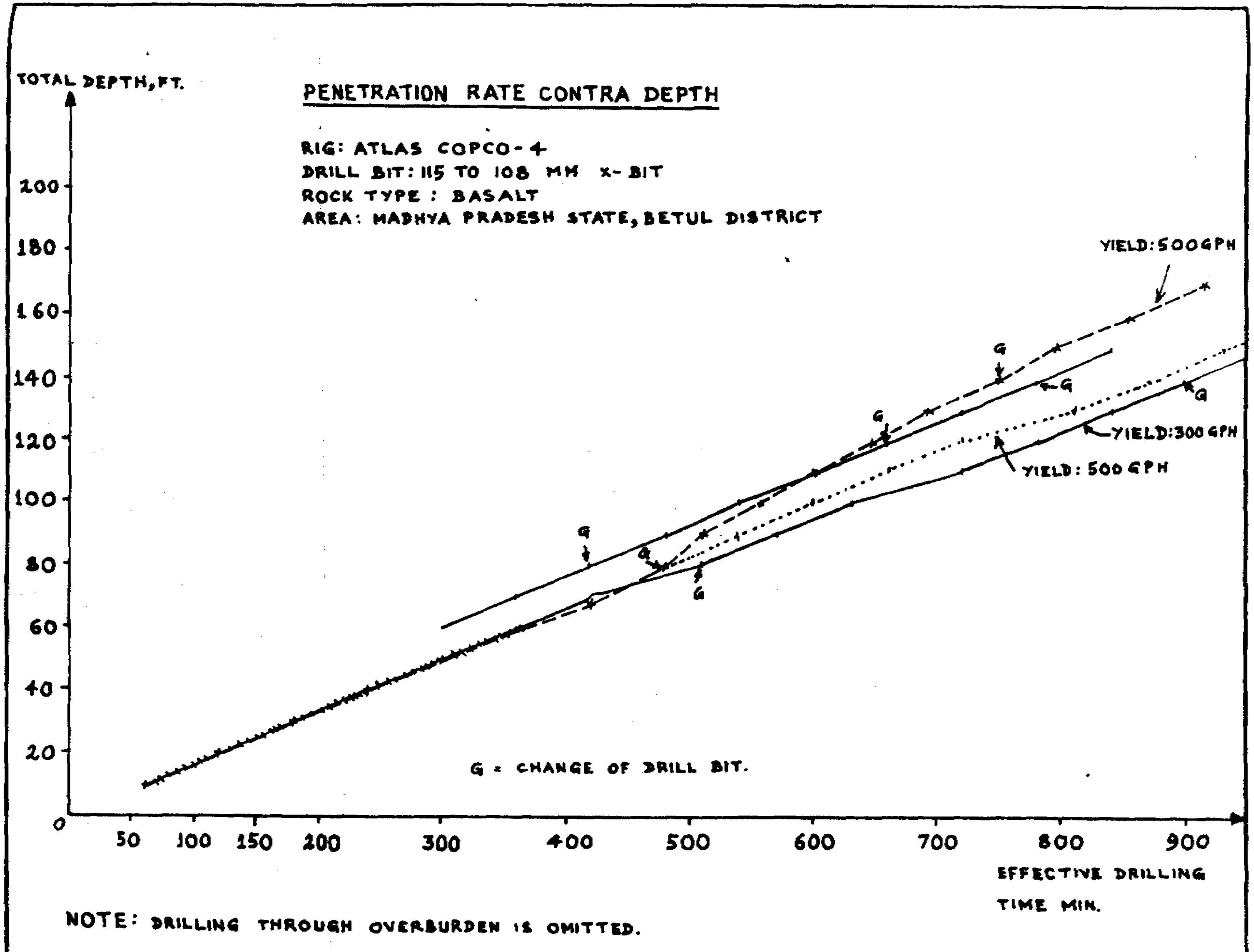


NOTE: GRAPH 1, BIT SIZE: 19'-140' 109 MM; 140'-165' 102 MM (NO REGRINDING PROBABLY DONE).

GRAPH 2, BIT SIZE: 10'-73' 115 MM; 73'-100' 110 MM; 100'-145' 102 MM.

GRAPH 3, BIT SIZE: 4'-23' 113 MM; 23'-40' 110 MM; 40'-82' 108 MM.

FIGURE 17



TOTAL DEPTH, FT.
PENETRATION RATE CONTRA DEPTH
RIG: ATLAS COPCO-4
DRILL BIT: 115 TO 108 MM X-BIT
ROCK TYPE : BASALT
AREA: MADHYA PRADESH STATE, BETUL DISTRICT
YIELD: 500 GPH
YIELD: 300 GPH
YIELD: 500 GPH
G
G = CHANGE OF DRILL BIT.
0
20
40
60
80
100
120
140
160
180
200
50
100
150
200
300
400
500
600
700
800
900
EFFECTIVE DRILLING TIME MIN.
NOTE: DRILLING THROUGH OVERBURDEN IS OMITTED.

FIGURE 18

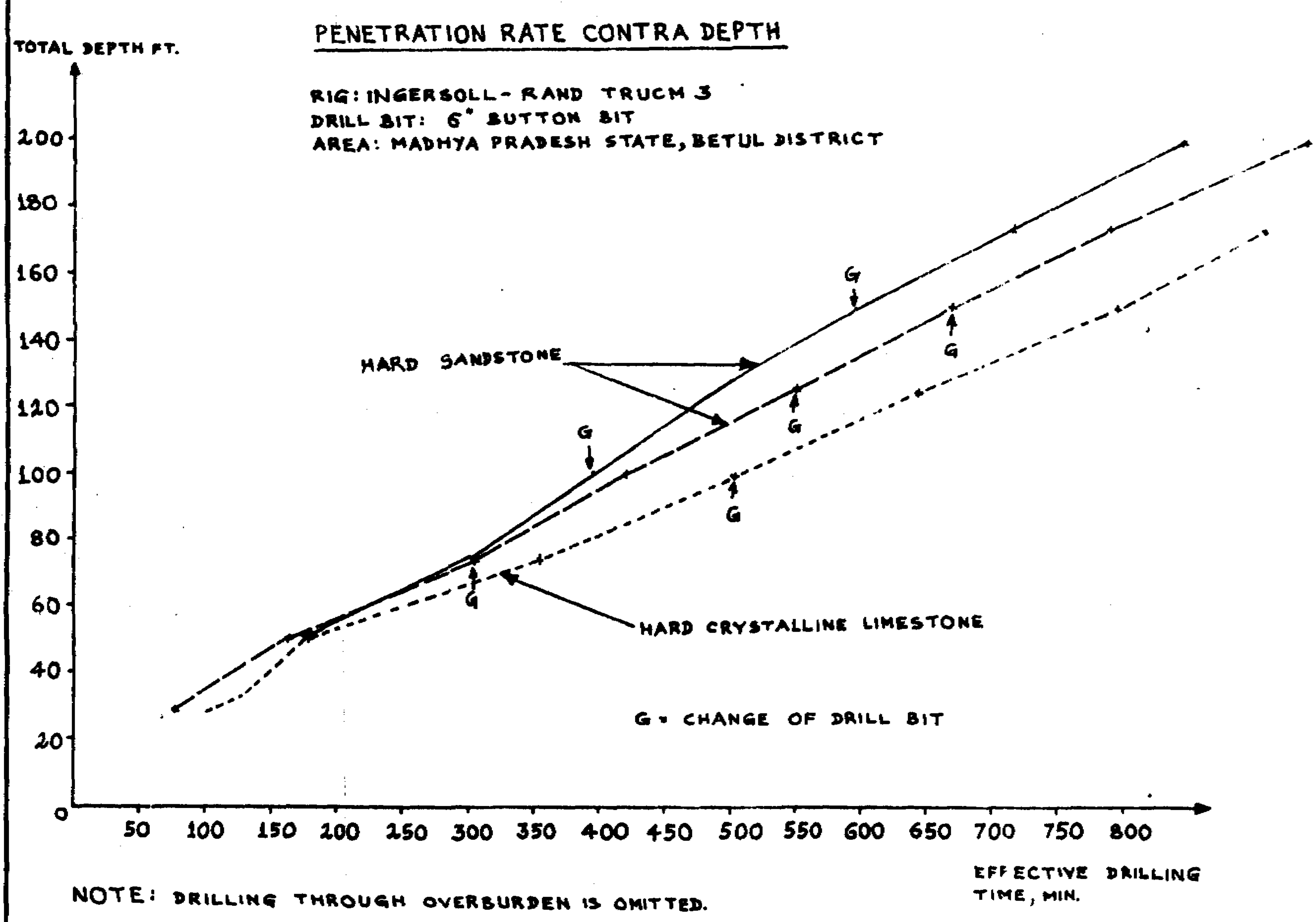

PENETRATION RATE CONTRA DEPTH
RIG: INGERSOLL-RAND TRUCM 3
DRILL BIT: 6" BUTTON BIT
AREA: MADHYA PRADESH STATE, BETUL DISTRICT
TOTAL DEPTH FT.
200
180
160
140
120
100
80
60
40
20
0
50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800
EFFECTIVE DRILLING TIME, MIN.
HARD SANDSTONE
HARD CRYSTALLINE LIMESTONE
G
G = CHANGE OF DRILL BIT
NOTE: DRILLING THROUGH OVERBURDEN IS OMITTED.

FIGURE 19

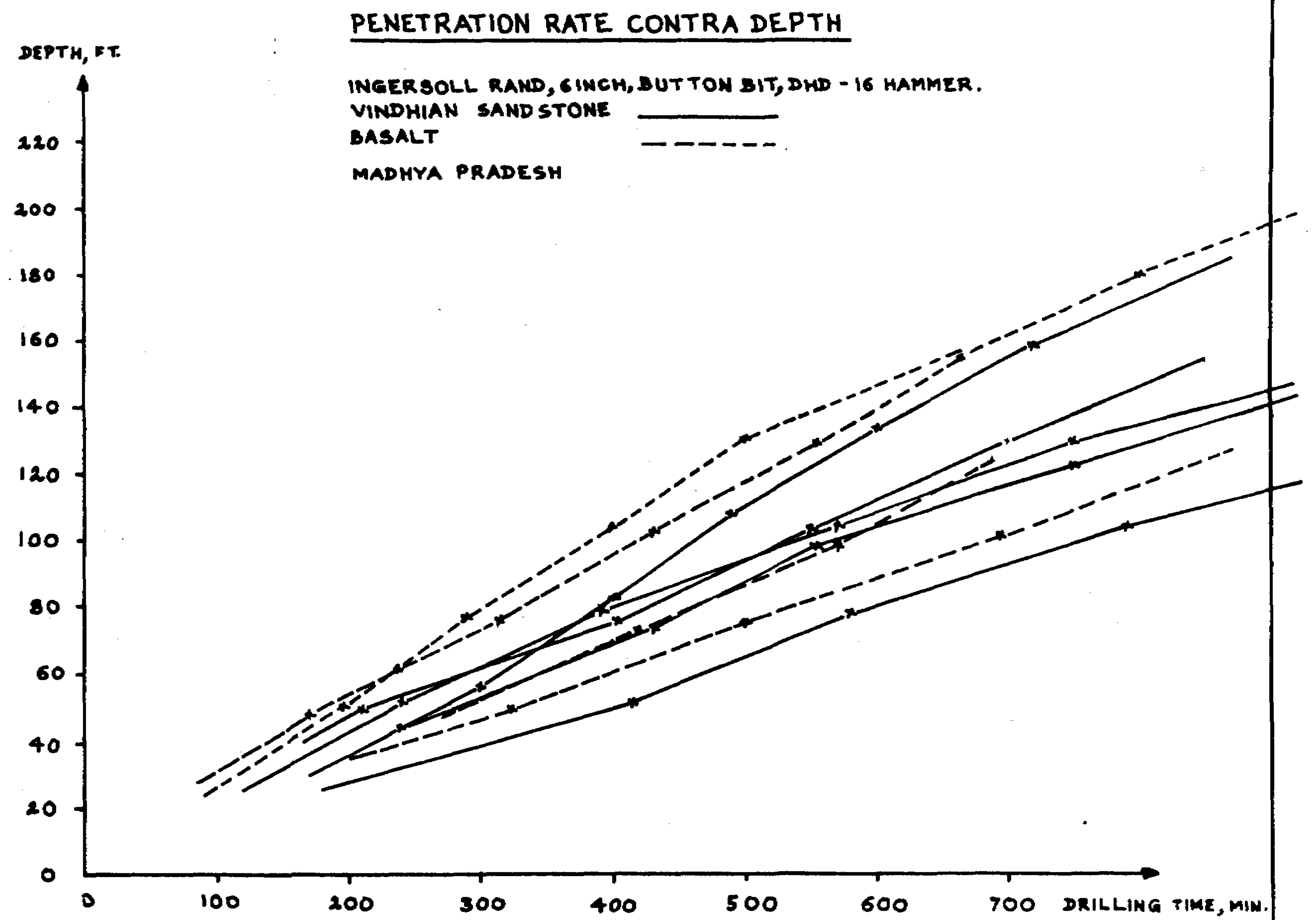

PENETRATION RATE CONTRA DEPTH
INGERSOLL RAND, 6 INCH, BUTTON BIT, DHD - 16 HAMMER.
VINDHIAN SANDSTONE
BASALT
MADHYA PRADESH
DEPTH, FT.
0
20
40
60
80
100
120
140
160
180
200
220
0
100
200
300
400
500
600
700
DRILLING TIME, MIN.

FIGURE 20

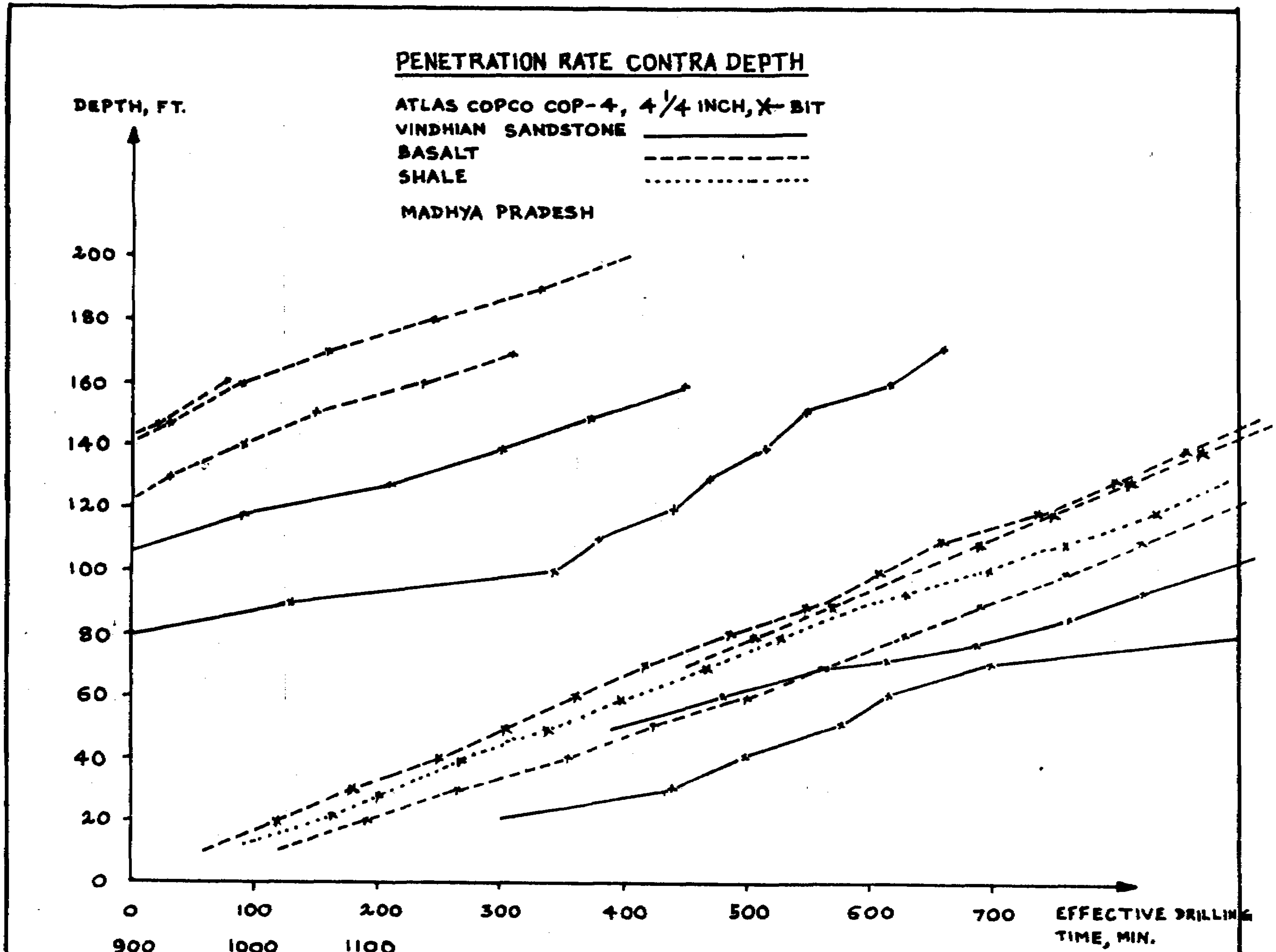

PENETRATION RATE CONTRA DEPTH
ATLAS COPCO COP-4, 4 1/4 INCH, X-BIT
VINDHIAN SANDSTONE
BASALT
SHALE
MADHYA PRADESH
DEPTH, FT.
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
900
1000
1100
EFFECTIVE DRILLING TIME, MIN.

FIGURE 21