HYDROGEOLOGY OF R190
MINERALIZED REGION
GREAT SLAVE REEF PROJECT.
WESTMIN RESOURCES LIMITED

prepared for:

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1.0 INTRODUCTION

1.1 Terms of Reference

The purpose of this investigation is to provide descriptions of the hydrogeologic conditions in and around the R190 and X25 mineralized regions, in order to improve the data base for future dewatering and permeability-reduction modelling of the R190 ore zone, and for associated engineering studies.

Works completed in the course of the study are:
1. study existing data, maps, reports and aerial photographs;
2. examine selected core from Westmin's Great Slave Reef project area, and Cominco's open pits and M40 underground mine at Pine Point;
3. take selected core samples for lab-analysis of porosity and permeability;
4. review available geological maps, sections and reports of the Great Slave Reef and Pine Point areas;
5. review available reports describing analysis of pumping tests carried out in the Great Slave Reef Project area;
6. review reports of regional hydrogeology including the Pine Point area;
7. analyse Westmin's pumping-test data, and determine aquifer coefficients; and boundary conditions in and around the R190 and X25 mineralized regions;
8. make a preliminary estimate of deconfining and dewatering rates at R190;
9. describe data gaps and complementary works required to improve the reliability of the analysis.

1.2 Information Sources and Acknowledgments

A. W. Randall, Westmin Resources Limited (WRL), provided geological reports[1,2] maps and sections, aerial photographs, core descriptions and verbal descriptions of the geology of the Great Slave Reef (GSR) area; and reports describing the pumping tests completed at X25 and R190 sites,[3,4,5] and the regional hydro-

1.2 Information Sources and Acknowledgments (cont'd)

geology in the GSR-Pine Point area[6]. Verbal discussions were held amoungst A. Randall and R. Lane, WRL, the writer and Dr. U. Weyer, National Hydrology Research Institute (NHRI), Calgary, concerning his report on the regional hydrogeology around the Pine Point area. Mr. Randall and R. Lane, assisted the writer in field examination of GSR core at Pine Point, and in interpreting the geological data; Pine Point Mines' geological and engineering staff conducted descriptive seminars for A. Randall, R. Lane and the writer, as well as tours of selected open pits and their underground mine, and described some dewatering history and conditions at Pine Point; Pine Point Mines' staff met with the writer and discussed the regional groundwater-flow model[7] described in the report of Geologic Testing Consultants Ltd., the NHRI study and regional effects of dewatering at Pine Point; copies of several annual water-quality reports of Pine Point Mines were obtained from the N.W.T. Water Board, Yellowknife; regional topographic maps were obtained from A. Randall and from Environment Canada; other references cited are listed in report Section 9.0.

2.0 GEOGRAPHY

2.1 Location

The Great Slave Reef project covers an area of about 260 square kilometres between Buffalo River and Birch Creek (Figure 1). The area is roughly divided north and south by No. 5 highway and the Pine Point rail spur. Mineralized regions lie in the central part of the area, north of the highway and railroad.

2.2 Topographic Setting and Drainage

The GSR project area lies across the central parts of Birch Creek and Twin Creek catchments, which are tributary to Great Slave Lake, and on the west side of Buffalo River catchment, north of highway No.5. Land surface elevations drop from about 230 metres at the southern edge of the project area to 175 metres at the northern edge, however, local ridges up to 10 metres in height are present. Those ridges generally form lateral boundaries between tributary catchments, e.g. just east and north of R190 site. Surface drainage in the area is poorly integrated, and forms muskeg and swamps where locally dammed by beach ridges and longitudinal sand dunes.

2.3 Climate

AES data show that the GSR area receives about 340 mm of precipitation annually, of which about 47 percent is snowfall. Mean daily temperatures above freezing occur during May through October; annual evaporation and transpiration losses approximate 73 percent of annual precipitation.

3.0 HYDROGEOLOGY

3.1 Concepts

The hydrogeology of an area describes the occurrence and movement of water over and through surficial materials and bedrock that underlie the area, and their chemical and physical interactions. The occurrence and movement of groundwater within saturated flow regions are controlled by the nature and distribution of hydraulic parameters, such as porosity, hydraulic head and conductivity, and storativity. Flow velocity is directly proportional to the hydraulic conductivity and hyraulic gradient. The direction of flow is in the negative direction (opposite) of the hydraulic gradient. In isotropic materials the groundwater flow direction is parallel to the negative hydraulic-gradient direction, whereas in anisotropic materials the flow is in the direction of maximum hydraulic conductivity. Under natural conditions, the path of groundwater flow is across less conductive strata, and along the more conductive strata.

Groundwater flow, may be quantified where sufficient hydraulic data exist, however the lack of such data usually results in the indirect mapping of flow system geometry and hydraulic boundaries from geological boundaries. Hydraulic tests are done in order to quantify hydraulic coefficients and validate the assumed relationship between geologic and hydraulic boundaries.

In the GSR area, particularly around the R190 and X25 mineralized regions, a great deal of exploration drilling has been done, geological sections drawn, and two long-term pumping tests done at those sites. Similar exploration work, as well as mining and pit dewatering, has been done in the adjacent Pine Point property over a span of several years. Available reports on work done in both of these areas have provided the basis for this preliminary analysis which is described in following sections of the report.

3.2 Geologic Setting and Apparent Aquifer Geometry

Surficial geology of the GSR area is poorly known. General descriptions have been made of surficial materials in the adjacent Pine Point area. The four main types of surficial materials identified were interpreted[8] to be present in the GSR area, as well, i.e. stony sand to sandy clay till; shallow beach sand over till and beach ridges; lacustrine plains and shallow beach deposits over lacustrine materials; sandy gravel outwash; organic materials over beach sands and lacustrine materials. Pure clay deposits in the area have been used in highway construction.

Drilling data and geological sections show that thicknesses of surficial materials over the area range between 25 and 90 metres. Greatest thicknesses are over collapse structures, e.g at X25 test site, and in apparent bedrock channels. Drilling data indicate that the upper part of the surficial materials has a sandy, gravelly texture, whereas the lower part has a silty clay texture.

The interconnection between collapse depressions and preglacial channels in the bedrock surface may be important where materials in the collapse region are conductive. Under such conditions the bedrock channels could be a source of recharge to dewatered zones.

Bedrock within the zone of investigation consists of a sequence of gently folded, west dipping, stratified rocks (Figures 2 & 3), considered to be associated with a reef complex. From subcrop to the base of exploration the main hydraulic units are: 1) the Upper Slave Point limestone sequence (about 60 metres thick), which has pitted and scattered vuggy zones (Plate 1), toward the base; 2) Amco Shale-Watt Mountain argillaceous, micritic limestone sequence (Plate 2), about 15 metres thick; 3) the Presquile unit, formed of medium to coarse grained, moderate to extreme vuggy dolomite (Plate 3), which is about 70 metres thick in the central part of the area (main hinge) and thins northward and southward (Figure 4); 4) the Pine Point unit of medium grained sandstone, dolomite, and limestone that contain scattered vugs and pitted zones (Plate 4). The limey Hay River Shale formation forms the subcrop westward from it's eastern erosional edge, which lies just east of the R190 mineralized region.

3.2 Geologic Setting and Apparent Aquifer Geometry (cont'd)

The Presquile unit wedges out to the north, as illustrated in Figure 3. The southern limit of the Presquile unit has not been mapped west of Buffalo River, however, the eastern and southern limits have been defined in the Pine Point area (Figure 4).

All of the bedrock units are jointed and fractured in outcrop (Plate 5) and in core samples. The nature and degree of fracturing was measured as RQD values* in the cored intervals of selected boreholes (Appendix A), located along a north-south line across the GSR area (Figure 4), and in the area of R190. Visual estimates of primary (intergranular) and secondary porosities were made, as well (Appendix A). Selected core samples were taken for laboratory analysis of porosity and permeability (Appendix B).

Generally, the Slave Point unit is massive with poor development of high-angle joints. The lowest RQD values (Appendix A) are associated with a vuggy zone located near the base of the rock unit. There is a fractured, apparent weak zone located at the base of the shaly Amco Shale-Watt Mountain unit and at the apparent disconformity at the top of the underlying Presquile unit (commonly choked with green clay and mud).

The Presquile unit appears to be structurally weak, generally with low RQD values. Distinct fractures cannot be observed in the core, and most of the rock breaks are through vugs or along remnant fossil boundaries. Parts of the vugs are infilled with calcite and sulfur crystals, some of which are bitumen coated in the upper part of the rock unit.

The basal Pine Point unit contains a few well-defined high-angle joints, but appears stronger than the Presquile unit. Some pitted zones with weak vug development are present in the basal unit. In lower parts of the sequence, fractures and vugs are gypsum healed, e.g. core 75-1.

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* RQD is the Rock Quality Designation, and is specified as the ratio of the total length of core pieces over 10 cm (4 inches) to the length of the cored interval, expressed as a percentage.

3.3 Apparent Aquifer Hydraulic Properties, Geometry and Boundary Conditions Inferred from Geology

Apparent aquifer coefficients and boundaries can be estimated visually from the structural logs (Appendix A), described to follow. The main aquifer appears to be the very vuggy Presquile unit, which ranges up to 70 metres thick (Figure 4). Visual estimates of secondary porosity in this rock unit range from 10 to over 20 percent (Tables 1a and 1b). Permeameter tests of Presquile core samples (Table 2) give porosity values ranging from 3.7 to 19.5 percent. Air conductivity measurements for those samples range from 1.7 x 10^{-10} to 1.21 x 10^{-4}metres per second (m/s); water conductivity values would be slightly lower. The high values are from the tests on the NQ core samples (47.6 mm) from DDH 464. Core samples from other drill holes are of BQ(36.5 mm) size. Hydraulic conductivity measurements were made on intact core, and as a result, do not include fracture conductivity which may be high.

Other regions that appear porous and conductive are the two-to-three metre thick zones located in the Slave Point unit above the Amco Shale, and in the upper part of the basal Pine Point unit (Tables 1a and 1b). Permeameter tests of samples give porosity values ranging from 2.3 to 21 percent. Hydraulic conductivity values for those samples range from less than 0.86 x 10^{-10} to 0.66 x 10^{-6} m/s. The higher conductivity values are of the basal Pine Point samples, which appears to be cleaner and more permeable.

The Amco Shale-Watt Mountain strata appears relatively tight, or of low permeability. It is important to note that the permeameter-test values have not measured hydraulic effects of rock fractures and joints.

Dewatering experiences at Pine Point Mines (personal communication) indicate that in the Pine Point area aquifers are present in the Slave Point unit, at the top of the Watt Mountain member, at the upper Presquile contact, below the C Horizon, and at the top and bottom of the Pine Point group. In the Pine Point Mines area the Presquile unit forms the subcrop east of the townsite, and is confined or partly confined by overlying tills.

3.3 Apparent Aquifer Hydraulic Properties, Geometry and Boundary Conditions, Inferred from Geology (cont'd)

In the GSR area the entire Presquile unit appears to form the main aquifer, confined above by the Amco Shale - Watt Mountain sequence, partly confined below by less-conductive Pine Point rocks, and confined to the north by the Buffalo River shale onlap. Southern and western boundaries of the Presquile unit have not been delimited, however a southern boundary is indicated by extension from Pine Point Mines area (Figure 5). The presence of gypsum infilling in fractures and vugs appears to increase southward. The presence of gypsum-plugged rock units in the south could form the southern boundary.

3.4 Hydraulic Head Distribution and Regional Groundwater Flow

Irregardless of the transmissivity of a rock unit, a hydraulic gradient must be present for flow to occur. The direction of the hydraulic gradient is from lower to higher heads. In the GSR area measured hydraulic heads in drillholes cored through the Presquile unit (Figure 4) are lower toward Great Slave Lake and higher southward, which condition indicates a regional hydraulic gradient toward the south (about 1.5 m per km). As a result the direction of regional groundwater flow is northward, parallel to the direction of the negative hydraulic gradient or the maximum axis of the hydraulic conductivity tensor. Water level measurements at R190 and X25 sites (Figures 5 & 6) indicate that hydraulic heads along the hinge (east northeastward) are nearly level, which means that there is little to no hydraulic gradient or groundwaterflow along the hinge between the X25 and R190 test sites.

In the northern part of the GSR area, north of the 600 foot (183 m) contour line, regional groundwater discharge is present in the forms of springs, seepage and phreatophytic plants. Artesian flows from deep drill holes in the northern part of the area (Figure 4) indicate, as well, that the area is one of regional grounwater discharge. Some of that regional discharge could be diverted by the dewatering process should mining occur in the GSR area.

4.0 AQUIFER HYDRAULICS

4.1 X25 Pumping Test Data Analyses

A pumping test was completed at X25 site (August 3-14, 1978) and the data analysed by others[3], using the unsteady-state, leaky-aquifer method of Hantush and Jacob(1955)[9]. Transmissivity values were calculated to range from 230 square metres per day (m^2/d), or 15,400 imperial gallons per day per foot (igpd/ft) to 15,500 m^2/d (1,039,300 igpd/ft); the medium value was estimated to be 1450 m^2/d (97,222 igpd/ft);

Drawdown data from the observation wells monitored during the X25 pumping test were replotted versus the log of pumping duration. These plots were used to observe the rates of change in drawdown during pumping, in order to define the pumping durations during which drawdown values are functions of transmissivity and storativity, conditions which occur during early pumping times. During the later part of the pumping test drawdown rates appear to have been affected by boundary conditions that may be related to the collapse structure in the X25 region or, to more remote boundaries. Erratic drawdown in some observation wells after 100 minutes of pumping may be related to recharge from the ground surface along the well casing.

Drawdown data at the 100 minutes of pumping time were considered to be the least affected by boundary conditions or other effects. Thus these drawdown data were plotted versus logs of their distance from the pumping well (Figure 10), and distance drawdown lines drawn. From the slopes of those distance-drawdown curves, calculations were made of transmissivity and storativity (Table 3), and range from 910 to 5200 m^2/d (aquifer coefficient values from all test analyses are given in both metric and imperial units in Table 8) Storativity values range from 0.33×10^{-3} to 2.06×10^{-3}. The highest hydraulic conductivity values are for drillholes 201 and 203, located nearest to the pumping well. These high values may indicate the nature of the anisotropic conditions within the Presquile aquifer (extreme conductive zones may be isolated within less conductive parts of the aquifer), or the presence of direct hydraulic interconection at the bedrock or ground surfaces. Extreme conductive zones in the Presquile unit could be formed by cobble-to-boulder sized open vugs, such as can be seen in the wall rocks of Pine Point Mines' M-40 underground mine or by well-developed open fractures, such as can be seen in Pine Point Mines open pits (Plate 5). The low hydraulic conductivity value for DDH 188 may be representative of regions where vug and fracture development are less, or where those openings were infilled with soil or rock.

Drawdown values at 1000 minutes were plotted, as well, and the drawdown-log distance curves drawn. The slopes of those curves are steeper than for the 100 minute interval, which indicates that drawdown may have been affected by recharge during the later time interval. The majority of transmissivity and storativity values are considered to range from 960 m^2/d to 1080 m^2/d (Table 8), and from 0.45×10^{-3} to 0.89×10^{-3} respectively.

4.2 R190 Pumping Test Data Analyses

Two long-term pumping tests and a velocity log were run at R190 site in March-April, 1980, and in November, 1980. The velocity log indicates that most of the flow entering the borehole during the test originated in the Presquile rock unit, (Figure 11). The caliper log shows that the Presquile unit appears badly caved throughout, whereas the Slave Point unit appears very competent (Figure 11) . Severe caving is apparent in the upper part of the Amco Shale-Watt Mountain unit, as well.

Analysis of the March, 1980, pumping test data (5.2 days) was done by others[5], using the "early-time" drawdown data and the Theis method of analysis[10]. Later time-drawdown data was not used due to fluctuations of the pumping rate. Median transmissivity and storativity values were calculated to be 10,800 m^2/d (724,140 igpd/ft) and 1.1×10^{-3}, respectively.

Analysis of the November, 1980, pumping test data was done by others,[6] using both the Cooper-Jacob modification of the Theis method[11], and the type-curve method of Streltsova[12], used for analysing effects of delayed yield in fractured formations. Arithmetic-mean values of transmissivity and storativity (using the Streltsova method) were calculated to be 2982 m^2/d (199,943 igpd/ft) and 2×10^{-2}, respectively. Arithmetic mean values of transmissivity and storativity (using

the Cooper-Jacob method and late-time drawdown data (after 10,000 minutes)) were calculated to be 2340 m^2/d (156,900 igpd/ft) and $6x10^{-2}$, respectively[5]. The presence of anisotropic permeability distribution in the Prequile aquifer was illustrated in the November, 1980, analysis (opcit).
The November, 1980, pumping test data have been re-analysed in this report using the following methods; Chow's time-drawdown method[13], and the Theis time-drawdown method (opcit) both combined with the method of image wells described by Ferris et al[14]; a distance-drawdown variation of the Cooper-Jacob method (op cit).

The drawdown versus time method allows the plot of drawdown versus time data at an observation well to be compared with similar drawdown-time plots at the other observation wells and the pumping well. Where the slopes of the plots are the same for early pumping times (before the depression cone reaches a hydraulic boundary) the aquifer is isotropic and homogeneous. Where the slope of the drawdown-time plot at an observation well changes, a boundary effect is indicated. The drawdown-time plot gives the time that the boundary effect reaches the observation well. A range in the slopes of early drawdown-time plots from different observation wells before a boundary is reached indicates that the aquifer is anisotropic, or that the aquifer region around the well is plugged (drilling mud, and so on).

The drawdown versus distance method allows the shape and extent of the depression cone to be drawn at selected pumping durations. Where the aquifer is isotropic the drawdown-distance plot line remains constant during early pumping times (before a hydraulic boundary is reached), and contains the drawdown value of each observation well. Hydraulic boundaries may be either recharge or discharge boundaries. The barrier boundary condition has the same effect as interference from another pumping well (discharging image well) located on the opposite side of the boundary (further described in the following section). The effect of a discharging image well, or barrier-boundary condition, is to increase the rate of drawdown. Transmissivity and storativity values calculated from drawdown data after a barrier boundary has been reached would result in those values being undervalued by one hundred percent for each boundary effect.

4.2 R190 Pumping Test Data Analyses (cont'd)

The drawdown-log time plots of the R190 data (Figures 12a and 12b) show a multiple barrier boundary condition after 1000 minutes of pumping. The slopes of the drawdown-log time curves before 1000 minutes of pumping were used to calculate transmissivity and storativity (Table 4), using the method of Chow (opcit). Transmissivity and storativity values from the Chow method range from 6540 m^2/d to 11,200 m^2/d, and 0.114 x 10^{-3} to 2.5 x 10^{-3}, respectively. The relatively-low transmissivity value at DDH 424 may be caused by a low permeability condition in the mineralized zone at DDH 424, or to plugging of the aquifer around the drillhole by drilling mud. The relatively-low storativity value at X25 indicates that the relatively-high conductive zone between the pumping well and X25 has a relatively-high compressive strength.

Analysis of the multiple boundary-condition effects shows that the distances of the three discharging image wells range from 1300 to 12,900 metres (image well No. 1), 5408 to 23100 metres (image well No.2), and 8900 to 45,600 metres (image well No.3). The wide range of calculated distance to each image well is partly due to the inherent error in selecting the zero drawdown time (t_0) using the graphical method, and partly due the anisotropic conditions in the aquifer. Distances to the actual boundaries are one-half the calculated distances to the image wells.

Analysis of the log-drawdown data versus log-time data (from Figures 13a, 13b and 13c) were made by the Theis method (op cit), and are tabulated in Table 5. Transmissivity and storativity values ranged from 10,100 to 10,600 m^2/d, and from 0.56x10^{-3} to 19.5x10^{-3}, respectively.

Analysis of the boundary conditions indicates that the distances of the three discharging image wells range from 2940 to 7700 metres (image well No. 1), 4050 to 12,300 metres (image well No.2) and 9700 to 18000 metres (image well No.3). Corresponding barrier boundaries would be about one half those distances from the R190 site.

4.2 R190 Pumping Test Data Analyses (cont'd)

The slopes of the drawdown-log distance plots for early pumping times at R190 were used to calculate transmissivity and storativity values (Table 6), using a variation of the Cooper-Jacob method (op cit). The drawdown-log distance curves were constructed by selecting points of equal time intervals from the drawdown versus log-time curves (Figures 12a and 12b). Those values were plotted versus the logs of their distances from the pumping wells (Figure 8). The calculated transmissivity and storativity values ranged from 9330 m^2/d to 11,600 m^2/d, and from 0.11 x 10^{-3} to 78.5 x 10^{-3}, respectively. The high storativity value for DDH 412 may be caused by a time lag in the water level response at R190. The aquifer coefficients in Table 6 were used to calculate the image-well distances, using the boundary arrival times taken from the drawdown versus log-time curves (Figures 12a and 12b). Based on those calculations the distances to the three apparent image wells range from 3700 to 13,000 metres (image well no.1), 7400 to 24,000 metres (image well No.2), and 13,500 to 15,000 metres (image well No.3).

The transmisssivity and storativity values from Table 6 were used, as well, to calculate zero drawdown distances for selected pumping times at R190. Those distances were used to construct the drawdown cone limits for the various pumping durations (Figure 4). The drawdown cone limits for the first image-well time indicate that the first image well may be located in an east northeasterly direction east of Buffalo River (Figure 5).

The drawdown-log distance plots (Figure 8) show that there was considerable well loss during the pumping test (the well efficiency is calculated to be 63 percent). That condition is thought to have been caused by the high rate of pumping from the relatively small-diameter well (12.5 inches), and perhaps from dissolution of hydrogen sulphide gas in the low pressure zone around the pump. Well loss means that a seepage face exists above the water level in the pumping well, and that only part of the available drawdown is used to produce water. As a result, the cost of pumping would be greater (because of the greater lift), and transmissivity and storativity values calculated from drawdown data in the pumping well, would be undervalued. In the R190 test transmissivity and storativity values were calculated from observation well data, and were not affected by the well loss condition.

4.2 R190 Pumping Test Data Analyses (cont'd)

The transmissivity and storativity values at R190 calculated by the different methods in this report compare well (Table 8). These transmissivity values approximate those obtained by Golder (op cit), as well, however the Golder storativity values have a much higher range. The relatively-low transmissivity and relatively-high storativity values obtained in the Brown-Erdman analysis (Table 8) are due to the use of the late drawdown-time data (after 10,000 minutes), and the use of the Streltsova method.

4.3 Boundary Conditions

Figure 14 illustrates that a barrier boundary has the same effect on drawdown rates in a pumping well and piezometer as a discharging well located on the opposite side of the boundary (image well), and that a recharge boundary acts similar to a recharging image well. The hydraulic conductivity, storativity and boundary distances determine the time after pumping starts that boundary effects arrive at the pumping and observation wells (Figure 15). The number of boundaries present and their configuration determine the rate of change in drawdown versus time. Figures 12a and 12b illustrate that the slopes of successive limbs of the drawdown-log time curves are multiples of the initial limb. The exact ratio of the fourth limb to the first limb cannot be determined from the semi-log plots.

The barrier boundary conditions in the GSR area, determined from geology, indicate that those boundary conditions could be represented as an open box (Case 3, Figure 15), however the ratios of the image distances (given in Tables 4, 5 and 6) indicate that parallel boundary effects were measured (Case 2, Figure 15). It should be noted that during the R190 test less than 10 percent of the available drawdown was used, which means that not all of the boundary effects may have developed, such as are shown in Cases 2 or 3 (Figure 15), or that may occur during dewatering at R190. Some of the boundaries that may develop could be recharge boundaries, such as were indicated from the X25 test data. The multiple barrier boundary condition apparent in the R190 test data could be due to facies changes at the lateral limits of the Presquile unit (Figure 5), or to

4.3 Boundary Conditions (cont'd)

local changes in transmissivity and storativity within the Presquile unit, or to hydraulic boundaries caused by dewatering. Local changes in transmissivity and storativity have been described in reports of pit dewatering at Pine Point Mines, and from analysis of pumping test data at Pine Point Mines and at X25 site. The existance of a hydraulic boundary becomes apparent, as well, from a study of Figure 5. The 186 metre piezometric level in the drawdown cone (from Pine Point dewatering) has advanced southward across the Presquile unit from its (1968/69) prepumping northern position. The western edge of the drawdown cone would form a hydraulic barrier to an advancing drawdown cone from the west. The present position of the western edge of the Pine Point drawdown cone may be completely across the Presquile unit, and as for west as Buffalo River.

5.0 DEWATERING R190

5.1 Concepts and Basic Assumptions

Dewatering at R190 would take place under changing hydraulic conditions during pumping. Initially, pumping would occur under confined conditions, and the first part of pumping would be "deconfining" the aquifer around the region to be mined. During the deconfining process some leakage would occur through the confining beds (above and below).

The second part of pumping would be "dewatering" the aquifer. During the dewatering process the amounts of leakage from overlying and underlying beds would increase.

During both pumping stages the drawdown cones would be limited by the barrier boundaries (apparent from the R190 pumping test data). The boundary configuration at R190 is not known at this time, however, the effects of those boundaries can be approximated where the given assumptions are valid, (specified in following sections).

5.2 Deconfining the R190 region

Different sets of calculations were made (Table 7) to show the range of pumping rates required to deconfine the aquifer where different boundary conditions and aquifer properties exist. For the first calculation, aquifer coefficients were given the values calculated for the X25 observation well, as given in Table 6 and illustrated by the long axis of the drawdown cone of influence (Figure 5). These specifications would result in a large drawdown cone due to pumping, and relatively few boundary effects. The calculations show that the assumed multiple barrier boundary effect would reduce the required pumping rate to $4.0\ m^3/s$ (52,800 igpm) from $10.2\ m^3/s$ (the pumping rate that would be required where no boundaries are present).

For the second calculation, aquifer coefficients were taken equal to those calculated for piezometer 416 as given in Table 6. The use of these coefficients result in a more restricted drawdown cone, as illustrated by the width of the drawdown cone in Figure 5, and closer barrier boundaries. The calculations show that the multiple barrier boundary effect would reduce the required pumping rate from $10.3\ m^3/sec$ to $3.3\ m^3/sec$ (43,560 igpm).

5.3 Dewatering the R190 Region

The purpose of the second stage of pumping is to dewater the aquifer around R190. During this process the drawdown cone in the aquifer is expected to have the same shape but to expand much less rapidly because of the large increase in the storativity (specific yield) value (0.2 versus .00011). As a result, boundary effects would be reduced, as shown in the following calculations.

The dewatering pumping rate may be calculated from the multiple-well equation $Q = 4\pi KDs/W(u_r) + \Sigma_i W u_i)$. Where $KD = 1.06\text{x}10^4$, $s = 70\text{m}$ (assumed aquifer thickness D), and dewatering time t would be 6 months, or 182.5 days, and $S = 0.2$, the travel distance of the drawdown cone would be $r_o = (2.25KDt/S)^{0.5}$. Substituting, $r_0 = (2.25\text{x}1.06\text{x}10^4\text{x}182.5/0.2)^{0.5} = 4665$ m. Because the nearest image well is 13000 m away, there would be no boundary effect and $\Sigma_i W(u_i) = 0$. Furthermore, $u_r = r^2S/4kDt$, and $u_r = 100^2\text{x}0.2/(4\text{x}1.06\text{x}10^4\text{x}182.5) = 2.58\text{x}10^{-4}$, where r = 100m (diameter of the dewatered base), and $W(u_r) = 7.69$ (from Tables[15]).

5.3 Dewatering the R190 Region (cont'd)

The required 6 month dewatering rate $Q = 4\pi x1.06x10^4x70/(7.69) = 1.21x10^6 m^3/d$ = $14m^3/s$ (185,200 igpm). In order that the first barrier boundary might be reached, the duration of dewatering under the specified conditions would have to be: $t = r_i^2 S/2.25kD = 13000^2 x0.2/(2.25x1.06x10^4)$ = 1417days, or 3.9 years.

Where the average transmissivity value would be 50 percent less (5300 m^3/d), the required pumping rate would be reduced, as well, by 50 percent.

Where the radius r_w of the base of the dewatered region (well field ring) would be reduced by 50 percent, $u_r = 50^2 x0.2/(4x1.06x10^4x182.5) = 6.46x10^{-5}$, $W(u_r)$ = 9.07 (from Tables), and the six month dewatering rate $Q = 4\pi x1.06x10^4x70/9.07$ = $1.02\ x10^6\ m^3/d$, or 11.9 m^3/sec (157000 igpm), which would be a reduction of the pumping rate by (14-11.9)/14 x 100, or 15 percent.

Where the mean storativity (specific yield) value would be reduced by 50 percent, S = 0.1, and $u_r = 2.58x10^{-4}x0.1/0.2 = 1.29x10^{-4}$, $W(u_r)$ = 8.37. The travel distance of the cone of influence ro = $(2.25x1.06x10^4x182.5/0.1)^{0\ 5}$ = 6600 m. Where the first barrier boundary would be 13000 metres away there would be no boundary effect, and the reduction in the pumping rate would be due only to the reduction in storativity, which would be (8.37-7.69)/7.69x100 = 9 percent.

On the other hand, where the first barrier boundary distance would be less than 5600 metres, as given in Table 6 for the observation piezometers other than X25, the effects of the first boundary would be to reduce the pumping rate, as follows. For the first boundary effect $\Sigma_i W(u_i)$ = 5.17 (Table 7), and $Q = 4\pi x1.06x10^4x70/(7.69+5.17) = 725,000\ m^3/d$, or 8.4 m^3/s (110,800 igpm).

The foregoing calculations show that very conservative estimates of the dewatering pumping rate (not counting leakage) approximate 14 m^3/s. The calculations show, as well, that where individual parameters would be 50 percent less than estimated or where a barrier boundary effect would occur, pumping requirements could be as much as 50 percent less (7 m^3/s). Where those conditions are accumulative pumping requirements could be as low as 3.5 m^3/s.

5.4 Leakage Effects

Both deconfining and dewatering of the aquifer around the R190 region are expected to produce leakage from the overlying and underlying saturated strata. The rates of leakage would be directly proportional to leakage areas, vertical hydraulic conductivities, and hydraulic gradients. Leakage estimates are given to follow using the Darcy equation and Hubbert's point-sink analytical model[16].

Downward leakage would occur at the top of the Presquile aquifer, over the area of the drawdown cone. This area would be greatest at the end of the dewatering process, and would reach the barrier boundaries. Where the image well distance would be 13,000m (east-northeast) and 24,000m (west-southwest), the related boundary distances would be 6,500 m and 12,000m. The north and south boundaries of the Presquile aquifer are approximated from Figure 5 to be 5500m and 11,500m from R190 site. These boundaries would produce a sub-rectangular area of 18,500 m x 17,000 m, or about 3×10^8 m^2.

Where the average vertical hydraulic conductivity of the Amco Shale-Watt Mountain unit is 10^{-9} m/s (10 x the permeameter test values, Appendix B), and no conductive conduits exist in local collapse structures, and the upward hydraulic gradient is unity (the case in a perched flow system), downward leakage Ld = $10^{-9} \times 1 \times 3 \times 10^8$ m^3/sec, = <u>0.3 m^3/s</u> (about 4000 igpm). Where the average vertical hydraulic conductivity would be 10^{-8} m/s, leakage Ld = $3 \times 10^{-8}/10^{-9}$ = <u>3m^3/sec</u>, (about 40,000 igpm).

Upward leakage would occur across the bottom of the dewatered zone at the base of the main Presquile aquifer. Kv of the Pine Point unit is taken to be 0.66 x 10^{-6} m/s (measured in the permeameter test of the NQ core sample, Appendix B). The drop in hydraulic head in the underlying Pine Point strata would approximate the depth of dewatered region, taken to be 180m. This head loss would be distributed in the Pine Point strata, laterally and downward, in proportion to the log of the distance (assumed to equal the depth of the dewatered region, or 180 m). Flow into the lower part of a spherical point sink of 100 m radius is given by Hubbert's[17] equation: $Q = 2\pi K_v(h_2 - h_1)/(1/r_1 - 1/r_2)$. Where $K_v = 0.66 \times 10^{-6}$m/s, h_2 = 180 m, h_1=0, r_2 = 100+180 m, and r_1 = 100 m, $Q = 2\pi \times 0.66 \times 10^{-6} \times (180-0)/(1/100-1/280)$$m^3$/s, or <u>0.12 m^3/s</u> (1530 igpm).

5.4 Leakage Effects (cont'd)

A ten fold increase in vertical conductivity would result in similar increase in the upward leakage rate,i.e. 0.12 m^3/s x10 = 1.2 m^3/s (15,800 igpm). Thus the total upward and downward leakage rate is estimated to be 0.3 m^3/s + 0.12 m^3/s, or 0.42 m^3/s (5500 igpm). Where conductivities are an order of magnitude higher than expected, leakage total rates would be 0.42x10 = 4.2 m^3/s (55,000 igpm). However, because the drawdown-time curves indicate that the aquifer is confined high leakage rates from the Pine Point unit are not expected.

6.0 GROUTING POTENTIAL AND EFFECTS AT R190

6.1 Grouting Potential

Calculated hydraulic conductivity values for the Presquile unit range from 1.13×10^{-3} to 1.93×10^{-3} m/sec (Table 7), which is equivalent to the hydraulic conductivity of clean sand or a clean sand and gravel mixture[17], which are groutable. Pumping-tests results indicate that the Presquile unit is anisotropic and may contain isolated open pockets formed by vugs or fractures.

Results of large-scale grout testing in deep alluvial sediments at a number of dam sites, e.g. the Serre-Ponçon Dam site and the High Aswan Dam site, have led to the following conclusions[18]: 1) where the hydraulic conductivity of the untreated sediment (K) is greater than 10^{-4} m/sec, grouting with an appropriate mixture of cement and clay reduces the hydraulic conductivity to about 2×10^{-6} m/sec, irrespective of the original value of K; 2) if the original value of K is less than 10^{-4} m/sec, the K value of the grouted sediment (K_g) increases with the decreasing K values; sediment with a K value of less than 10^{-5} m/sec cannot be grouted with clay-cement grout. Grout curtains up to 520 feet in depth have been successfully constructed in coarse alluvial sands and gravels, e.g. the Serre-Ponçon Dam on the Durance River in southern France, the Mission Dam on the Bridge River, British Columbia, and the Rocky Reach Dam on the Columbia River in Washington State using either Solestance or Swiger methods [18,19]. Both methods require drilling of several rows of boreholes (about 12 cm. diameter) to the base of the section to be grouted.

6.1 Grouting Potential (cont'd)

The boreholes should be from 3 to 4.5 metres o.c., and the rows about 3 metres apart. The number of rows depends on the desired hydraulic gradient across the grout curtain (European experience recommends a minimum grout curtain width equal to 25% to 30% of the expected head drop across the grout curtain). The boreholes are grouted in sections and in stages using appropriate clay-cement and clay-cement-chemical mixtures. Grouting materials coarser than 200 mesh should not comprise more than 1% to 2% of grout materials. Grout testing should be done to determine grout specifications, well spacing, and so on.

6.2 Grouting Effects

Considering that the expected head drop across a grout curtain around the R190 ore region would average about 130 metres under mining conditions, minimum grout-curtain thickness should be 130/4, or 33 metres, according to European recommendations. At a 3 metre row spacing,the number of rows should be 33/3, or 11, or from 5 to 6 rows at a 5 metre row spacing (the well and row spacing would vary with the hydraulic conductivity, or the test results).

Where the diameter of the mine and the hydraulic conductivity of the grout curtain are known, the leakage (Q) through the grout curtain can be estimated using Hubberts' line-sink analytical model: $Q = 2\pi KL(h-h_0)/\ln r/r_0$. Where the radius of the mine (r_0) = 100 m, and $K = 2x10^{-6}$ m/s, $Q = 2\pi x2x10^{-6}x70x130/\ln 133/100$ m^3/s, or <u>0.4 m^3/s</u>, (5,300 igpm).

Leakage into the mine from overlying beds can be estimated from Hubbert's half point-sink equation $Q = 2\pi Kv(h-h_0)/(1/r-1/r_0)$(op cit). Where k_v of overlying strata = 10^{-9} m/sec, and the head is distributed over a distance equal to the depth of the top of the mine, then $Q = 2\pi x10^{-9}x100/(1/100-1/200)$, or <u>$1.26x10^{-4}$ m^3/s</u> (2.7 igpm), a negligable amount.

Leakage into the mine from underlying beds would be <u>0.12 m^3/s</u> (1530 igpm), as given in section 5.4. Total leakage into the mine region would be 0.4 m^3/s + 0.12 m^3/s = <u>0.52 m^3/s</u> (6830 igpm).

7.0 IMPROVING RELIABILITY

7.1 Aquifer Coeficients and Boundary Conditions

The foregoing calculations show that the existence and distance of multiple barrier boundaries are most important conditions in limiting the dewatering rate around the R190 mineralized region. Analysis of the X25 and R190 test data indicate that high conductive zones are present in the Presquile aquifer along the hinge, and that these zones appear restricted or bounded. Verbal information of Pine Point Mines dewatering experiences indicate that similar high conductive zones may be present, as well, across the hinge. X25 pumping test data indicate that significant vertical leakage may occur through collapse structures during pumping.

The reliability of the dewatering estimates could be improved through better location of barrier boundaries and better definition of aquifer coefficients. This could be done through careful examination of all hydraulic test data and relevant geological data from the Great Slave Reef-Pine Point Mine area.

Estimates of deconfining and dewatering rates could be improved through the use of a properly-constructed, three-dimensional computor model. Such a model could be used, as well, to predict effects of various grout curtain configurations or grouted regions in and around the R190 mineralized region. This could be done through careful examination of all hydraulic test data and relevant geological data from the GSR - Pine Point Mine area.

8.0 RESULTS AND RECOMMENDATIONS

8.1 Results

Results of the initial study indicate that the Presquile rock unit is the main aquifer, and that the Presquile aquifer is hydraulically confined above and below by less-conductive rock units, and internally by multiple barrier boundaries.

The process of dewatering the Presquile aquifer around the R190 mineralized regions can be separated into the initial deconfining stage, and the subsequent

8.1 Results (cont'd)

dewatering stage. The deconfining stage means lowering the piezometric head from near the ground surface to the top of the Presquile aquifer. The dewatering stage means lowering the unconfined water table around the R190 region to the base of the Presquile, as well as pumping the leakage that would occur from the overlying Amco Shale-Watt Mountain rock unit, and from the underlying Pine Point rocks.

Where the duration of the deconfining process would be six months, the required pumping rate could range from <u>3.3 m^3/sec</u> (m^3/s) to <u>10.3 m^3/s</u> depending on the existence of the apparent barrier boundaries. Where the dewatering duration would be six months the required pumping rate could range from <u>3.5 m^3/s</u> to <u>14 m^3/s</u>, depending on the existence and location of the apparent barrier boundaries, and whether the aquifer coefficients have values near the bottom or top of their calculated ranges.

Leakage, from overlying and underlying confining strata, would reach a maximum during the dewatering stage, and would have to be added to the dewatering rate. Expected leakage is estimated to total about 0.42 m^3/s, however where confining materials are much more conductive, or where vertical conduits to the base of surficial materials are present, leakage rates could be much higher.

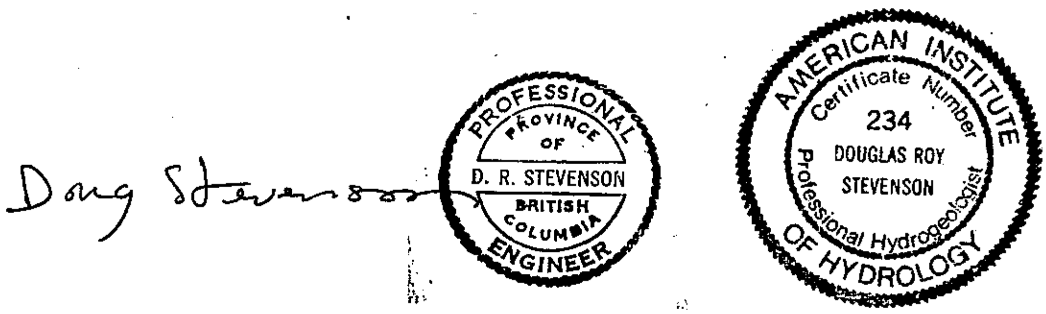
If a 33 metre grout curtain would be constructed around the R190 ore zone within the Presquile rock unit, and the hydraulic conductivity reduced to $2x10^{-6}$m/s, subsequent dewatering of the mine region could approximate 0.52 m^3/sec (6830 igpm), where the conditions on which the calculations are based exist.

8.2 Recommendations

The multiple barrier boundary conditions apparent in the Presquile aquifer containing the R190 mineralized region, could have the effect of reducing the required pumping rate by 60 percent during the deconfining stage, and by 40 percent during the dewatering stage. It is important to define these boundaries as well as the transmissivity distribution. This could be done through careful examination and re-analysis of dewatering and pumping test data at Pine Point Mines, and by carrying out an injection pressure test program in selected existing open boreholes. Results from both of these studies would provide important inputs into a three-dimensional dewatering design model.

These works should be done in cooperation with Pine Point Mines, and in time to collect the required data that could be generated from the dewatering of their N81 open pit.

Surficial materials in the GSR area should be mapped in detail to locate and describe the physical properties of granular materials that would be required for construction and grouting purposes.



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10.0 TABLES

Table 1a: RQD Values and Secondary-Porosity Estimates of Core in the Vicinity of R190, Great Slave Reef Project Area

	468 RQD	468 SP	334 RQD	334 SP	333 RQD	333 SP	412 RQD	412 SP	421 RQD	421 SP	464 RQD	464 SP	426 RQD	426 SP	620 RQD	620 SP
HRS								5-10 / 149-65								
							163		158		161					
	15 / 185-90				0 / 198	5-10 / 198	0 / 206		10 / 196-205					5-10 / 195-201		
						10 / 227-36	20 / 206-15		20 / 216-23		0-5 / 281-302		10 / 195-201			5-10 / 335-41
SP					15 / 248-51	5-10 / 266-73	0 / 215		0 / 223-26				0-5 / 231-8	5-10 / 240-46		
							10 / 228-35	5-10 / 235-62	5-20 / 251-73							
		10-20 / 290-95				10 / 300-10	0 / 262	5-10 / 321-33	5 / 306-10	5-10 / 300-04				5-10 / 270-305		
			5-10 / 321			5-15 / 319-30	0 / 295	5-10 / 352-75		5-10 / 320-45	0 / 346-7		10 / 310-25			5-10 / 323-64
	317				352		into the Watt									
Amco																
	338								351		353		325		364	
Watt	0-20				0 / 361				0-20 / 371-95				10 / 346-50			
	356								377		368		347		383	
CH					0 / 369-96							376	0-20 / 350-466			
	358		366		372		394		385		378					
	10-15	15-20	10-20 / 378-94		0 / 418						10 / 453-71			15-20	PQ	15-20
	370			5-10			too		0 / 403-5	10-20		15-20	0-20 / 470-655			
						5-20										
			0-15 / 405-24	408	0-10 / 418-48		broken			395	5-15 / 492-642	497		475		
				419						5-10				5-10		506
PQ						436	to		0-15 / 415-45	403		5-10		491	CH	
			0-15 / 428-38	5-10												514
					0-15 / 462-517	>20	sample			10-15		515		10-15		
				438					0-10 / 455-81				PQ			10-15
				10-15		500	565					10-15		558		
				461						566			EB	5-10		
				10-15 / 465-87	CH	0-5			0-15 / 503-93			615		628		
			0-20 / 504-17							10-20						
						517						5-10		0-5		
										606						
			10 / 527-36									642		655		
			10-15													

Notes:

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled.

SP - secondary porosity (%)

Table 1b: RQD Values and Secondary-Porosity Estimates of Core Along a North-South Section Across the Great Slave Reef Project Area Between R190 and X25.

	355 RQD	355 SP	507 RQD	507 SP	75-1 RQD	75-1 SP	34 RQD	34 SP	5 RQD	5 SP	327 RQD	327 SP	637 RQD	637 SP	575 RQD	575 SP	796 RQD	796 SP
SP	10/206 20/334	0-5	0/235	5-10/255 10/265 10/295	10/238-48	5-10/238-55	20/196 10-15/240-50	15-20/187 5-10/225 5-10/235-50	20-25/200-10 10/215	5-10/145-55 5-10/185 5-10/200-15 10/225 5-10/240	130-150 core missing 168-285 core missing		130-140 core missing 15-20/255-65		0/153 5-20/215-35	5-10/215-25		
					287		285		250									
Amco	30/377	0-5							10-20/255-65		20/300 0/316				10/255-65	5-10/250-60 5-10/275-85	5/305-10	0-15/305-10
					303		305		265						290			
Watt Mtn.		0-5	10/339				30/330				20/340		0-10/330-40		20/305-15 20/320-40			
							330		305		355			335			329	
CH	10-20/397-408		0/350					15-20 (330–350)	0-30/304-50	15-20 (305–440)	10-15/360-410	15-20 (355–420)		10-15/338-45	0-20/408-55	BRS intercal'd	5/355-65	10-20 (329–465)
					325								340					
PQ	10/420-30 5-20/450-85	10-20	5-30/403-455	10-20	25/320 15/348 5-15/368-82	15-20	30/336-45 355-360 core missing	350	0/375-90 100/420 20-40/424-60	440 10-15 450	30/410-15	420	0/365-75 15-20/385-415	345 15-20 415 455 0-5 500	0/455-65 BF 0-30/510-55	5-10/495-550 5-10/575	10/370-75	
					431												465	
CF						5-10			5-20/470-500	5-10			415-455 core missing					10-15
					450				500				500				475	

Notes:
RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled.
SP - secondary porosity (%)

Table 1b: RQD Values and Secondary-Porosity Estimates of Core Along a North-South Section Across the Great Slave Reef Project Area Between R190 and X25.

	355 RQD	355 SP	507 RQD	507 SP	75-1 RQD	75-1 SP	34 RQD	34 SP	5 RQD	5 SP	327 RQD	327 SP	637 RQD	637 SP	575 RQD	575 SP	796 RQD	796 SP
					450				500								475	
B/E	10 / 495-503	10-15	10 / 475	10-15	0 / 451	5-10				5-10							0-20	PQ 10-15
			10-20 / 516-30		20 / 495-505	500				550								520
				5-10	20 / 520				20 / 560	0-5								E/B 5-10
			10 / 540		30 / 550	5-10 / 545				575							530	
					20 / 620													
					10 / 705													
					20 / 721													
					10 / 736													
					20 / 840-50													
					10-15 / 875-90													
					0 / 936													
					20 / 985													
					0-10 / 1015-25													
					0-10 / 1035-45													

Notes:
RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled.
SP - secondary porosity (%)

Table 2: Laboratory Measurements of Porosity and Hydraulic Conductivity of Great Slave Reef Core Samples

Rock	Depth (ft)	Diamond Drill Hole Number 5	34	355	412	426	575	464†
HR	159				4.6(0.94x10^{-8})*			
SP	163				3.1(0.26x10^{-9})			
	193	2.3(10^{-10})						
	203				6.3(1.72x10^{-10})			
	227		4.1(1.63x10^{-9})					
	245	5.6(0.86x10^{-10})				2.6(1.72x10^{-10})		
	258		21.0(0.92x10^{-8})					
	312							10.1(0.74x10^{-7})
	326				4.6(0.26x10^{-9})			
	332			22.0(0.66x10^{-7})				
	370					4.1(1.27x10^{-8})		
Amco	280						2.7(<0.86x10^{-10})	
Watt	303	5.8(<10^{-10})						
	324		1.3(<0.86x10^{-10})					
PQ	320	4.8(1.7x10^{-10})						
	341		9.4(0.77x10^{-9})					
	382							2.1(0.8x10^{-9})
	416					9.0(0.69x10^{-9})		
	433	3.7(0.2x10^{-8})		9.2(0.43x10^{-9})				
	484							18.5(1.21x10^{-4})
	521					9.7(0.6x10^{-9})		
EB	394						12.7(0.34x10^{-9})	
	449	3.8(2.36x10^{-7})						
	462	8.0(5.7x10^{-8})						
	525						2.8(1.72x10^{-10})	
	548		7.1(0.53x10^{-8})					
	585						0.3(<0.86x10^{-10})	
	600							17.1(0.66x10^{-6})
	619					11.3(0.64x10^{-7})		

* 4.6(0.94x10^{-8}) means 4.6 percent porosity (hydraulic conductivity as metres per second).

† Large diameter core (47.6 mm - NQ), all others 36.5 mm - BQ.

TABLE 3: Aquifer Parameters Based on X25 Test Drawdown Versus Log-Distance Analysis

OW	r(m)	NPL (m)	Drawdown at pumping time (min)		t = 100-min				t - 1000 min	
			100	1000	Δs_r m/l.c	KDx10^3 (m^2/d)	r_0 (m)	S*x10^{-3}	Δs_r (m/l.c)	KDx10^3 (m^2/d)
PW	0.16	188.9	7.3	7.8						
201	21.3	185.5	4.9	5.1	1.03	2.05	-	-	1.28	
203	20.7	184.5	6.1	6.1	0.407	5.2	-	-	0.8	
188	42.7	185.5	0.15	0.2	2.9	0.73	46	-	3.17	
105	50.3	185.2	1.3	1.95	2.32	0.91	177	-	2.35	
200	65.5	184.9	2.03	2.42	1.95	1.08	720	0.33	2.05	
189	99.1	184.5	1.0	1.32	2.2	0.96	270	2.06	2.35	
199	320	186.9	---	---	2.03	1.04	510	0.62	2.1	
82	168	184.7	1.1	1.42	2.0	1.06	610	0.45	2.05	
73	198	185.8	0.68	1.2	2.1	1.01	420	0.89	2.13	
98	232	187.8	0.12	0.34	2.2	0.96	270	2.06	2.35	
163	315	188.9	0.1	0.42	2.03	1.04	520	0.6	2.23	
131	395	185.4	0.25	0.70	2.03	1.04	520	0.6	2.1	
172	488	185.2	0.26	0.6	2.03	1.04	520	0.6	2.13	
127	451	186.0	0.08	0.36	2.0	1.06	610	0.45	2.1	

* KD = $2.3Q/2\pi \Delta s_r$, where U_a = 0.02, (Jacob)(u = $Sr^2/4KDt$, where r = observation well distance), Q = 5.78×10^3 m^3/d, and KD = $2115/\Delta s_r$.
883 Lgpm

S = $2.25\ KDt/r_0^2$, where r_0 = distance of cone of influence, and u = 0.02

r = distance from pumping well (metres).

r_0 = radius of the zone of influence.

NPL = non-pumping water level.

ΔS_r = slope of drawdown versus log distance plot (Figure 8).

TABLE 4: Aquifer Parameters Based on R190 drawdown versus log time analysis, and method of images

Obs well	s_a (m)	Δs_a (m/l.c.)	ta (min)	$W(u_a)$	(u_a) $\times 10^{-3}$	KD $\times 10^3$	r (m)	S $\times 10^{-3}$	t0 (min)	Boundary time (min) t1	t2	t3	Image well distances (m) ri1	ri2	ri3
418	0.7	0.25	16	6.44	0.9	11.2	21.3	0.99	2.5×10^{-2}	980	3000	9800	1300	7800	15400
412	0.6	0.27	25	5.11	3.43	10.37	31.4	2.5	0.13	1400	3800	10500	3300	5400	8900
426	0.6	0.25	100	5.52	2.3	11.2	130	0.42	0.35	720	3600	12000	5900	13200	24100
422	0.6	0.27	108	5.11	3.43	10.37	133	0.60	0.62	1600	3400	11000	6800	9800	17700
424	0.4	0.4	2750	2.15	0.7	6.54	147								
468	0.6	0.3	325	4.6	5.5	9.33	177	1.48	3.2	1600	5200	17500	4000	7100	13100
416	0.6	0.27	275	5.11	3.43	10.37	233	0.50	1.8	1500	4400	10000	6700	11500	17400
620	0.4	0.3	210	3.0	30	9.13	362	1.22	9.7	1650	4400	14500	4700	7700	14000
621	0.4	0.3	570	3.0	30	9.13	644	1.05	26	1800	5000	14500	5400	8900	15200
X25	0.2	0.3	600	1.27	191	7.73	4129	0.144	130	1120	3600	14000	12900	23100	45600

Semi-Log analysis after Chow (1952), Data taken from semi-log plots (s vs log t) in Figure 10

$F(u_a) = s_a/\Delta s_a$, where s_a = drawdown due to pumping at time t_a, and Δs_a = drawdown due to pumping per log-cycle of time (before boundary effects);

$W(u_a)$ and u_a from Chow's well function tables[13]

$KD = Q\,W(u_a)/4\pi\Delta s_a$, where KD = transmissivity (m^2/d), and Q = pumping rate (1.53×10^4 m^3/d); aquifer thickness D = 70 m,

Storativity $S = 4\,u_a KD t_a/r^2$, where r = distance of pumping well (metres) from observation well;

Boundary times are the times after pumping begins that boundary effects can be measured in observation wells;

Image well distances are calculated distances of image wells from observation wells, ie.

$ri1 = r(t1/to)^{0.5}$, $ri2 = r(t2/to)^{0.5}$, and $ri3 = r(t3/to)^{0.5}$, where to is time of zero drawdown from semi-log plots.

nm = not measurable.

TABLE 5: Aquifer Parameters, Based on R190 Log Drawdown Versus Log Time Analysis, And Method of Images

Obs	W (u)	1/u	s	t	KD m^2/d	S	Boundary times (min)			r*	Image-well times (min)				Image well distance (m)		
well			(m)	(min)	$x10^3$	$x10^{-3}$	t1	t2	t3	(m)	ti0	ti1	ti2	ti3	ri1	ri2	ri3
418	1	100	0.115	30	10.6	19.5	1000	4200	17000	21.3	1.5	44000	100000	320000	3600	5400	9700
412	1	100	0.115	9.2	10.6	2.74	1500	3700	10000	31.4	4.8	4200	80000	300000	2940	4050	7850
426	1	100	0.115	32	10.6	0.56	1400	4200	14000	130	2.8	7000	25000	48000	6500	12300	17000
422	1	100	0.12	51	11.1	0.89	1500	3600	11000	133	4.1	7200	25000	67000	5600	10400	17000
424	1	100	0.51	-	2.39	-	nm	nm	nm	147	-	nm	nm	nm	-	-	-
468	1	100	0.12	120	10.1	1.07	1800	4000	12000	177	9.5	8600	25000	60000	5300	9100	14100
416	1	100	0.12	120	10.1	0.62	2000	4200	11000	233	9.7	10500	26000	58000	7700	12100	18000
620	1	100	0.12	395	10.1	0.82	1900	3600	10000	362	31	12000	19000	48000	7100	9000	14200
621	1	100	0.12	1100	10.1	0.74	1600	3300	10000	644	95	9400	20000	52000	6000	9300	15000
X25	1	1000	0.12(?)	1950	10.1(?)		nm	3500	5400	4129	nm	nm	17000	36000	-	-	-

NOTES:

Log-Log analysis after Theis (1935)[10], and method of images after Ferris et al (1962)[14].

Data are taken from Log s vs. Log t curves (Figures 13a, 13b, and 13c).

KD = $QW(u)/4\pi s$, where KD = transmissivity (m^2/d), Q = pumping rate ($1.53x10^4 m^3/d$), W(u) = well function of u, s is drawdown in metres at time t (days).

S = $4KDt/(1/u)r^2$, where S = storativity, r= distance to the pumping well (metres).

Boundary times are the times after pumping begins that boundary effects can be measured in the observation well.

Image well times are times after pumping begins that equal increases in drawdown due to image wells can be measured in the observation well.

Image well distances are calculated distances of image wells from the observation well, i.e. $ri1 = r(ti1/ti0)^{0.5}$, $ri2 = r(ti2/ti0)^{0.5}$, and $ri3 = r(ti3/ti0)^{0.5}$.

* r = distance of observation well from pumping well.

TABLE 6: Aquifer Parameters Based on R190 Drawdown Versus Log Distance Analysis

obs well	Nov.1,1983, r*(m)	NPWL (m)	Sept.30 1983 NPWL (m)	Drawdown at time t: t=115 (min)	t=600 (min)	t=6000 (min)	t=30000 (min)	t = 115 min: Δs_r m/1c	$KD \times 10^3$ m^2/d	r_0 (m)	S $\times 10^{-3}$	Boundary times (min): t1	t2	t3	Zero drawdown distance (m): ro1	ro2	ro2
418	0.18	183.2	183.4	0.92	1.2	1.62	2.27	0.67	8.36	460	7.1	1200	6600	14000	varies with di-		
412	21.4	183.4		0.48	0.68	1.98	1.87	0.82	6.83	125	7.8	1400	3800	10500	rection		
426	130	183.4	184.0	0.62	0.8	1.33	1.97	0.6	9.33	1500	0.75	720	3600	12000	3700	8400	1500
422	133	183.4		0.61	0.8	1.28	1.98	0.6	9.33	1500	0.75	1600	3400	11000	5600	8100	14600
424	147	183.4		0	0	0.67	1.5	>0.8	<6.83	147	<0.3						
468	177	184.8	185.0	0.47	0.68	1.17	1.88	0.6	9.33	1100	1.39	1600	5200	17500	4100	7500	13500
416	233	182.9		0.48	0.68	1.17	1.87	0.6	9.33	1500	0.75	1500	4400	10000	5400	9200	13900
620	362	184.7		0.32	0.58	1.40	1.77	0.6	9.33	1250	1.07	1650	4400	14500	4700	7700	14000
621	644	185.6	185.3	0.18	0.4	0.89	1.62	0.6	9.33	1250	1.07	1800	5000	14500	5000	8300	14100
X25	4130	183.7		0.05	0.20	0.80	1.56	0.53	10.6	4130	0.11	1150	3600	14000	13000	23100	45600

Semi log analysis after Cooper - Jacob (1946)

* r(m): observation well distance (metres)

NPWL: non-pumping water level.

DTW: Depth to water

t(m): Drawdown in metres, after various pumping durations (Nov. 1-24, 1980).

$KD = 2.3Q/2\pi \Delta s_r$, when $Sr^2/4KDt = .02$

$S = 2.25\ KDt/r_0^2$, where r_0 = radius of the cone of influence due to pumping.

$Q = 1.53 \times 10^4\ m^3/d$. (2337 igpm)

$r_0 = (2.25\ KDt/S)^{0.5}$.

Distance of travel of the cone of influence in the direction of X25 site at 1200 minutes $(0.83d) = (2.25 \times KDt/S)^{0.5} = (2.25 \times 1.06 \times 10^4 \times 0.83/0.11 \times 10^{-3})^{0.5}$ = 13,400 metres from R190 test well.

TABLE 7: Pumping Requirements to Deconfine the R190 Aquifer.

$S = 0.11 \times 10^{-3}$, $u_i = 1.42 \times 10^{-11} r_i^2$

Image Well	$r_{i(m)} \times 10^5$	u_i	$W(u_i)$
I_1	0.13	2.4×10^{-3}	5.46
I_2	0.24	8.18×10^{-3}	4.24
I_3	0.37	1.94×10^{-2}	3.38
I_4	0.50	3.55×10^{-2}	2.79
I_5	0.61	5.28×10^{-2}	2.41
I_6	0.74	7.77×10^{-2}	2.05
I_7	0.87	1.07×10^{-1}	1.82
I_8	1.11	1.75×10^{-1}	1.32
I_9	3.70	1.94×10^{-1}	0.05

$S = 0.75 \times 10^{-3}$, $u_i = 1.1 \times 10^{-10} r_i^2$

Image Well	$r_{i(m)} \times 10^4$	u_i	$W(u_i)$
I_1	0.54	3.2×10^{-3}	5.17
I_2	0.92	9.3×10^{-3}	4.11
I_3	1.46	2.34×10^{-2}	3.22
I_4	2.0	4.4×10^{-2}	2.59
I_5	2.38	6.23×10^{-2}	2.26
I_6	2.92	9.38×10^{-2}	1.88
I_7	3.46	1.32×10^{-1}	1.59
I_8	3.84	1.62×10^{-1}	1.41
I_9	4.38	2.11×10^{-1}	1.18
I_{10}	4.92	2.66×10^{-1}	0.99
I_{11}	5.30	3.09×10^{-1}	0.88
I_{12}	5.84	3.75×10^{-1}	0.74
I_{13}	6.38	4.48×10^{-1}	0.62
I_{14}	6.76	5.03×10^{-1}	0.56
I_{15}	7.30	5.86×10^{-1}	0.47

*Image well distance r_i is given from case 2 (Figure 15)

At the end of 6 months (182.5 days) of pumping, the most distant image effect is given by the equation

$r_i = (2.25\ KDt/S)^{\frac{1}{2}}$, where t = 182.5 days,
KD = 10600m^2/day, $S = 0.11\times10^{-3}$

$r_i = (2.25 \times 1.06\times10^4 \times 182.5 / 0.11\times10^{-3})^{\frac{1}{2}} = \underline{2.0\times10^5 m}$

$u_i = r_i^2\ S/4KDt = r_i^2 \times 0.11\times10^{-3}/(4 \times 1.06\times10^4 \times 182.5) = 1.42\times10^{-11} r_i^2$

TABLE 7: (continued)

* The rate of pumping is given by the formula[14]:

$Q = 4\pi KDs/(W(u_r) + \Sigma_i W(u_i))$, where deconfinement drawdown s = 100 m,

$Q = 4\pi \times 1.06\times10^4 \times 100/(W(u_r) + \Sigma_i W(u_i))$, and $u_r = r^2 S/4KDt$

Where r = diameter of dewatering well ring = 100 m, and $S = 0.11\times10^{-3}$

$u_r = 100^2 \times 0.11\times10^{-3}/(4 \times 1.06\times10^4 \times 182.5) = 1.42\times10^{-7}$

From tables[15] $W(u_r) = 15.19$, $\Sigma_i W(u_i)$ from above table.

Case # 1. no image wells, $\Sigma_i W(u_i) = 0$, $Q = 4\pi \times 1.06\times10^4 \times 100/15.19 = 8.77\times10^5\ m^3/d$
$= \underline{10.2\ m^3/sec}$ (134,000 igpm)

Case # 2. three image wells, $\Sigma_i W(u_i) = 13.08$ (from above table)
$Q = 4\pi \times 1.06\times10^4 \times 100/(13.08 + 15.19) = 471,000\ m^3/d$
$= \underline{5.45\ m^3/sec}$ (72,000 igpm)

Case # 3. multiple image wells, $\Sigma_i W(u_i) = 23.52$, ($r_i = 3.7\times10^5$ m)
$Q = 4\pi \times 1.06\times10^4 \times 100/(23.52 + 15.19) = 344,100\ m^3/d$
$= \underline{4\ m^3/sec}$ (52,600 igpm)

Where $S = 0.75\times10^{-3}$, $KD = 9330\ m^2/day$, t = 182.5 days, s = 100 m

$r_i = (2.25 \times 9330 \times 182.5/0.75\times10^{-3})^{\frac{1}{2}} = \underline{71,500\ m}$

$u_i = r_i^2 \times 0.75\times10^{-3}/(4 \times 9330 \times 182.5) = \underline{1.1\times10^{-10}\ r_i^2}$

$Q = 4\ KDs/(W(u_r) + \Sigma_i W(u_i))$, and $u_r = r^2 S/4KDt$

Where r = 100 m, $S = 0.75\times10^{-3}$. $KD = 9330\ m^2/d$, t = 182.5 days

$u_r = 100^2 \times 0.75\times10^{-3}/(4 \times 9330 \times 182.5) = 1.1\times10^{-6}$, from tables $W(u_r) = 13.14$

Case # 1. where no image wells exist, $\Sigma_i W(u_i) = 0$
$Q = 4\pi \times 9330 \times 100/13.14 = 892,300\ m^3/d$
$= \underline{10.3\ m^3/sec}$ (136,300 igpm)

Case # 2. Where three image wells exist, $\Sigma_i W(u_i) = 12.5$
$Q = 4\pi \times 9330 \times 100/(13.14 + 12.5) = 457,300\ m^3/d$
$= \underline{5.3\ m^3/sec}$ (69,900 igpm)

Case # 3. Where multiple image wells exist, $\Sigma_i W(u_i) = 27.67$
$Q = 4\pi \times 9330 \times 100/(27.67 + 13.14) = 287,400\ m^3/d$
$= \underline{3.3\ m^3/sec}$ (43,900 igpm)

Table 8. Comparison of Aquifer Coefficients Determined by Various Methods and Authors.

Test Site	KD* range majority (extremes) m²/d x 10³	KD* range majority (extremes) igpd/ft x 10⁵	K* range majority (extremes) m/s x 10⁻³	S* range majority (extremes) x 10⁻³	Pumping rate m³/s (igpm)	Pumping duration min (days)	Analysis method	Author	Comment
X 25	1.0 – 2.83 (0.23 – 15.5)	0.67 – 1.9 (0.154 – 10.4)	0.173 – 0.49 (0.04 – 0.27)		0.067 (883)	15850 (11)	unsteady – state, leaky aquifer [9] (log dd vs log t)	Golder [3]	
X 25	0.96 – 1.08 (0.73 – 5.2)	0.64 – 0.72 (0.49 – 3.49)	0.157 – 0.187 (0.126 – 0.90)	0.45 – 0.89 (0.33 – 2.06)	0.067 (883)	15850 (11)	unsteady – state, non-leaky aquifer [11] (dd vs log r)	SIG*	early time data (100 min) used to calculate KD & S
R 190	9.94 – 11.75 (7.86 – 13.05)	6.66 – 7.88 (5.27 – 8.75)	1.72 – 2.03 (1.36 – 2.25)	0.78 – 2.86 (0.48 – 5.23)	0.172 (2345)	7500 (5.2)	unsteady – state, non-leaky aquifer [10] (log dd vs log t)	Golder [4]	analysis based on the first 2000 minutes of pumping
R 190	2.63 – 3.2 (1.43 – 3.54)	1.77 – 2.15 (0.96 – 2.38)	0.45 – 0.55 (0.25 – 0.61)	1 – 82 (0.03 – 12)	0.177 (2345)	33262 (23.1)	unsteady – state fracture flow method [12]	Brown-Erdman [5]	anisotropic aquifer conditions noted
R 190	2.25 – 2.46 (2.14 – 2.56)	1.51 – 1.65 (1.44 – 1.72)	0.39 – 0.425 (0.25 – 0.44)	13 – 110 (0.4 – 3440)	0.177 (2345)	33262 (23.1)	unsteady – state, non-leaky aquifer [11] (dd vs log t)	Brown-Erdman [5]	late time data used (after 10,000 min) possible multiple negative boundary condition noted
R 190	7.73 – 10.37 (6.54 – 11.2)	5.18 – 6.95 (4.38 – 7.51)	1.34 – 1.79 (1.13 – 1.93)	0.50 – 1.48 (0.144 – 2.5)	0.177 (2345)	33262 (23.1)	unsteady-state, non-leaky aquifer [13] (dd vs log t)	SIG*	early time data (before 1000 min) used to calculate KD and S, multiple boundary conditions
R 190	10.1 – 10.6 (2.39 – 11.1)	6.77 – 7.11 (1.60 – 7.44)	1.74 – 1.83 (0.41 – 1.92)	0.62 – 2.74 (0.56 – 19.5)	0.177 (2345)	33262 (23.1)	unsteady-state, non-leaky aquifer [10] (log dd vs log t)	SIG*	" " " " method of images used to determine barrier boundary distances
R 190	6.83 – 9.33 (6.83 – 10.6)	3.95 – 6.25 (1.07 – 7.10)	1.18 – 1.61 (1.18 – 1.83)	0.75 – 1.39 (0.11 – 7.8)	0.177 (2345)	33262 (23.1)	unsteady—state non-leaky aquifer [11] (dd vs log r)	SIG*	early time data (115 min) used to calculate KD & S. method of images used to locate barrier boundary distances

KD = Transmissivity in square metres per day (m^2/d) and imperial gallons per day per foot

K = Hydraulic conductivity in metres per second (m/s)

S = Storativity (dimensionless)

SIG = Stevenson International Groundwater Consultants Ltd.

Superscript numbers in column titled "Analysis method" refer to references cited (P.23)

11.0 PLATES

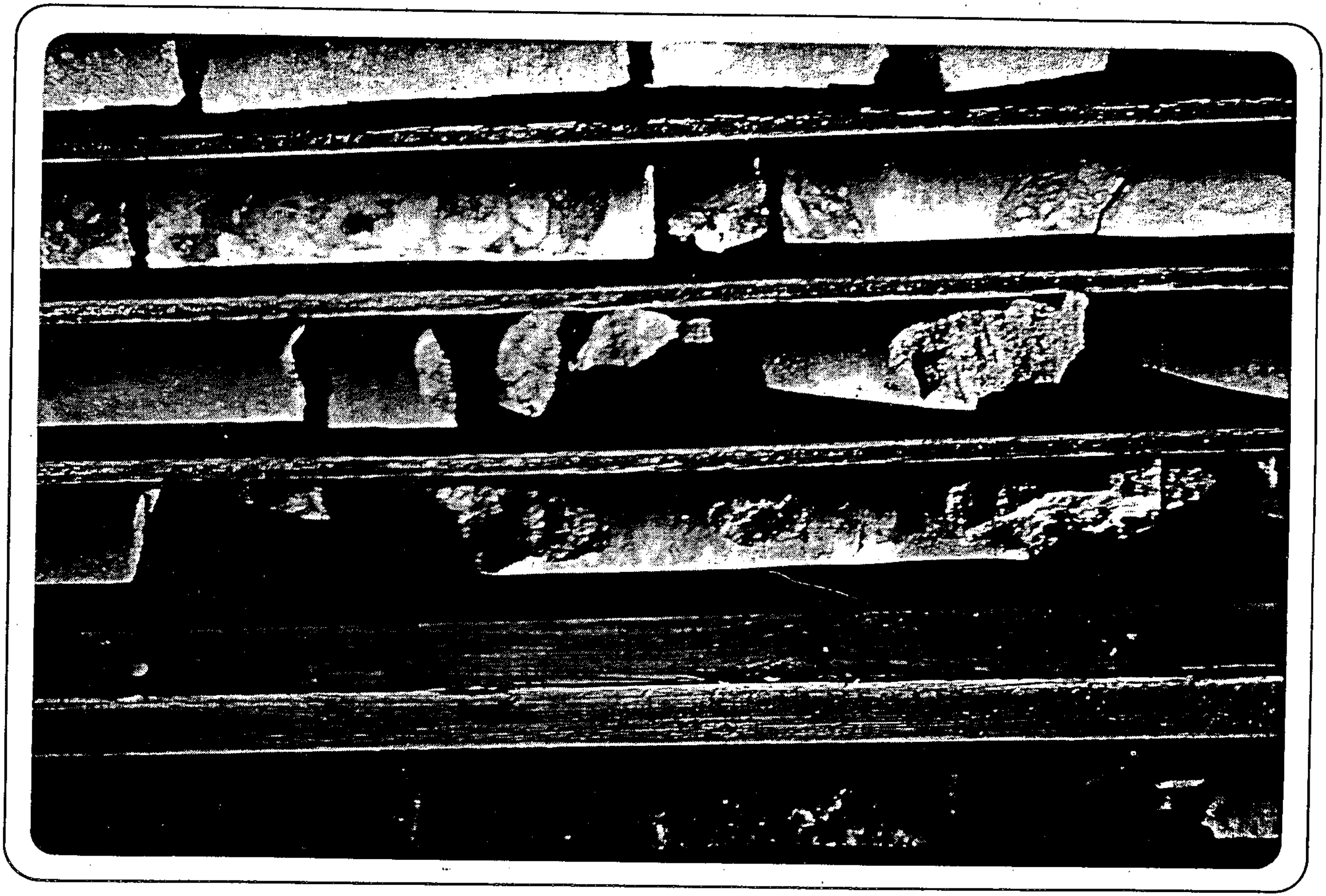


Plate 1: Oil stained, poor vuggy limestone/dolomite, Slave Point unit, Great Slave Reef core No. 412.

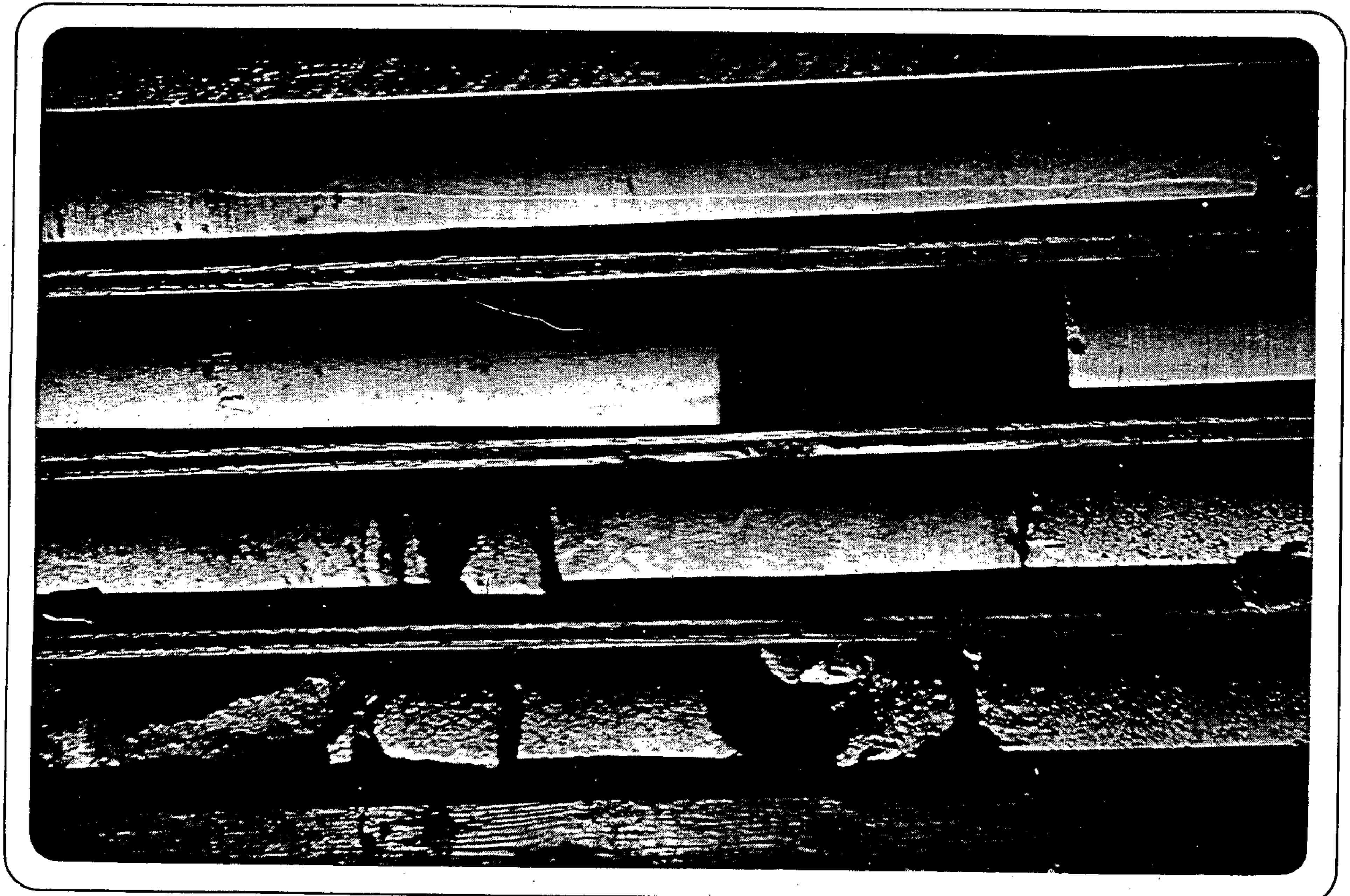


Plate 2: Tight, argillaceous, fine - grained limestone, Watt Mountain unit, Great Slave Reef core No. 334.

Plate 3: Oil stained, moderate vuggy dolomite, near the top of the Presquile unit, Great Slave Reef core No. 334.

Plate 4: Small vugs, pitted regions and a healed joint at the top of the Pine Point unit, Great Slave Reef core No. 334.

Plate 5: Vertical open fractures on the south wall of open pit J44, Pine Point Mines, N. W. T.

12.0 ILLUSTRATIONS

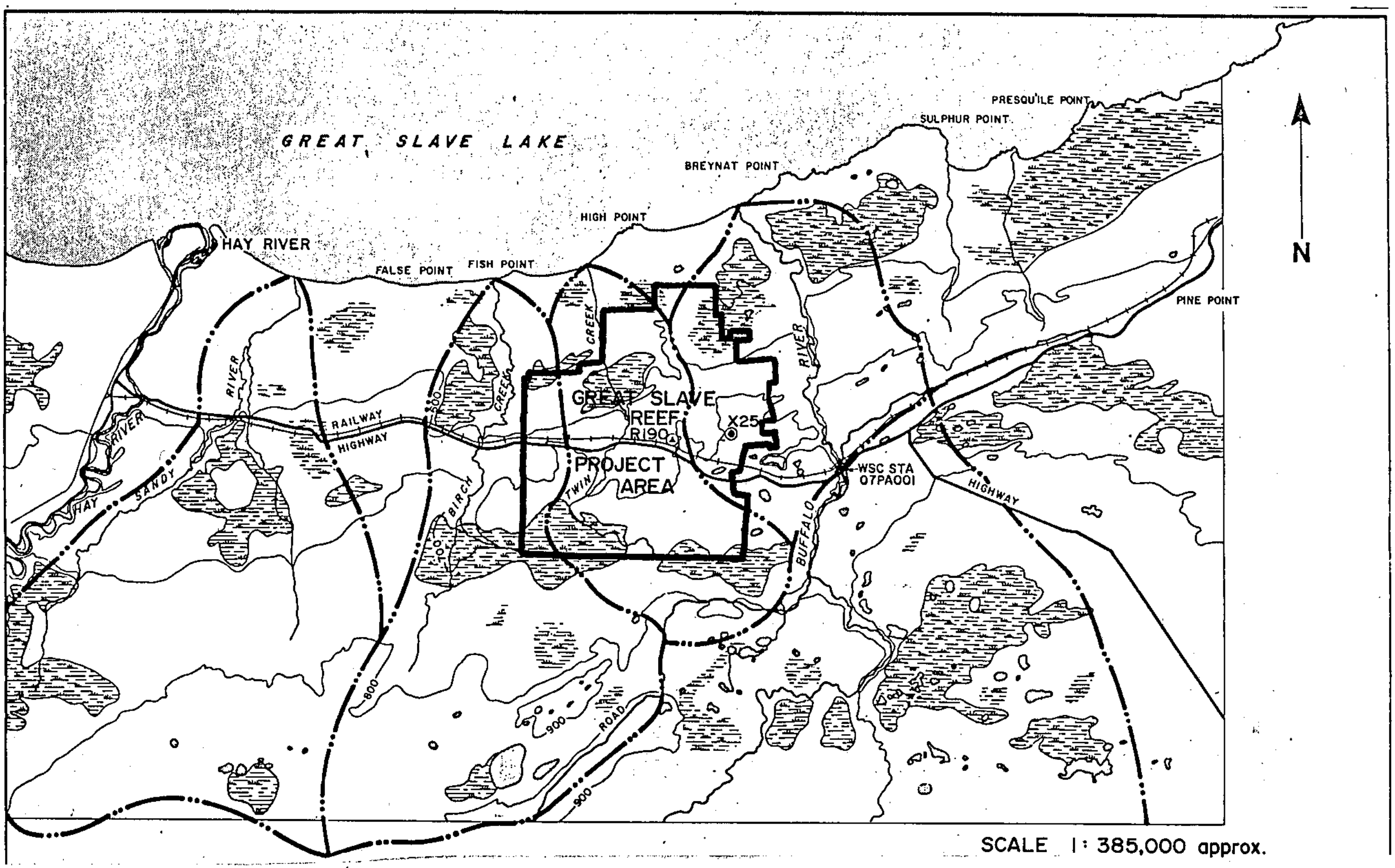


FIGURE 1. TOPOGRAPHY AND DRAINAGE PATTERNS AROUND THE GREAT SLAVE REEF PROJECT AREA. (after Figure 4.3-1[8])

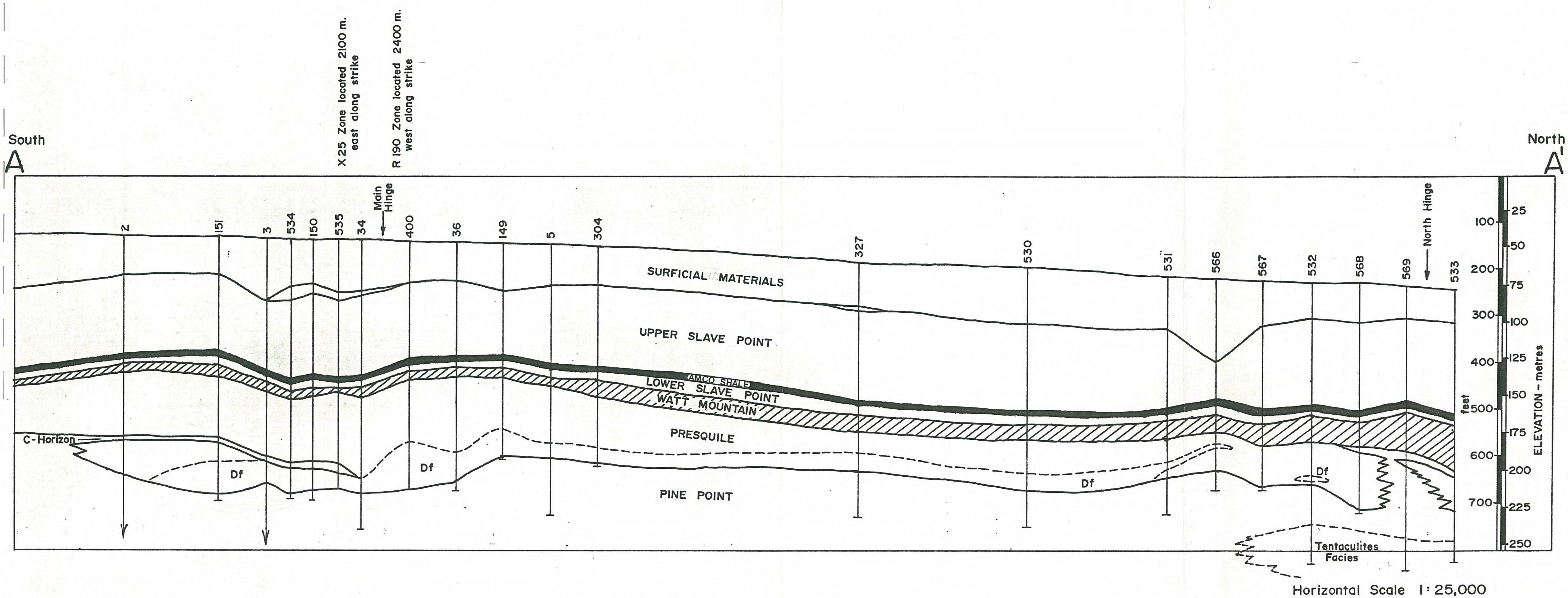


FIGURE 2. NORTH-SOUTH STRATIGRAPHIC SECTION THROUGH THE GREAT SLAVE REEF PROJECT AREA
(after Westmin Resources Limited cross section, Feb. 1982)

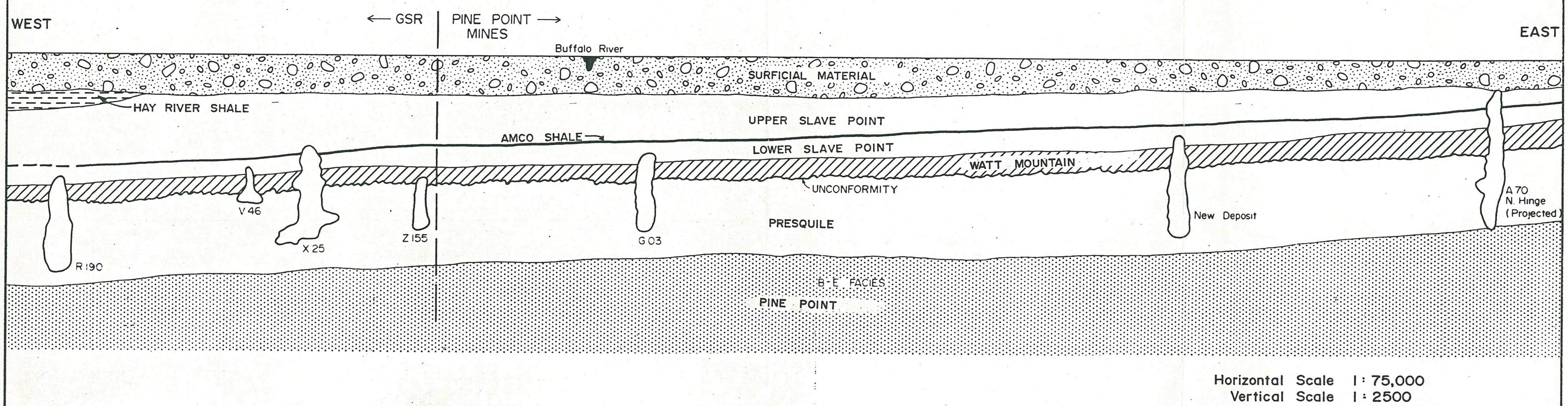


FIGURE 3. EAST-WEST STRATIGRAPHIC SECTION THROUGH THE CENTRAL PARTS OF GREAT SLAVE REEF AND PINE POINT MINES PROJECT AREAS, WITH ADJACENT MINERALIZED ZONES PROJECTED INTO THE SECTION PLANE. (after Westmin Resources Limited Diagramatic Long Section Parallel Main Hinge)

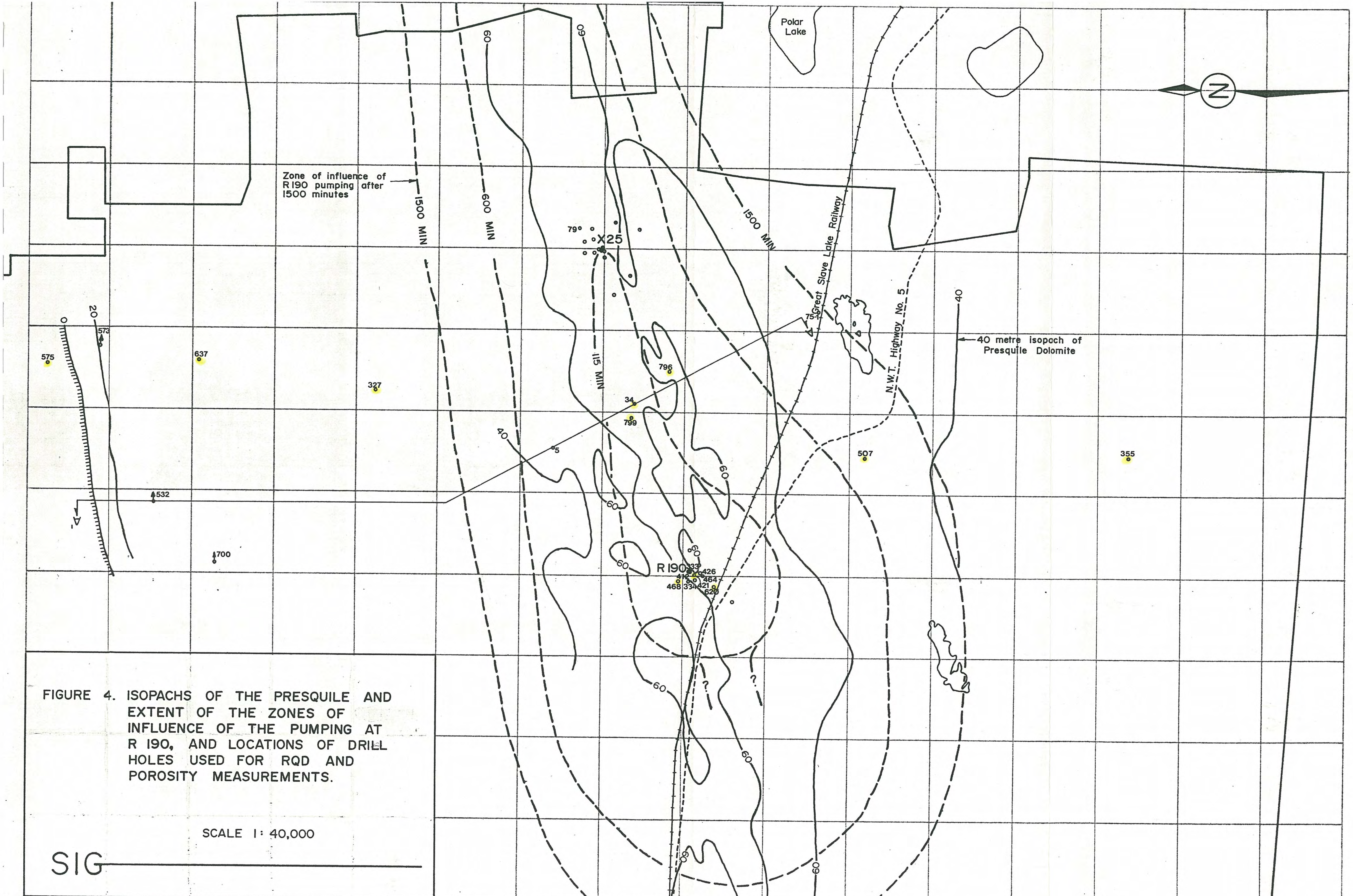


FIGURE 4. ISOPACHS OF THE PRESQUILE AND EXTENT OF THE ZONES OF INFLUENCE OF THE PUMPING AT R 190, AND LOCATIONS OF DRILL HOLES USED FOR RQD AND POROSITY MEASUREMENTS.

SCALE 1: 40,000

SIG

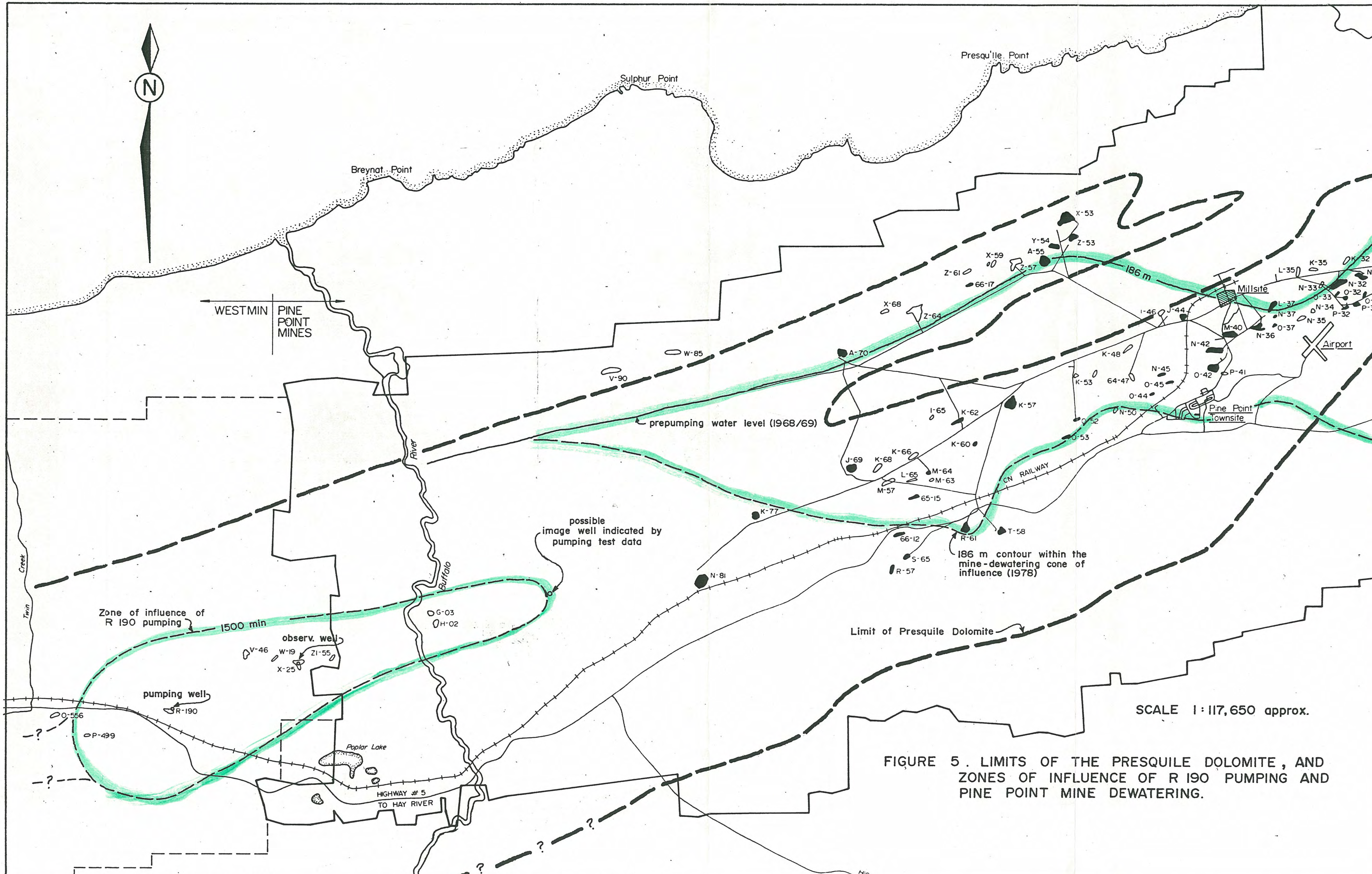


FIGURE 5. LIMITS OF THE PRESQUILE DOLOMITE, AND ZONES OF INFLUENCE OF R 190 PUMPING AND PINE POINT MINE DEWATERING.

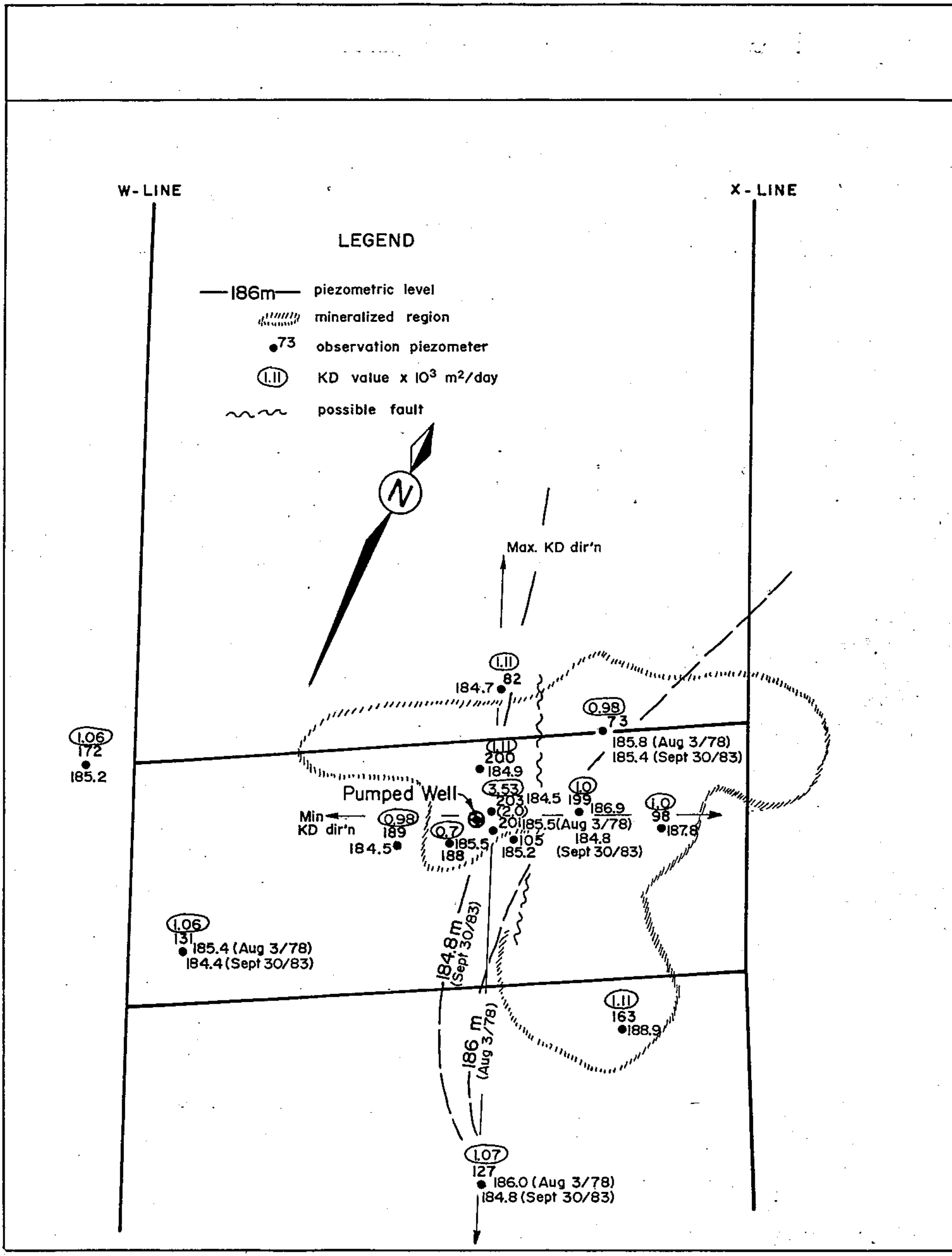


FIGURE 6. X25 PIEZOMETER LOCATIONS AND WATER LEVELS. (after Figure 19[3])

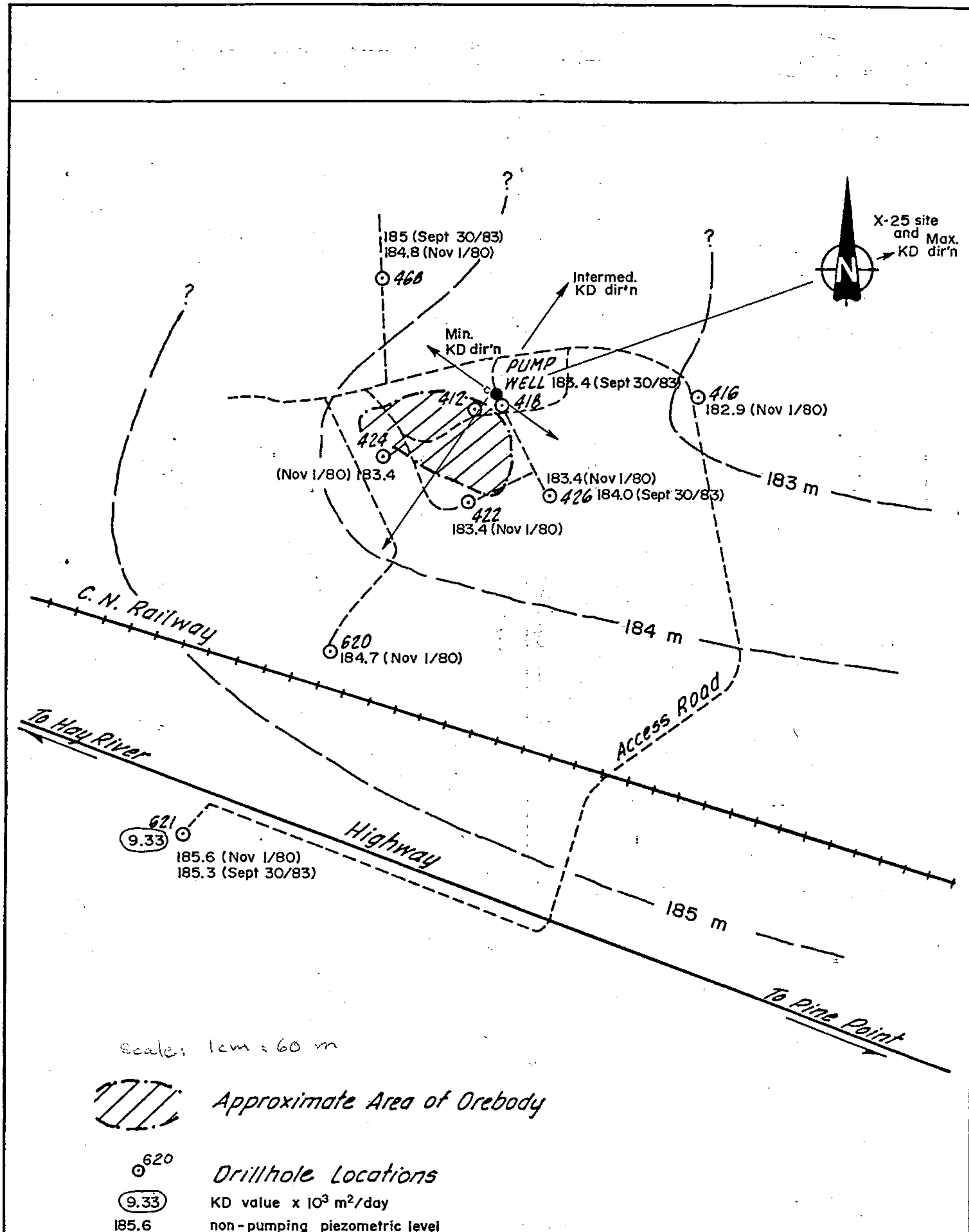


FIGURE 7. R 190 PIEZOMETER LOCATIONS AND WATER LEVELS (after Figure 2[4])

FIGURE 8. DRAWDOWN VERSUS LOG TIME PLOTS OF DATA FROM SELECTED OBSERVATION WELLS DURING THE X25 PUMPING TEST, GREAT SLAVE REEF PROJECT.

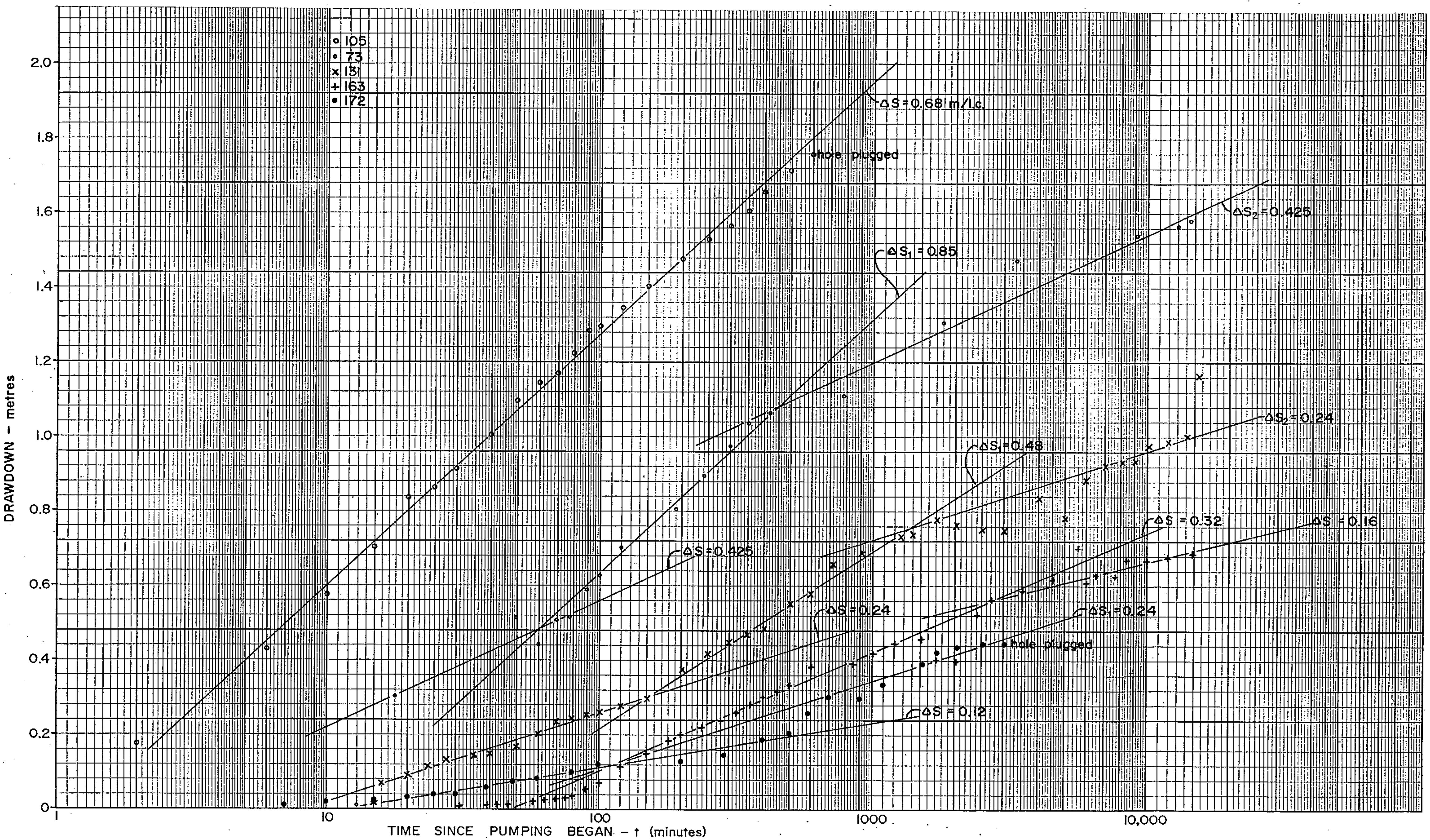
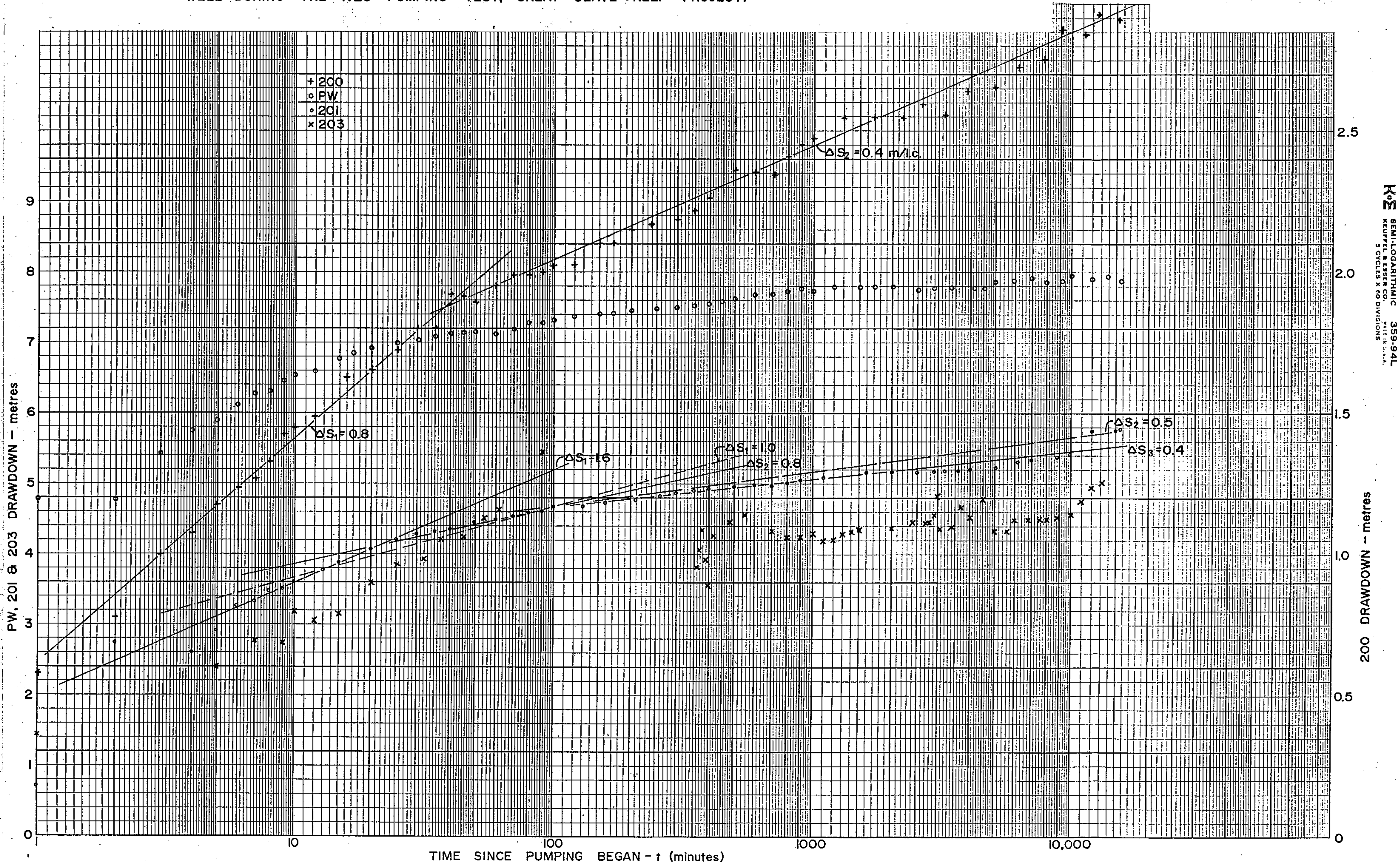


FIGURE 9. DRAWDOWN VERSUS LOG TIME PLOTS OF DATA FROM SELECTED OBSERVATION WELLS AND THE PUMPING WELL DURING THE X25 PUMPING TEST, GREAT SLAVE REEF PROJECT.



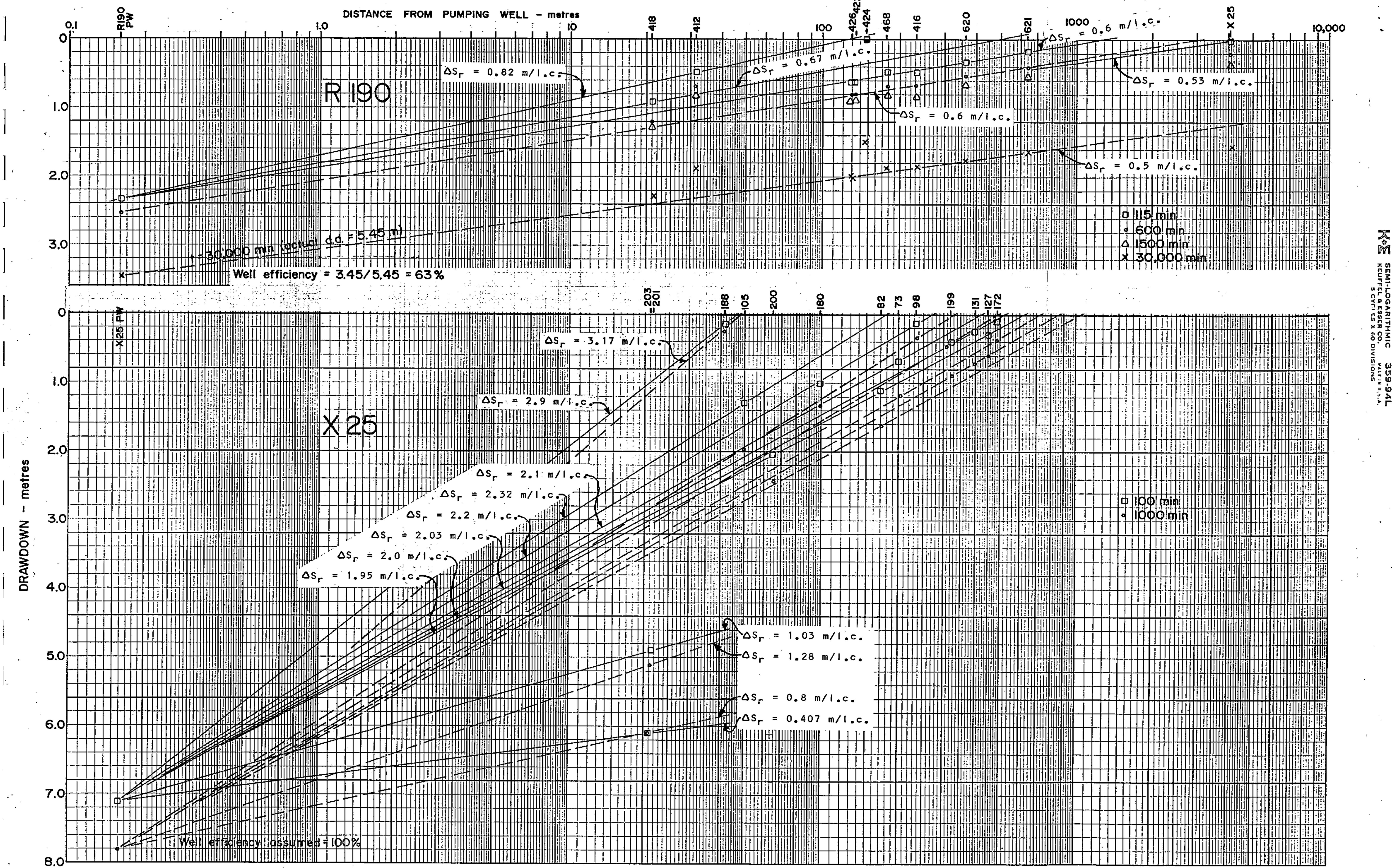


FIGURE 10. DRAWDOWN VERSUS LOG DISTANCE PLOTS OF X25 AND R190 PUMPING TEST DATA, GREAT SLAVE REEF PROJECT.

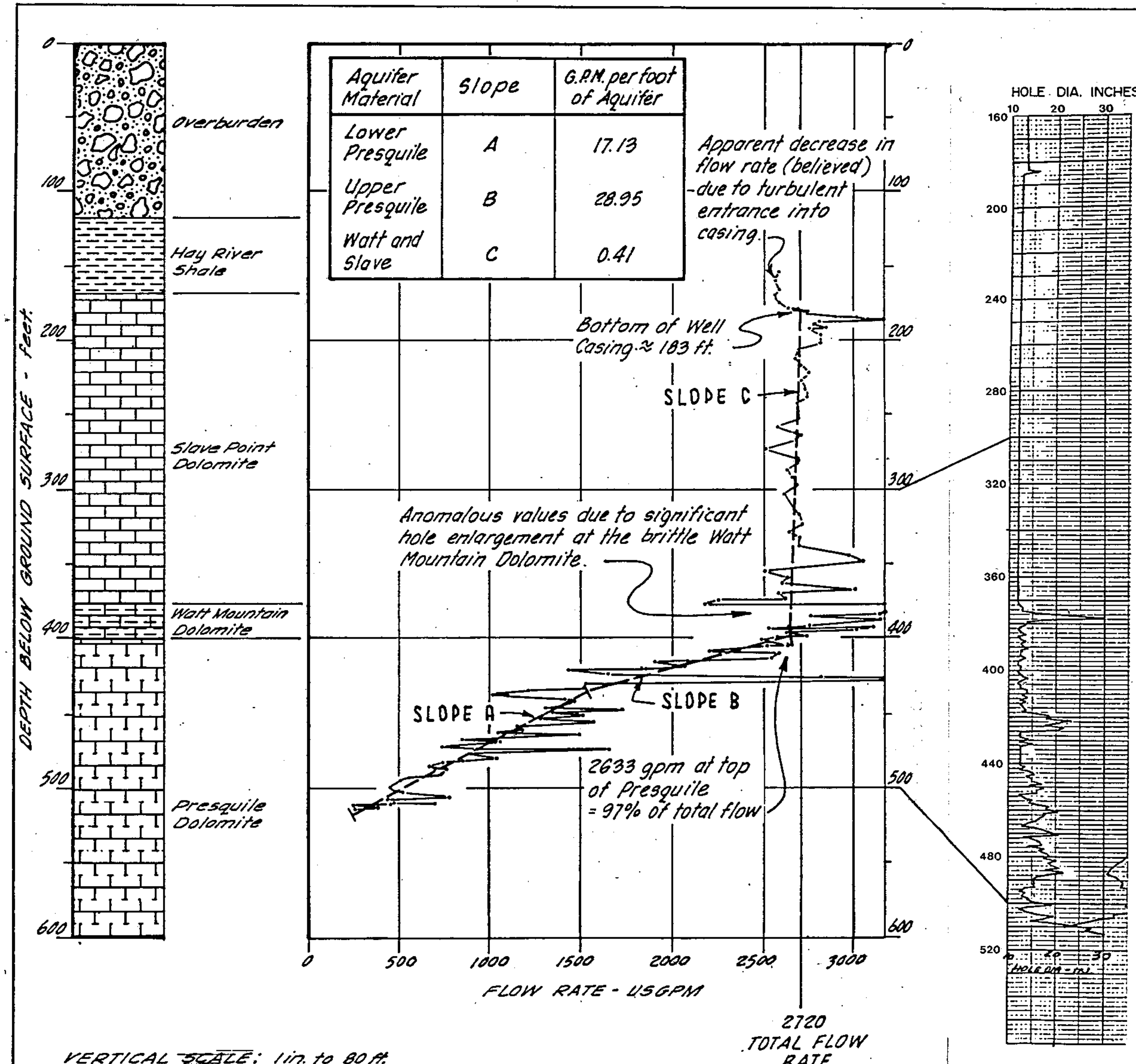


FIGURE II. VELOCITY AND CALIPER LOGS OF R190 WELL (after Figures 7 and B3-2[4])

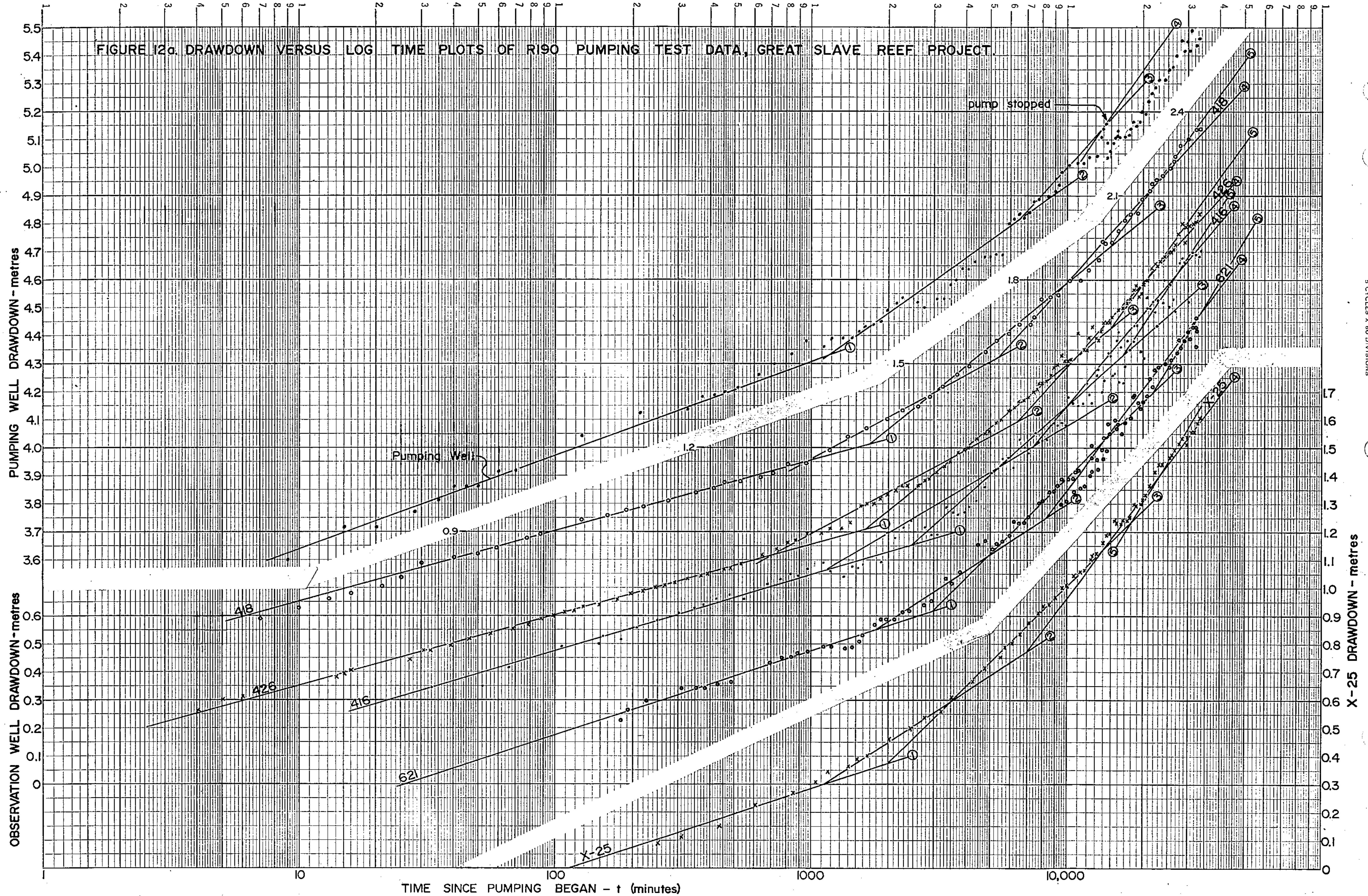


FIGURE 12a. DRAWDOWN VERSUS LOG TIME PLOTS OF R190 PUMPING TEST DATA, GREAT SLAVE REEF PROJECT.

FIGURE 12b. DRAWDOWN VERSUS LOG TIME PLOTS OF R190 PUMPING TEST DATA, GREAT SLAVE REEF PROJECT.

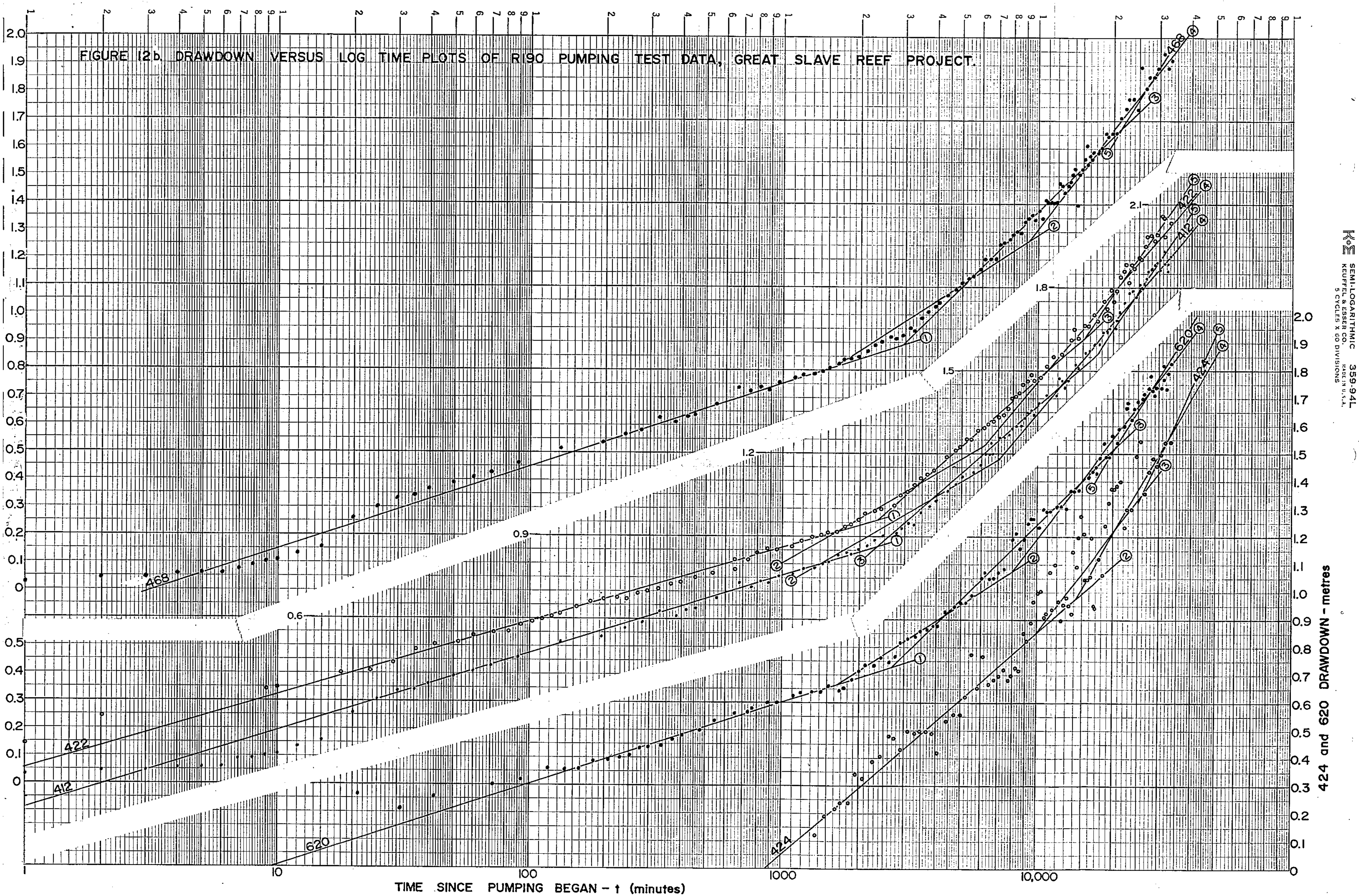


FIGURE 13a. LOG DRAWDOWN VERSUS LOG TIME PLOTS OF R 190 PUMPING TEST DATA, GREAT SLAVE REEF PROJECT.

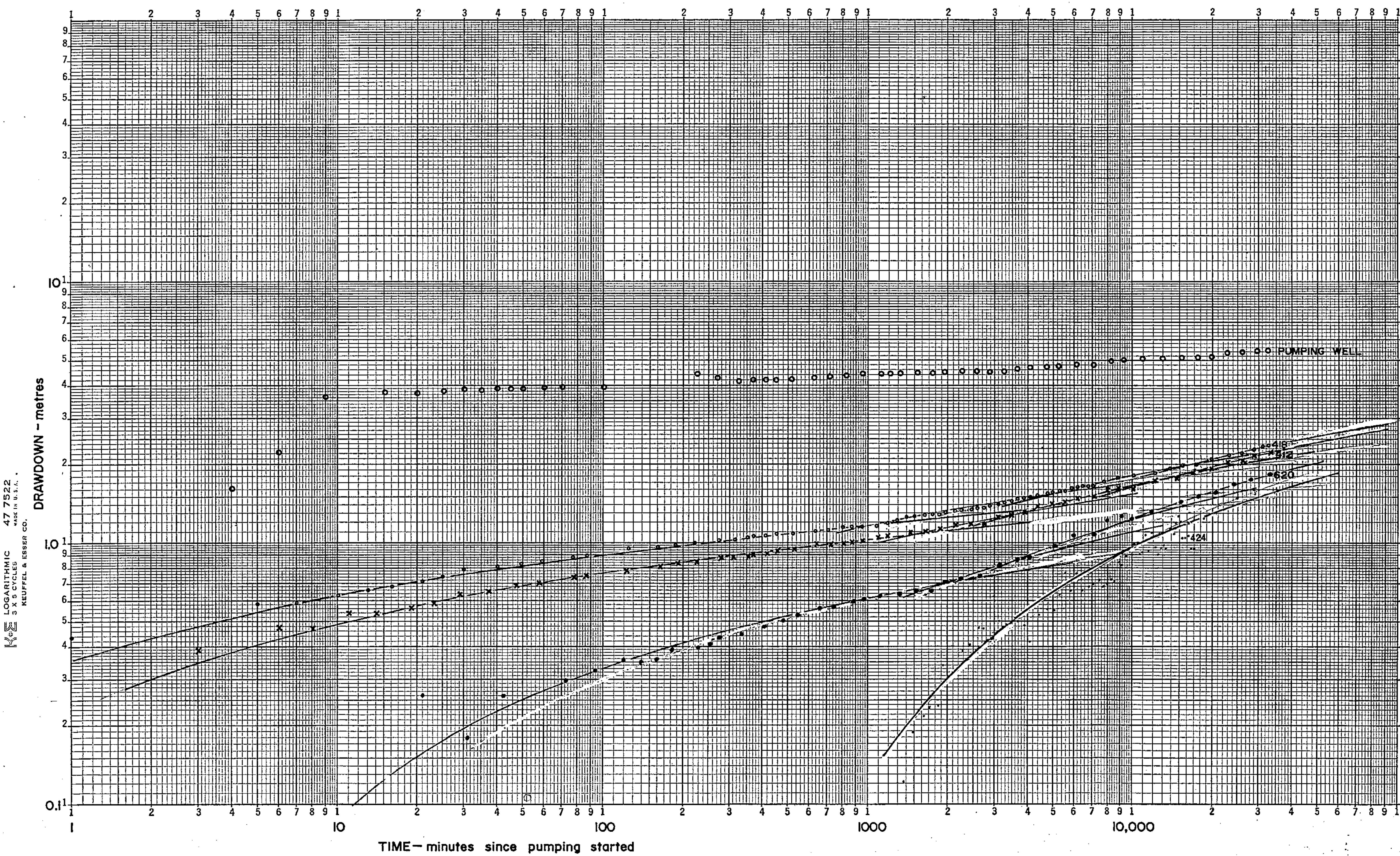


FIGURE 13b. LOG DRAWDOWN VERSUS LOG TIME PLOTS OF R190 PUMPING TEST DATA, GREAT SLAVE REEF PROJECT.

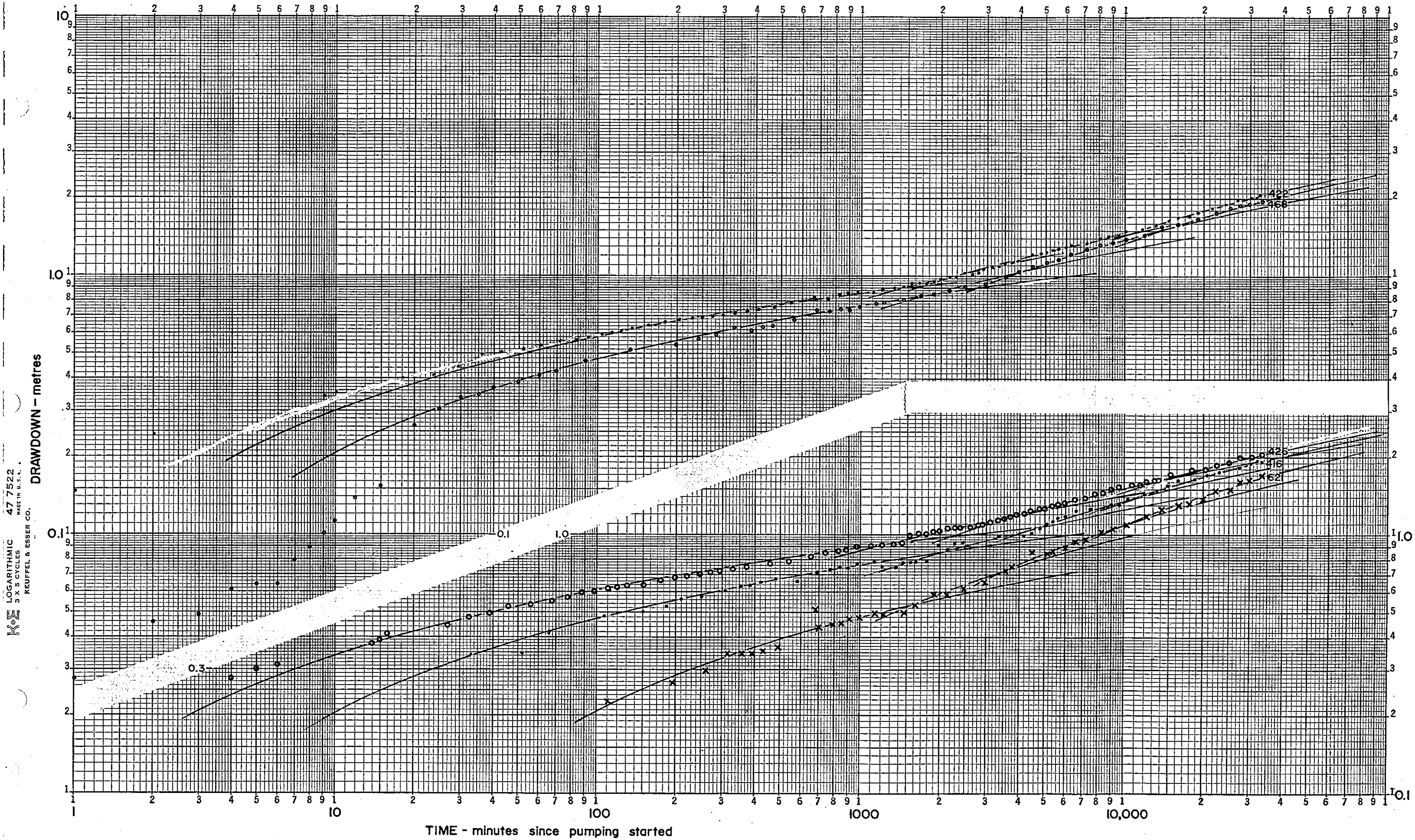
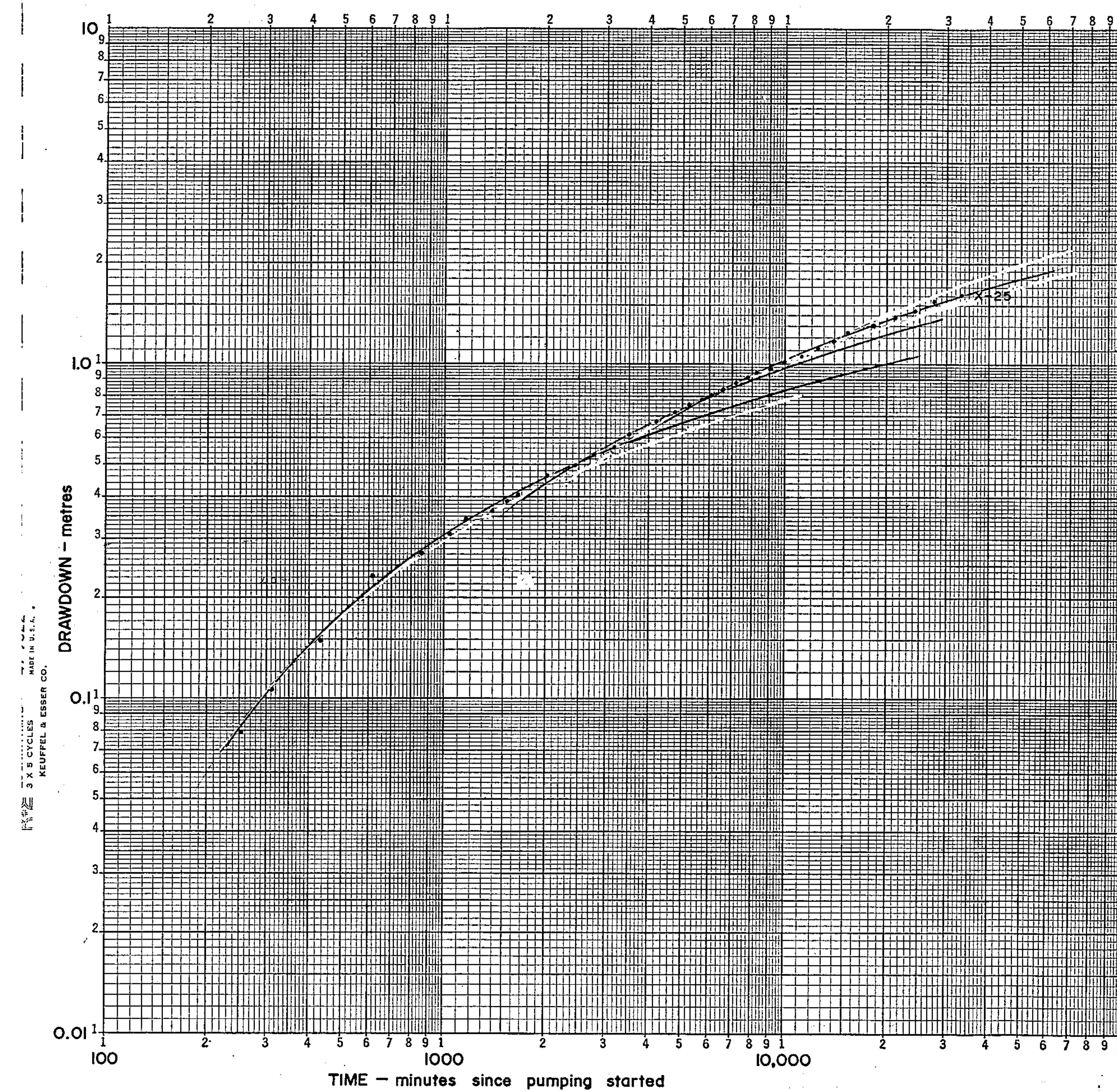


FIGURE 13c. LOG DRAWDOWN VERSUS LOG TIME PLOT OF R190 PUMPING TEST DATA COLLECTED AT X 25, GREAT SLAVE REEF PROJECT.



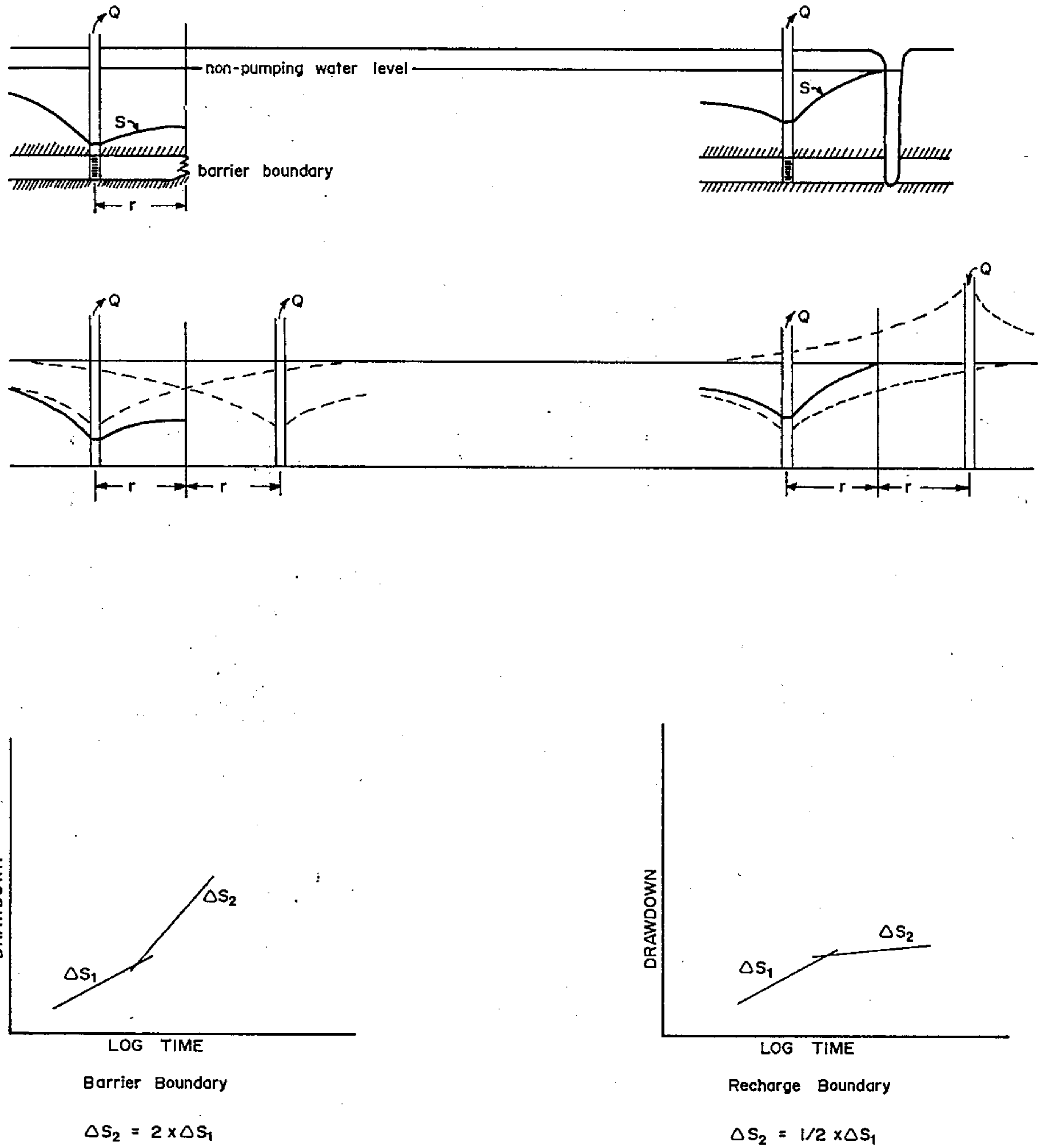
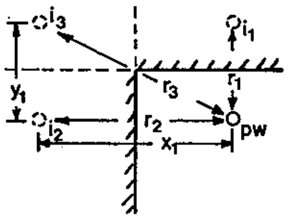


FIGURE 14. EFFECTS OF BARRIER AND RECHARGE BOUNDARIES ON DRAWDOWN RATES IN PUMPING AND OBSERVATION WELLS.

CASE I. Rectangular barrier boundaries represented by three discharging image wells.



slopes of drawdown – log t curves are:

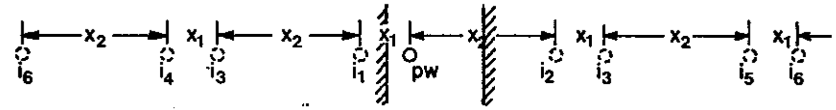
ΔS_1

$\Delta S_2 = 2 \times \Delta S_1$ (add i_1 effect)

$\Delta S_3 = 3 \times \Delta S_1$ (add i_2 effect)

$\Delta S_4 = 4 \times \Delta S_1$ (add i_3 effect)

CASE 2. Parallel barrier boundaries represented by an infinite number of discharging image wells.



$r_1 = x_1$

$r_2 = x_2$

$r_3 = x_1 + x_2$

$r_4 = 2x_1 + x_2$

$r_5 = x_1 + 2x_2$

$r_6 = 2(x_1 + x_2)$

slopes of the drawdown – log t curves are:

ΔS_1

$\Delta S_2 = 2 \times \Delta S_1$ (add i_1 effect)

$\Delta S_3 = 3 \times \Delta S_1$ (add i_2 effect)

$\Delta S_4 = 5 \times \Delta S_1$ (add effects of $2i_3$)

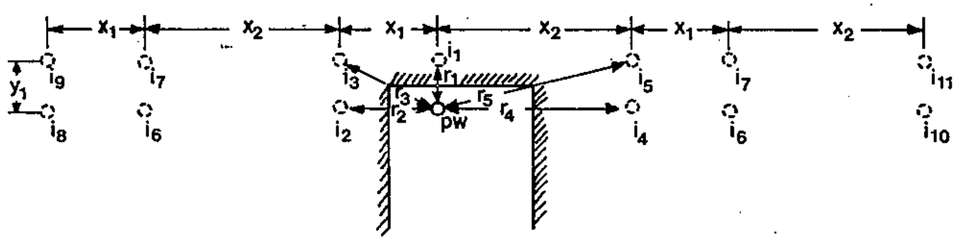
$\Delta S_5 = 6 \times \Delta S_1$ (add i_4 effect)

$\Delta S_6 = 7 \times \Delta S_1$ (add i_5 effect)

$\Delta S_7 = 9 \times \Delta S_1$ (add effects of $2i_6$)

and so on

CASE 3. Three rectangular boundaries represented by an infinite number of discharging image wells.



$r_1 = y_1$

$r_2 = x_1$

$r_3 = (x_1^2 + y_1^2)^{1/2}$

$r_4 = x_2$

$r_5 = (x_2^2 + y_1^2)^{1/2}$

$r_6 = x_1 + x_2$

$r_7 = ((x_1 + x_2)^2 + y_1^2)^{1/2}$

slopes of the drawdown – log t curves are:

ΔS_1

$\Delta S_2 = 2 \times \Delta S_1$ (add i_1 effect)

$\Delta S_3 = 3 \times \Delta S_1$ (add i_2 effect)

$\Delta S_4 = 4 \times \Delta S_1$ (add i_3 effect)

$\Delta S_5 = 5 \times \Delta S_1$ (add i_4 effect)

$\Delta S_6 = 6 \times \Delta S_1$ (add i_5 effect)

$\Delta S_7 = 8 \times \Delta S_1$ (add effects of $2i_6$)

$\Delta S_8 = 10 \times \Delta S_1$ (add effects of $2i_7$)

and so on

FIGURE 15. RELATIONS BETWEEN MULTIPLE BOUNDARY EFFECTS ON DRAWDOWN RATES IN PUMPING WELLS AND CLOSE OBSERVATION WELLS.

13.0 APPENDICES

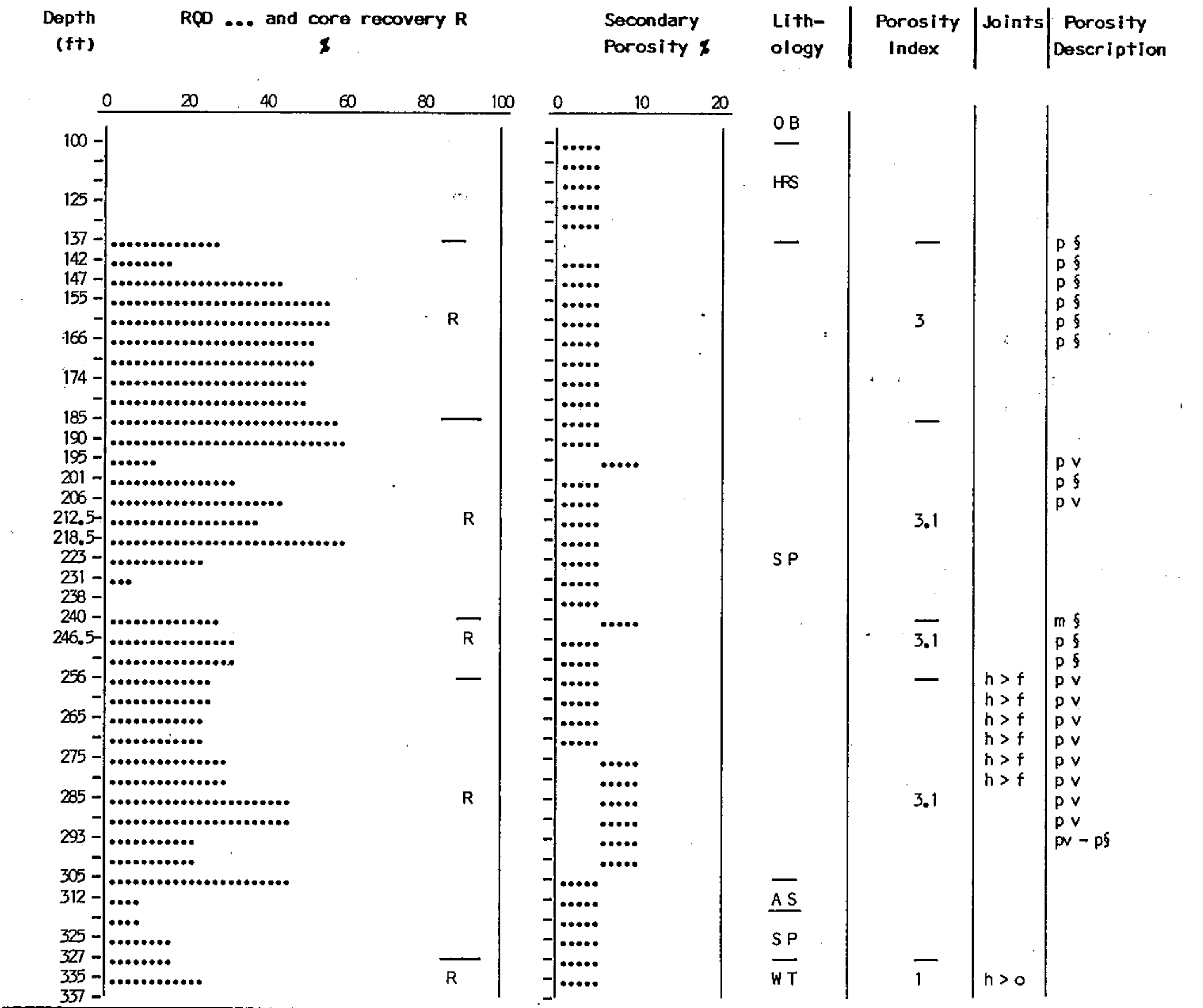
Appendix A

Structural properties of diamond drill core
from Great Slave Reef project area.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 426



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

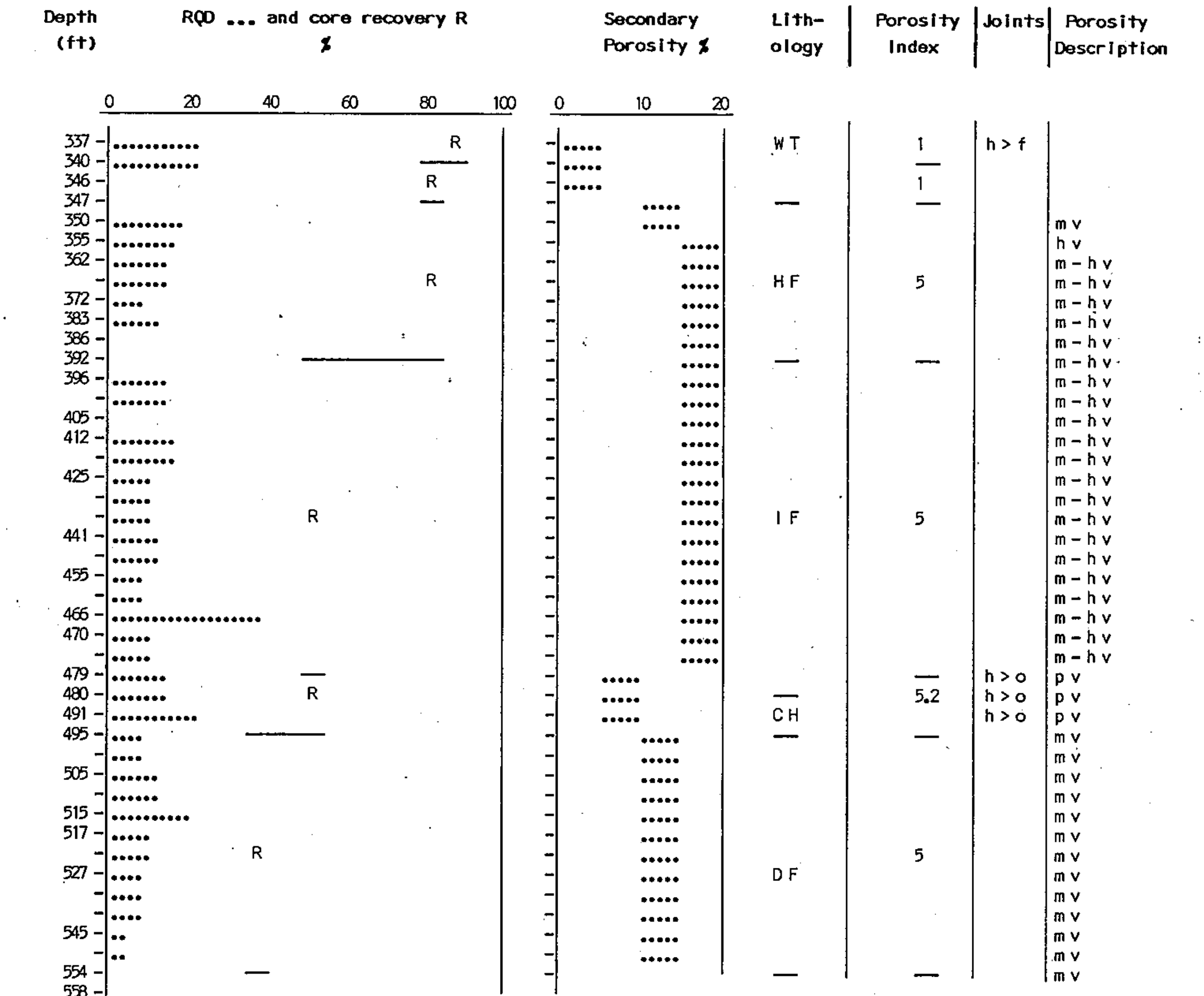
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 426



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 426

Depth (ft)	RQD ... and core recovery R % (0 20 40 60 80 100)	Secondary Porosity % (0 10 20)	Lith- ology	Porosity Index	Joints	Porosity Description
558		•••••			l > o	p v
		•••••			l > o	p v
567	•••	•••••			l > o	p v
	•••	•••••			l > o	p v
575	•••	•••••			l > o	p v
	•••	•••••			l > o	p v
584		•••••			l > o	p v
		•••••			l > o	p v
	R	•••••		4/5.1	l > o	p v
600		•••••	E B			
615	••••••••••••	•••••			l-h >o	mv - p§
617	••••••••••••	•••••			l > o	mv - p§
	••••••••••••	•••••			l > o	mv - p§
628	••••	•••••			l > o	mv - p§
633		•••••			l > o	
		•••••			l > o	
645	•••	•••••				
655	—		—	—		—

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

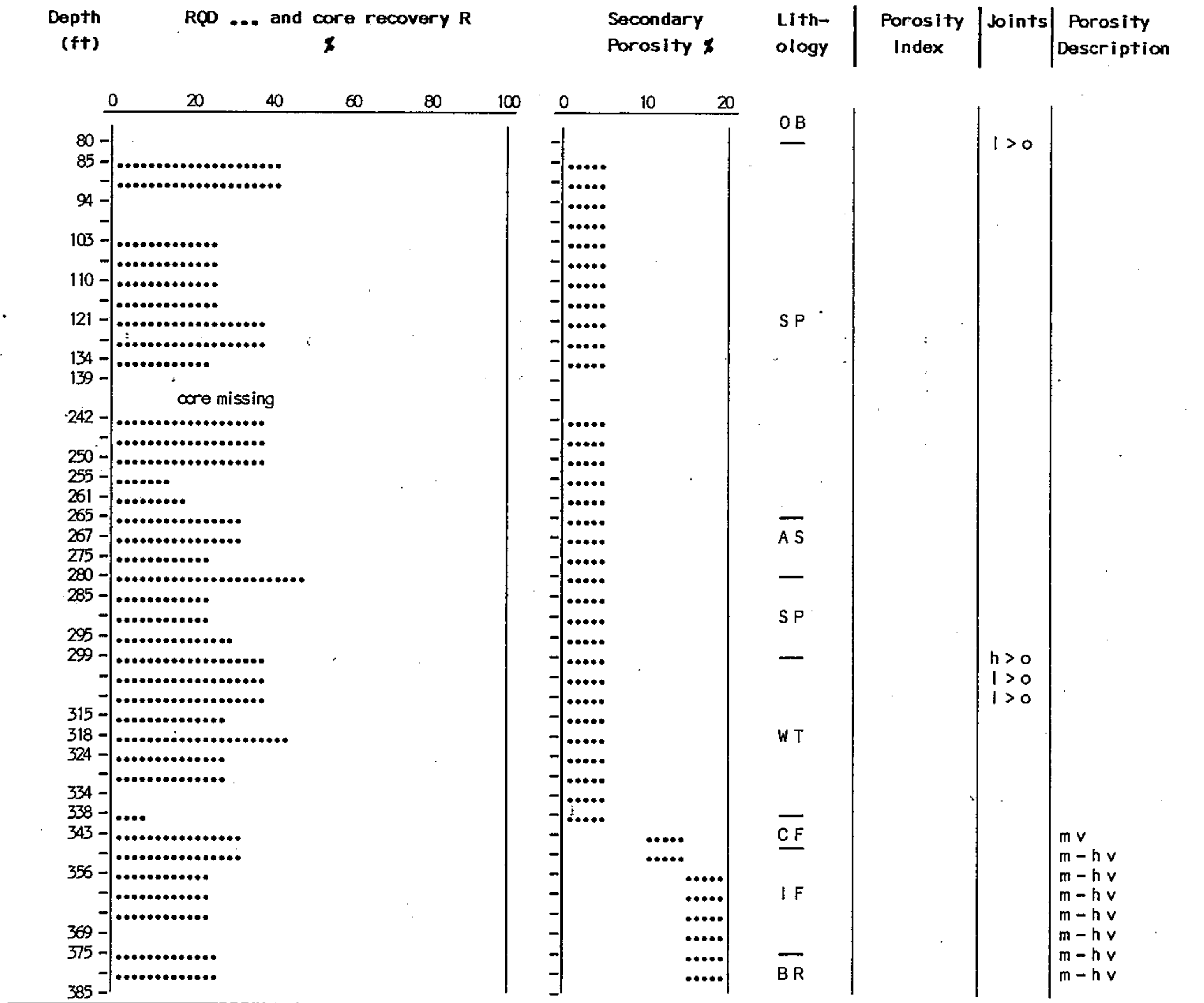
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 637



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

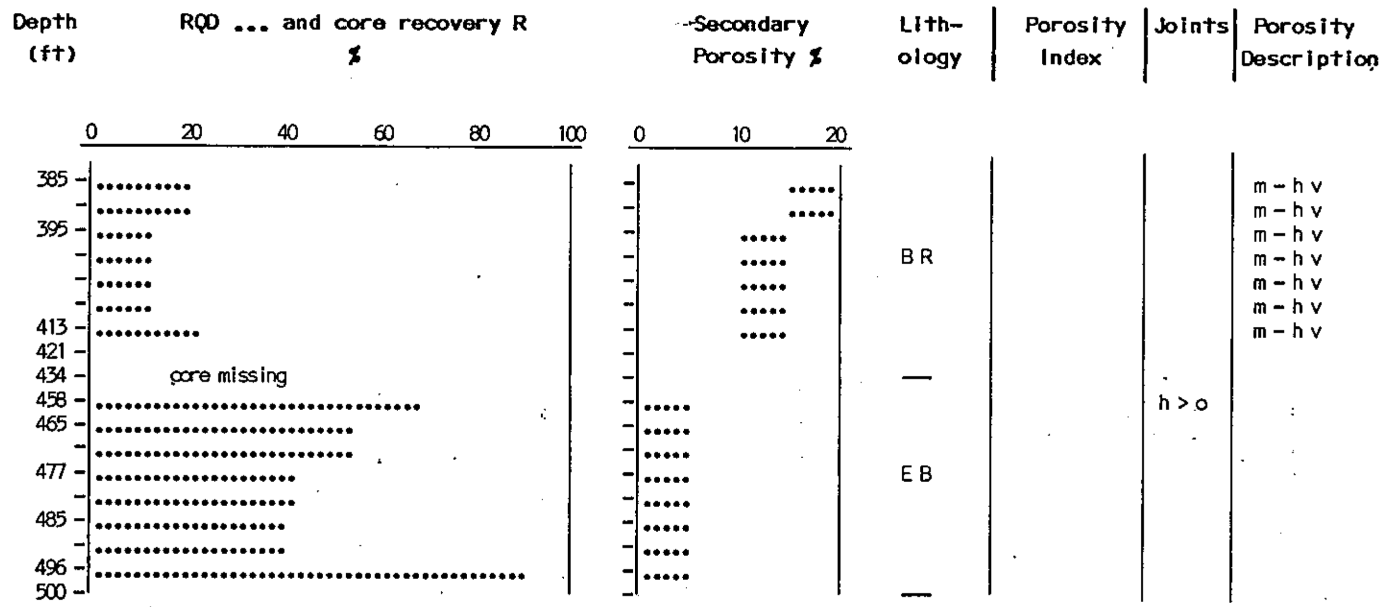
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 637



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

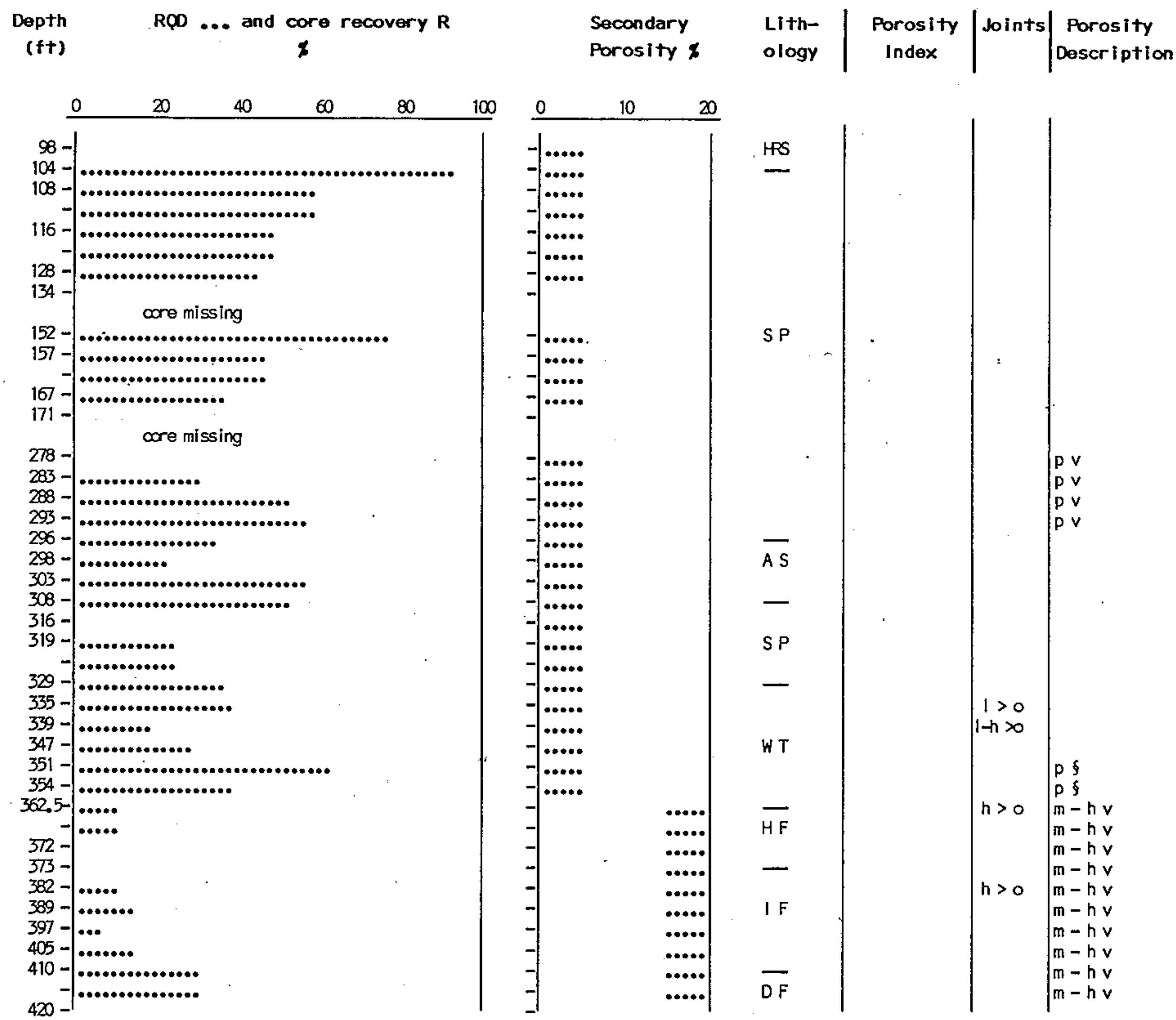
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 327



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

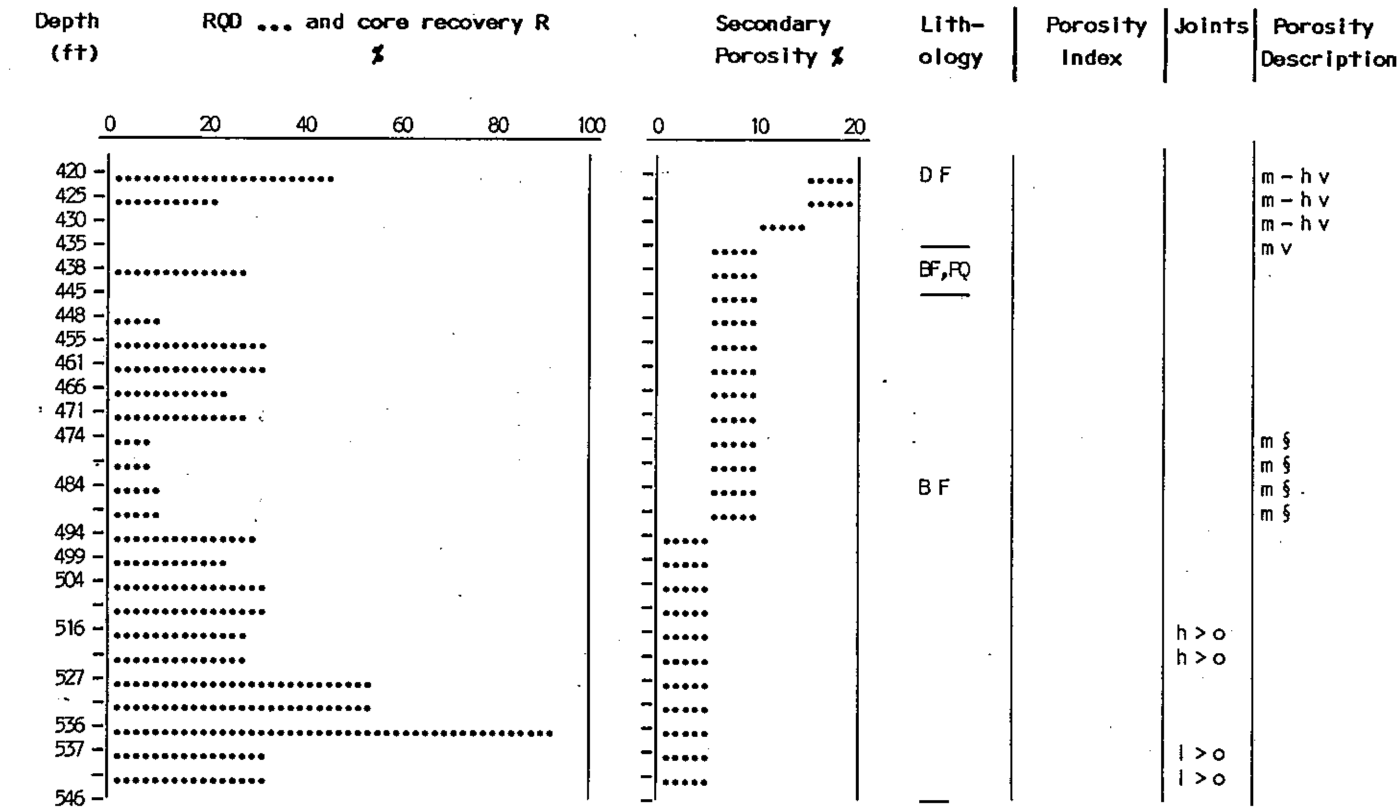
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 327



RQD – rock quality designation – total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity – porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index – classification system for rock fractures. (WRL)

Core recovery – total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

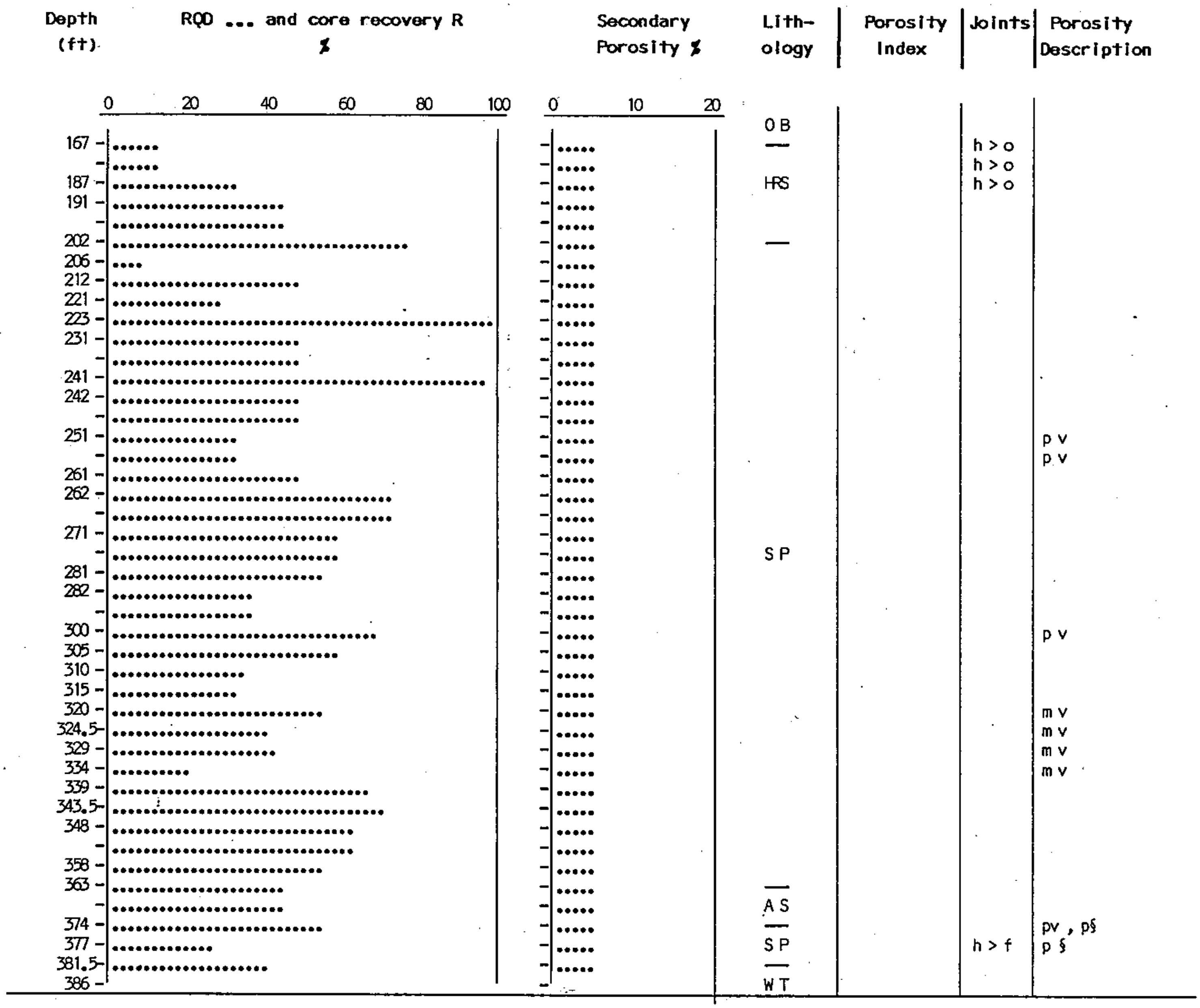
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 355



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

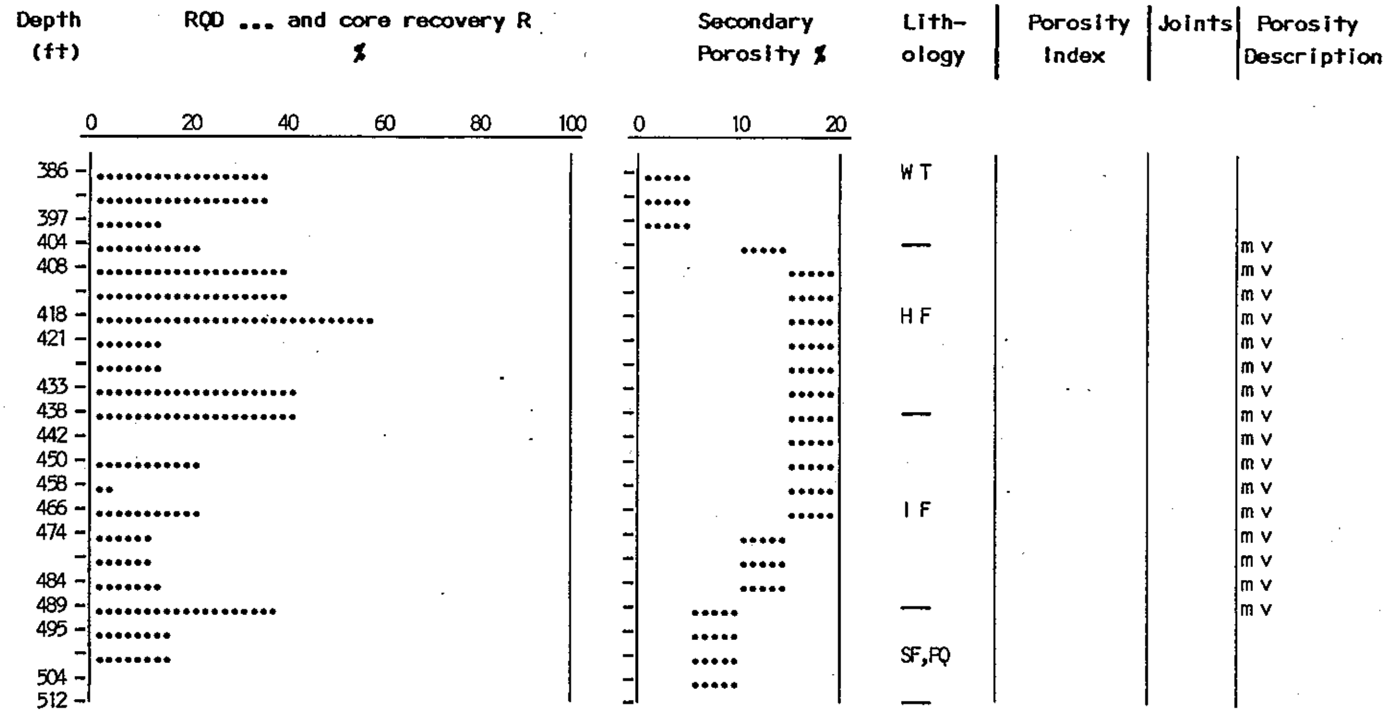
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 355



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 464

Depth (ft)	Lithology	Porosity Index	Joints	Porosity Description
114	HRS		l >	
161			l >	p§ , pv
-		1	l >	p§ , pv
193			l >	
-			l >	
226			h > o	
-		1/4.1	h > o	
241				
-				
263				
-	SP	3		
281				
286				p§ , pv
-		3		p§ , pv
301				
302				p §
306				p§ , pv
-		3		p§ , pv
318				p§ , pv
323				p§ , pv
330		1/3		p§ , pv
339	AS			p§ , pv
346	SP	3		
347			l > o	
353			l > o	
356	WT			
363		1		
367.5				
376	CF		l >	h v
379			l >	h v
-	HF	5	l >	h v
415			l >	h v
420			l >	h v
-			l >	h v
450				h v
453	IF	5		
-				
471				
-				
485				
492	DF	5		
-				

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 464

Depth (ft)	RQD ... %	Core recovery R %	Secondary Porosity %	Lith-ology	Porosity Index	Joints	Porosity Description
506	•••••••	R	•••••	—	1/3.1		
514	•••••••	—	•••••	CH	—		
515	•••••		•••••	—	5		
-	•••••		•••••		5		
-	•••••	R	•••••		5		
561			•••••	DF	5		
565	••		•••••		5		h v
-	••		•••••		5		h v
584	••	—	•••••	—	—		h v
-	••	R	•••••		1/3.1		h v
615	••••••		•••••	EF	1/3.1	l > o	
616	••••••	—	•••••		—		
-	••••••	R	•••••		1/4.1		
642		—		—			

RQD – rock quality designation – total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity – porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index – classification system for rock fractures. (WRL)

Core recovery – total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 75-1

Depth (ft)	RQD ... and core recovery R % (0–100)	Secondary Porosity % (0–20)	Lithology	Porosity Index	Joints	Porosity Description
156						p v
161					h > o	
166						
171						
176					h > o	
181					h > o	p v
186					h > o	
191		0 - 30				h v
196						m v
201						
206						
211					h > o	
216					h > o	
220			S P			
225						p v
230						
235						
238					h > o	m v
248					h > o	p - m v
258						m v
262					h > f	
267						
272						
277						p v
282						
287						
292						p v
297						p v
302			A S		h > f	
306.5					h > f	p v
311.5			W T		h > f	
316					h > f	
320.25					h > f	
325.5						m v
330.75						m v
335					h > f	m v
338.5					h > f	m v
343.5						m v
348						m v
353						m v
358			P Q			m v
363						m v
368						m v

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

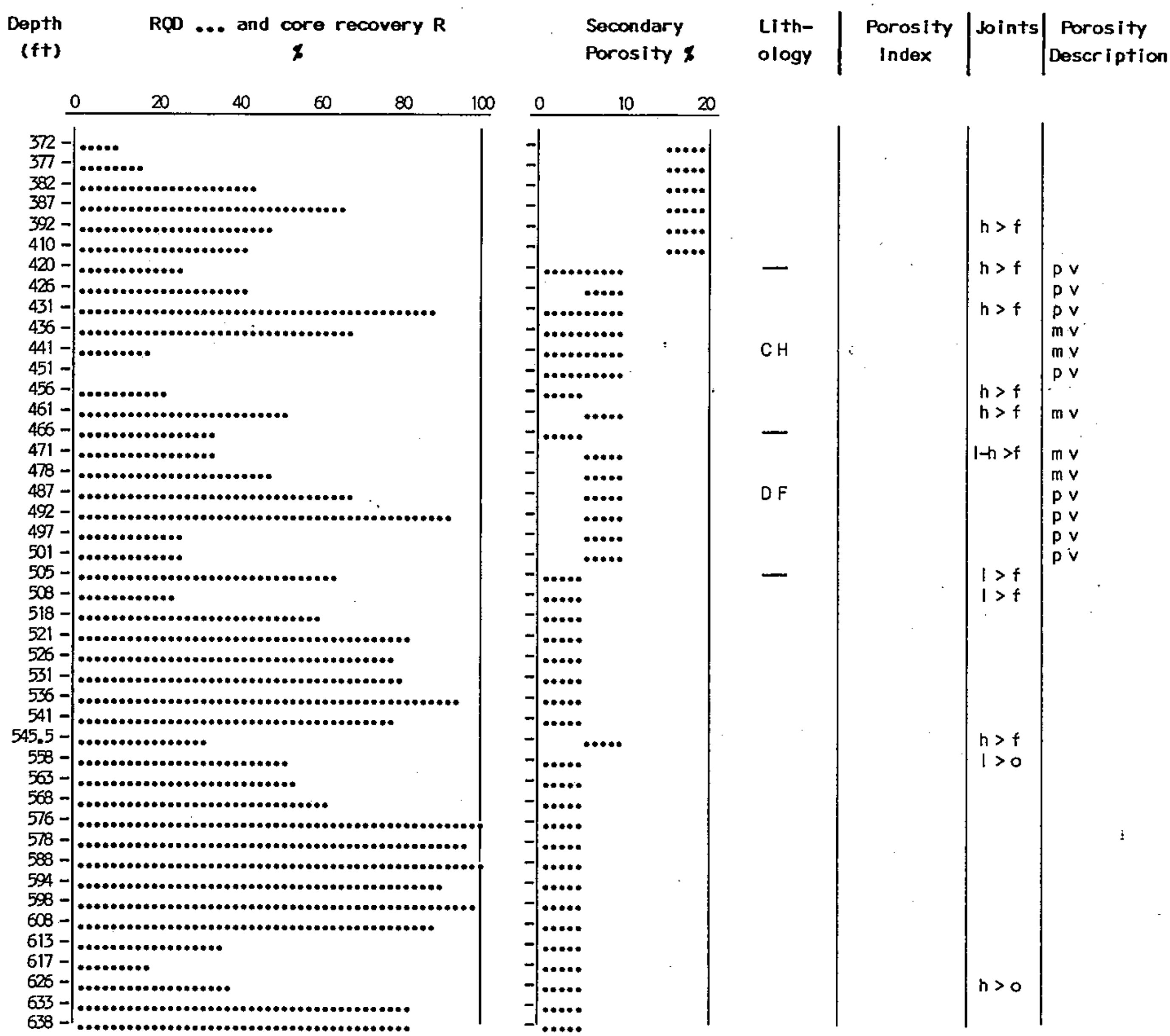
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 75-1



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

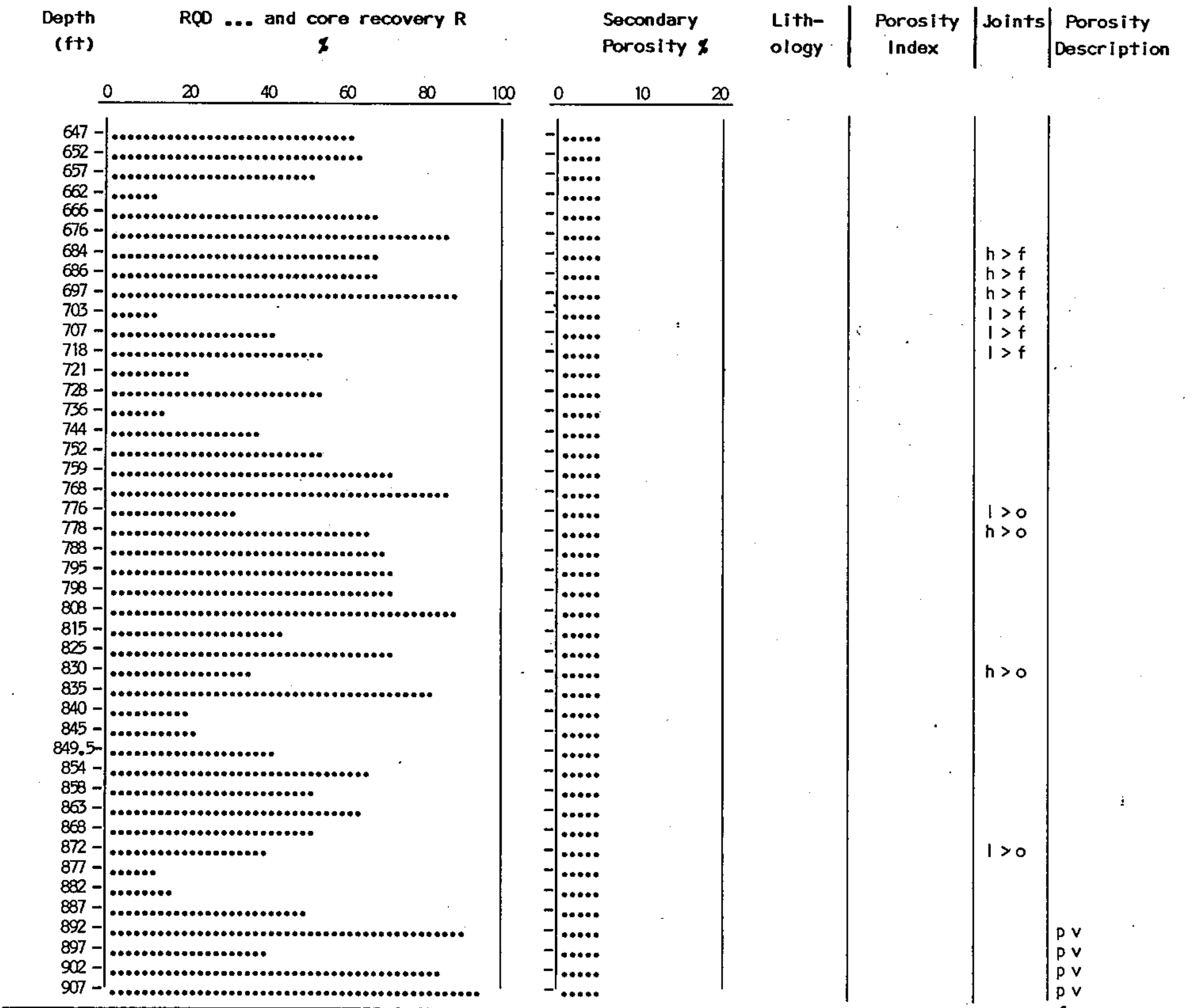
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 75-1



Depth (ft)	Joints	Porosity Description
647		
652		
657		
662		
666		
676		
684	h > f	
686	h > f	
697	h > f	
703	l > f	
707	l > f	
718	l > f	
721		
728		
736		
744		
752		
759		
768		
776	l > o	
778	h > o	
788		
795		
798		
808		
815		
825		
830	h > o	
835		
840		
845		
849.5		
854		
858		
863		
868		
872	l > o	
877		
882		
887		
892		p v
897		p v
902		p v
907		p v

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

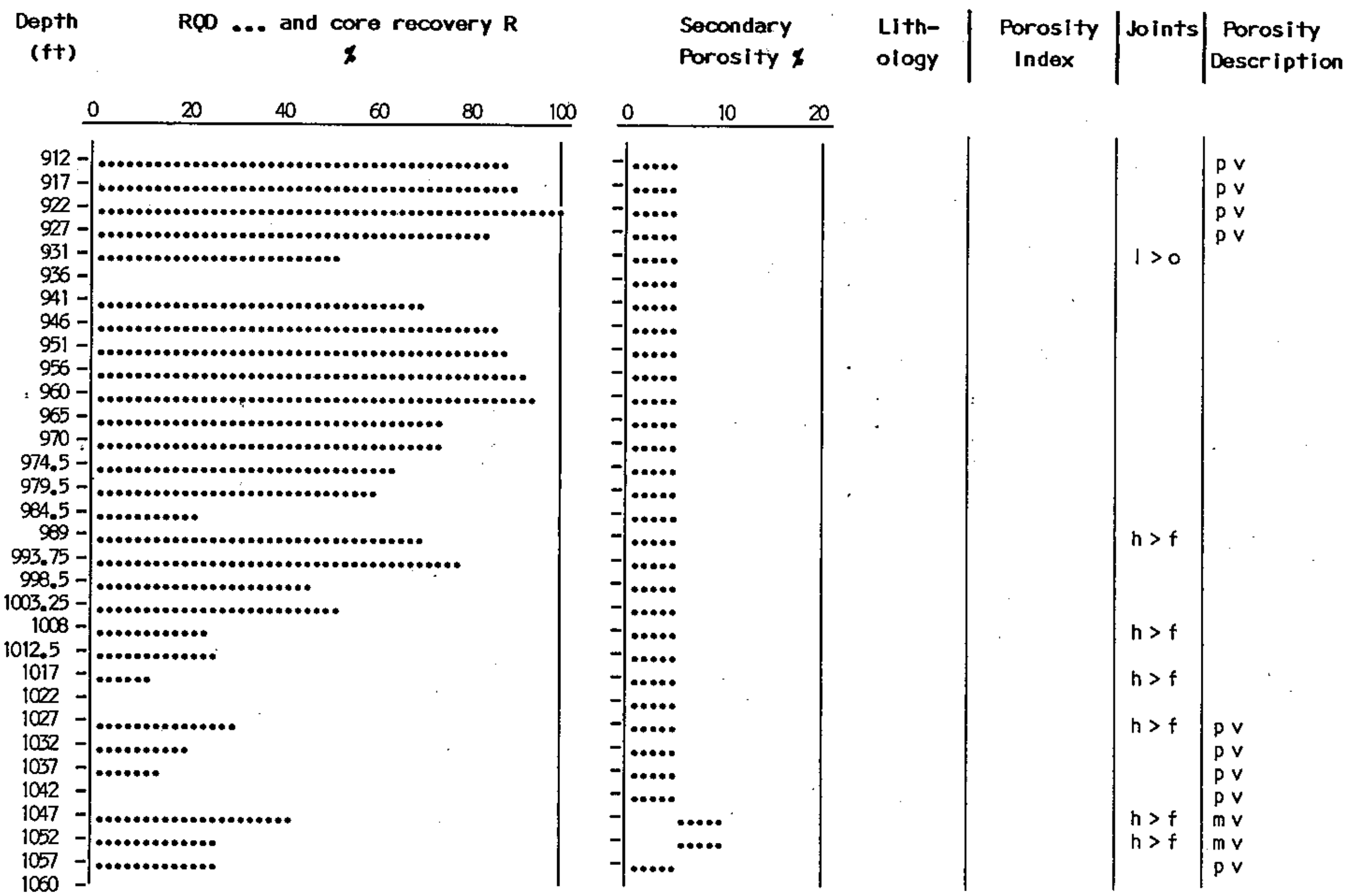
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 75-1



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

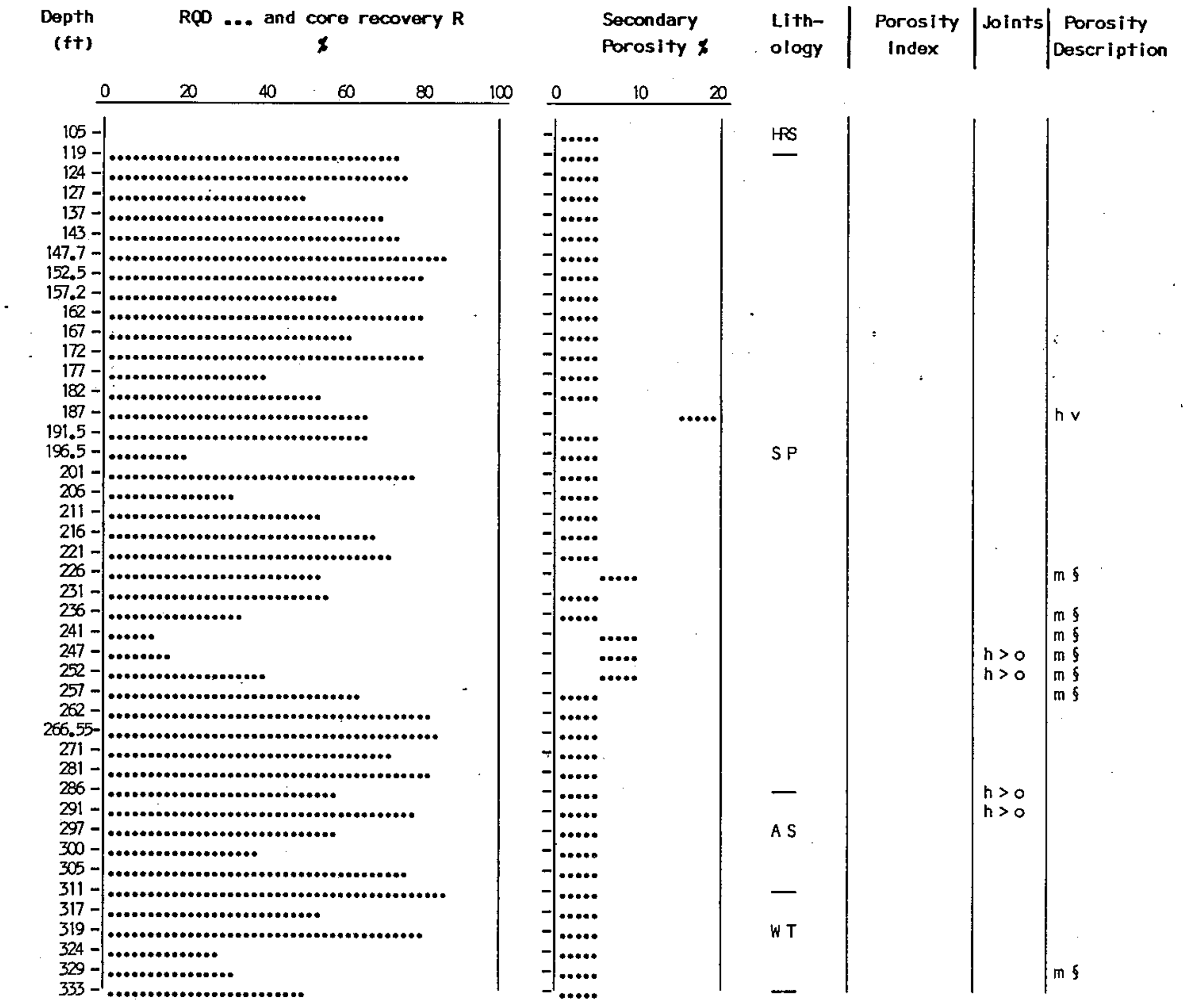
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 34



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

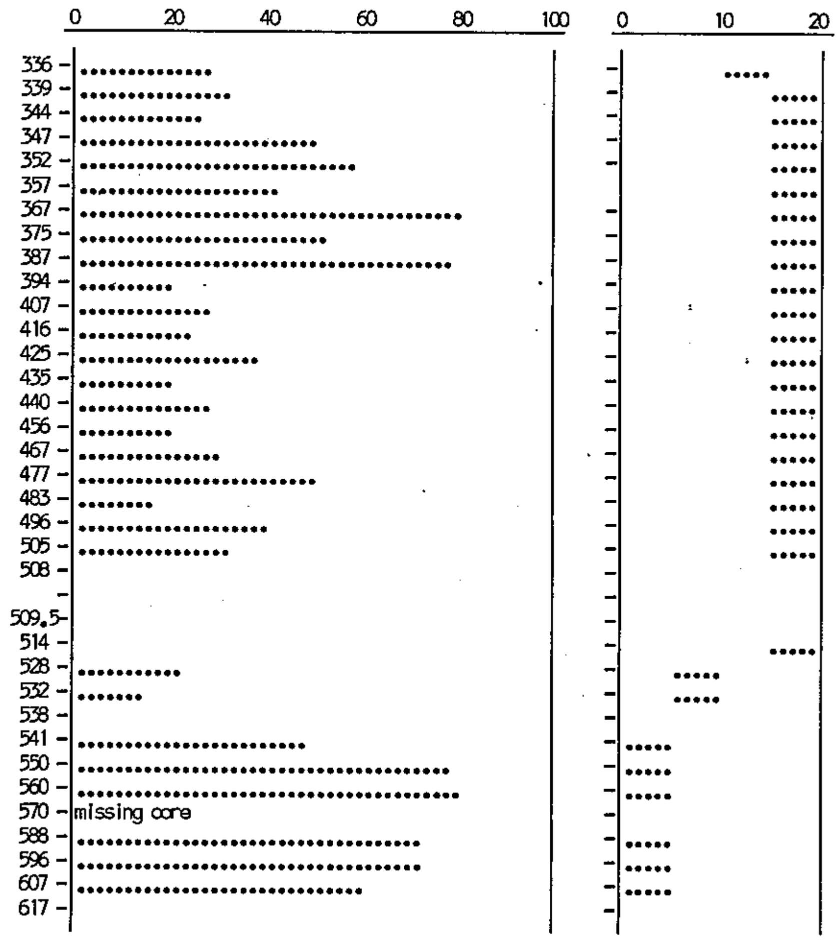
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 34



Depth (ft)	Lithology	Porosity Index	Joints	Porosity Description
336				
339				
344				
347				
352				
357				h v
367				h v
375				h v
387				h v
394	PQ			h v
407				h v
416			l > o	h v
425			l > o	h v
435			l > o	h v
440				h v
456				h v
467				h v
477			l-h >f	h v
483			l-h >f	h v
496				h v
505			h > o	h v
508				
	CH			
509.5				
514			h > o	h§ , mv
528	BR		h > o	
532			h > o	m v
538				
541			h > o	p §
550				
560				
570 (missing core)	BE			
588			h > o	p v
596				
607			h > o	
617				

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

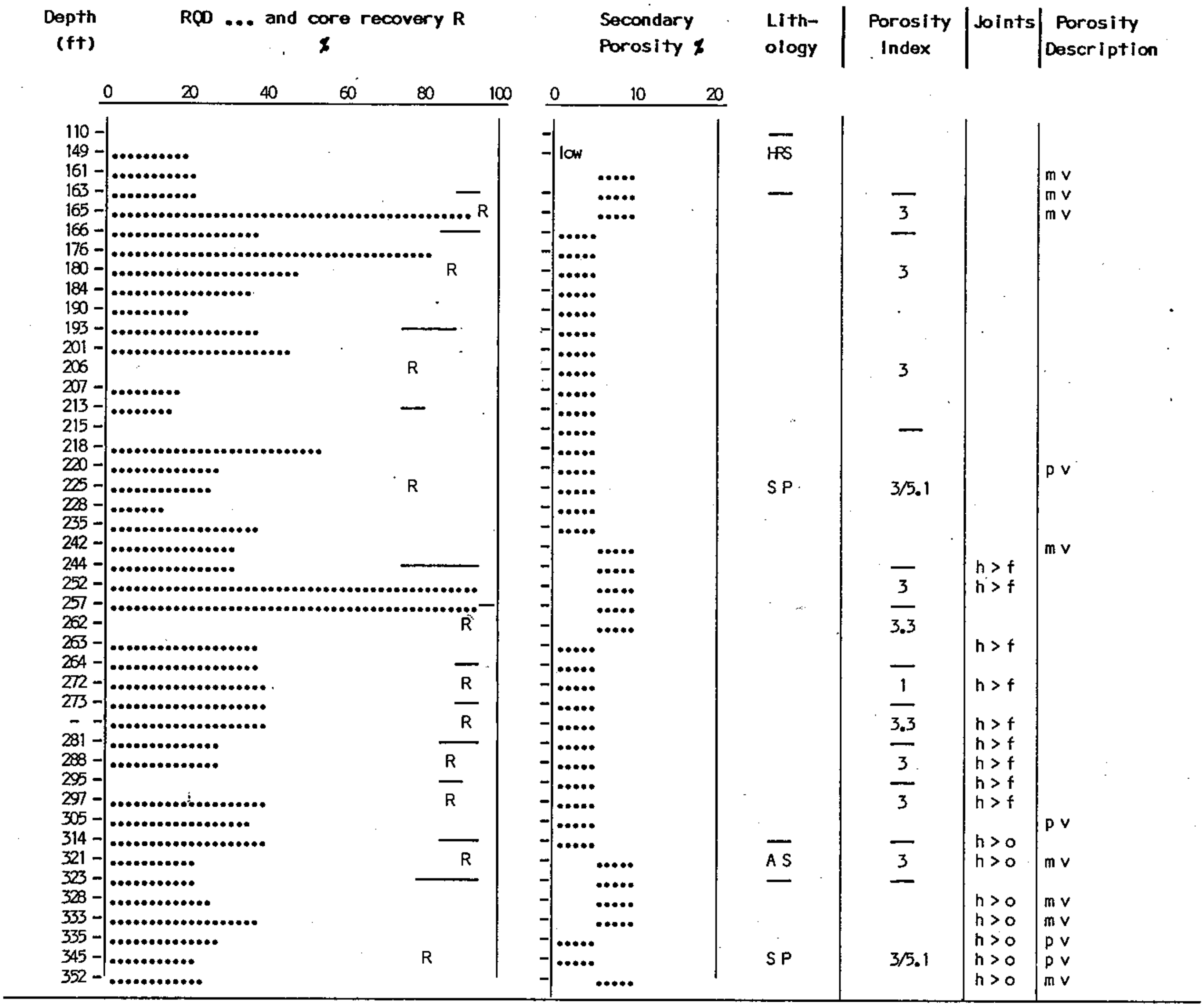
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 412



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

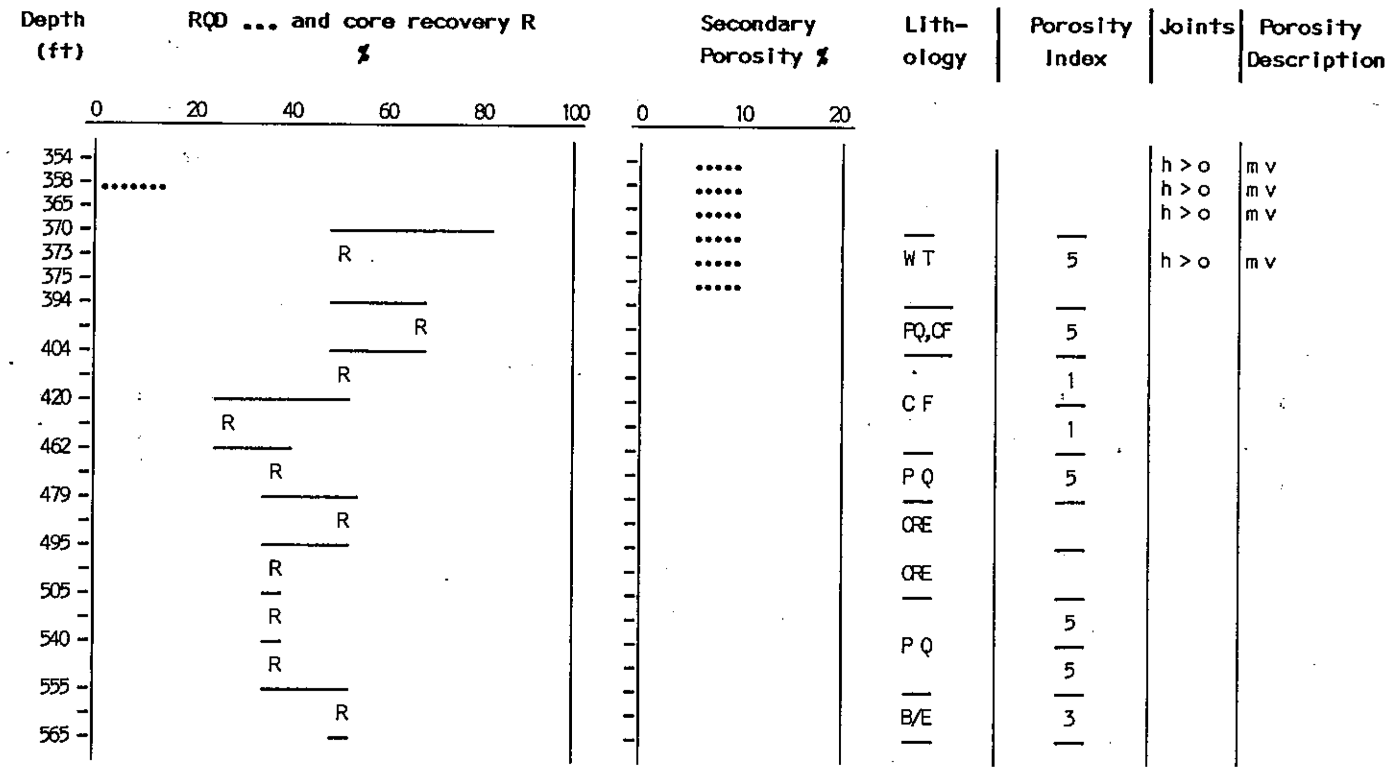
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 412



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

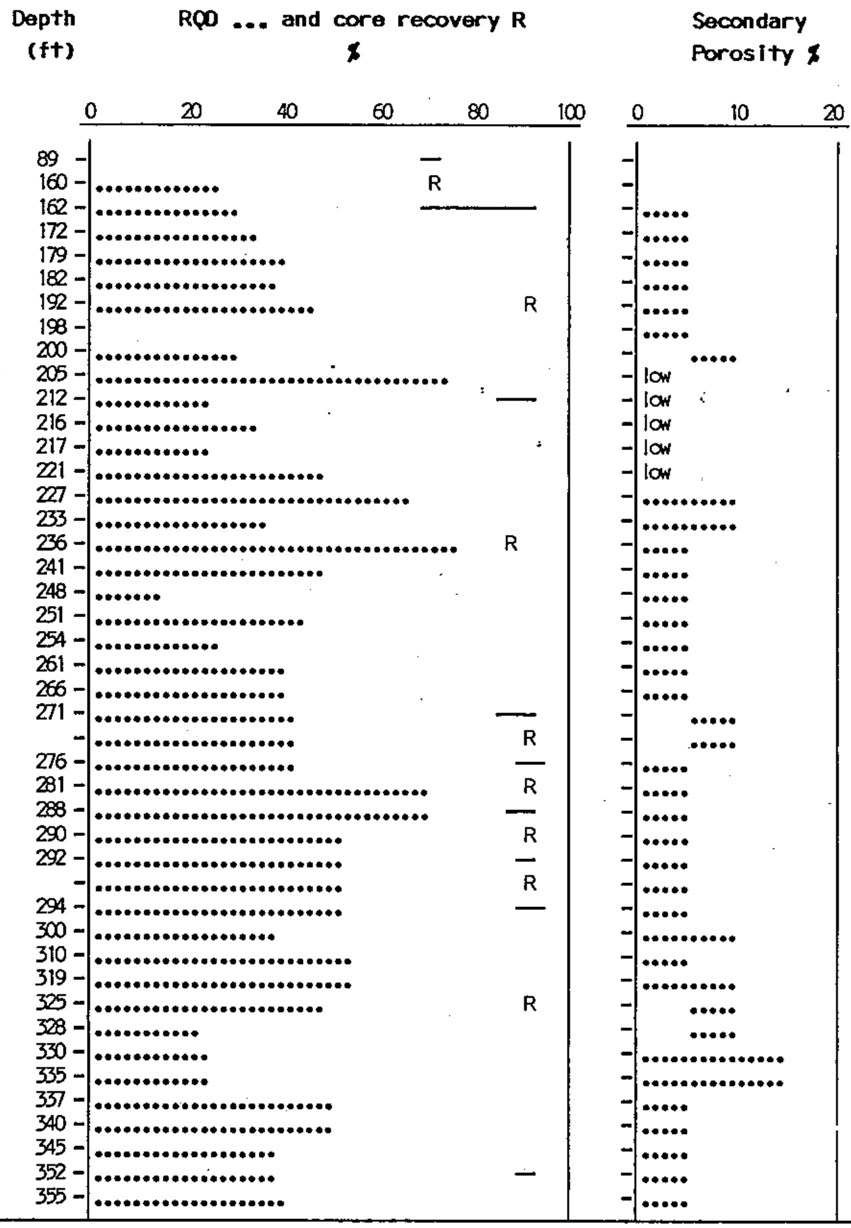
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 333



Depth (ft)	Core recovery R	Secondary Porosity %	Lithology	Porosity Index	Joints	Porosity Description
89						
160	R		HRS			
162			—	—	l > f	
172						
179						
182						
192	R			3.1/5.1		
198						
200						
205		low				
212		low		—		
216		low				
217		low				
221		low			h > o	
227						m v
233						m v
236	R		SP	4/5		p v
241						
248						
251						
254						
261					h > o	
266						
271						
	R			3		
276						
281	R			3		
288						
290	R			3	h > o	
292						
	R			3	h > o	
294						
300					h > o	
310						
319						m v
325	R			4		m v
328						m v
330						h v
335						
337			AS		h > o	
340						
345			SP		h > f	
352				—		
355						

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

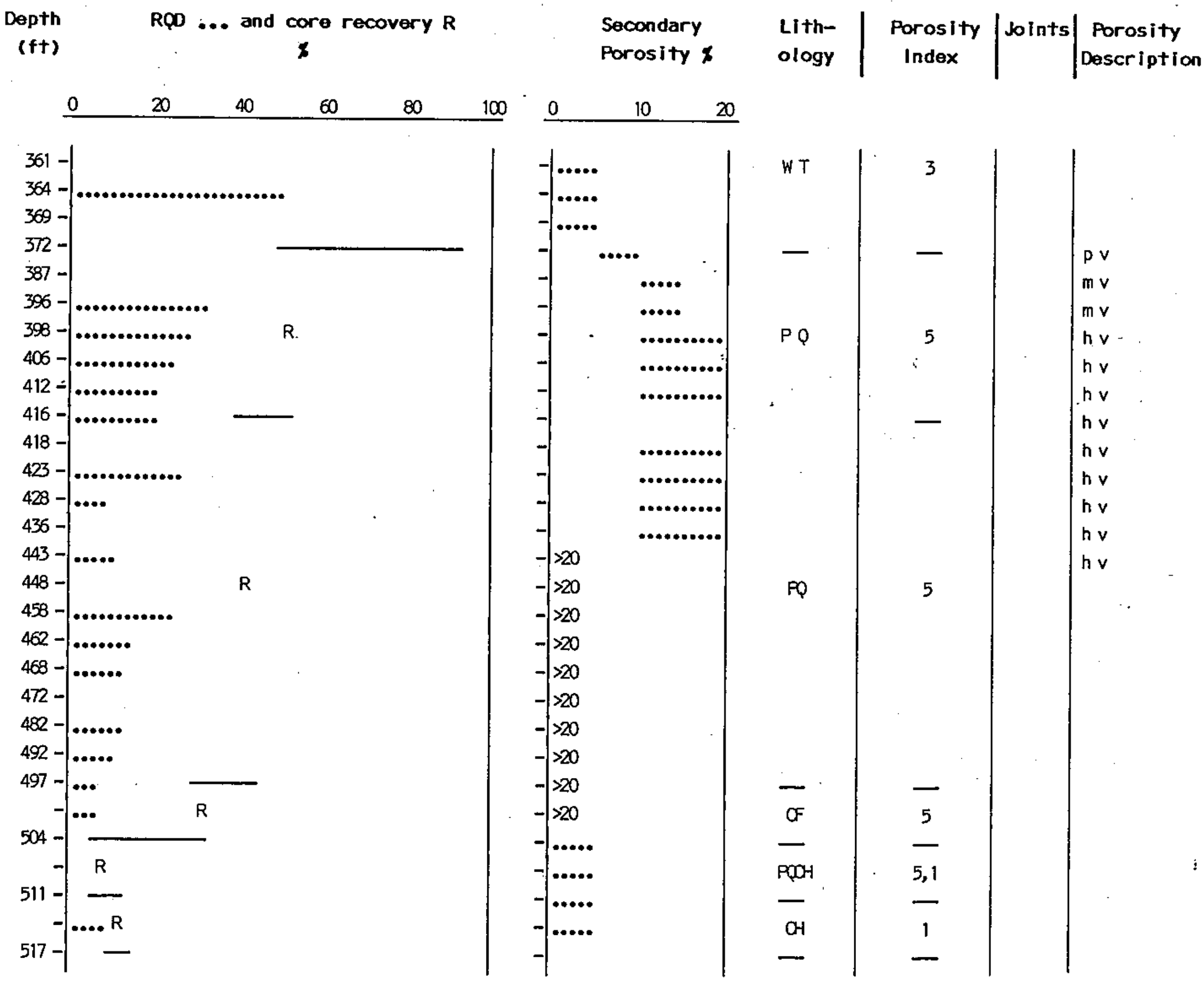
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions.

Hole # 333



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

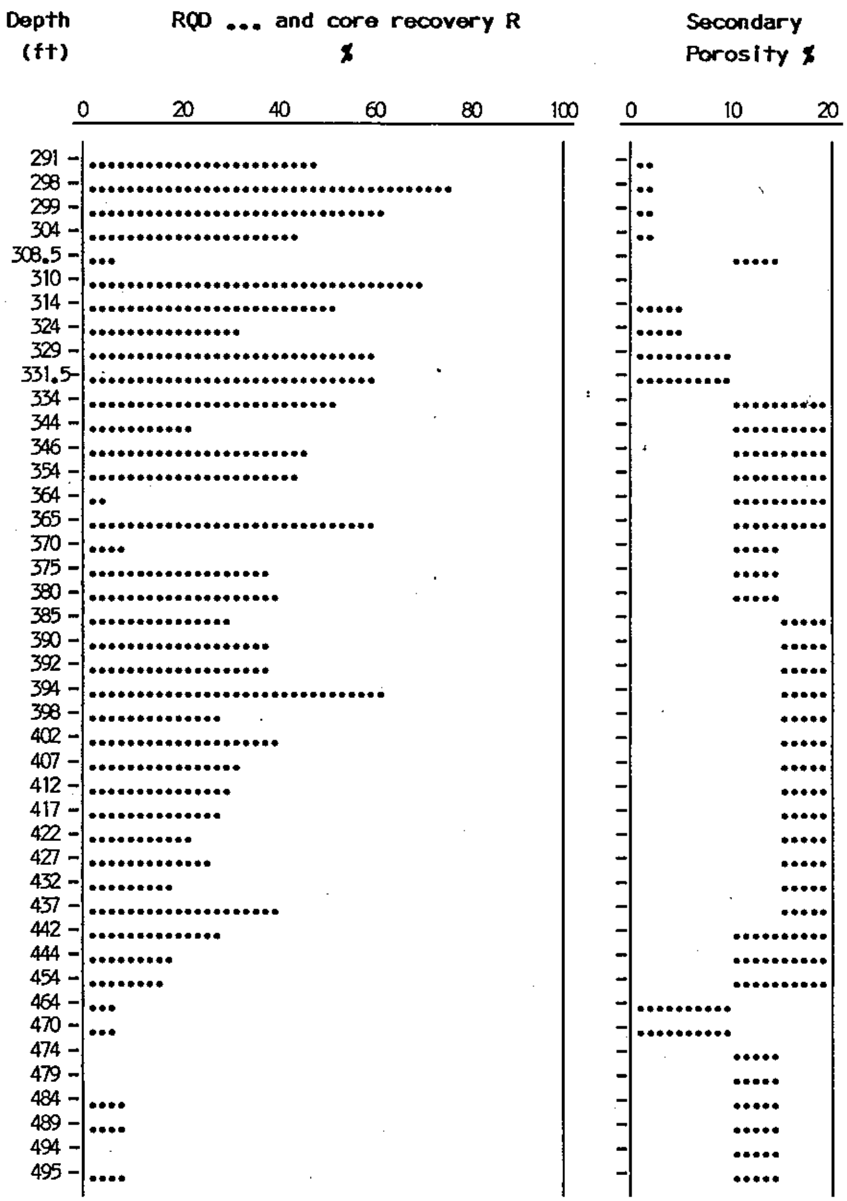
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 796



Depth (ft)	Lithology	Porosity Index	Joints	Porosity Description
291	AS			
298	—			
299				
304	SP			
308.5				m v
310	—		h > o	
314	WT		h < o	
324			h > o	
329	—			
331.5	CF			
334	—			m – h v
344			h > o	m – h v
346				m – h v
354				m – h v
364			h > f	m – h v
365	HF		l > f	m v
370			l > f	m v
375			l > f	m v
380			l > f	m v
385				h v
390				h v
392	—			h v
394				h v
398				h v
402				h v
407				h v
412				h v
417				h v
422				h v
427	IF			h v
432				h v
437				h v
442			l–h> f	m – h v
444			l–h> f	m – h v
454			l–h> f	m – h v
464				
470	—			
474	CH		l–h >	
479	—		l–h >	
484	DF		l–h >	
489	—		l–h >	
494			l–h >	
495	BR		l–h >	

RQD – rock quality designation – total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity – porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index – classification system for rock fractures. (WRL)

Core recovery – total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

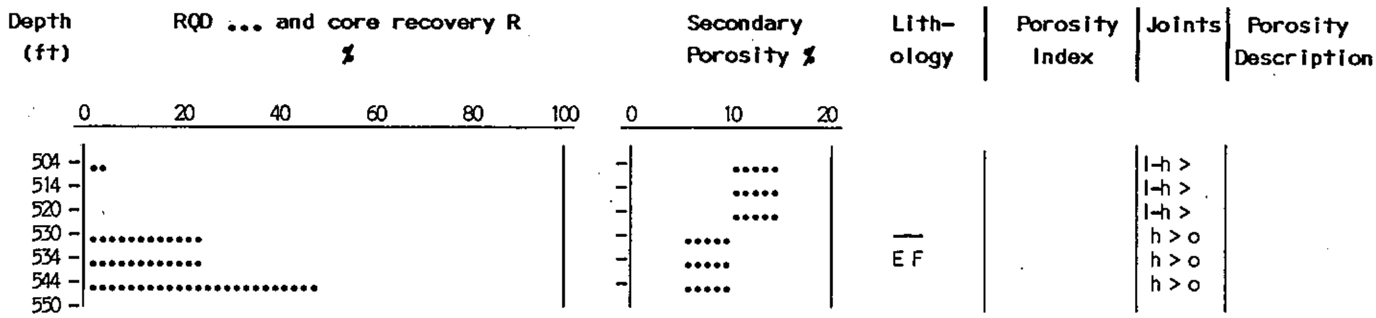
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 796



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, $ = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 575

Depth (ft)	RQD ... and core recovery R % (0–100)	Secondary Porosity % (0–20)	Lithology	Porosity Index	Joints	Porosity Description
91	••••	•••••	—		h > o	
105	••••••••••••••••	•••••			h > o	
115	••••••••••••••••	•••••				
118	•••••••••	•••••				
123	•••••••••••••••••	•••••				
128	••••••••••••••	•••••				
133	•••••	•••••				
138	•••••••••••••••••••••••••	•••••				
145	••••••••••••••••	•••••				
153		•••••				
155	•••••••••••••••••••••••••	•••••				
163	•••	•••••			l > o	
172	••••••••••	•••••			l > o	
180	••••••••••••••	•••••			l > o	
185	••••••••••••••••••••••	•••••	SP		l > o	
190	••••••••••••••••••••••••••••••	•••••			l > o	
195	•••••••••••••••••••••••••	•••••			l > o	
200	••••••••••••••••••••••••••••••	•••••			l > o	
205	••••••••••••••••••••••••	•••••			l > o	
210	•••••••••••••••••••	•••••			h > o	
215	••••••••••••	•••••			h > o	p §
220	••••••••	•••••				p §
225	•••••••••	•••••				
232	••••	•••••			h > o	
237	•••••••••••••	•••••			l >	
242	•••••••••••••••••••••••	•••••			l >	
247	••••••••••••••••••••••	•••••			l >	
252	•••••••••••••••••••••••••••	•••••				p v
257	••••••	•••••			l > f	p v
265	•••••••••••••••••	•••••	—		l > f	p v
269	•••••••••••••••••••••	•••••	AS			
274	•••••••••••••••	•••••			h > f	
279	•••••••••••••••••••••••	•••••	—			p§ , pv
284	••••••••••••••	•••••				p§ , pv
289	•••••••••••••••••	•••••	SP			p§ , pv
295	••••••••••••••••	••••				
301	••••••••••••••••	••••	—			
305	•••••••••••••••••••••••••••••••••	••••				
307	•••••••••••	••••				
312	••••••••••	••••	WT			
317	••••••••••••••••••	••••				
322	•••••••••	••••				
327	•••••••••	•••••				pv , p§
335						

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 575

Depth (ft)	RQD ... and core recovery R % (0–100)	Secondary Porosity % (0–20)	Lith-ology	Porosity Index	Joints	Porosity Description
582	•••••••	•••••	TF			
592	•••••••••••••••••••••••••	•••••			h > o	
600						

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 575

Depth (ft)	RQD ... and core recovery R % (0–100)	Secondary Porosity % (0–20)	Lith-ology	Porosity Index	Joints	Porosity Description
582	....	.....	T F			
592	....	.....			h > o	
600						

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

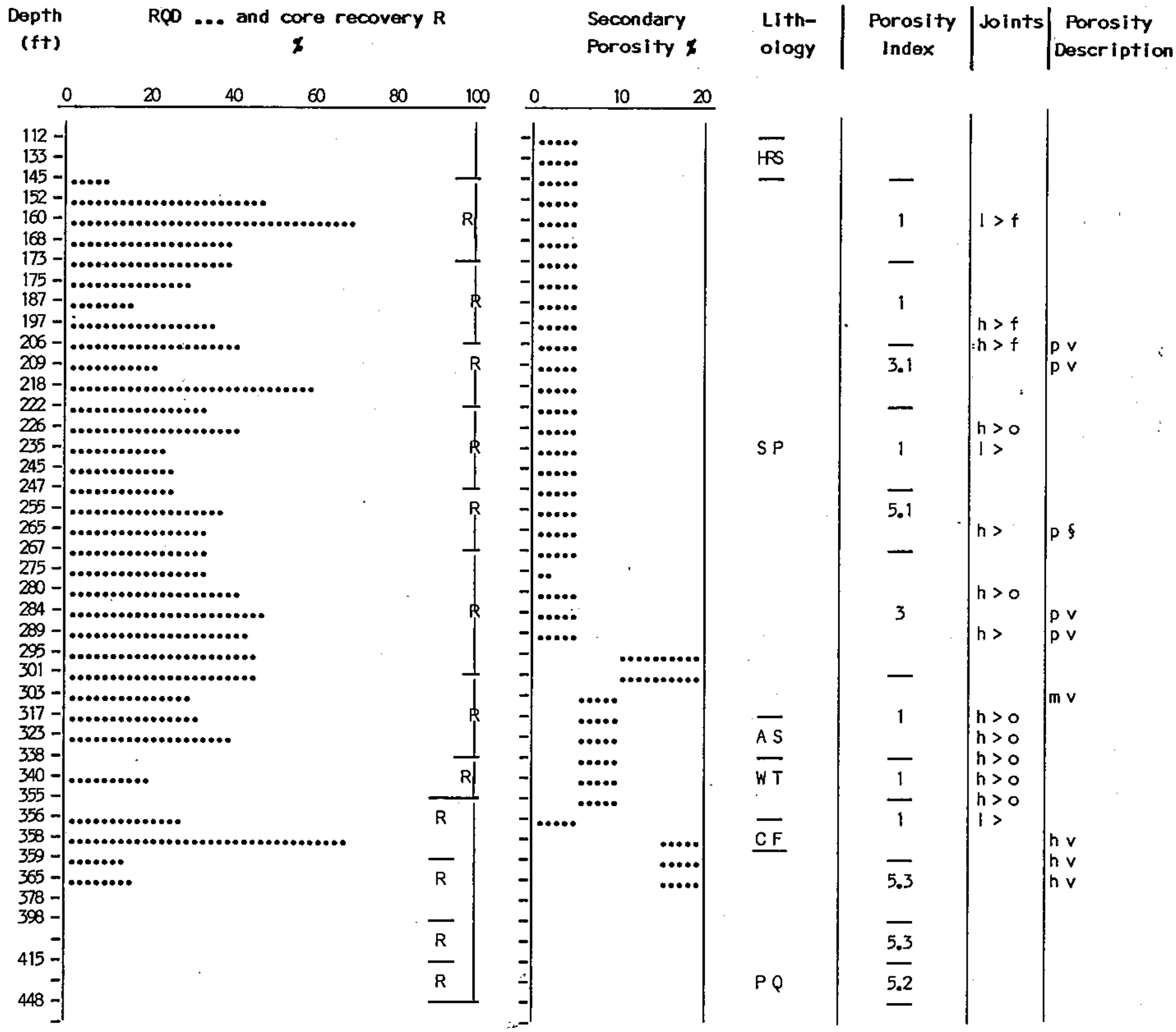
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 468



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 468

Depth (ft)	RQD ... and core recovery R % (0–100)	Secondary Porosity % (0–20)	Lith-ology	Porosity Index	Joints	Porosity Description
448–462	R		PQ	5.2		
462–516	R		PQ	5.2		
516–533	R		PQ	4		
533–560	R		BR	4		
560–595	R		B/E	5.1		

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

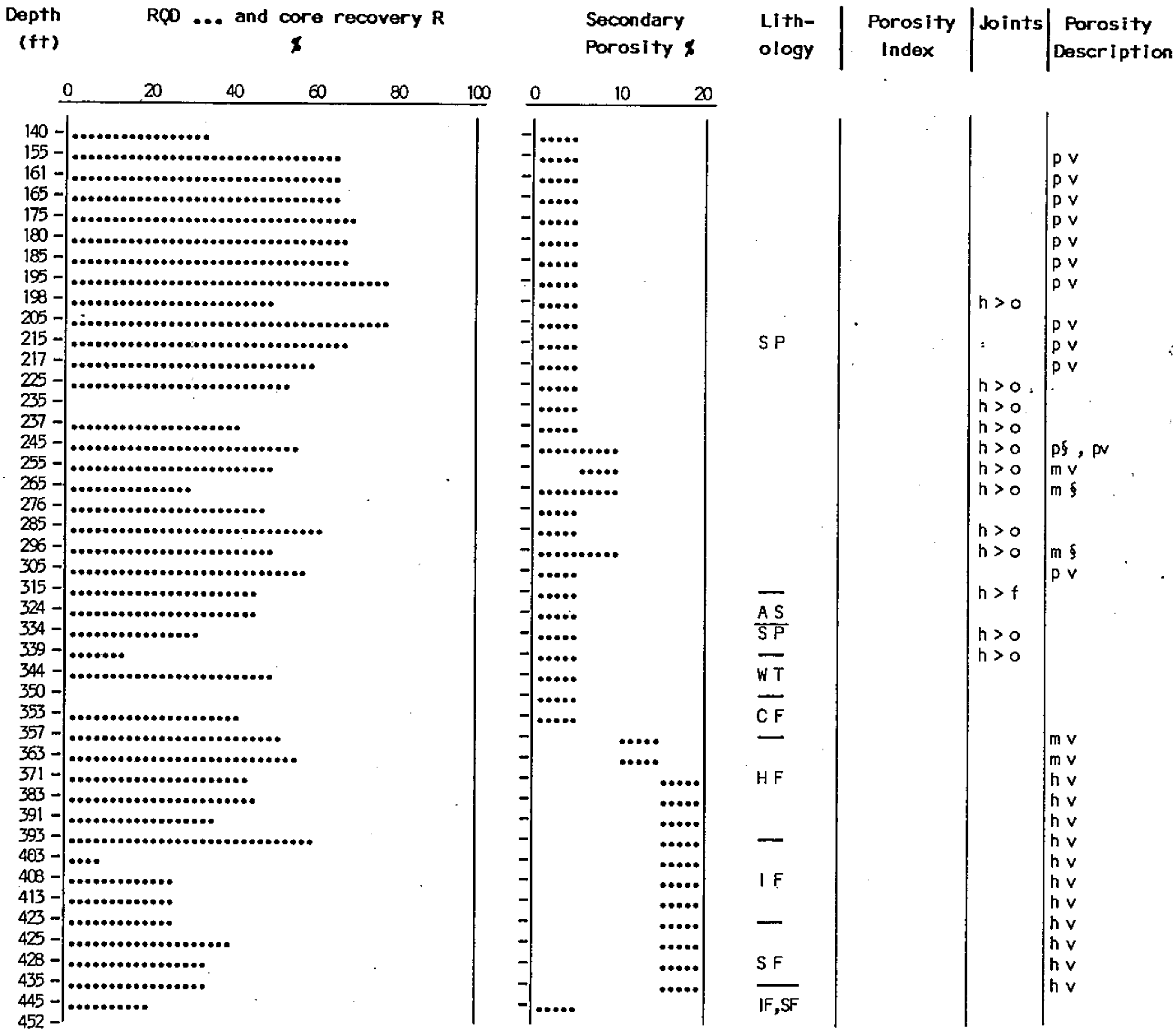
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 507



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity Index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

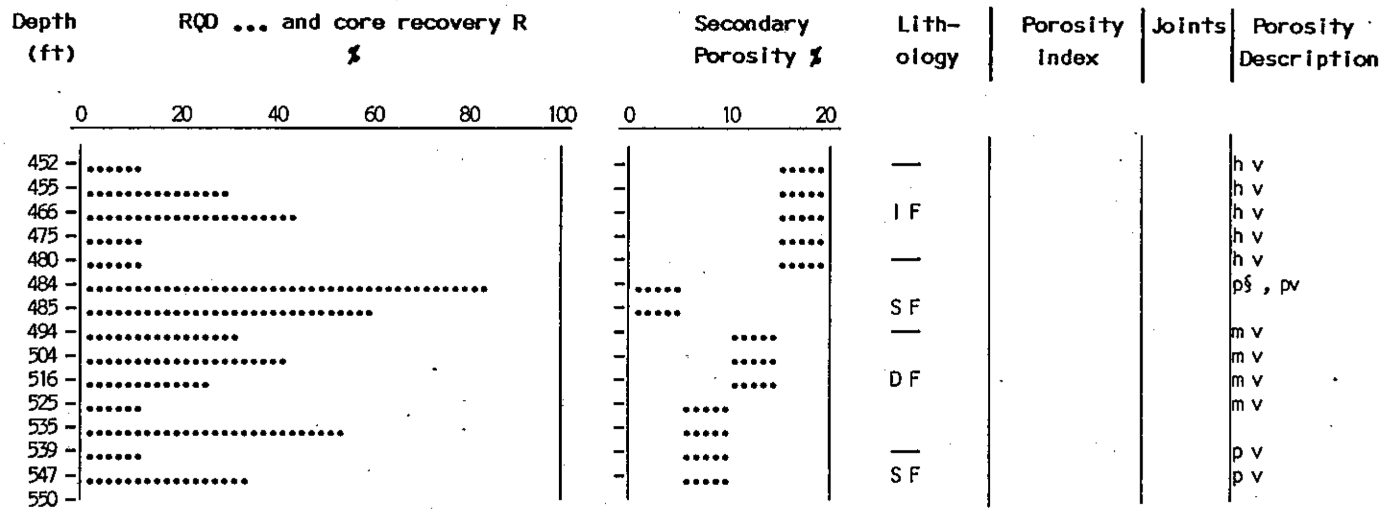
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 507



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

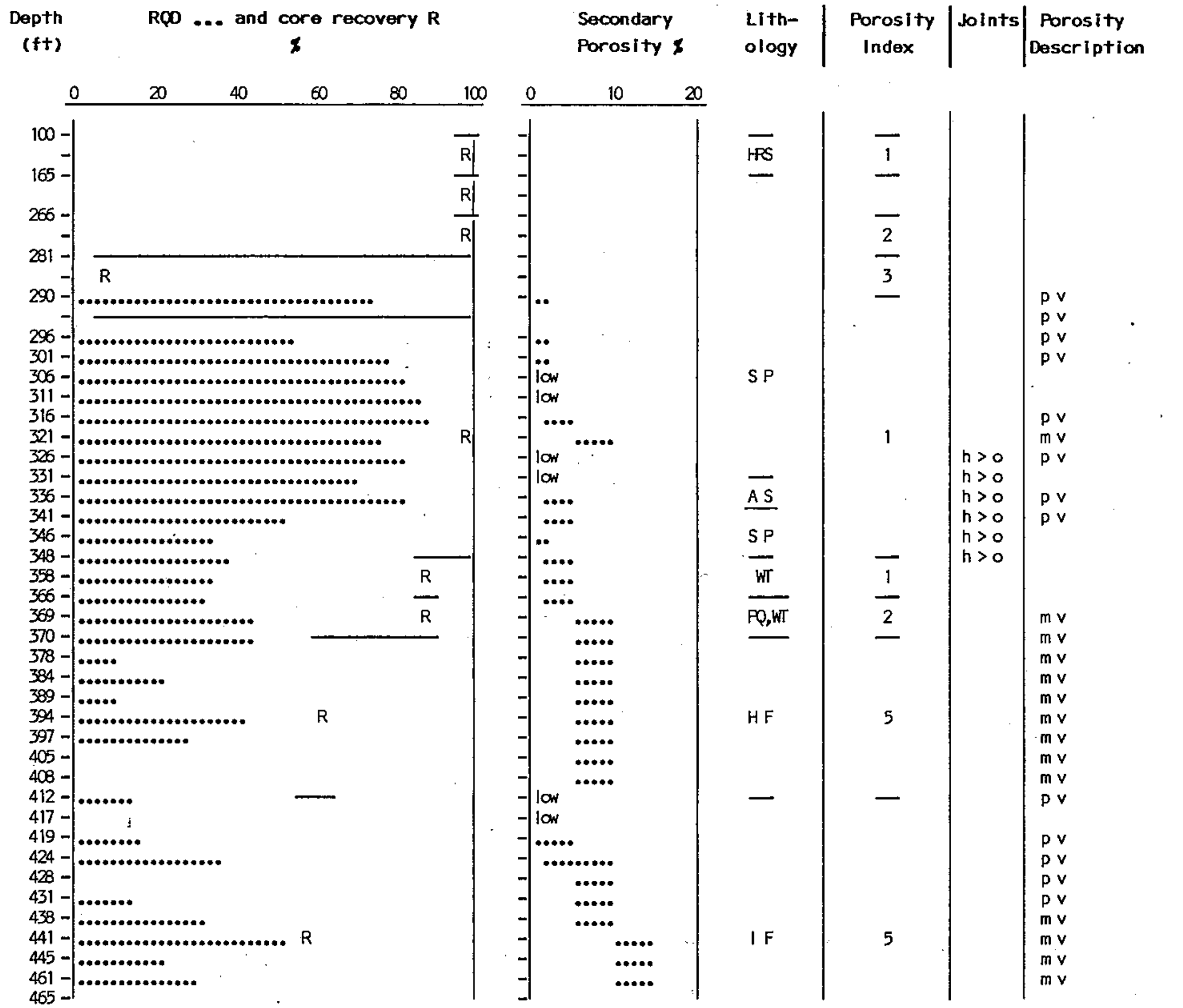
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 334



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

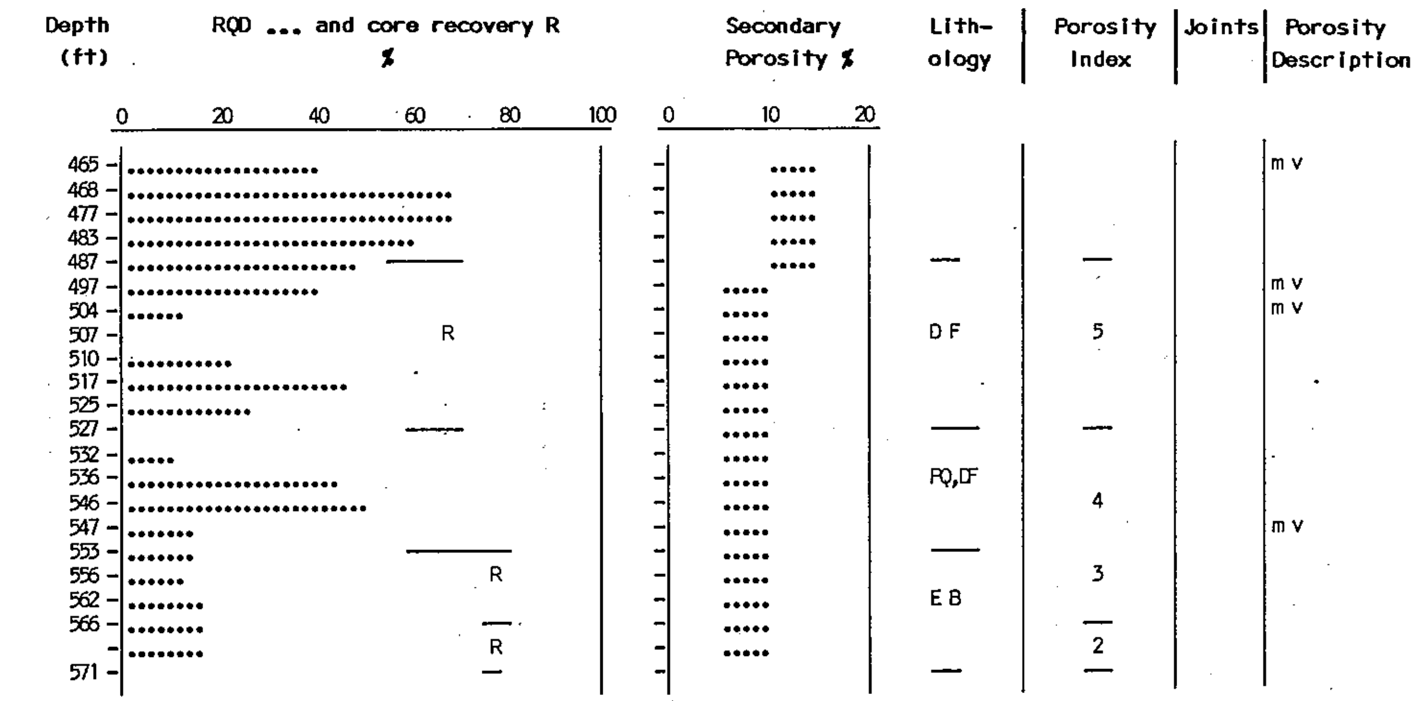
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 334



RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

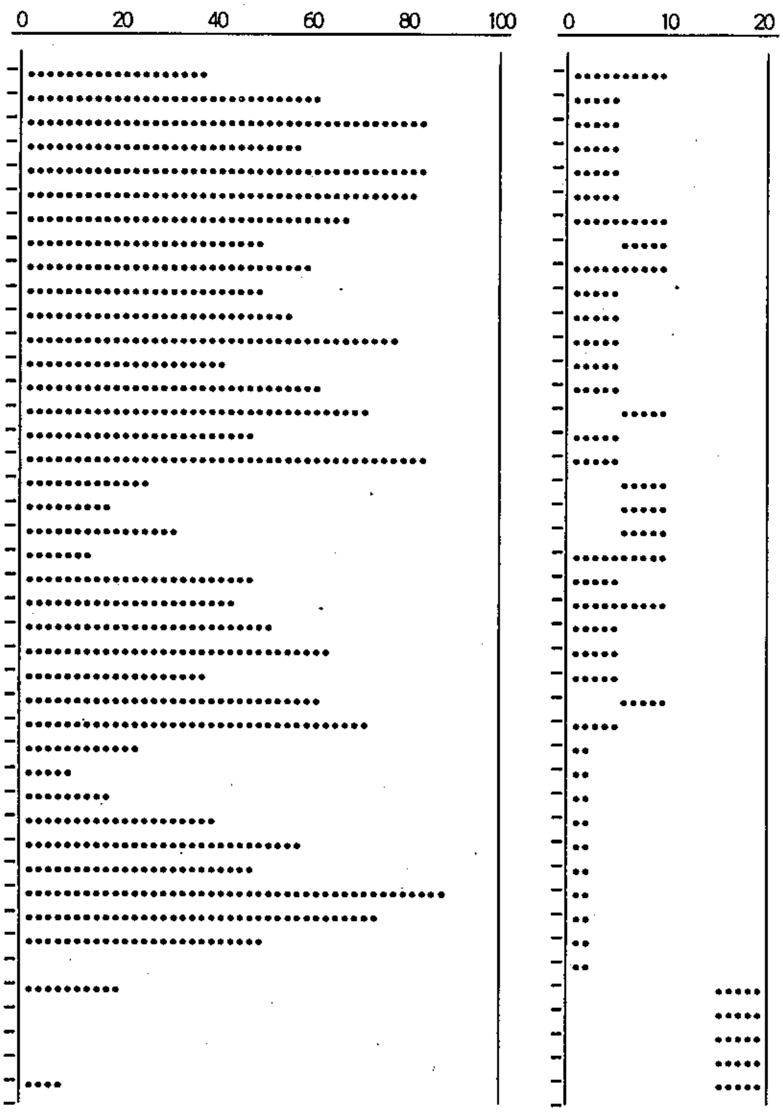
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 5



Depth (ft)	Lithology	Porosity Index	Joints	Porosity Description
88				p§ , pv
103				
111			h > o	
120			h > o	
130				
138				
146				p v
151				
156				p v
161				
166				
171				
176				
181	S P			
186				m v
188				
197				
203				m §
208				m v
212				m v
215				m v
220			h > o	
225			h > o	m v
230			h > o	
235				
240				
243				m§ , pv
248				
253				
257	A S			
263.5				p §
274				
275				
280				
285	W T			
290				
295			h > o	
304			h > o	
305				h v
310	C F			h v
313				h v
315				h v
318				h v
323				

RQD - rock quality designation - total length of unbroken pieces of core, each greater than four inches long, expressed as a percentage of the length of hole drilled. (SIG)

Secondary porosity - porosity of the rock mass due to solution cavities, open fractures and partings. (SIG)

Porosity index - classification system for rock fractures. (WRL)

Core recovery - total length of core recovered expressed as a percentage of length of hole drilled. (WRL)

Joints l> = low angle, h> = high angle (greater than 60°), o = open, f = filled.

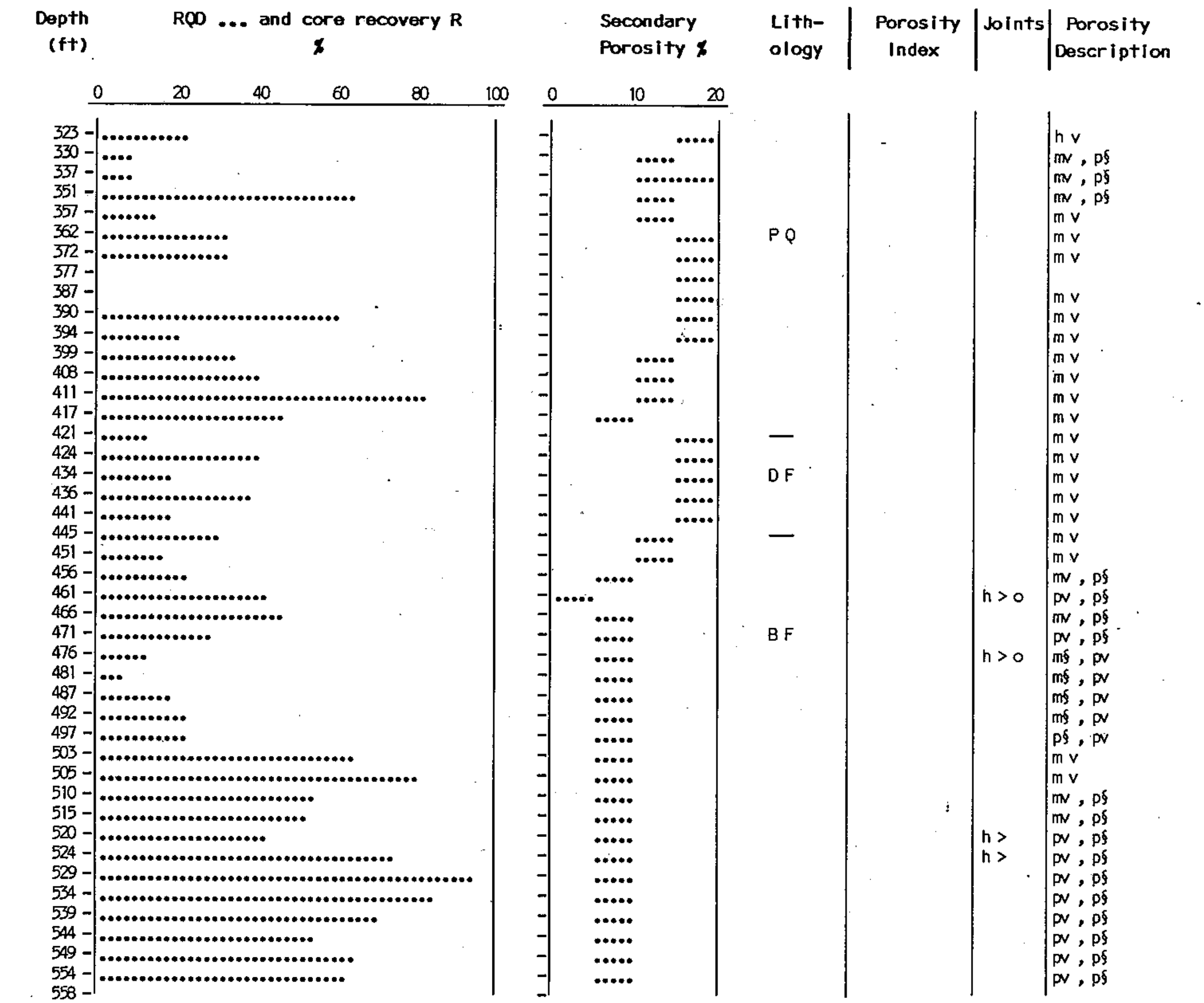
Porosity Description v = vuggy porosity, § = pitted porosity, p = poor, m = moderate, h = heavy.

eg. m-hv means moderate to heavy vuggy porosity.

WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 5



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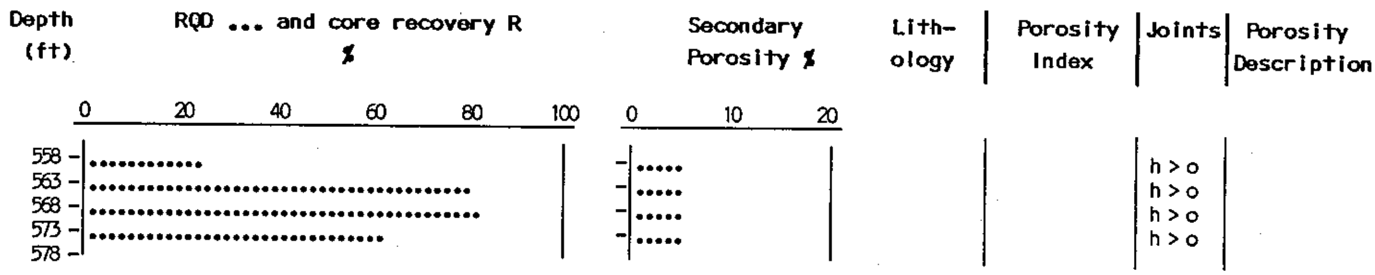
Diamond Drill Core Descriptions

Hole # 5



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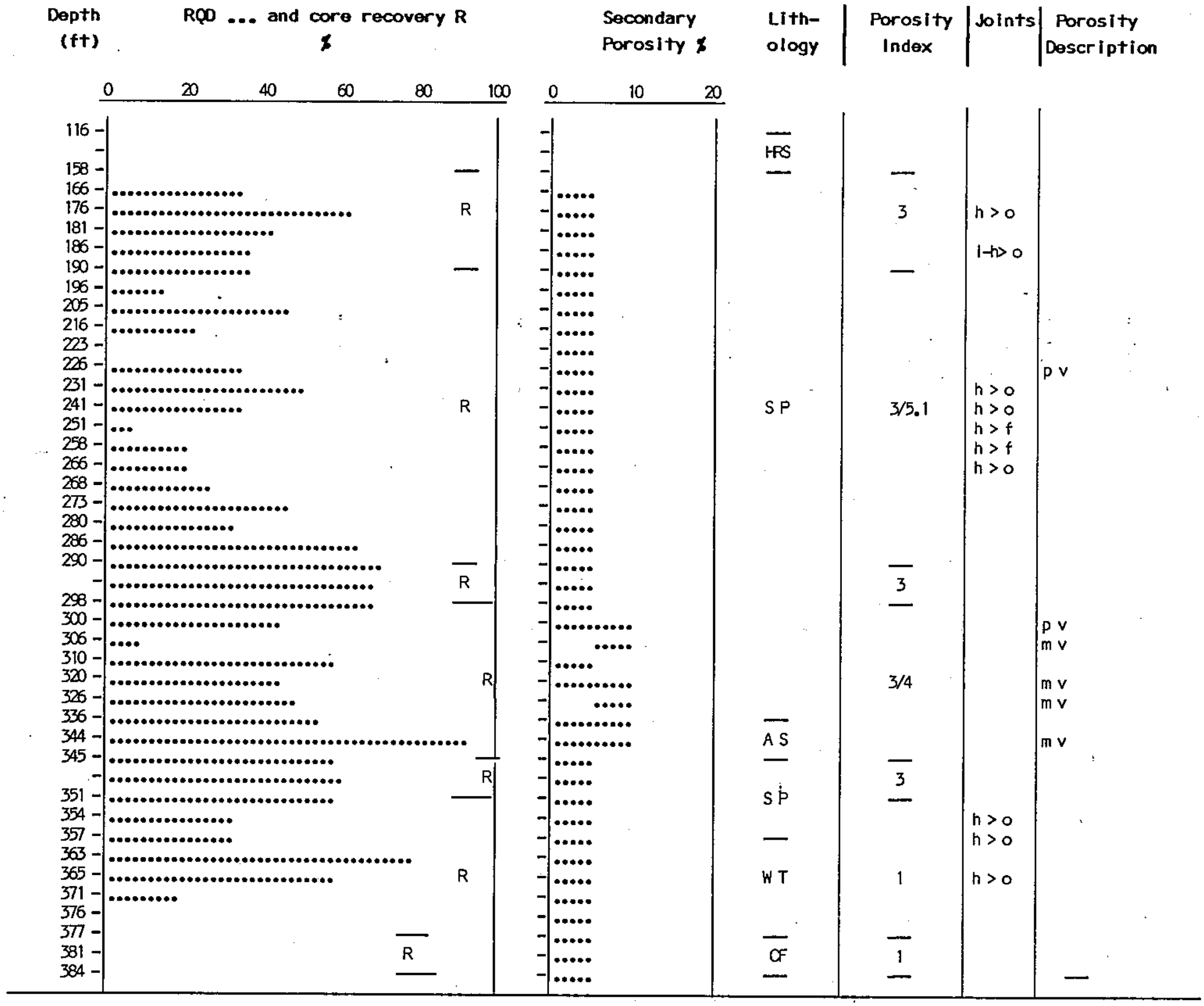
WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 421



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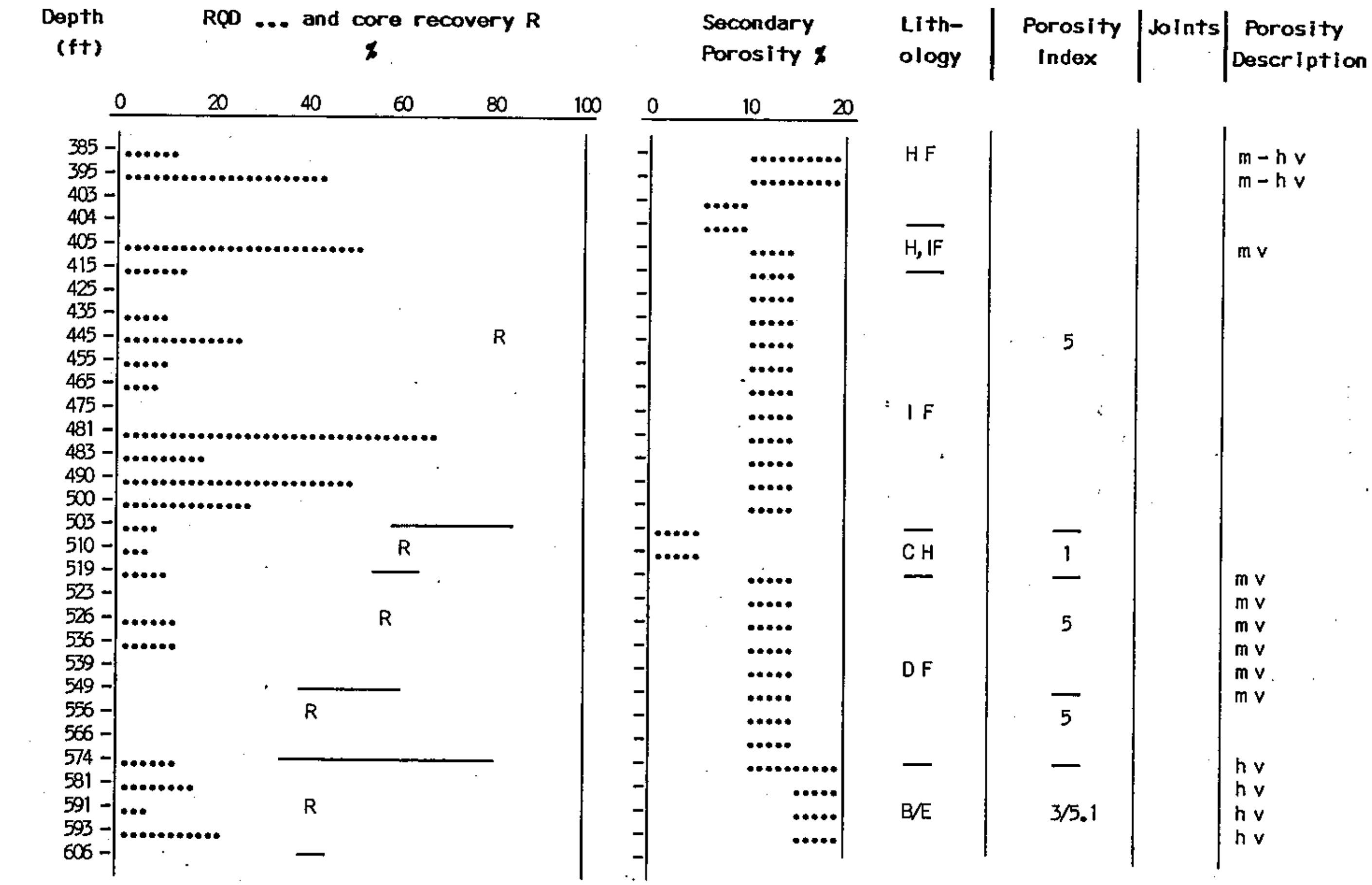
WESTMIN GREAT SLAVE REEF PROJECT

Diamond Drill Core Descriptions

Hole # 421



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Appendix B

Laboratory analysis of hydraulic properties of diamond drill core from Great Slave Reef project area.

CORE LABORATORIES — CANADA LTD.

SMALL SAMPLE CORE ANALYSIS

COMPANY	STEVENSON INTERNATIONAL GROUNDWATER CONSULTANTS LTD.	FORMATION		PAGE	1 of 3
WELL		CORING EQUIPMENT		FILE	7004-83-840
FIELD	SELECTED SAMPLES	CORE DIAMETER (mm)		DATE	1983 11 03
LOCATION		CORING FLUID		ANALYSTS	
ELEVATION					

CLEANING

Solvent	TOLUENE
Extraction Equipment	VAPOUR PHASE
Extraction Time	3 DAYS
Drying Equipment	GRAVITY
Drying Time	48 HOURS
Drying Temperature	132 °C

ANALYSIS

- [ ] Pore Volume measured by Boyle's Law in a Hassler holder using helium
- [X] Grain Volume measured by Boyle's Law in a matrix cup using helium
- [ ] Porosity determined by summation of fluids (retort)
- [ ] Fluid saturations by retort
- [ ] Water saturation by Dean-Stark
- [ ] Oil saturation by weight difference (Dean-Stark)
- [X] Permeability measured on 38 mm diameter drilled plugs
- [ ] Permeability measured on 20 mm cubes

REMARKS

DESCRIPTIONS

Conglomerate = cgl
Sandstone = ss
Siltstone = sltst
Shale = sh, shy
Limestone = ls
Dolomite = dol
Gypsum = gyp
Anhydrite = anhy
Halite (salt) = hal
Ironstone = fe
Chert = cht
Pyrite = pyr
Sulphur = sulf
Coal = coal
Carbonaceous Matter = carb
Pyrobitumen = pyrbit

Slightly Shaly = sshy
Moderately Shaly = mshy or shy
Very Shaly = vshy

Calcareous = calc
Limy = lmy
Pyritic = pyr

Glauçonitic = glauc
Silty = slt
Sandy = sdy
Carbonaceous = carb
Dolomitic = dol
Coal/Coal inclusions = coal
Laminae (Laminated) = lam
Fractures (vertical/horizontal/undifferentiated) = vert frac, hfrac, frac
Micaceous = mic
Stylolite (s) = sty
Oolitic = ool
Fossiliferous = foss
Intergranular = i

Vugs, Vugular, Vuggy
Pinpoint = ppv
Small Vug = sv
Medium Vug = mv
Large Vug = lv

COMPANY	STEVENSON INTERNATIONAL GROUNDWATER CONSULTANTS LTD.	PAGE	2 of 3
		FILE	7004-83-840
WELL	SELECTED SAMPLES	DATE	1983 11 03

CORE ANALYSIS RESULTS

SAMPLE NUMBER	DEPTH FEET	PERMEABILITY MILLIDARCYS	POROSITY PERCENT	GRAIN DENSITY	VISUAL EXAMINATION AND REMARKS
	DDH 5				
1	193	<0.01	2.30	2.83	dol i mv lmy
2	245	0.10	5.60	2.85	dol i sv lmy
3	303	<0.01	5.80	2.79	dol i lmy
4	320	0.02	4.80	2.82	dol i vugs
5	433	0.23	3.70	2.83	dol i vug
6	449	27.4	3.80	2.84	dol i vug
7	62	6.62	8.00	2.83	dol i ppv
	DDH 34				
8	227	0.19	4.10	2.83	dol i ppv
9	258	1.07	21.0	2.84	dol i
10	324	<0.01	1.30	2.86	dol i
11	321	0.09	9.40	2.84	dol i vug
12	548	0.62	7.10	2.82	dol i ppv
	DDH 355				
13	332	7.66	22.0	2.71	lsi vug
14	433	0.05	9.20	2.83	dol i vug
	DDH 412				
15	159	1.09	4.60	2.78	dol i lmy
16	163	0.03	3.10	2.82	dol i vug
17	203	0.02	6.30	2.74	dol i lmy
18	326	0.03	4.60	2.85	dol i mv
	DDH 426				
19	244	0.04	2.60	2.84	dol i ppv
20	370	1.48	4.10	2.83	dol i vug

COMPANY	STEVENSON INTERNATIONAL GROUNDWATER CONSULTANTS LTD.	PAGE	3 of 3
		FILE	7004-83-840
WELL	SELECTED SAMPLED	DATE	1983 11 03

CORE ANALYSIS RESULTS CONTINUED

SAMPLE NUMBER	DEPTH FEET	PERMEABILITY MILLIDARCYS	POROSITY PERCENT	GRAIN DENSITY	VISUAL EXAMINATION AND REMARKS
21	416	0.08	9.00	2.82	dol i vug
22	521	0.07	9.70	2.82	dol i vug lmy
23	619	7.45	11.3	2.86	dol i ppv
	DDH 464				
24	312	8.61	10.7	2.84	dol i sv mv lmy
25	382	0.09	2.70	2.83	dol i sv
26	484	14082.	18.5	2.84	dol i vug
27	600	76.4	17.1	3.05	dol i ppv pyr
	DDH 575				
28	280	<0.01	2.70	2.71	dol i ppv lmy
29	394	0.04	12.7	2.83	dol i
30	525	0.02	2.80	2.85	dol i
31	585	<0.01	0.30	2.59	ls shy

STEVENSON INTERNATIONAL GROUNDWATER CONSULTANTS Ltd.