WR28-2-520-128

HYDROGEOLOGIC INVESTIGATIONS
AT PROPOSED URANIUM MINE
NEAR DEWEY, SOUTH DAKOTA

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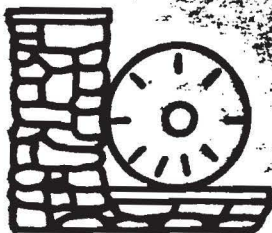
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HYDROGEOLOGIC INVESTIGATIONS AT

PROPOSED URANIUM MINE NEAR

DEWEY, SOUTH DAKOTA

Report No. WR28-2-520-128

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ABSTRACT

The Lakota and Fall River Formations represent aquifers of major importance in the Southern Black Hills Region as well as host rock for uranium ore. An 11-day constant discharge test involving 13 observation wells and numerous private wells was conducted in the Lakota aquifer at TVA's proposed uranium mine near Dewey, South Dakota. The pumping phase of the test was followed by several months of water-level recovery measurements. Results indicate that the test site is located in an area where the Lakota is exceptionally permeable having a transmissivity of 4,400 gpd/ft and a storativity of about 1×10^{-4}. Outside of this locality the Lakota transmissivity decreases substantially due to aquifer thinning and a change to finer-grained sedimentary facies. The drawdown response in the Fall River aquifer was substantially less than that observed during a similar test conducted at TVA's proposed Burdock mine, indicating that the Fuson shale unit lying between the two aquifers is a more effective aquitard in the Dewey area. It is further concluded that the nearby Dewey fault acts as a barrier to horizontal ground-water movement in the Lakota and Fall River aquifers.

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INTRODUCTION

The following report describes a hydrogeologic test conducted February 1982 at TVA's proposed uranium mine shaft site near Dewey, South Dakota (Figure 1). The Dewey test is one of a series of tests TVA has conducted in aquifer units of the Inyan Kara Group in the southwestern Black Hills area. The purpose of these tests is to obtain sufficient quantitative information about local hydrogeologic conditions to enable prediction of mine depressurization requirements and impacts to local ground-water users.

HYDROGEOLOGIC ENVIRONMENT

The principal aquifers in the region are the alluvial deposits associated with the Cheyenne River and its major tributaries, the Fall River formation, the Lakota formation, the Sundance formation, and the Pahasapa (or Madison) formation. Except for the alluvium, these aquifers crop out peripherally to the Black Hills where they receive recharge from precipitation. Ground-water movement is in the direction of dip, radially from the central Black Hills. In most instances, ground water in these aquifers is under artesian conditions away from the outcrop area, and water flows at ground surface from numerous wells in the area.

The Fall River and Lakota formations which form the Inyan Kara Group are the most widely used aquifers in the region. The alluvium is used locally as a source of domestic and stock water. The Sundance formation is used near its outcrop area in central and northwestern Fall River County. The Pahasapa (Madison) formation is locally accessible only by very deep wells and is the source for five wells in the city of Edgemont.
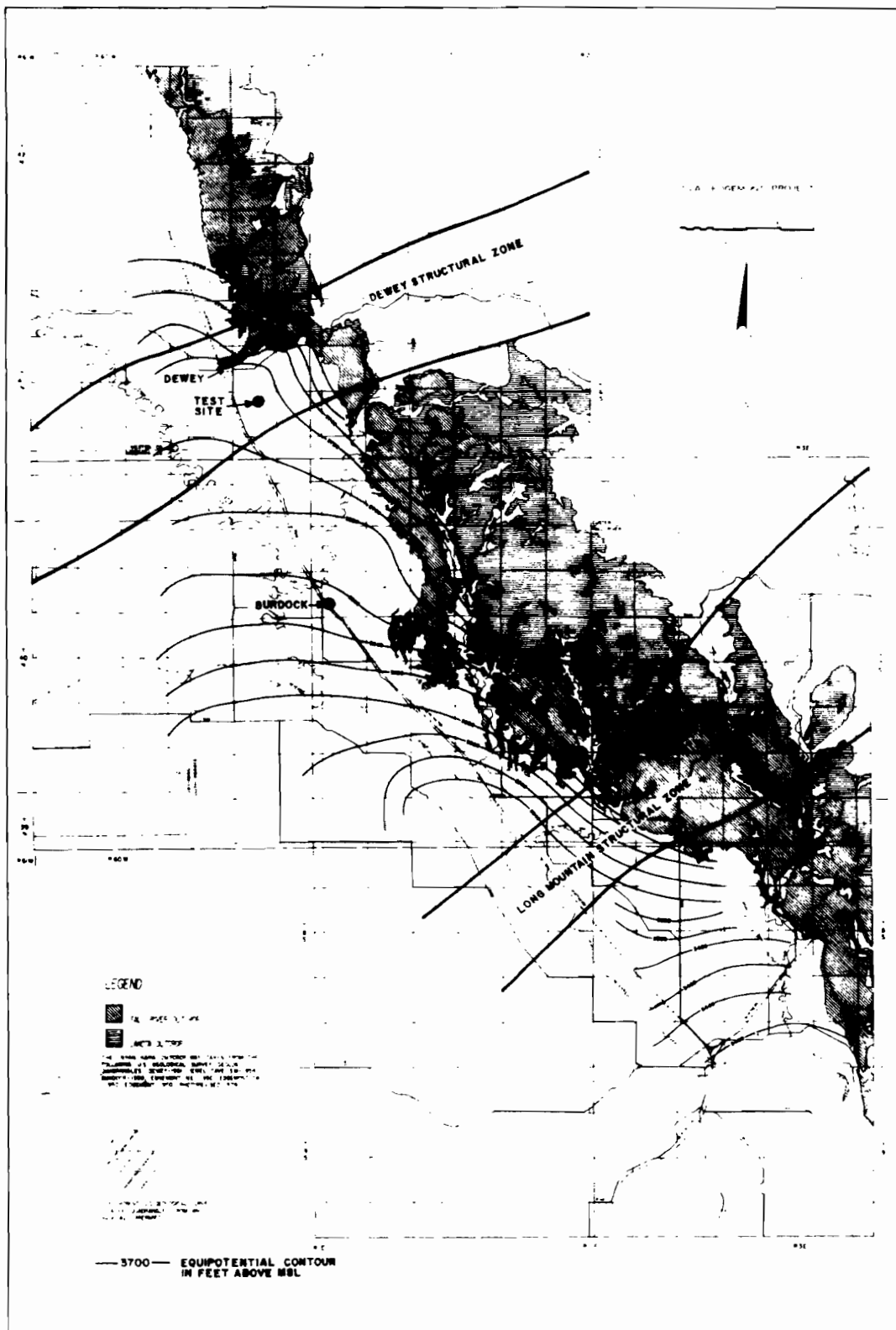
Figure I: Site Location and Potentiometric
Surface Map

The Fall River and Lakota aquifers are of primary concern because of the potential impact of mine dewatering on the numerous wells developed in these aquifers in the vicinity of the mine. At the proposed mine site, the Fall River consists of approximately 180 feet of interbedded fine-grained sandstone, siltstone and carbonaceous shale. The Fall River aquifer is overlain by approximately 400 feet of the Mowry and Skull Creek shales unit, which act as confining beds. Five domestic and stock-watering wells are known to be developed in the Fall River formation within a four-mile radius of the mine site.

The Fall River formation is underlain by Fuson member of the Lakota formation consisting primarily of siltstone and shale with occasional fine-grained sandstone lenses. Thickness of the Fuson is on the order of 100 feet in the site vicinity. The Fuson acts as a leaky aquitard between the Fall River and Lakota aquifers.

The Chilson member of the Lakota formation is the source for some 30 wells within a four-mile radius of the mine site. It also represents the primary uranium-bearing unit targeted for mining. The Chilson (also referred to as the "Lakota aquifer" in this report) consists of about 120 feet of consolidated to semi-consolidated, fine-to-coarse grained sandstone with interbedded siltstone and shale. It is underlain by the Morrison formation consisting of interbedded shale and fine-grained sandstone. Regionally, the Morrison is not considered an aquifer. Under conditions of ground-water withdrawal from the Chilson, the Morrison is expected to act as an aquitard.

Recharge to the Fall River and Lakota aquifers is believed to occur at their outcrop areas. Gott, et al. (1974), suggest on the basis of geochemical data that recharge to these aquifers may also be derived from the upward movement of ground water along solution collapses and breccia

pipes from the deeper Minnelusa and Pahasapa aquifers. The solution collapse and breccia pipe features lie within the Dewey and Long Mountain structural zones (Figure 1).

Inasmuch as the proposed mine site lies only about one mile south of the Dewey fault trace, one of the primary objectives of the test was to determine the hydrologic significance of the fault and its affect on the propagation of drawdown in the vicinity of the mine during depressurization. Vertical displacement on the major fault generally increases toward the southwest, and is on the order of 200 feet at the point where the fault trace crosses the South Dakota-Wyoming border. Thus, it appears that the Fall River and Lakota aquifers are completely offset by the fault in the site vicinity.

LAKOTA AQUIFER TEST

Design

The shaft site for the Dewey mining area had not been selected at the time the aquifer testing designs were made. The test site was, therefore, located in the general vicinity of the proposed mine site within close proximity to the Dewey fault. The test well was completed to a depth of 804 feet and was screened within the Chilson member of the Lakota Formation. A network of eleven observation wells were constructed along two perpendicular lines intersecting at the pumped well for the purpose investigating hydrologic boundary conditions. One line of wells was oriented normal to the Dewey fault trace, and the other was approximately normal to the aquifer outcrop belt to the east (see Figure 2). Seven of these wells were developed in the Chilson member, three in the Fall River formation,
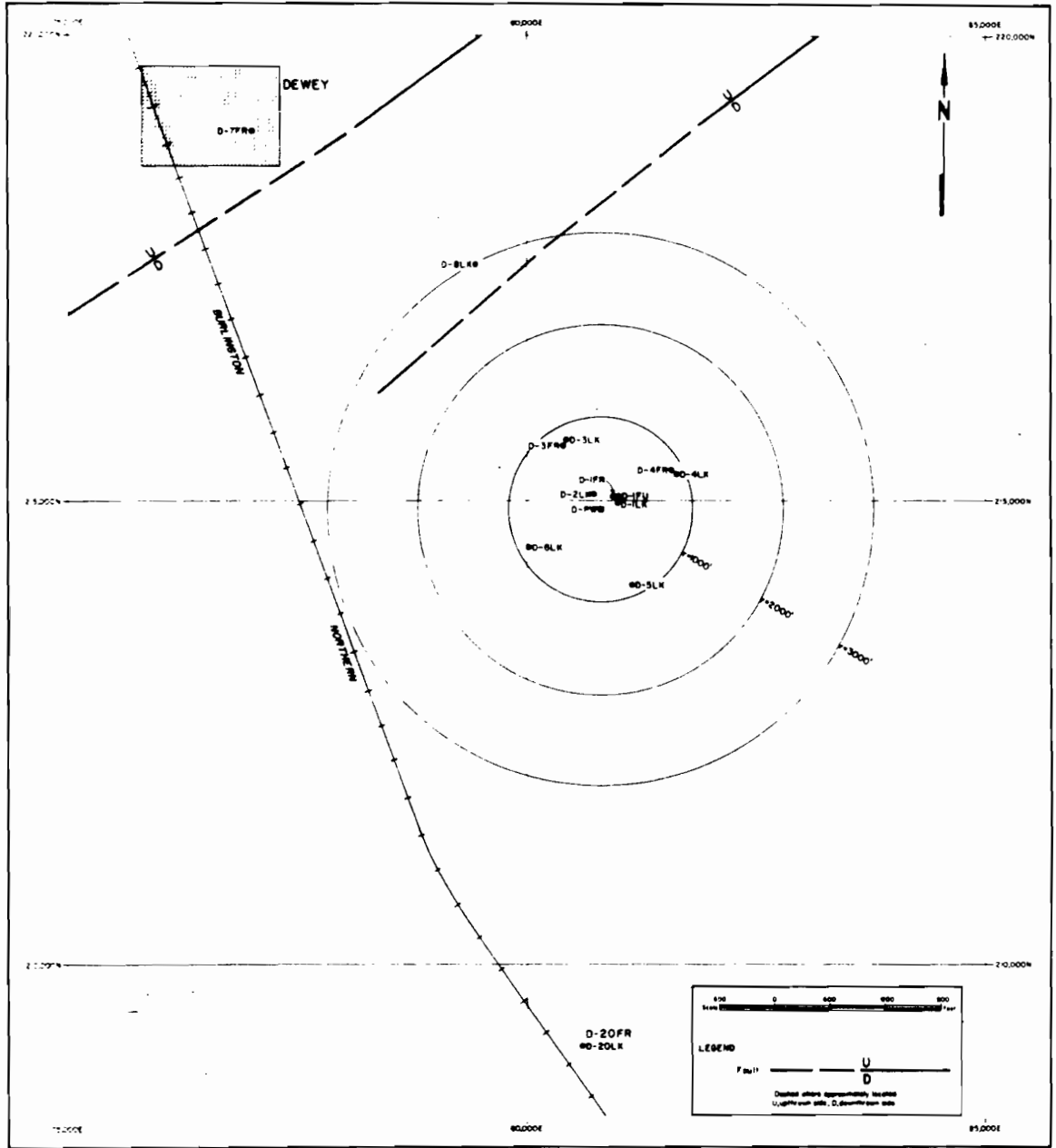
Figure 2: Well Location Map

and one in the Fuson. Preexisting observation wells BPZ-20LAK and BPZ-20FR (hereafter referred to as D-20LK and D-20FR, respectively) located about one mile south of the test well were also monitored during the test. Construction details for these wells are given in Table 1. In addition, periodic measurements of water level (or well flowrate) were made during the test at all private wells within the test site vicinity.

Based upon preliminary drilling results in the Dewey test site area and experience from the Burdock aquifer tests, it was expected that the Fall River and Lakota aquifers in the Dewey area would respond essentially as a single aquifer system. As a result less emphasis was placed on measurement of the Fuson aquitard properties.

Procedures

A constant-discharge aquifer test was initiated at 1000 hours on February 16, 1982. Discharge from the well was pumped into an arroyo which ultimately drained into a stock pond located about one mile west of the test site. There was no possibility of recirculation of well discharge water during the test due to the 400+ feet thickness of shale between ground surface and the top of the Fall River aquifer. The well pumping rate was monitored with an in-line flow meter and with an orifice plate and manometer device at the end of the discharge line. The pumping rate varied little during the test ranging from 493 to 503 gpm and averaging 495 gpm. The pumping phase of the test lasted 11 days and was followed by approximately 10 months of recovery measurements. Water level measurements in all wells were made with electric probes. Flow rates associated with offsite private wells were checked with a bucket and stop watch.

TABLE 1. Well Construction Data

Well No.	Depth (feet)	Casing Diameter (inches)	Depth Interval of Open Borehole or Well Screen (feet)	Distance From Pumped Well (feet)
D-PW	804	10	695-725, 755-800	--
D-1LK	800	4	712-800	189
D-1FU	620	4	609-620	229
D-1FR	580	4	504-580	186
D-2LK	800	4	692-800	191
D-3LK	800	4	715-800	851
D-3FR	590	4	505-590	810
D-4LK	780	4	714-780	905
D-4FR	580	4	503-580	879
D-5LK	835	4	735-835	872
D-6LK	810	4	715-810	890
D-7FR	120	4	119-120	5610
D-8LK	750	4	650-750	2785
D-20LK	860	4	798-860	5700
D-20FR	672	1	671-672	5700

Analysis

Semilogarithmic graphs of drawdown (s) versus time (t) for the pumped well and observation wells are given in Appendix A. The drawdown trends in wells D-PW, D-1LK and D-2LK are essentially the same, i.e., there is a period of roughly linear drawdown during the first 1000 minutes of the test, followed by a gradual increase in the rate of drawdown during the remainder of the test. The remaining Lakota wells exhibit s-t curves which have a continuous increase in slope throughout the test without stabilizing to a linear drawdown trend. A slight increase in hydrostatic water level was observed during the early period of the test in the Fall River and Fuson wells. This seemingly paradoxical behavior, known as the Noordbergum effect, is due to a transfer of stress from the pumped aquifer to the adjacent aquitards and aquifers (Gambolati, 1974). Drawdowns observed in the Fall River and Fuson wells were much less than those recorded during a similar test conducted near Burdock (Boggs and Jenkins, 1980). The Jacob straight-line method (Walton, 1970) was applied to the semilog graphs for the Lakota wells to obtain the values of transmissivity (T) and storativity (S) presented in Table 2. In the case of the closer observation wells, two straight-line data fits were possible: one using the early data and another using the late data. Only the late data for the more distant observation wells were analyzed by this method.

Logarithmic s-t graphs for all test wells are given in Appendix B. Theis curve-matching techniques (Walton, 1970) were applied to the Lakota aquifer curves to obtain the T and S estimates presented in Table 2. Due to the somewhat unusual shape of the s-t response curves, the only curve-match solutions possible were those using the early data.

TABLE 2.   Computed Lakota Aquifer Properties

Well	r (ft)	Jacob Method Drawdown T_e	S_e	T_1	Jacob Method Recovery T_e	T_1	Theis Method T_e	S_e
D-PW	0.67	4400	--	890	4890	680	--	--
D-1LK	189	5280	3.E-05	890	4890	650	5210	3.E-05
D-2LK	191	4400	3.E-04	910	4710	650	4090	2.E-04
D-3LK	851	--	--	920	--	670	6900	7.E-05
D-4LK	905	--	--	900	--	680	4090	8.E-05
D-5LK	872	--	--	900	--	670	4410	7.E-05
D-6LK	890	--	--	900	--	650	6030	8.E-05
D-8LK	2785	--	--	940	--	680	3180	5.E-05
D-20LK	5700	--	--	--	--	680	1400	3.E-05

Note: Transmissivity (T_e, T_1) in units of gpd/ft.

A semilog plot of the final drawdown in each Lakota well versus its radial distance from the pumped well is shown in Figure 3. The Jacob straight-line method was applied to this plot to obtain T and S values of 4400 gpd/ft and 10^{-6}, respectively, for the Lakota aquifer. The storativity value computed by this method is considered highly unreliable since it is two orders of magnitude lower than expected.

Water level recovery data for all wells are presented in Appendix C. Data are plotted as semilog graphs of residual drawdown versus t/t' (ratio of time since pumping started to time since pumping stopped). The Lakota graphs were analyzed using the Jacob method. Again, two straight-line fits are possible for the closer Lakota wells. Both are given in Table 2.

Fuson aquitard properties were estimated from the D-1 well group data using the ratio method (Neuman and Witherspoon, 1973). The vertical hydraulic conductivity of the aquitard (K'_v) is computed to be approximately 2×10^{-4} ft/d based on the average of several computed K'_v during the interval between 1800 and 5000 minutes. For purposes of the analysis, the specific storativity (S'_s) of the aquitard was assumed to be approximately equal to that computed for the Lakota aquifer (about 7×10^{-7} ft^{-1}).

Interpretation

The T estimates obtained from all methods using the early drawdown and recovery data are in reasonably good agreement. Values range from 3180 to 6900 gpd/ft and average approximately 4800 gpd/ft. The T of 4400 gpd/ft derived from the distance drawdown analysis is also consistent with the early T estimates. These values are believed to represent the transmissivity of the Lakota aquifer within the immediate vicinity of the test

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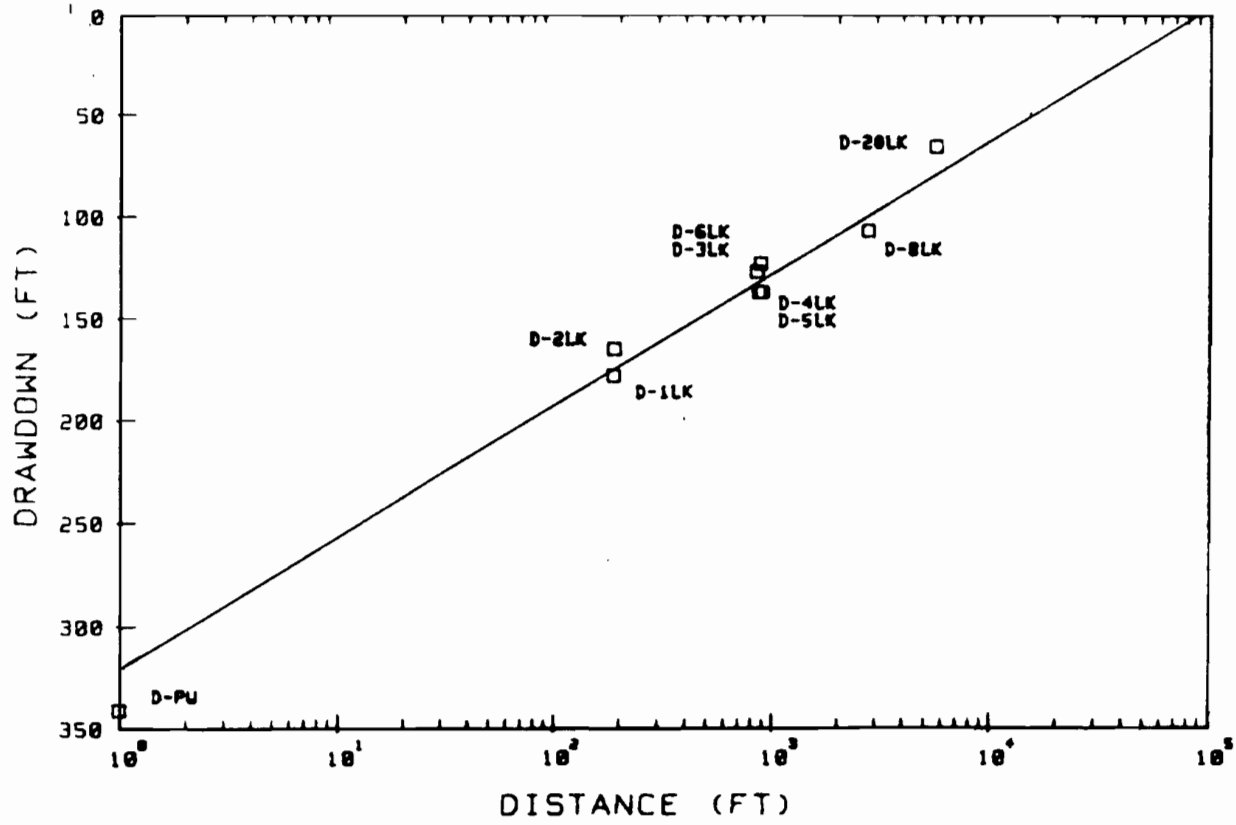
FIGURE 3.   DISTANCE-DRAWDOWN GRAPH

site, and are consistent with the physical characteristics of the aquifer materials within this area. The T values computed from the late drawdown data, although consistent from well to well, are not reliable since the rate of drawdown during the later stage of the test never stabilized to the linear or ideal Theis-curve trend. The late recovery data provide the best estimates of the regional or long-term transmissivity of the Lakota aquifer in the Dewey region because of the long duration of this phase of the test.

In general, drawdown response in the pumped well and closer observation wells is characterized by a period of approximately linear drawdown during the first 1000 minutes of the test, followed by a steadily increasing rate of drawdown until the end of the test. The recovery data reflects the same sort of trend. The late response may be interpreted as either the effect of barrier boundary conditions or a decrease in transmissivity with distance from the test site or both.

Most of the available hydrogeologic information indicates that the Dewey fault acts as a barrier to horizontal ground-water movement in the Inyan Kara aquifers. Vertical displacement along the Dewey fault is on the order of 200 feet in the test site vicinity causing the complete separation of the Lakota aquifer on either side of the fault. Despite the geochemical evidence of Gott, et al. (1974), that the fault may act as conduit for upward circulation of ground water from deeper aquifers to the Inyan Kara Group, a recharge condition is not reflected in the potentiometric surface configuration in the fault zone (Figure 1) or in the test results. A reduction in the rate of drawdown would be expected in the s-t graphs for observation wells closest to the fault if significant recharge occurred in the fault zone. Instead the opposite response is observed in the test data. The s-t curve for well D-8LK (the closest observation well to the fault)

exhibits the steepest slope during the late stage of the test, supporting the idea that the fault is a hydrogeologic barrier. Upward recharge may occur in the fault zone but at relatively low rates. Consequently, the fault does not behave as a recharge boundary.

Computer Simulations

A computer ground-water model of the Dewey region was developed to aid in interpreting the test results and refining aquifer parameters. A three-dimensional ground-water flow code developed by Trescott (1975) was used for the simulations. The Inyan Kara is conceptualized as a three-layer aquifer system consisting of the Lakota (Chilson) aquifer, the Fuson aquitard and the Fall River aquifer, with model layers having uniform thicknesses of 120, 100, and 180 feet, respectively. Impervious boundaries are set above the Fall River layer and below the Lakota layer to represent the relatively impermeable shales which bound the Inyan Kara Group. The model area and finite-difference grid are shown in Figure 4. The outcrop area of the Inyan Kara represents the eastern limit of the modeled region. The remaining three sides of the model are set at sufficient distances from the test pumping well to eliminate the possibility of artificial boundary effects in model simulations. The Dewey fault zone was treated as a barrier boundary.

Simulations were made using two basic conceptual models of the Inyan Kara aquifer system to determine which model best represented observed responses during the Dewey test. For case I, uniform T and S values of 4,400 gpd/ft and 1×10^{-4}, respectively were assigned to the Lakota aquifer. A uniform T was used for this case despite evidence of a much lower transmissivity outside of the immediate test site in order to determine
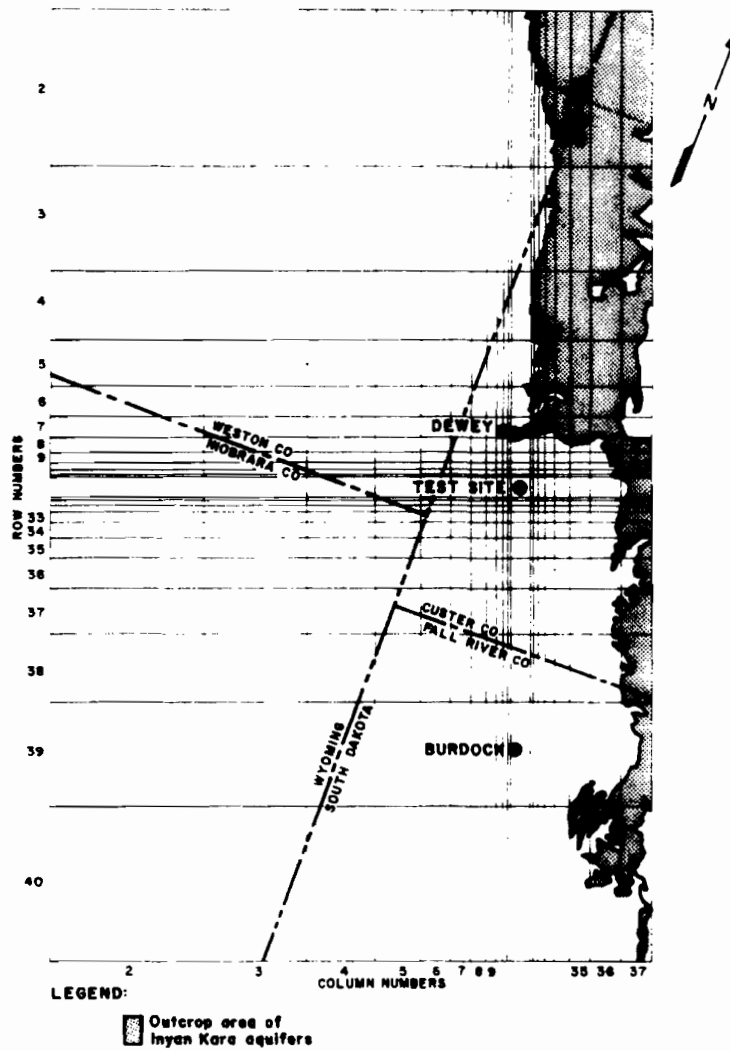
Figure 4: Ground-Water Model Grid

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whether the fault alone could account for late drawdown trends. The Fuson aquitard was assigned a uniform K'_v of 10^{-4} ft/d. The Fall River aquifer was represented by uniform T and S values of 400 gpd/ft and 10^{-4} respectively, based on the results of the Burdock tests (Boggs and Jenkins, 1980). A simulation was then made of the 11-day Dewey aquifer test using the average pumping rate of 495 gpm in an attempt to reproduce the test results. A comparison of computed and observed s-t graphs for the Lakota observation wells is shown in Figure 5. Clearly, the barrier boundary condition created by the fault does not fully account for the observed increase in drawdown rate during the latter part of the test.

In Case II, the model was modified to account for the suspected spatial variability of transmissivity in the Lakota aquifer. Geologic evidence indicates that the test site is located in an area where the Lakota is composed of an exceptionally thick course-grained sandstone. Outside of this locality the aquifer becomes thinner and its composition changes to finer-grained sedimentary facies. These changes are particularly evident in the area east of the site. The test results indicate a local T in the immediate site area of about 4,400 gpd/ft and a regional average of about 670 gpd/ft. These T estimates were used along with areal variations in the sandstone-shale composition of the Lakota aquifer in the site vicinity to arrive at the T distribution shown in Figure 6. Exploration borehole geophysical logs were used to estimate the relative amounts of sandstone and shale in the Lakota across the site area. The horizontal hydraulic conductivity of the sandstone is estimated at approximately 5.7×10^{-5} ft/sec based upon the near-field T estimate of 4,400 gpd/ft, an aquifer thickness of 120 feet, and the assumption that the aquifer in the immediate vicinity of the test well and closest observation wells is essentially all sandstone. The

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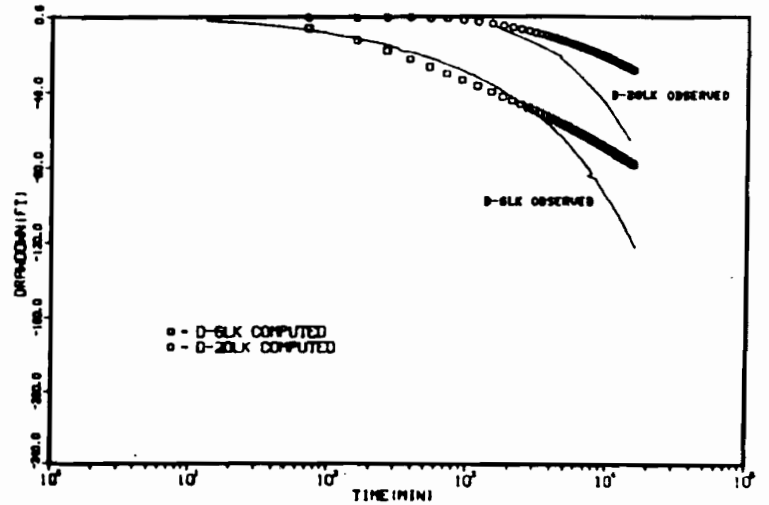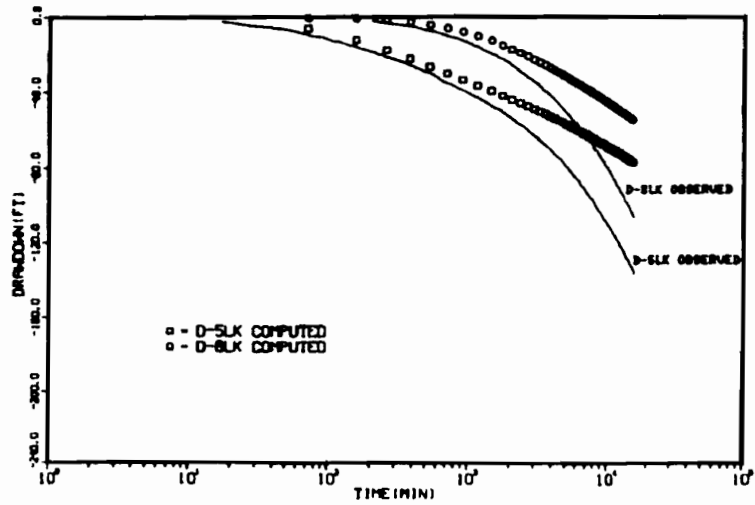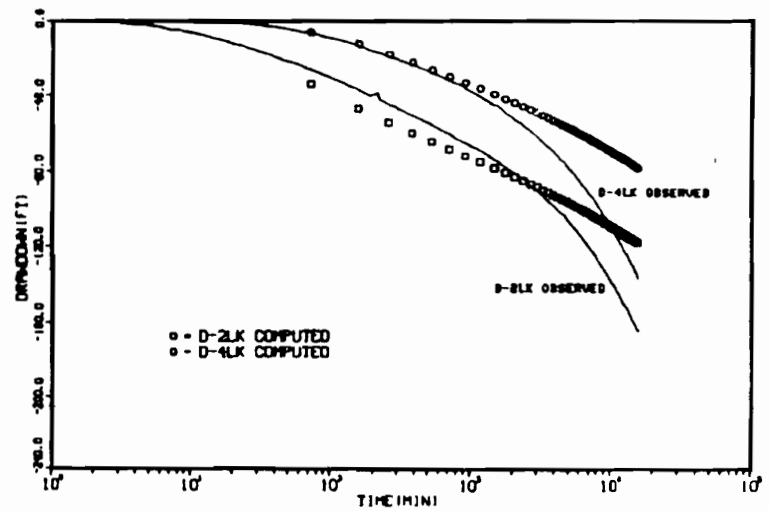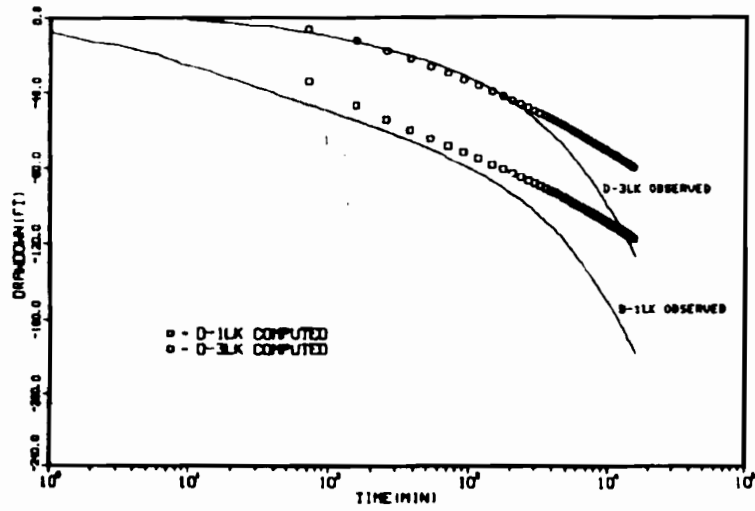
Figure 5.   Comparison of Observed and Computed Drawdown, Case I

Figure 6: Transmissivity Distribution, Case II

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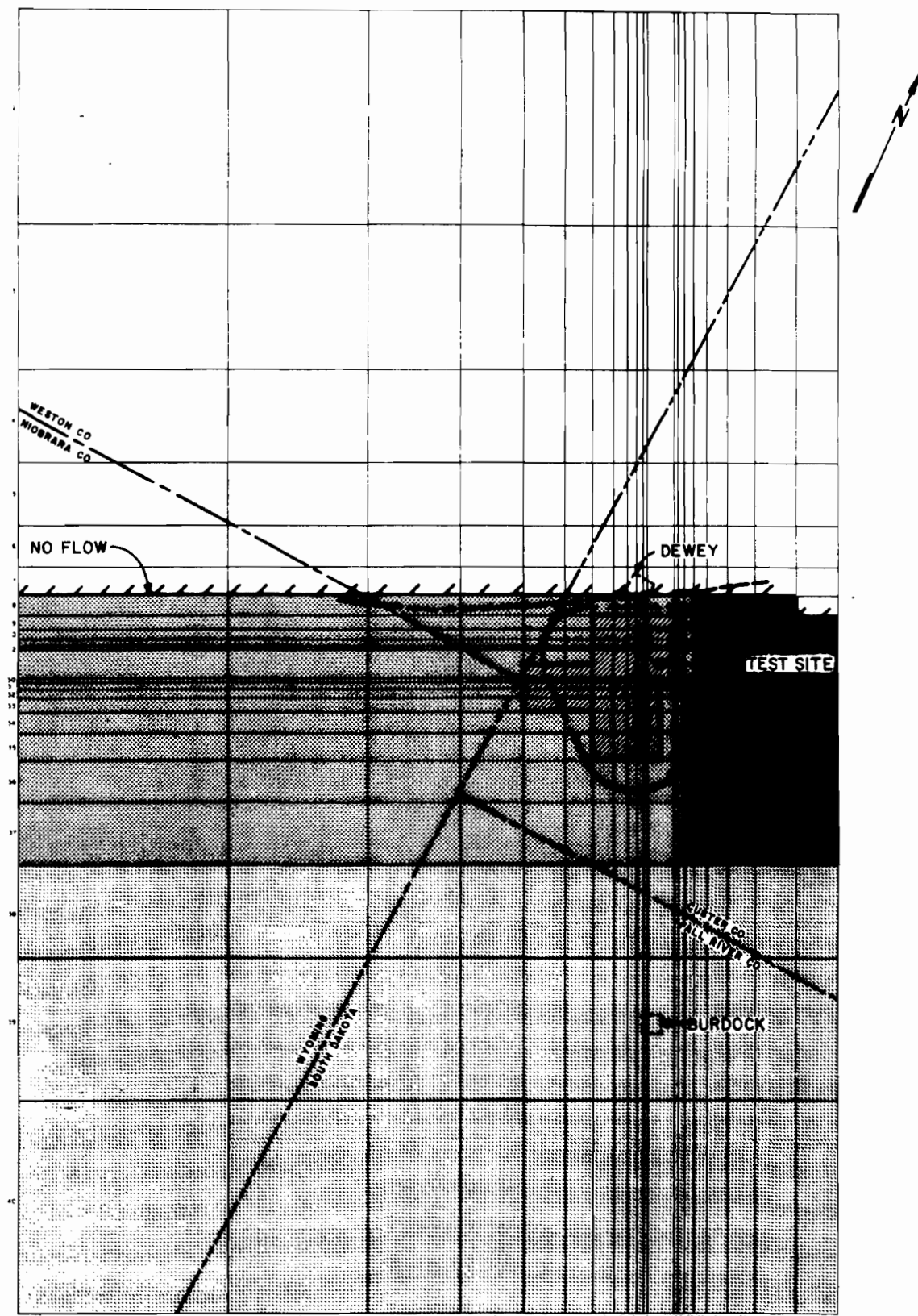
T=0
T=100 gpd/ft
T=600 gpd/ft
T=1400 gpd/ft
T=4400 gpd/ft
FAULT
APPROXIMATE LIMIT OF PUMPING TEST DRAWDOWN INFLUENCE

horizontal conductivity of the shale is estimated to be about 10^{-8} ft/sec assuming (1) the measured vertical conductivity of the Fuson shale is also representative of shale in the Lakota aquifer and (2) the ratio of horizontal to vertical conductivity is about 10:1. Given the estimated horizontal conductivities for the sandstone and shale, a representative average conductivity was computed for areas having similar aquifer sandstone-shale ratios. The representative average conductivity was computed from the geometric mean of the conductivity samples as suggested by Bouwer (1969). The transmissivity of 1,400 gpd/ft assigned to the southern portion of the model is based on results of the Burdock aquifer test. Note that although an attempt was made to assign realistic transmissivity values to the entire model region, model simulation results are mainly affected by the transmissivity distribution within the observed limits of influence of the 11-day aquifer test as indicated in Figure 6. Outside of this region the model is relatively insensitive to the assigned T values.

The Case II simulation results are shown in Figure 7. The agreement between the computed and observed drawdown trends in the Lakota wells is quite good overall. At least part of the discrepancy between observed and computed responses in these units is due to the fact that computed hydraulic heads are average values over the thickness of the aquifer or aquitard layer.

The observed drawdown trends could, perhaps, be reproduced using some alternative T distribution without the barrier boundary condition assumed for the Dewey fault. However, if the fault did not represent a barrier, substantial pressure changes should have been observed during the test in the private Lakota wells located north of the fault. These wells are located at approximately the same radial distance as observation well

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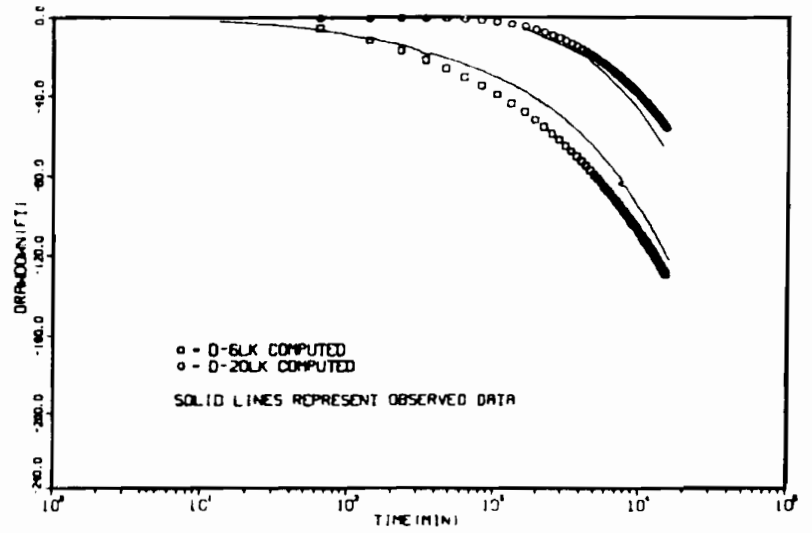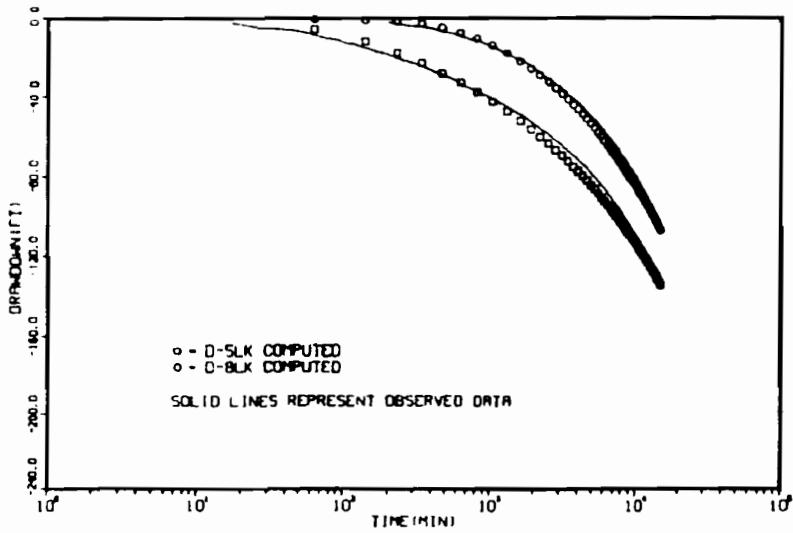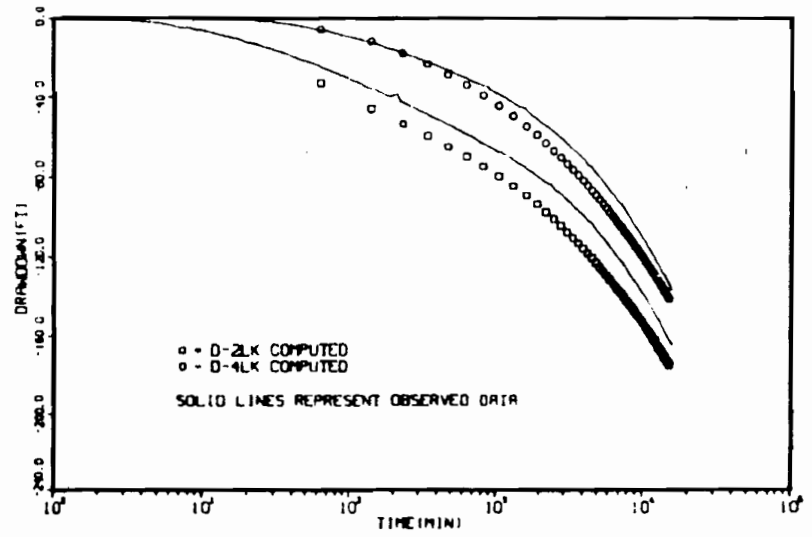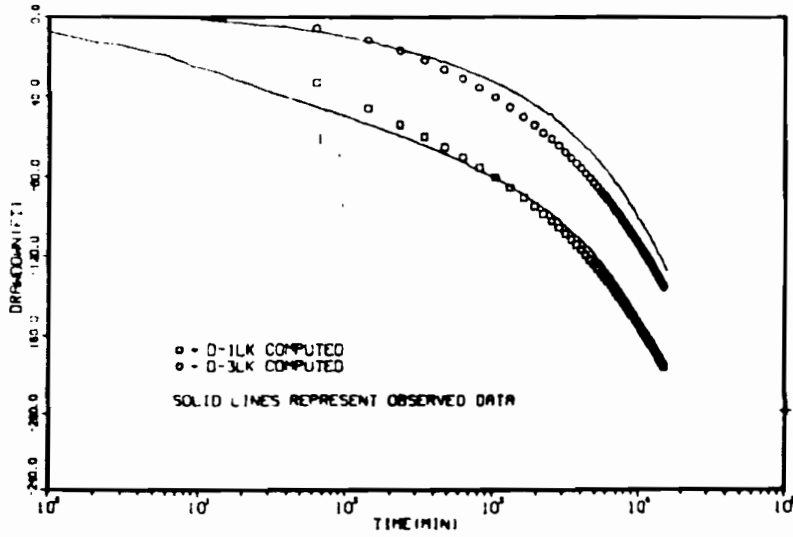
Figure 7.   Comparison of Observed and Computed Drawdown, Case II

D-20LK which exhibited 66 feet of drawdown at the end of the test. As no drawdown occurred in these wells, it is concluded that the Dewey fault represents a hydrogeologic barrier.

The Case II simulation results support the concept of the Lakota as a patchy aquifer of relatively low-transmissivity overall but having within it localized zones of substantially higher transmissivity. The proposed mine site lies within one of these high transmissivity localities. Although the T distribution used in the Case II model is based upon reasonable assumptions, it is considered only an approximation of actual conditions in the test site area. Nevertheless, this approximation is adequate for assessing long-term mine depressurization impacts. The significance of the Case II model result is that it provides an interpretation of the test results which is consistent with what is known or suspected about the hydrogeologic conditions in the site region.

CONCLUSIONS

Hydrogeologic investigations in the Dewey area indicate that the proposed mine site lies within an area where the Lakota Formation is composed of relatively thick permeable sandstone. The transmissivity of the Lakota aquifer in this locality is estimated to be approximately 4,400 gpd/ft. Storativity of the aquifer is about 10^{-4}. Outside of this area the Lakota transmissivity decreases substantially. The variation in transmissivity over the region is consistent with geologic evidence of thinning of the Lakota sandstone away from the test site and a change to finer-grained sand and shale facies. The significance of this condition is that long-term mine depressurization rates and drawdown response in the Dewey vicinity will be

governed by the lower transmissivity material. As a result, dewatering rates will be lower and the areal extent of drawdown impacts smaller than if the higher transmissivity prevailed.

There is evidence that hydraulic communication between the Fall River and Lakota aquifers occurred during the Dewey test. However, the degree of interconnection between these units is substantially less than that observed at the Burdock test site. The vertical hydraulic conductivity of the intervening Fuson aquitard estimated from the Dewey test data is approximately 10^{-4} ft/d. This value is about an order of magnitude lower than the estimate obtained at Burdock. The difference is somewhat surprising in that the Fuson aquitard is thinner in the Dewey area than at Burdock. A possible explanation may be that the direct avenues of hydraulic communication (e.g., numerous open pre-TVA exploration boreholes) believed to exist at Burdock, are not present in the Dewey area.

Evaluation of the drawdown responses recorded in test wells and private wells during the aquifer test and review of existing subsurface geologic data indicates that the Dewey fault zone acts as a hydrogeologic barrier to horizontal ground-water movement between the Inyan Kara aquifers located on opposite sides of the fault zone. Some upward vertical recharge to the Inyan Kara may occur in the fault zone as suggested by Gott, et al. (1968). However, rate of recharge from this source must be relatively small, otherwise recharge effects would be apparent in the aquifer test results and in the configuration of the steady-state potentiometric surface. It is expected that the fault will significantly reduce mining drawdown impacts on ground-water supplies located north of the fault zone.

3. The model should be calibrated by adjustment of hydraulic parameters to reproduce the existing steady-state potentiometric surface shown in Figure 1. The hydraulic properties for the Inyan Kara units measured at the Dewey and Burdock test sites should be held constant in the calibration process, while parameter adjustments are made in other areas to obtain a reasonable match between the computed and observed potentiometric levels. An estimate of net ground-water recharge can be obtained from the calibrated model by assigning observed potentiometric head values to the model nodes which lie within the aquifer recharge (outcrop) area. The aquifer recharge fluxes may be incorporated directly into the model to more accurately represent drawdown conditions in the outcrop areas during mine depressurization simulations.

4. Significant pumping stresses on the Inyan Kara aquifers other than the TVA mining operations should be identified and incorporated into the model.

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FIGURE A-1: DRAWDOWN GRAPH FOR WELL D-PW
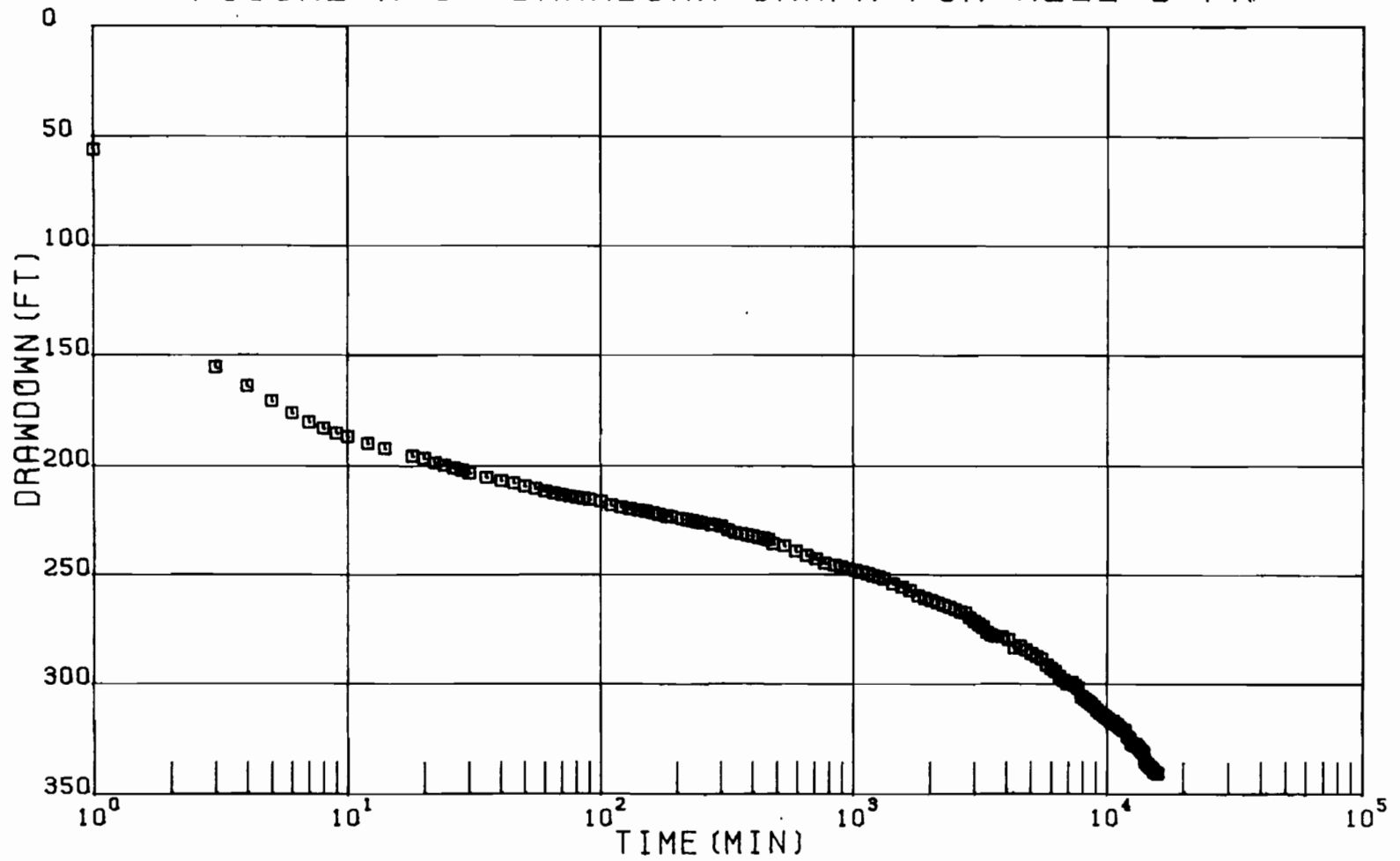
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FIGURE A-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

Legend:
- □ D-1LK
- ○ D-1FR
- △ D-1FU

Y-axis: DRAWDOWN (FT) from -25 to 200

X-axis: TIME (MIN) from 10^0 to 10^5
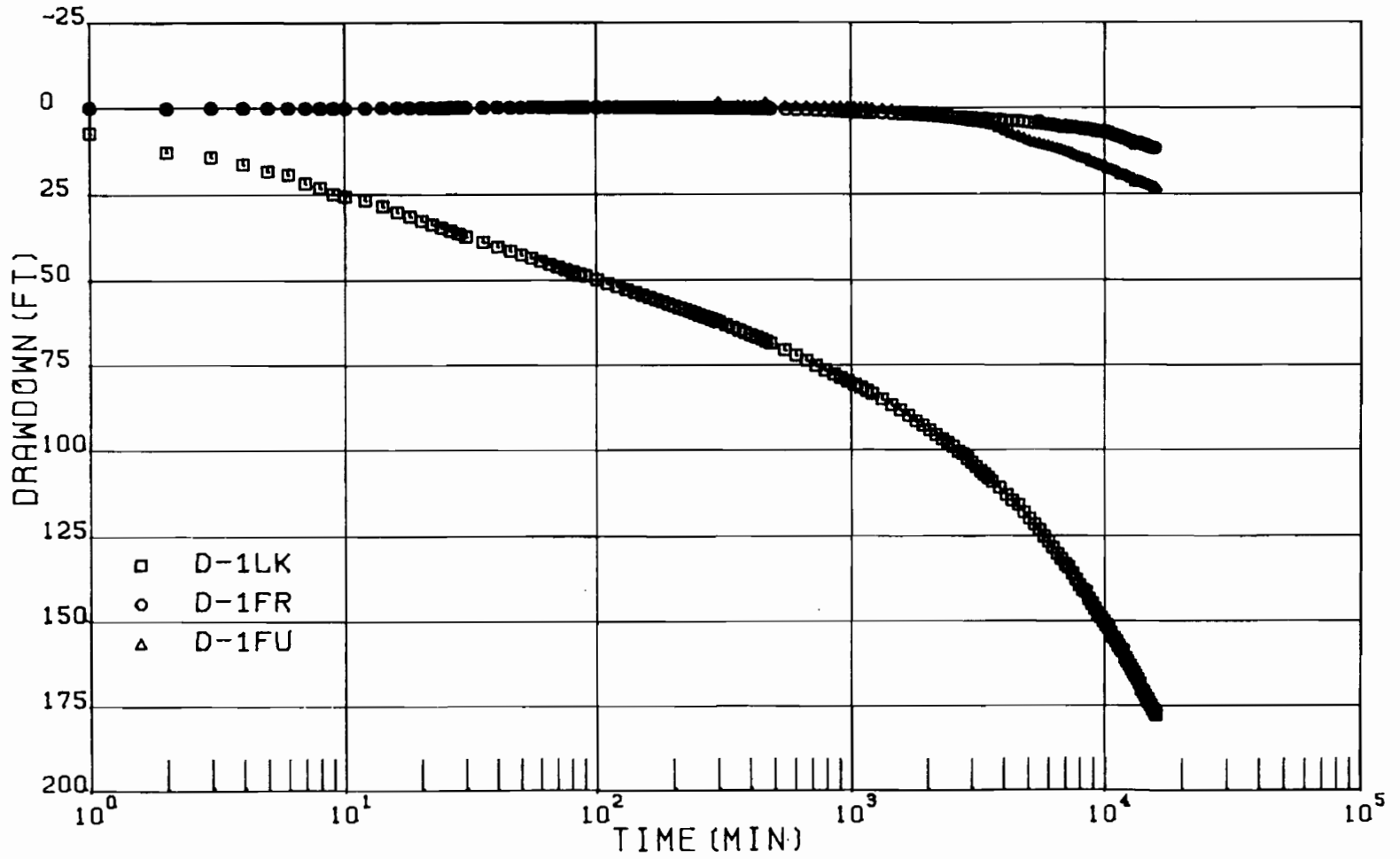
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FIGURE A-3: DRAWDOWN GRAPH FOR WELL D-2LK
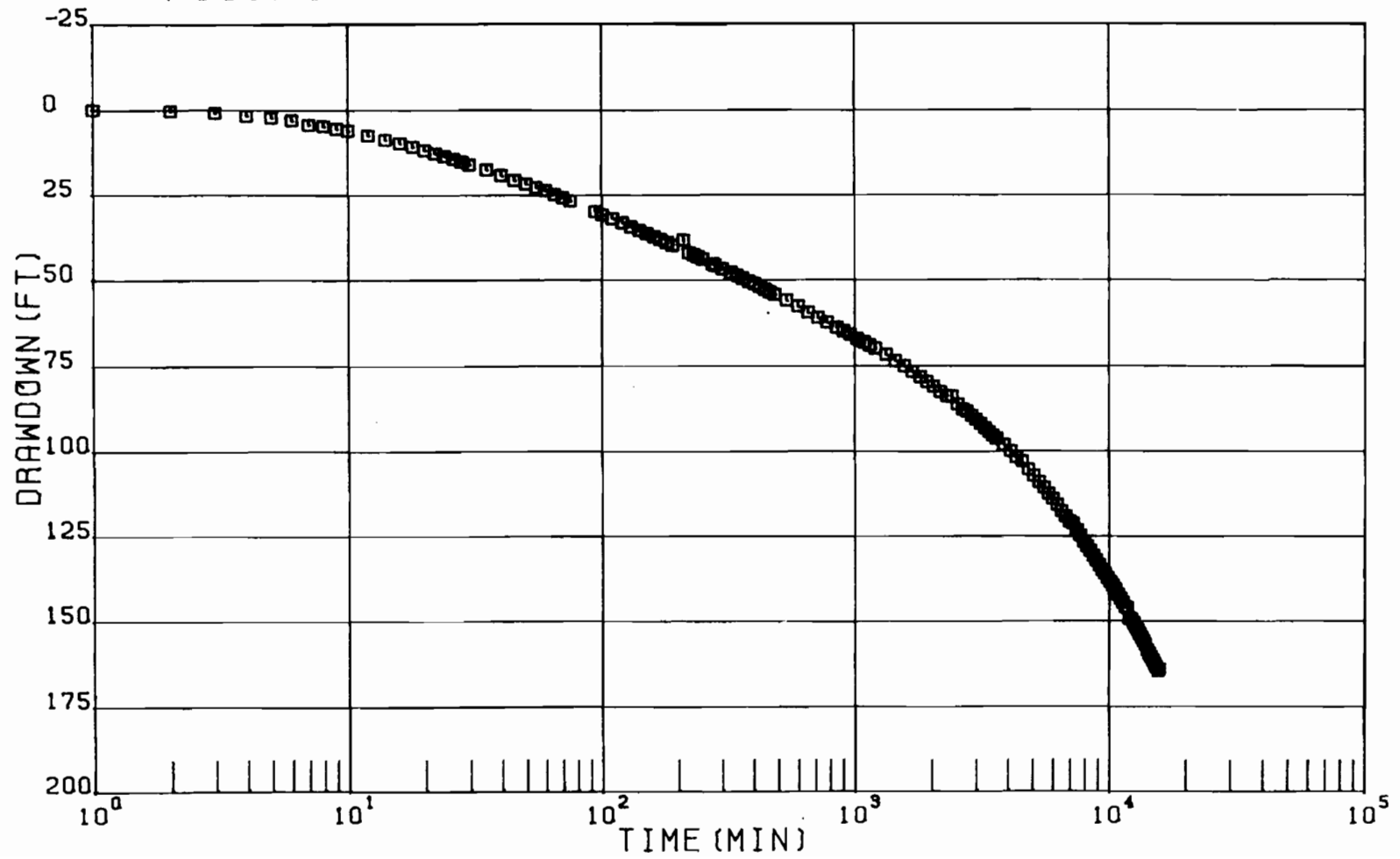
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FIGURE A-4: DRAWDOWN GRAPH FOR D-3 WELL GROUP
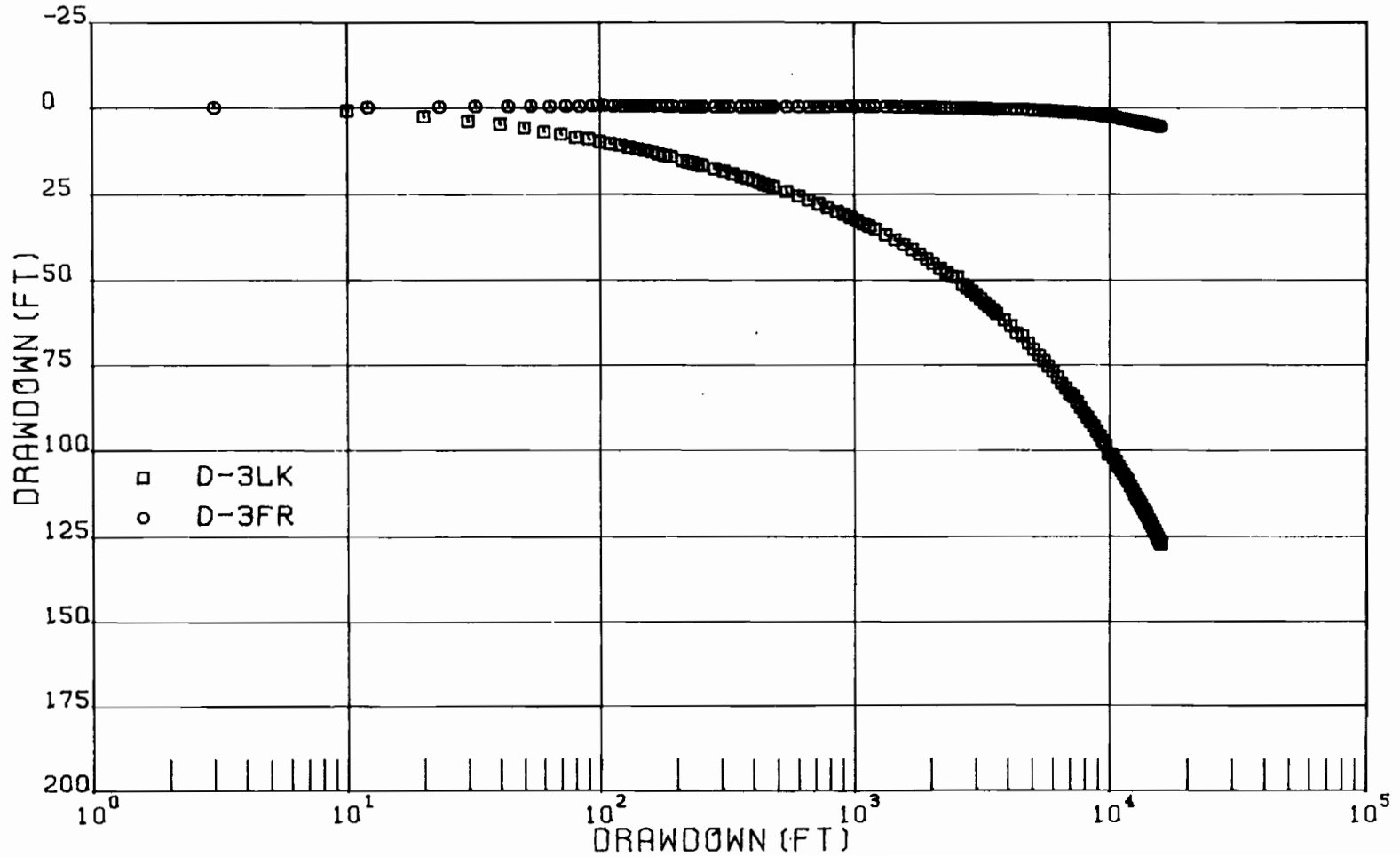
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3.4-E-114

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Appendix 3.4-E

FIGURE A-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP
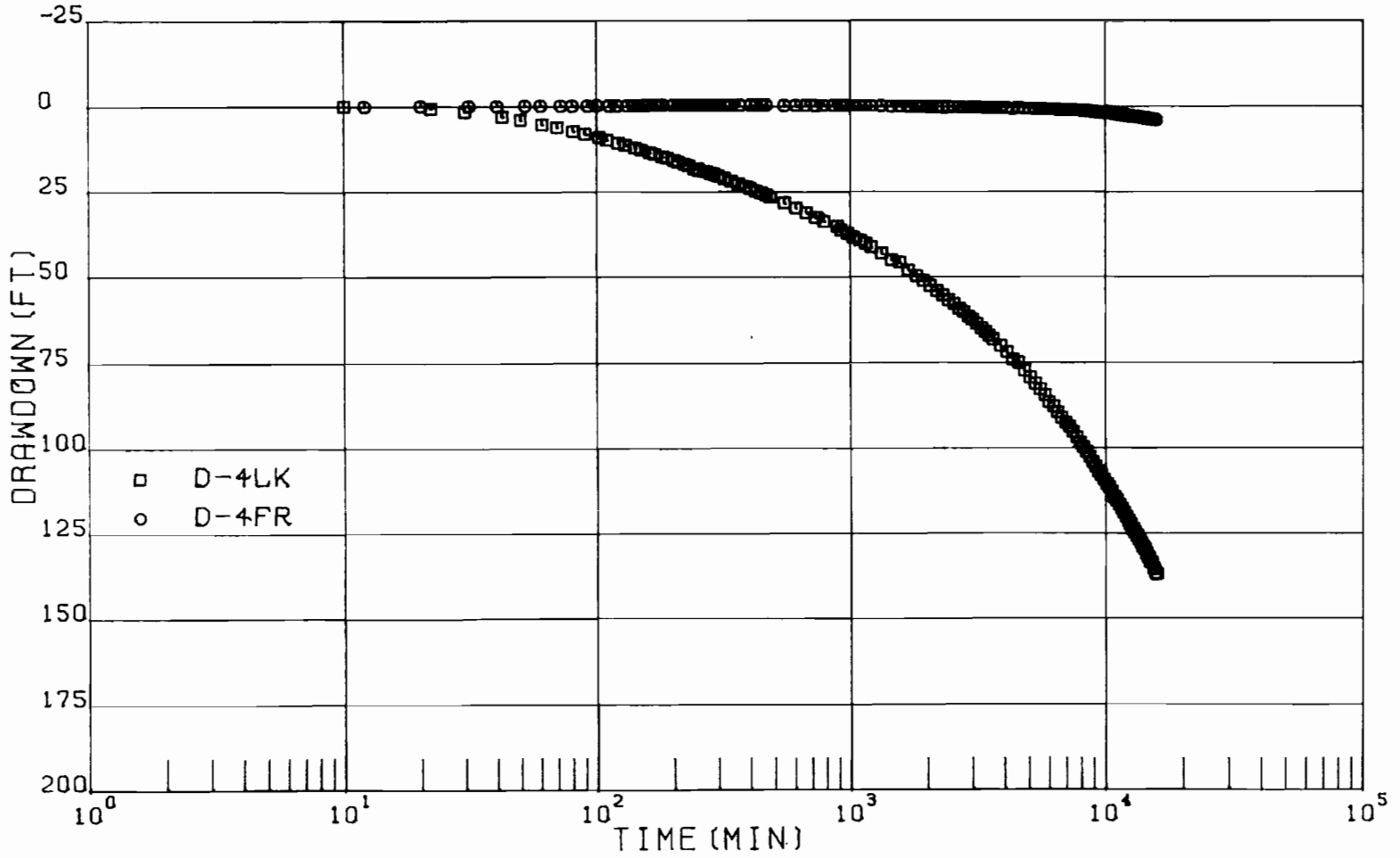
WR28-2-520-128.A-6

FIGURE A-6: DRAWDOWN GRAPH FOR WELL D-5LK
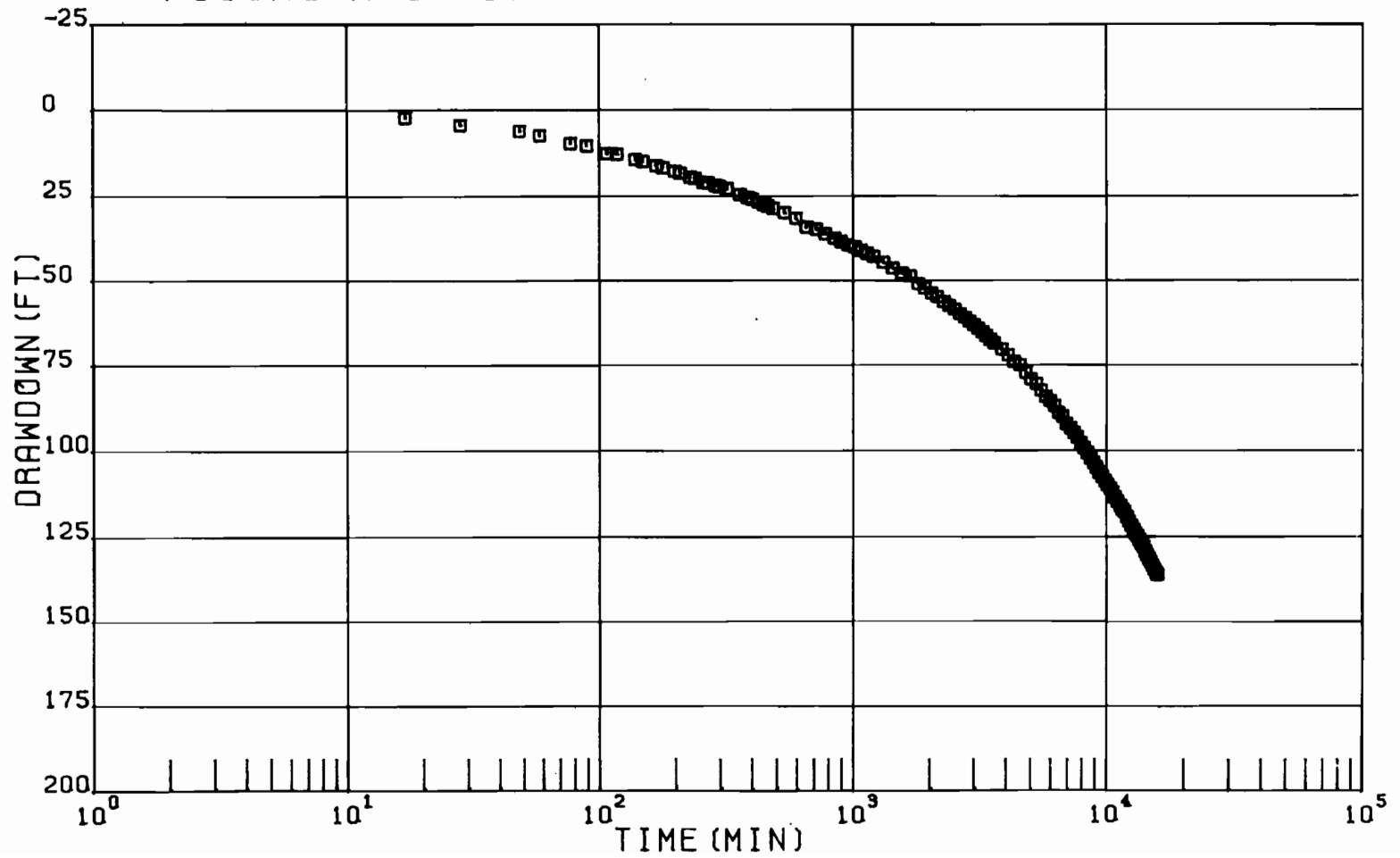
WR28-2-520-128.A-7

FIGURE A-7: DRAWDOWN GRAPH FOR WELL D-6LK

WR28.-2-520-128.A-8

FIGURE A-8: DRAWDOWN GRAPH FOR WELL D-8LK

WR28-2-520-128.A-9

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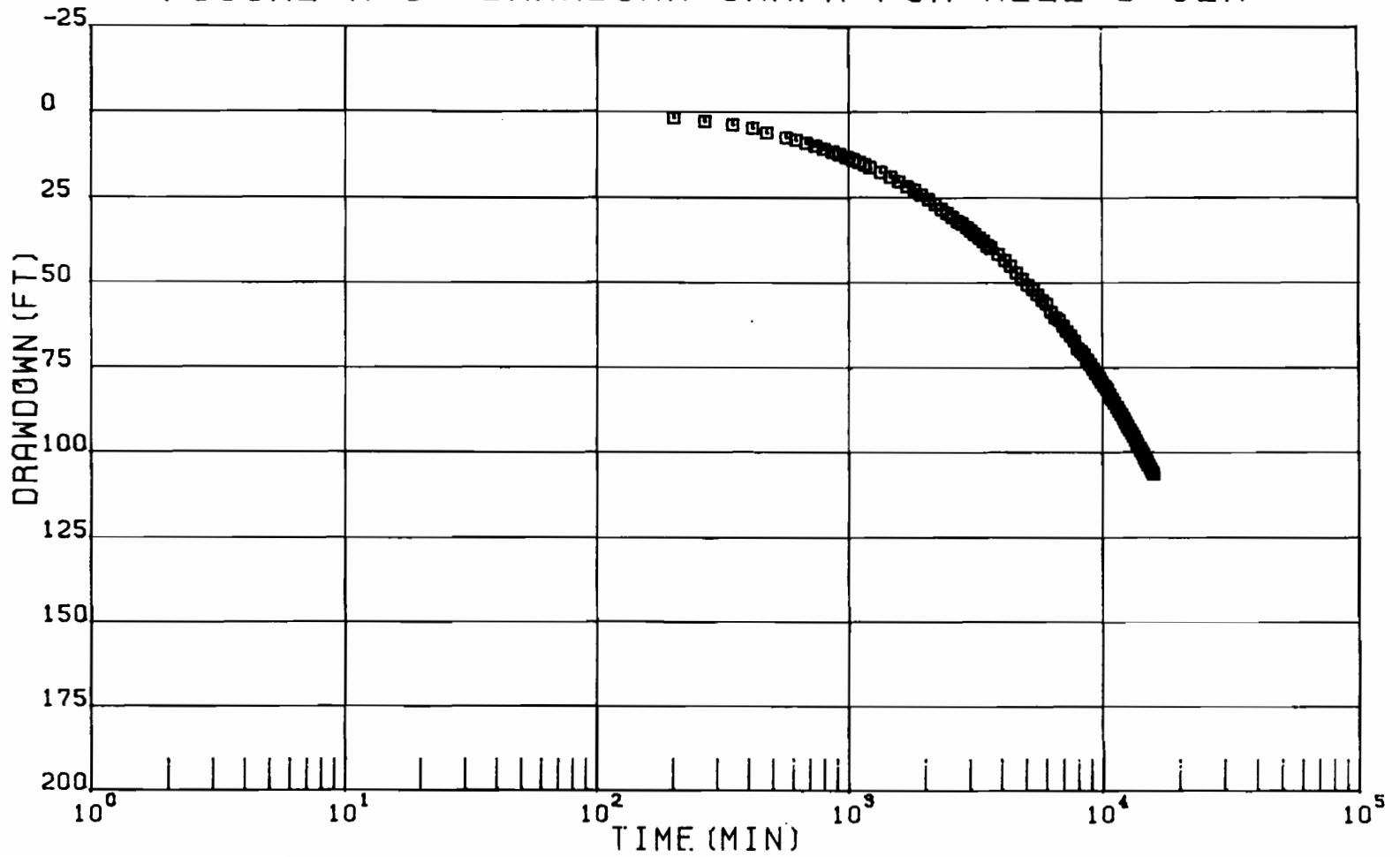
FIGURE A-9: DRAWDOWN GRAPH FOR WELL D-20LK
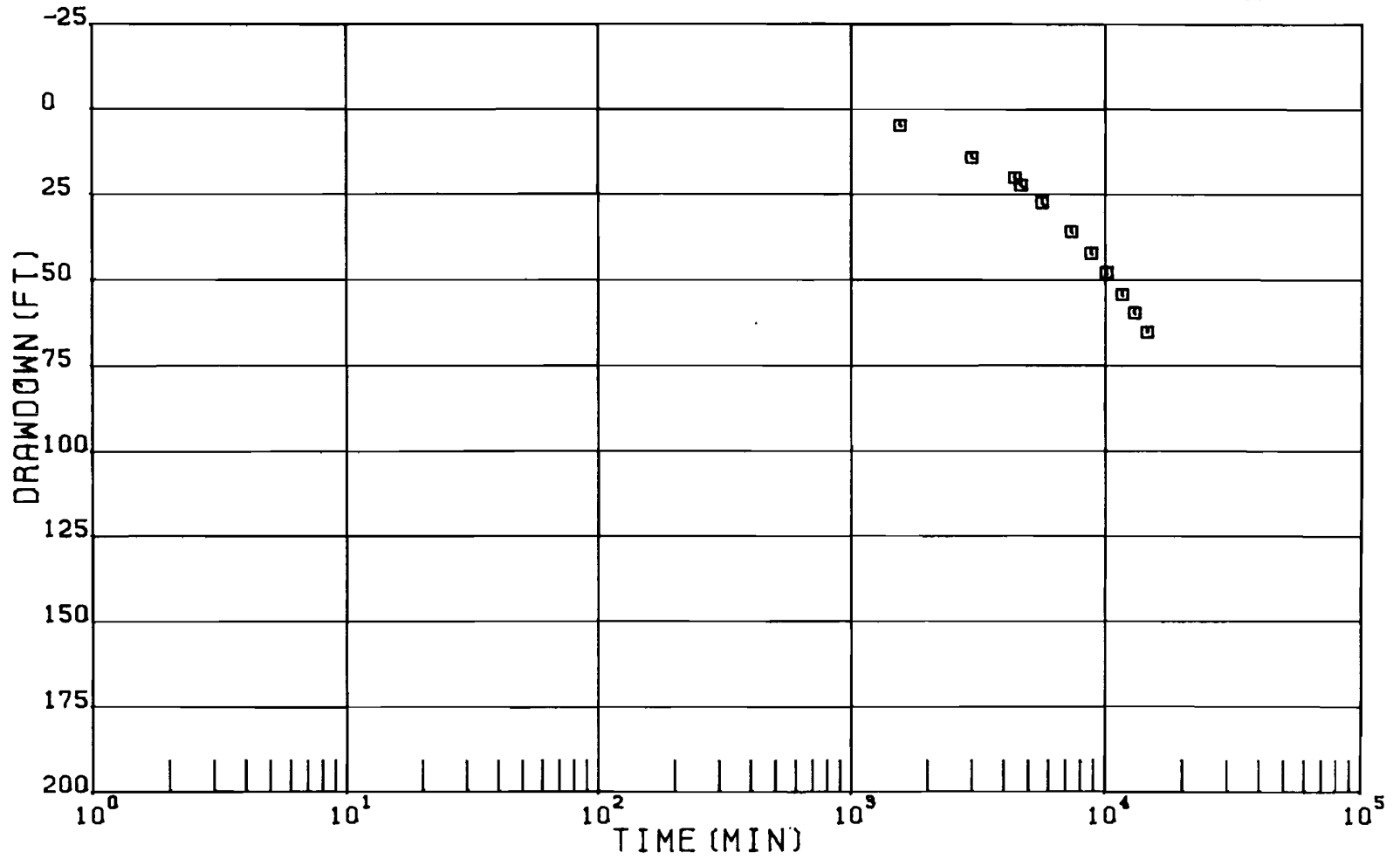
APPENDIX B

LOGARITHMIC TIME-DRAWDOWN GRAPHS

FIGURE B-1: DRAWDOWN GRAPH FOR WELL D-PW

WR28-2-520-128.B-2

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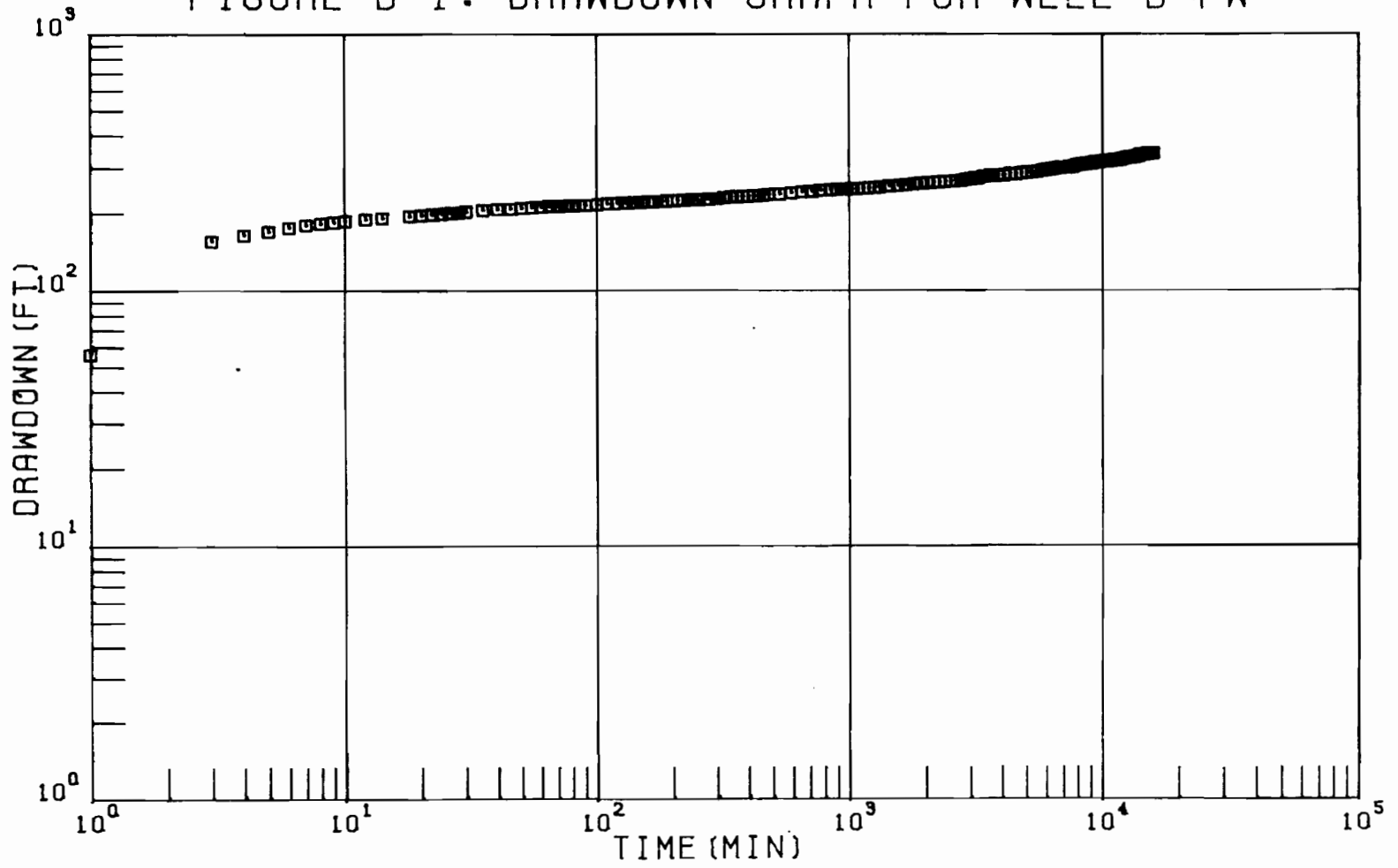
FIGURE B-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

□ D-1LK
○ D-1FR
△ D-1FU
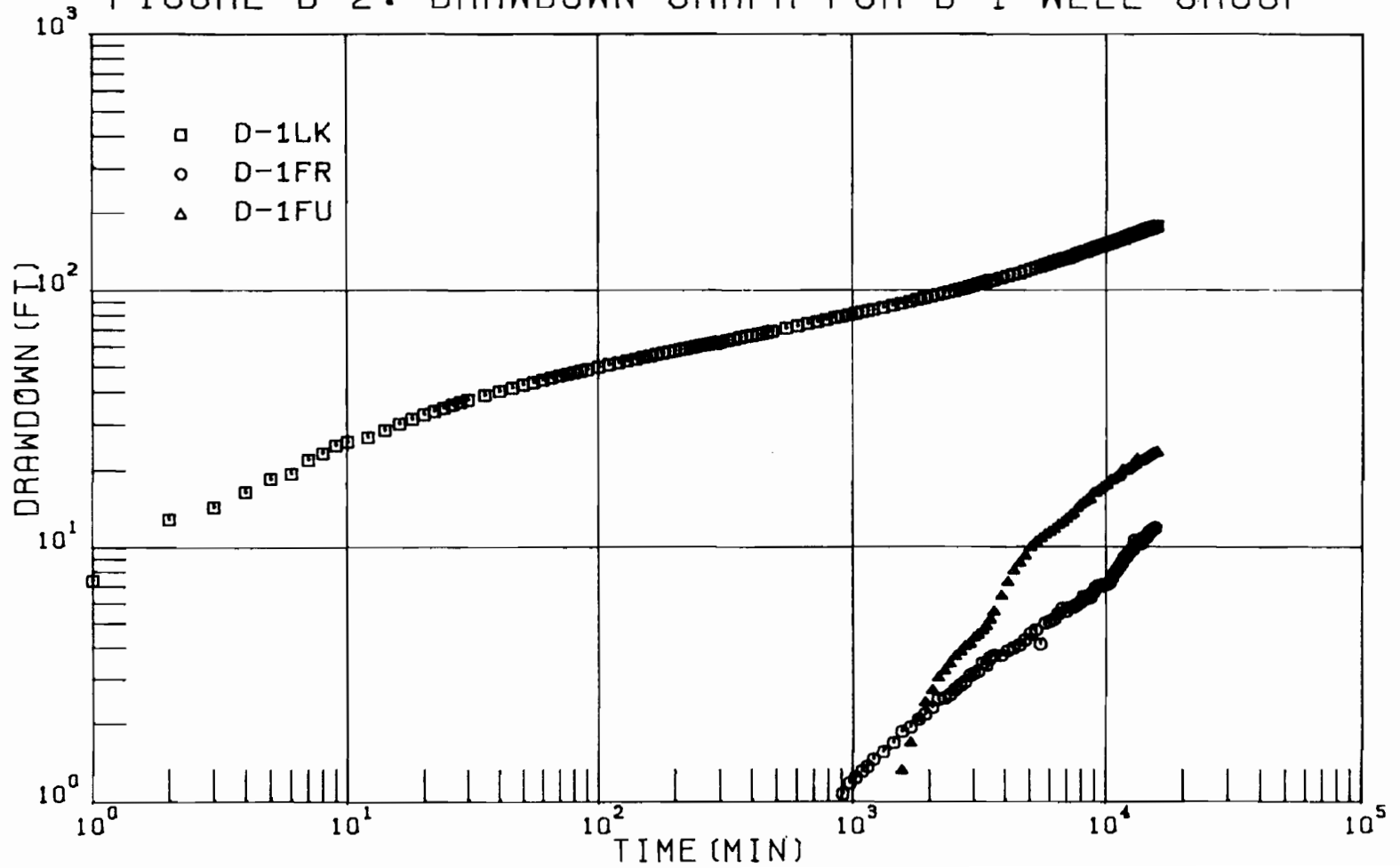
FIGURE B-3: DRAWDOWN GRAPH FOR WELL D-2LK
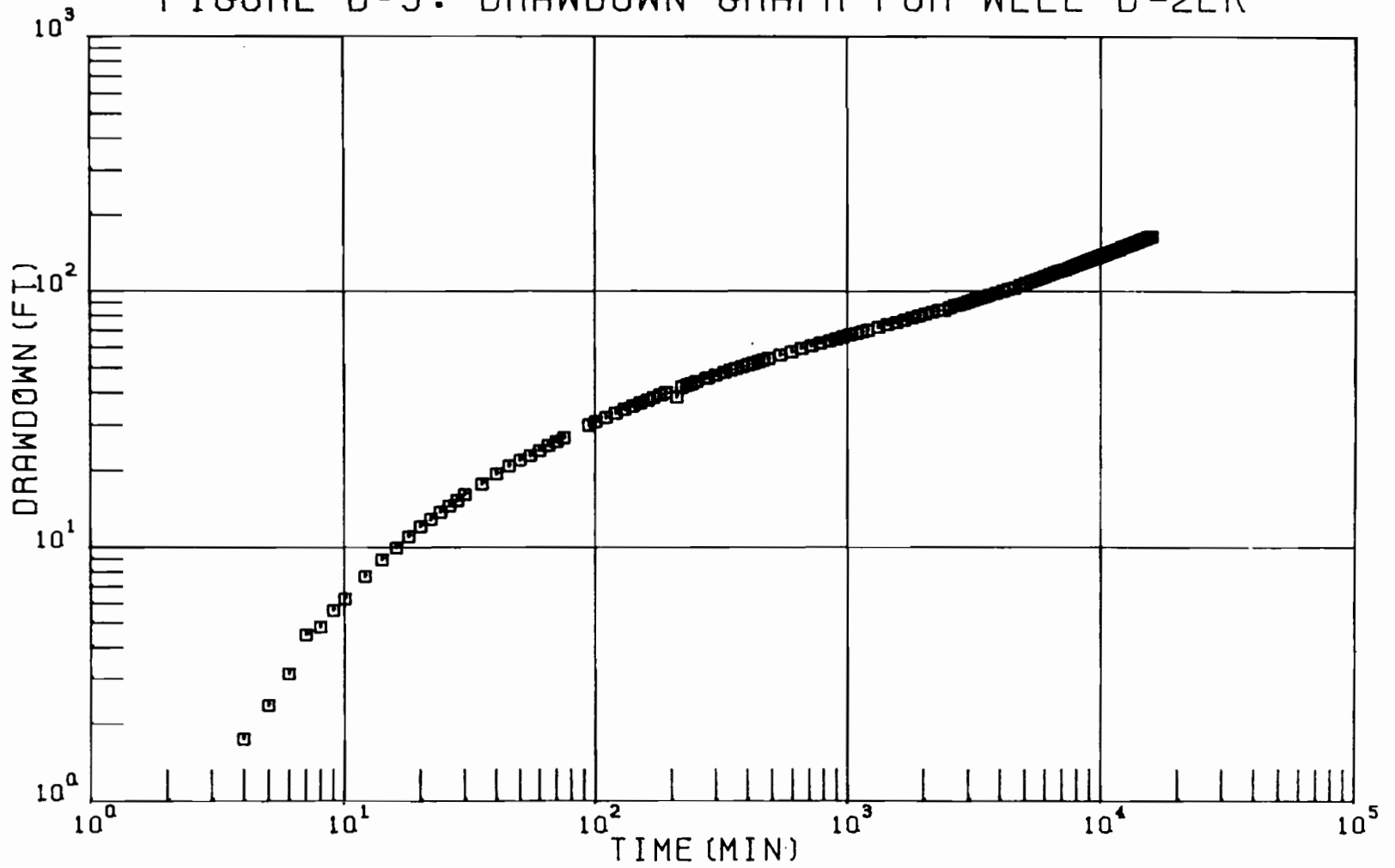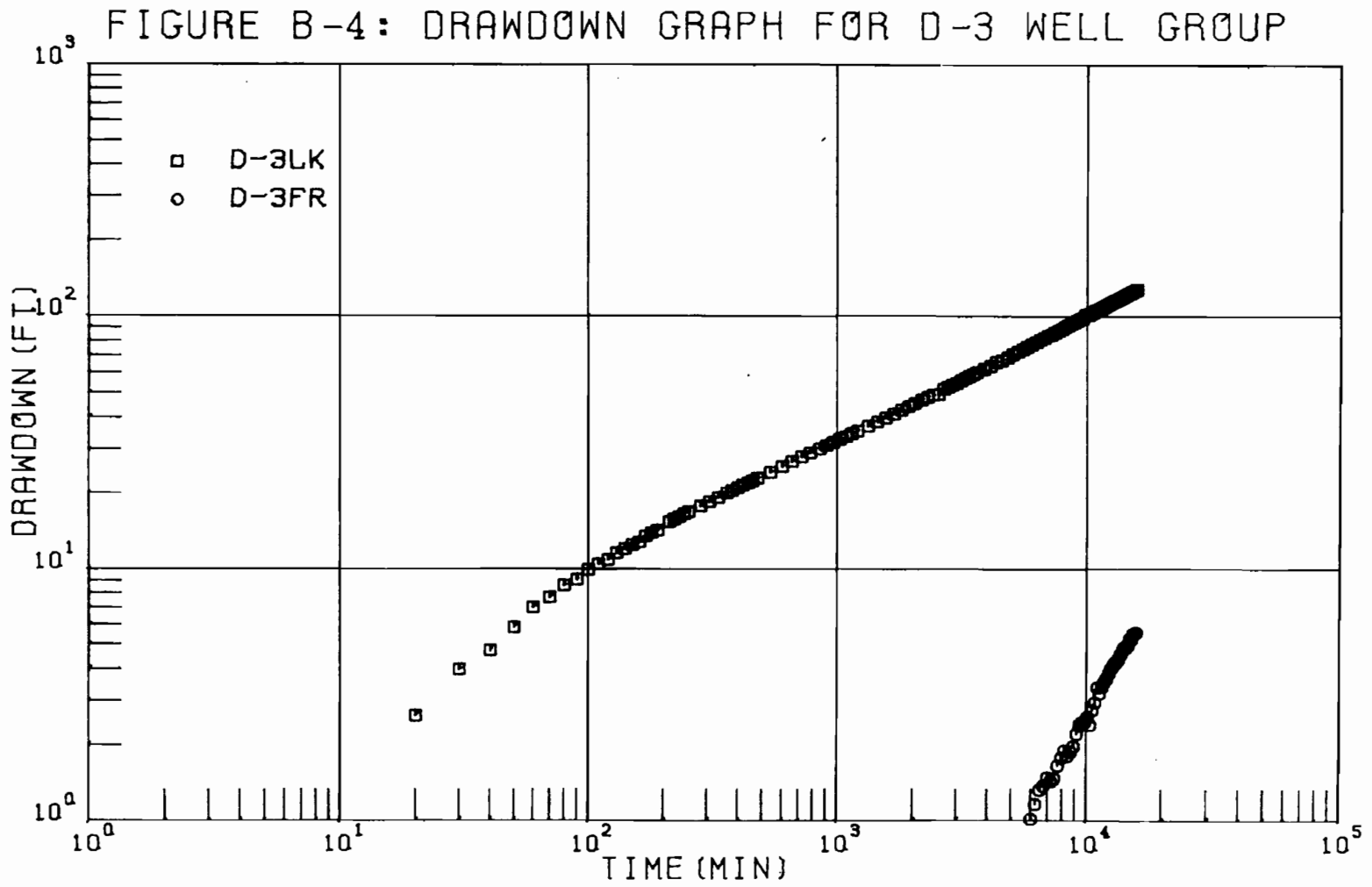
WR28-2-520-128.B-4

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FIGURE B-4: DRAWDOWN GRAPH FOR D-3 WELL GROUP

WR28-2-520-128.B-5

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FIGURE B-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP
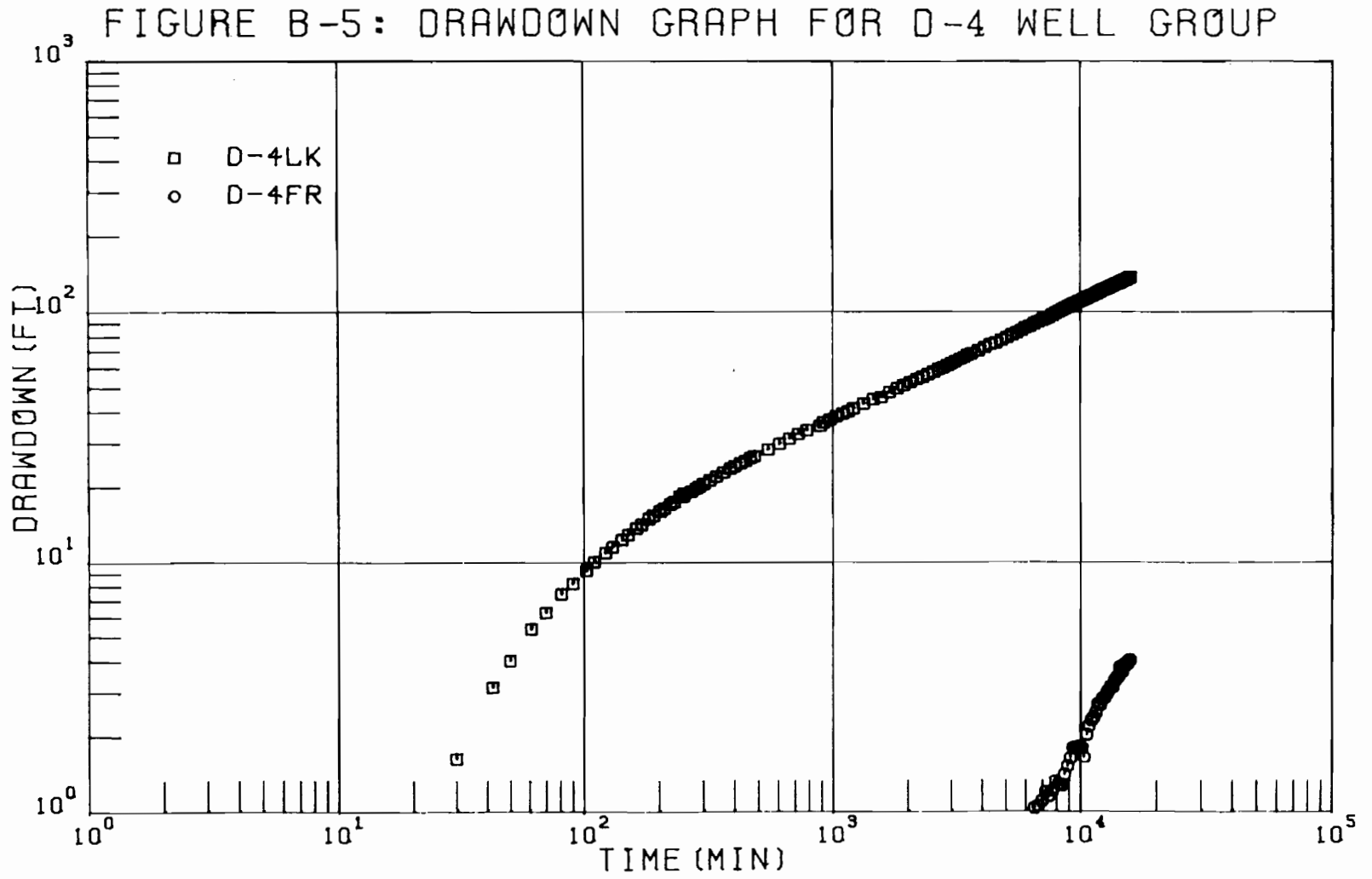
FIGURE B-6: DRAWDOWN GRAPH FOR WELL D-5LK

WR28-2-520-128.B-7

42
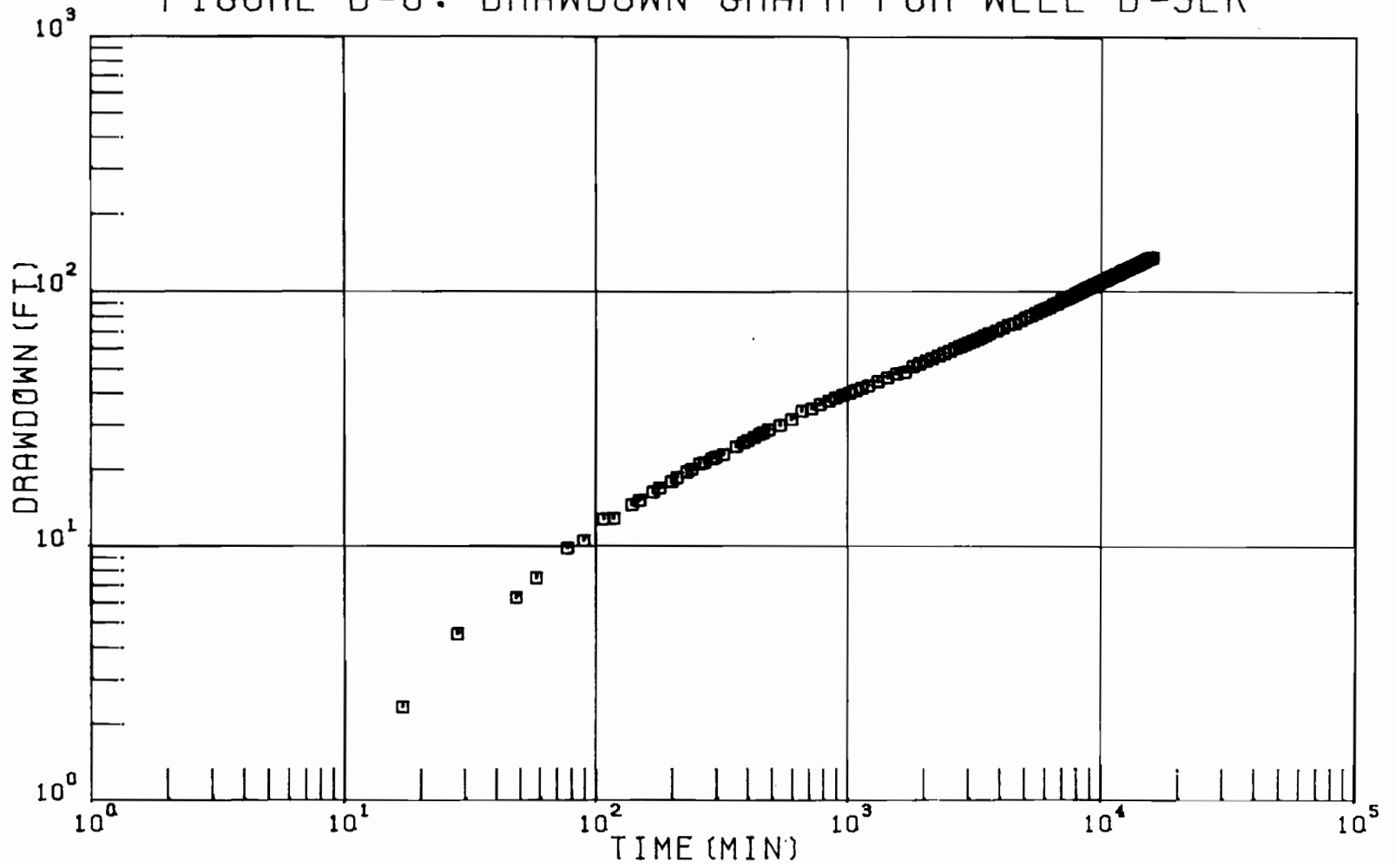
FIGURE B-7: DRAWDOWN GRAPH FOR WELL D-6LK

DRAWDOWN (FT)

TIME (MIN)
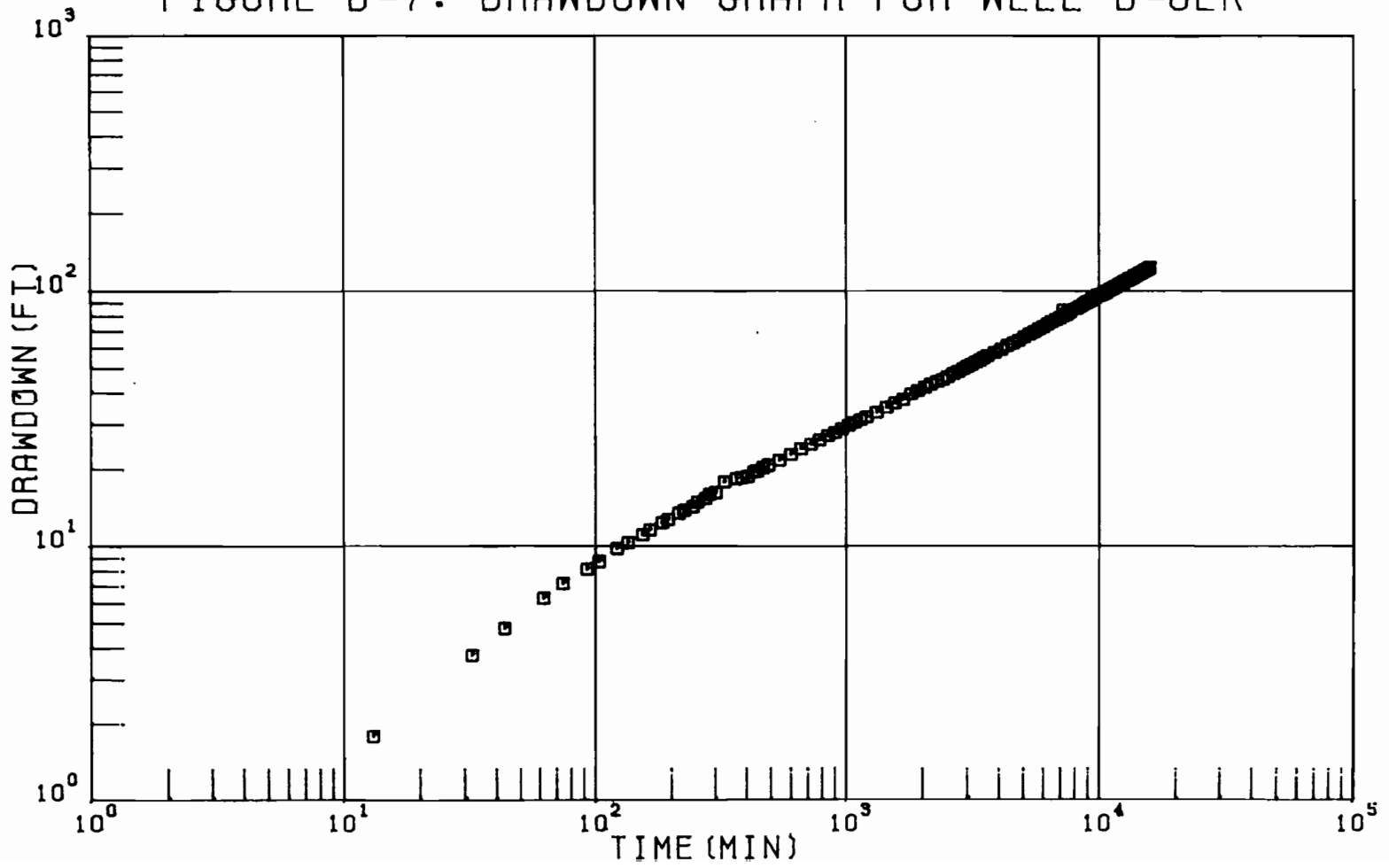
WR28–2–520–128.B–8

FIGURE B-8: DRAWDOWN GRAPH FOR WELL D-8LK
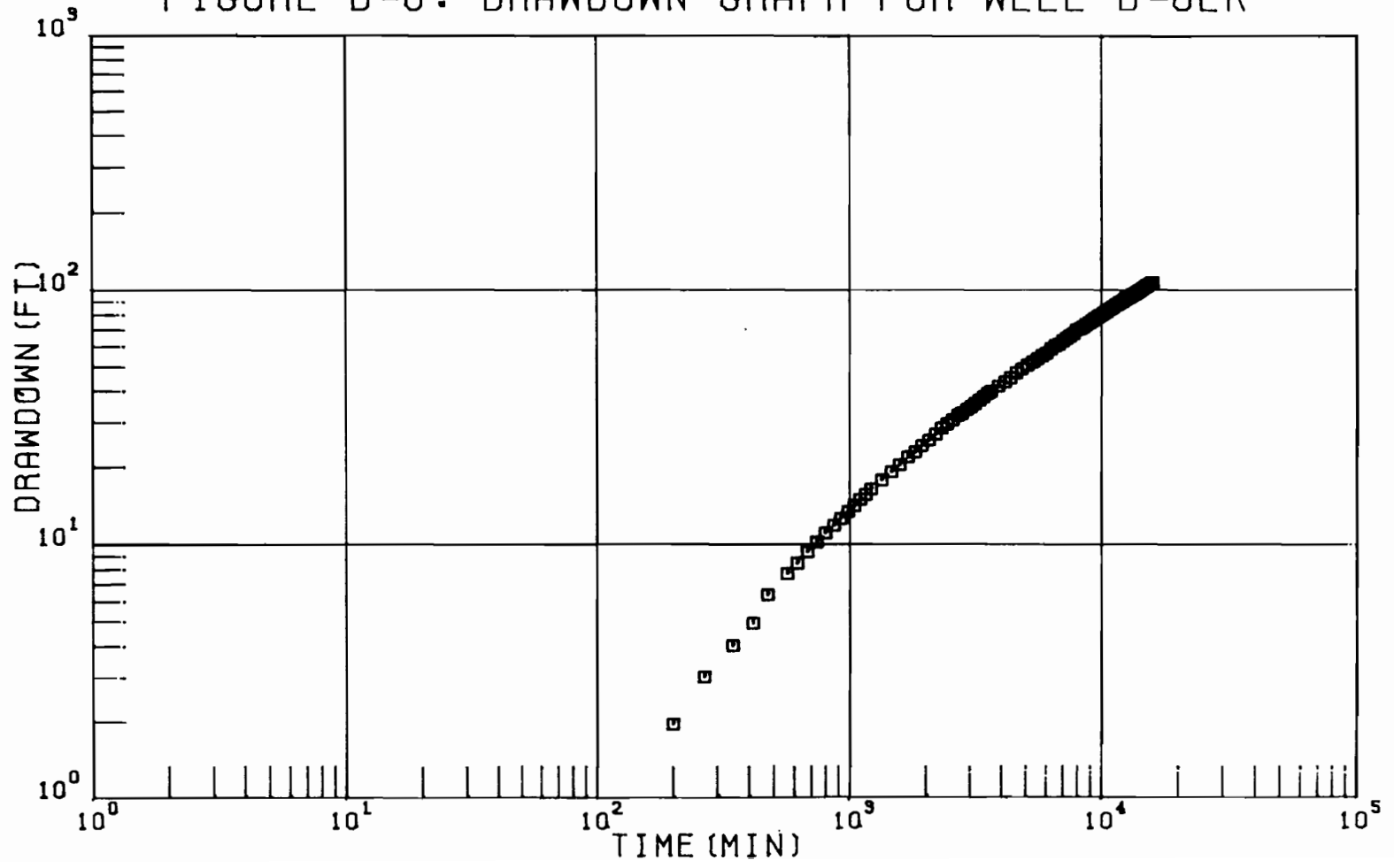
FIGURE B-9: DRAWDOWN GRAPH FOR WELL D-20LK
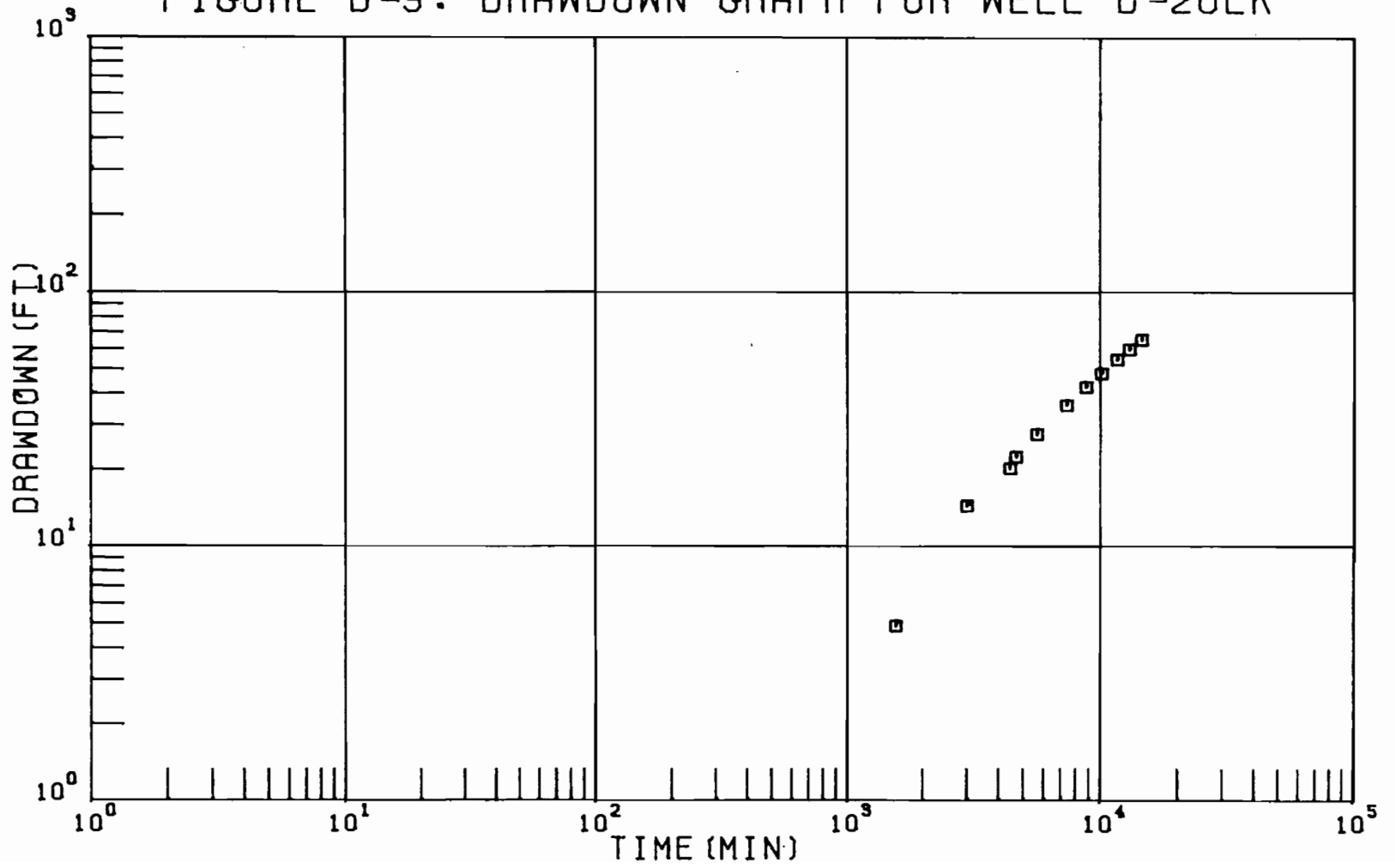
APPENDIX C

SEMILOGARITHMIC TIME-RESIDUAL DRAWDOWN GRAPHS

WR28-2-520-128.C-1

FIGURE C-1: RECOVERY GRAPH FOR WELL D-PW

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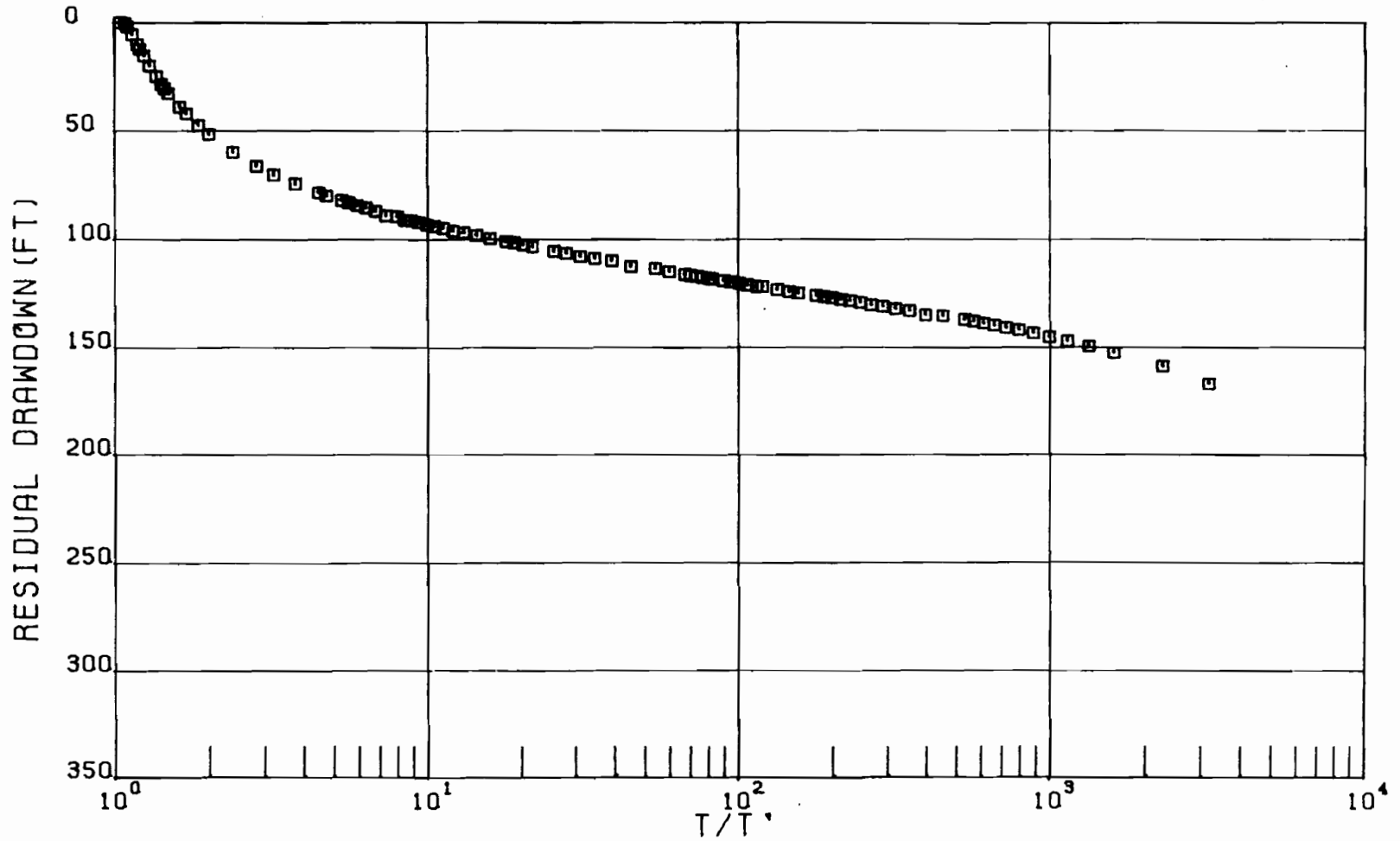
WR28-2-520-128.C-2

FIGURE C-2: RECOVERY GRAPH FOR D-1 WELL GROUP

W...J-2 ..O-..u.C-3
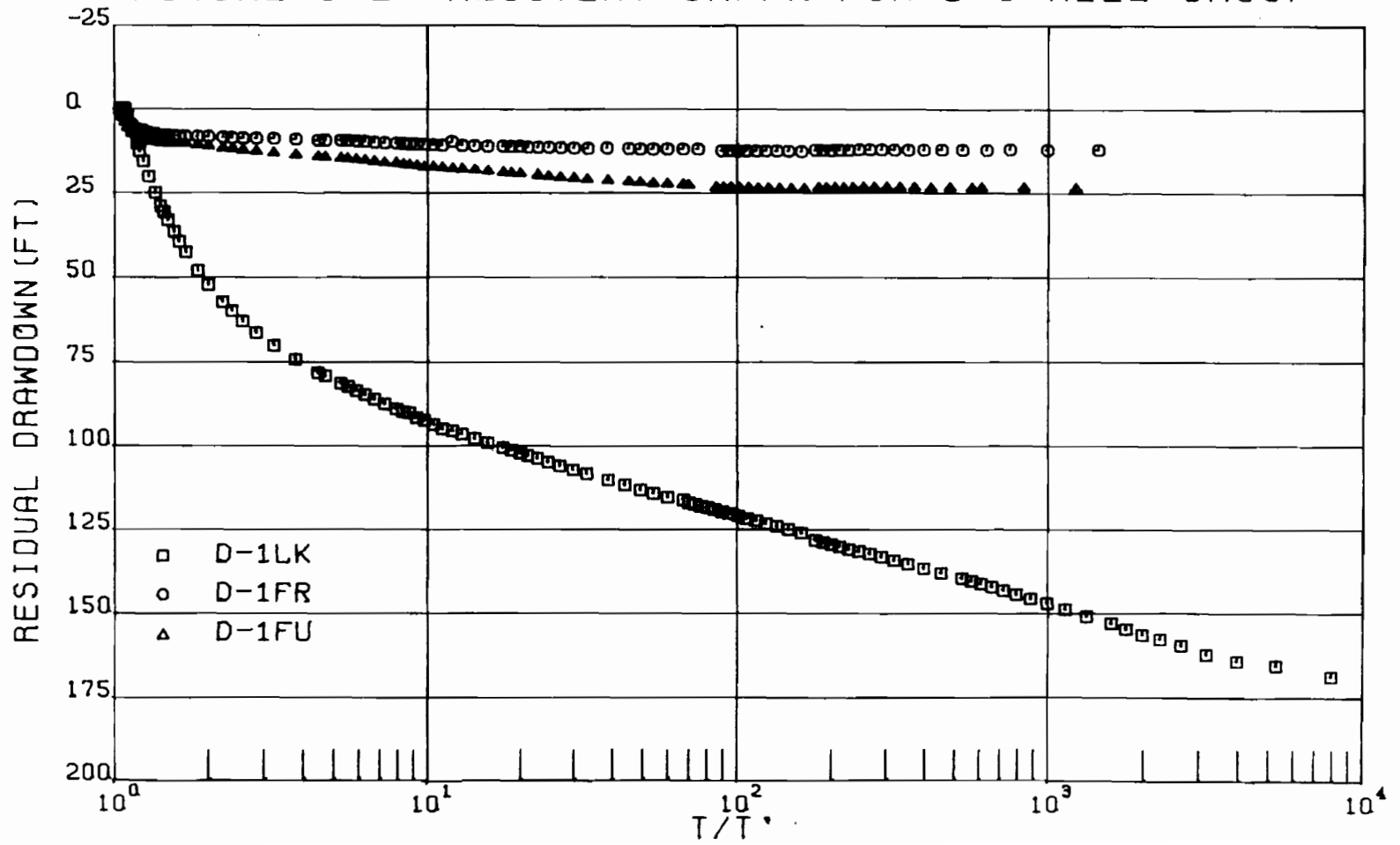
FIGURE C-3: RECOVERY GRAPH FOR WELL D-2LK

WR26-2-520-128.C-4
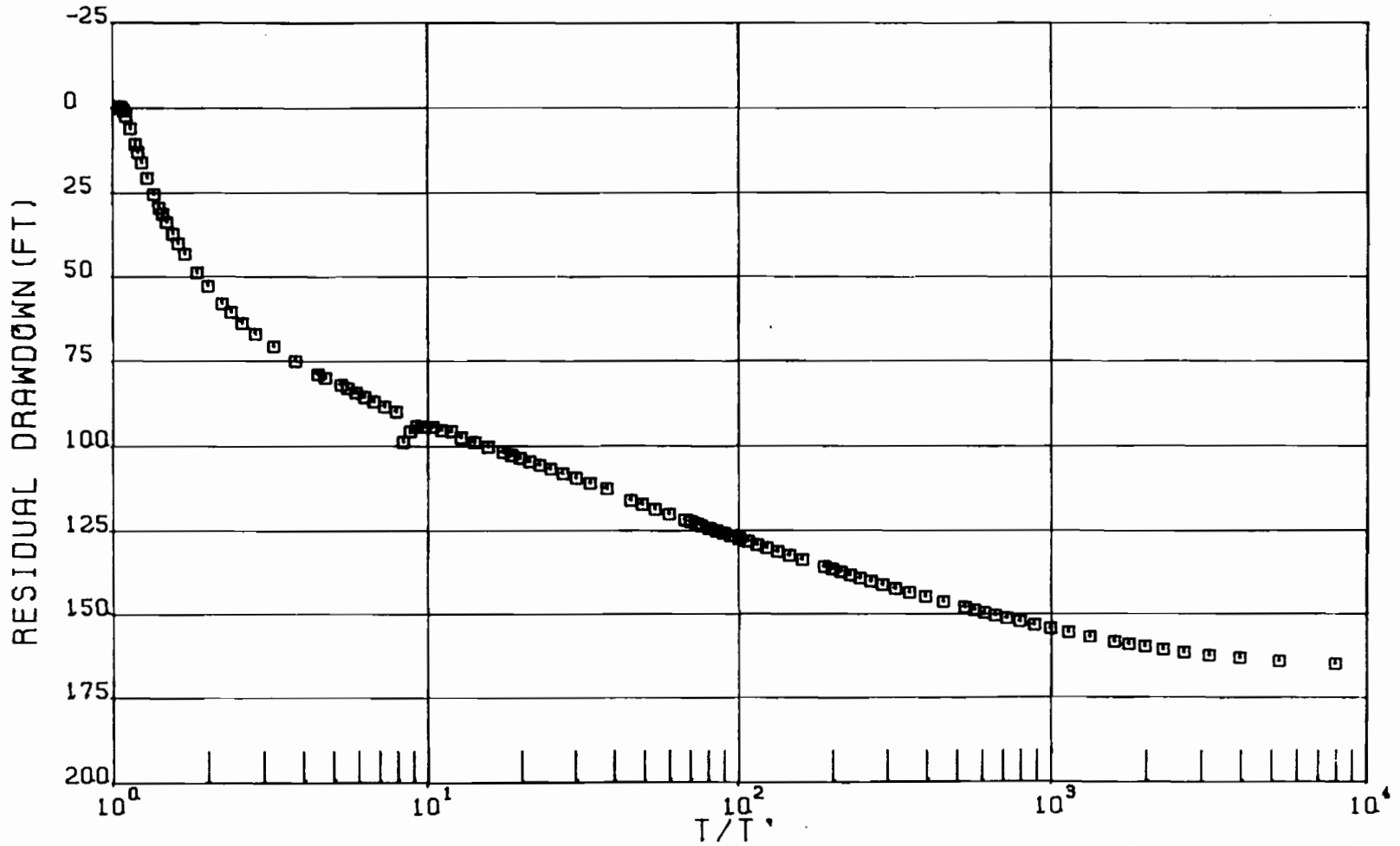
FIGURE C-4: RECOVERY GRAPH FOR D-3 WELL GROUP

wʜ28-ᴄ-ɔ2Q-ıᴄ8.C-ɔ
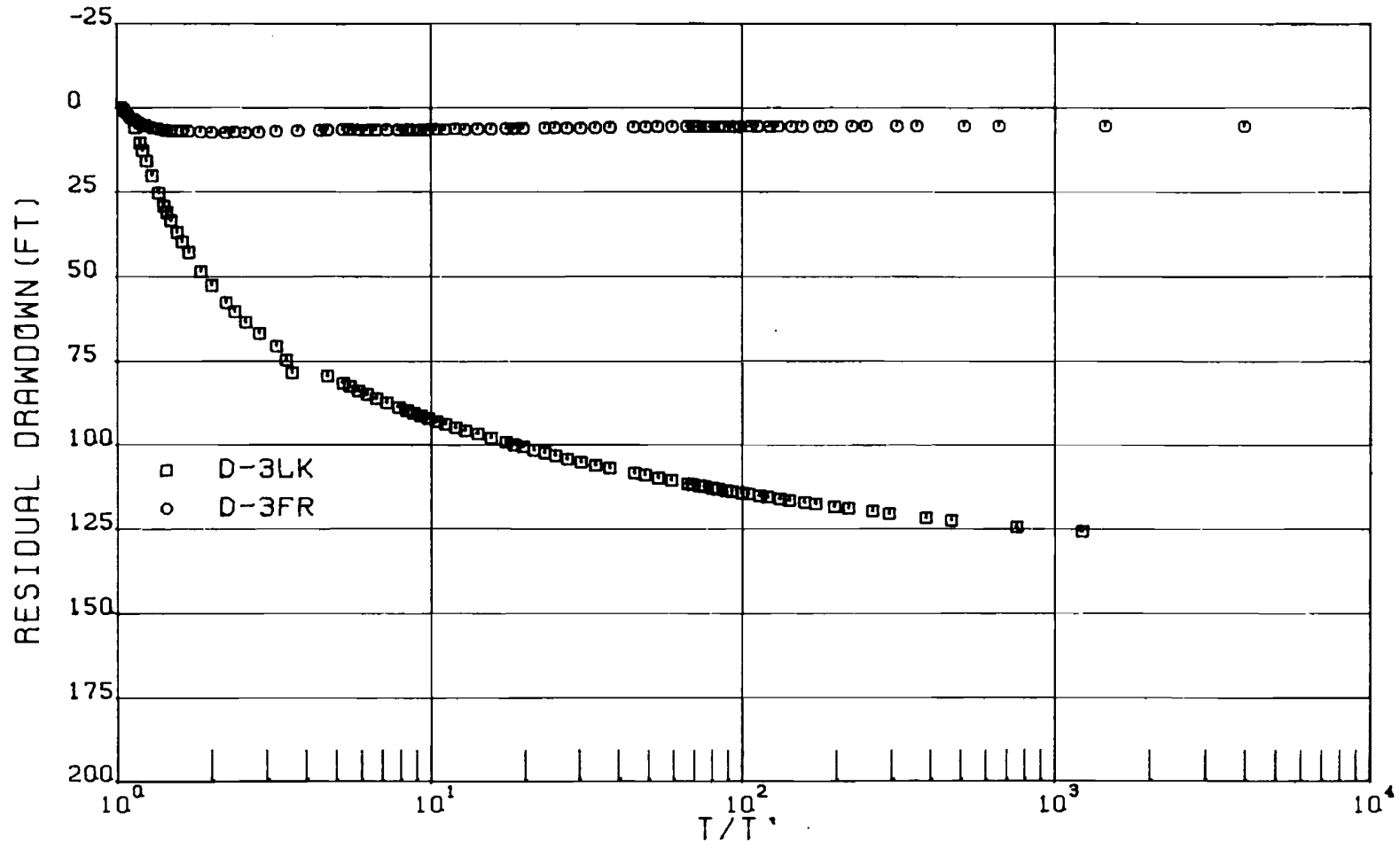
FIGURE C-5: RECOVERY GRAPH FOR D-4 WELL GROUP
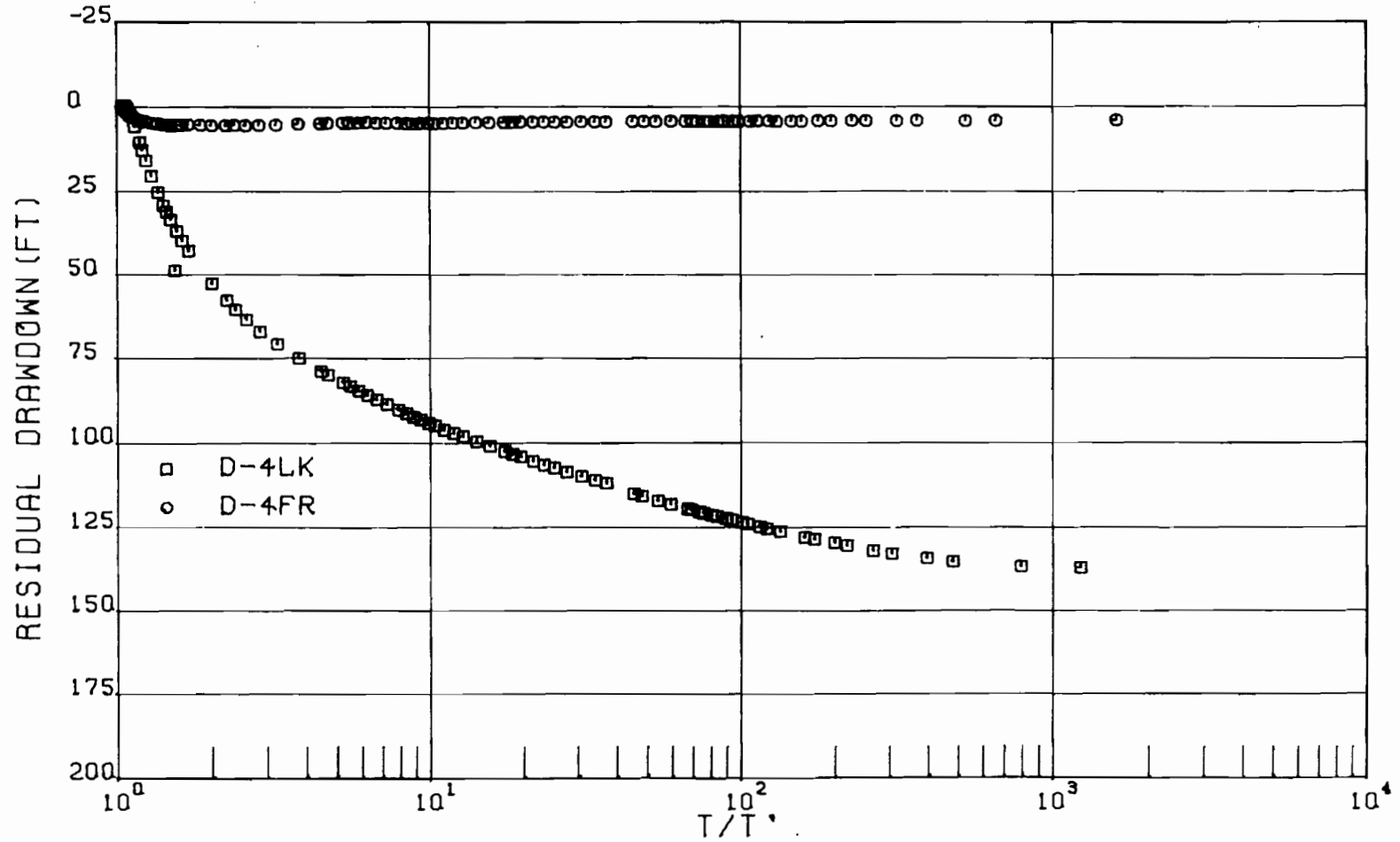
WhₐZd-5ₐu-128.c-6

FIGURE C-6: RECOVERY GRAPH FOR WELL D-5LK

ι....8-ε... ·128..ω 7
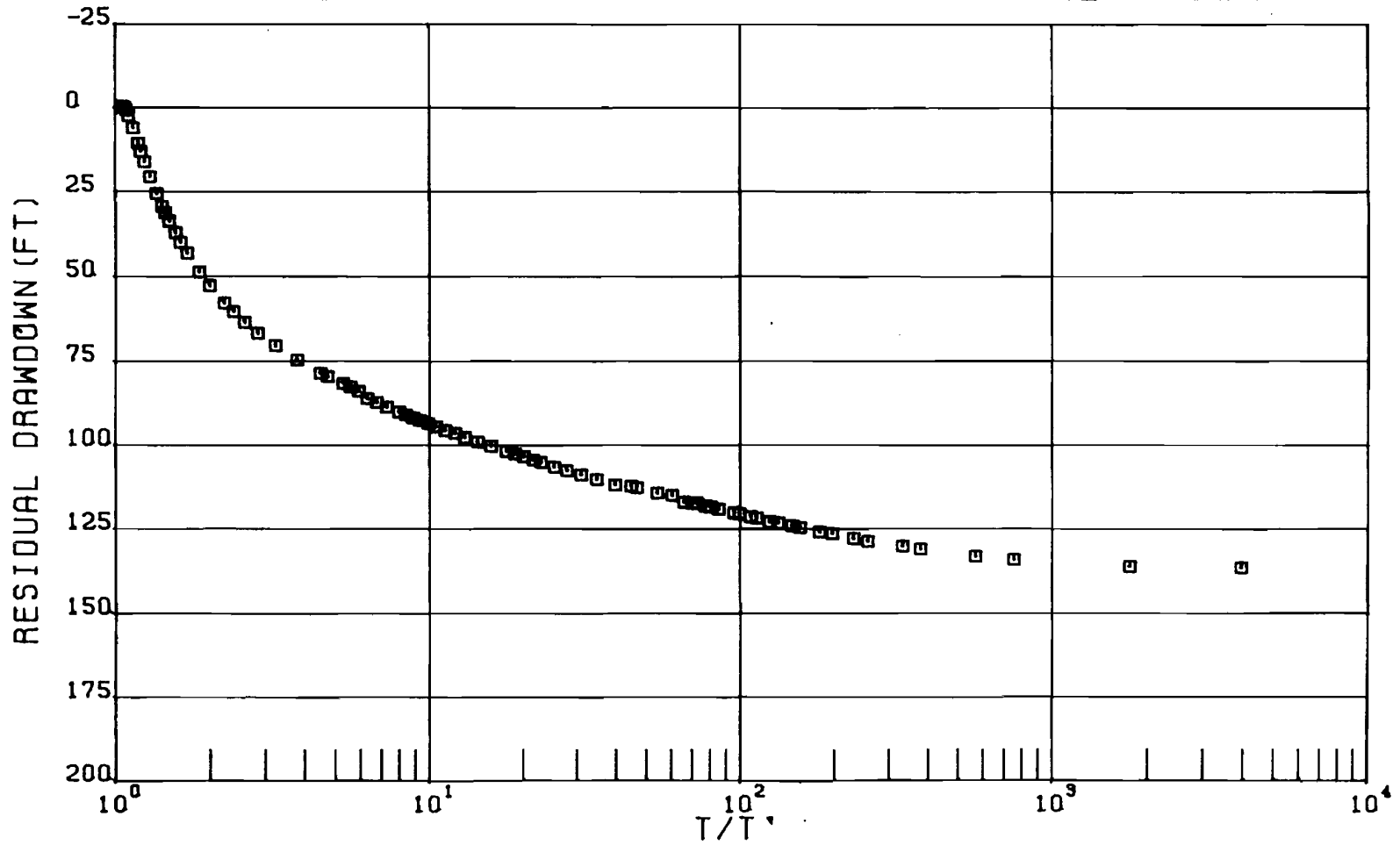
FIGURE C-7: RECOVERY GRAPH FOR WELL D-6LK
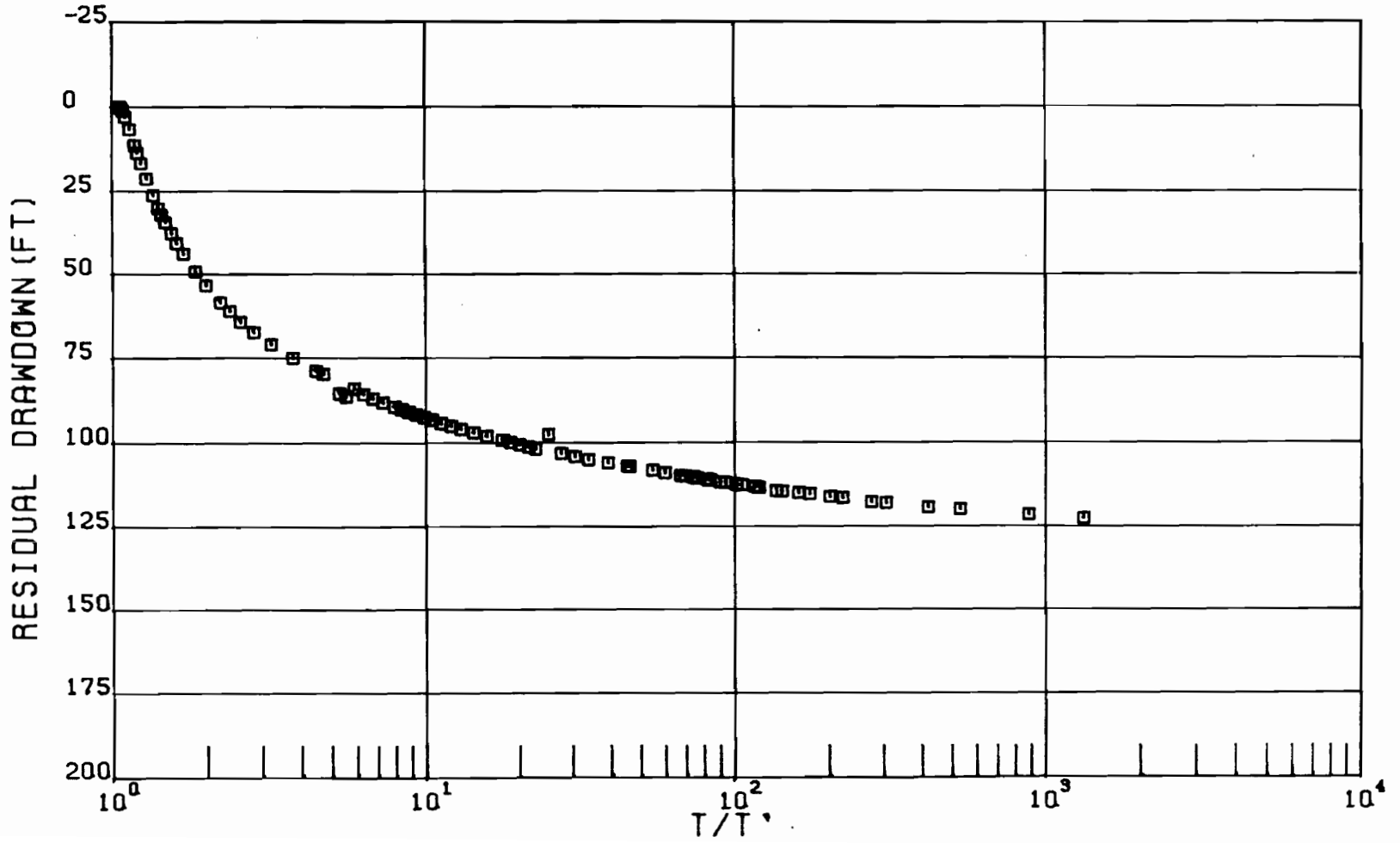
'R28-2-520-128.C-9

FIGURE C-9: RECOVERY GRAPH FOR WELL D-20LK