RESULTS OF RRGE-2 TO RRGI-6

PUMP/INJECTION TEST, MARCH, 1979

by

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1. OBJECTIVES

The objectives in testing included:

1. Assessment of Well RRGI-6 and receiving zone responses to injection.

2. Investigation of aquifer inhomogenities in the regions of Wells RRGE-2 and RRGI-6.

3. Investigation of potential mutual interferences within the Raft River aquifer system.

4. Prediction of behavior of Well RRGI-6 to extended periods of injection and to other temperature injection fluids.

2. SUMMARY OF RESULTS

The March-April 1979, 21 day injection test in RRGI-6 has shown the likelihood of direct communication between the injection zone in RRGI-6 and shallow groundwater aquifer penetrated by Monitor Well 4. Other monitor wells in the region of the injection field indicate that elastic deformation occurs locally in the shallow groundwater aquifers in response to injection to RRGI-6.

The indicated leakage to shallow aquifers increases the capability of RRGI-6 to accept injected fluids. The predicted buildup in wellhead pressure after three years of sustained injection into RRGI-6, using 65^{o}C fluid is 1770 kPa at 37.8 lps, 2340 kPa at 50.4 lps and 2906 kPa at 63 lps.

Interference buildup was noted at RRGI-7 in response to the 21-day injection of 37.8 lps to RRGI-6. Apparent interference drawdown responses at RRGP-4 and RRGE-3 in response to the 37.8 lps withdrawal from RRGE-2 are not sufficiently understood to permit potential interference prediction.

With the present pump setting of 245 m, 37.8 lps appears to represent the approximate maximum rate that RRGE-2 can be pumped on a sustained basis for five years.

3. TEST ORGANIZATION

The test was organized to permit constant-rate, variable head conditions both for withdrawal from RRGE-2 and injection to RRGI-6. Test rate was 37.8 lps.

Flow rates at RRGI-6 were controlled by a Fisher valve and recorded on continuous strip charts at each wellhead. Fluid temperatures at each wellhead were measured by thermocouple and recorded on continuous strip chart. Drawdown in RRGE-2 was measured by a bubbler tube purged with nitrogen and valved through a Heise 0-6900 kPa (gauge) or a 0-1380 kPa (absolute) digiquartz pressure trnasducer. Injection pressure at RRGI-6 was measured by a 0-2758 kPa (absolute) digiquartz pressure trnasducer. No bottom-hole pressure-temperature instrumentation was available for this test.

Pressure observations were recorded at RRGP-4, RRGE-3 and Monitor Wells 1 and 2 using 0-1380 kPa (absolute) digiquartz pressure transducers. Changes in water level at Monitor Wells 3, 4, 5, 6 and 7 were recorded by a Stevens Type F instruments.

4. TEST RESULTS

4.1 Duration and Interruptions

The test was initially commenced on March 19, 1979. On March 20th, after 665 elapsed minutes of pumping, mechanical failure caused the test to be aborted. The wells were permitted to recover for 610 minutes and the test recommenced at 11:34 on March 20, 1979. The test continued for 21 days until April 10, 1979. One interruption occured for a period of 7 minutes on March 27th after approximately 10,000 elapsed minutes in the test. The interruption was caused by electrical overloading by lightning. After 14 elapsed minutes the pumping rates of 37.8 lps were re-established at both wells.

4.2 Buildup Response, RRGI-6

Warmup flow into RRGI-6 was interrupted several times prior to startup in order to carry out repairs to the injection pump. The warmup flow was maintained uninterrupted at 6.3 lps for only 30 minutes immediately prior to startup. During this 30 minute period wellhead pressure declined from 525 kPa to 465 kPa. Wellhead temperature at RRGI-6 on startup was 104°C.

The injection rate of 37.8 lps was reached after approximately 2 minutes, and held constant within the permissible error range for the duration of the test, with the exception of a fourteen minute interruption on March 27th. After 21 days, the maximum buildup reached 1558 kPa. Wellhead temperature began to stabilize after approximately 600 minutes, however, it fluctuated over a range of 5°C until approximately 6000 elapsed minutes and within approximately 2°C for the remainder of the injection period.

Buildup response and wellhead pressure are shown on Figure 1. Several linear segments are identified in this semilogarithmic plot. In the initial 70 minutes, the time-buildup curve is linear with a slope of 180 kPa/cycle. During this period wellhead temperature increased by 6°C. The initial 20 minutes of injection represents displacement of the original borehole volume and is not subject to large temperature-induced changes in fluid characteristics. Since the wellbore had been preheated during the earlier aborted 11-hour test and by warmup flow prior to this test, the early buildup data may be representative of aquifer response to 110°C fluid.

The buildup is non-linear between 70 and approximately 200 minutes, reflecting the significant rise in temperature during this period. After 200 minutes, two apparent "recharge" boundaries are reflected in the buildup data. Figure 2 shows late buildup data in greater detail to illustrate interpreted boundaries. Between 200 and 1000 elapsed minutes the wellhead temperature fluctuated 4°C and buildup is linear with a slope of 152 kPa/cycle. The temperature change during this period could induce approximately 20 kPa change in wellhead pressure and for this reason the apparent linearity of buildup may be suspect.

Between 1000 and approximately 5000 elapsed minutes, buildup is linear with a lesser slope of 100 kPa/cycle, temperature is quasistable during this interval, and the reduced rate of buildup appears to represent a valid hydrologic boundary. The boundary has the effect of increasing the well's injectability, a response similar to a recharging boundary in a pumped well. After 5000 minutes, a further recharging type boundary is interpreted from the buildup data, reducing the slope-rate-of-buildup (s_{10}) to 83 kPa/cycle. After the interruption, at approximately 10,000 elapsed minutes buildup again assumed the slope of 83 kPa/cycle. Analysis of these late data indicate a Q/s_{10} ratio of 0.46 lps/kPa/log cycle or apparent kH value (effective) of 16,673 md-m.

4.3 Falloff Response, RRGI-6

RRGI-6 recovered satisfactorily following injection. Falloff in wellhead pressure vs. ratio of elapsed times (t/t') is shown on Figure 3.

Early falloff data in the initial 30 minutes of recovery provides a slope-rate-of-buildup (Q/s_{10}) of 130 kPa/cycle. This segment of the data is most representative because density and viscosity changes are minimal during this period. Late falloff data is increasingly influenced by density-viscosity changes as the borehole cools and is not considered representative of aquifer response.

4.4 Drawdown Response, RRGE-2

Time drawdown data and wellhead temperature at RRGE-2 are shown on Figure 4. The drawdown data are Heise guage observations of bubbler pressure. Purging difficulties with the bubbler tube render late drawdown readings unuseable. Pressure data is probably useful for the first 6500 elapsed minutes. The change of slope occurring after approximately 600 elapsed minutes is attributed to near stabilization of water temperature rather than a hydrologic boundary. The 450 kPa slope-rate-of-drawdown (s_{10}) provided in the interval 800 to 6000 minutes is probably representative of the aquifer response, indicating an apparent kH of 3125 md-m.

4.5 <u>Recovery Response, RRGE-2</u>

RRGE-2 recovered satisfactorily. Bubbler pressure recovery versus ratio elapsed times (t/t') is shown on Figure 5. Wellhead temperature is also included in this figure. Data within the first minute of recovery suggest a slope of 450 kPa/cycle. Later recovery data follows two linear trends and becomes non-linear in very late recovery. Much of the recovery data is influenced by temperature-induced density changes as the wellbore cools and, in addition, the data may be influenced by incomplete nitrogen purging. The very early recovery data, comprising only two readings in the first minute, shows agreement with late drawdown.

4.6 <u>RRGI-7 Response</u>

RRGI-7 showed an apparent small pressure response to injection at RRGI-6. During the initial week of injection, RRGI-7 wellhead pressure oscillated over a range of 0.7 kPa. This order of change is less than the accuracy of the recording instrument. Therefore, the wellhead pressure was considered essentially stable during this period. In the final two weeks of injection wellhead pressure increased steadily, reaching a maximum buildup of 12.2 kPa, twelve hours after injection stopped. The well did not recover satisfactorily following the test, leaving a residual buildup of 7 kPa. Buildup-with-time data is shown on Figure 6. Late buildup data conforms to a Theis non-leaky type curve. The curve fit provides hydraulic properties of 88.2 m^2/day transmissivity and .0082 storage coefficient.

4.7 <u>RRGP-4 Response</u>

In the week prior to testing, March 12th to March 18th, RRGP-4 wellhead pressure apparently fluctuated erratically between 924-1027 kPa. Immediately prior to the start of testing, wellhead pressure was 1020 kPa. Wellhead pressure declined during the eleven hour initial attempt to test, through the eleven hour recovery period following this, and continued to decline for two days after RRGE-2 stopped pumping. Maximum apparent drawdown reached at this time was 64 kPa. During the twenty day period following the test, wellhead pressure did not recover. The apparent drawdown of 64 kPa is less than the recorded fluctuations prior to testing. For this reason and a lack of recovery, it seems doubtful that the response represents interference drawdown. A plot of the apparent drawdown versus time conforms with the Theis non-leaky type curve in early time and indicates a possible barrier boundary in late time (Figure 7). In view of the well's behavior, the curve match may be fortuitous. No hydraulic properties were calculated.

4.8 RRGE-3 Response

In the week prior to testing, wellhead pressure at RRGE-3 was increasing at an average of 0.5 kPa/day. During the initial attempt to test, the subsequent recovery period and the 21 days of pumping-injection, wellhead pressure declined, reaching a maximum apparent drawdown of 91 kPa. In the 20 days following pumping-injection the wellhead pressure at RRGE-3 continued to decline by approximately 9 kPa. This behavior is not the anticipated response to interference and may represent response to other, as yet unidentified, influences. The apparent uncorrected drawdown versus time is shown on Figure 8. Late drawdown data conforms to the Theis non-leaky type curve. In view of the questionable behavior and uncertainty of cause, the curve match may be fortuitous and no hydraulic properties have been calculated.

4.9 Monitor Well Responses

Monitor wells 4, 5, 6 and 7 showed response to injection to RRGI-6. Two types of response are evident, as shown on Figure 9. The hydrographs of Monitor wells 5, 6 and 7 were interrupted during the 21 days of injection showing a decline in water level of approximately 0.25 meters. Water levels in these wells recovered following the injection period. This response is attributed to elastic deformation of the shallow aquifer materials resulting in local dilation with accompanying lowered water levels.

Monitor well 4 responded in the opposite manner, the hydrograph trend was interrupted during the injection test showing a marked increase in water level. This monitor well showed delayed recovery following injection; the completeness of recovery cannot be satisfactorily assessed because irrigation well withdrawals commenced about this time significantly influencing water levels. The response at Monitor well 4 indicates probable local fracture communication between the zones being injected in RRGI-6 and the shallow aquifer open to observation in Monitor well 4.

5. DISCUSSION OF TEST RESULTS

5.1 Summarized Hydraulic Properties

Summarized values obtained for S_{10}, Q/s_{10} and kH_a (apparent intrinsic permeability-thickness product) are shown for RRGI-6 in Table 1 and for RRGE-2 in Table 2.

Late buildup data in RRGI-6 provides Q/s_{10} ratio of 0.46 lps/kPa/log cycle or kH_a of 16.673 md-m. The late buildup data is interpreted to reflect the influence of a recharge (improved injectability) boundary and the calculated kH_a value is for this reason best considered to be the effective kH_a.

Well RRGE-2 has Q/s_{10} value of 0.09 lps/kPa/log cycle or kH_a of 3125 md-m.

The small response at RRGI-7 indicates values of 88.2 m^2/day for transmissivity and .0082 for storativity.

5.2 Analytical and Predictive Methods Used:

Extrapolation of slope-rate-of-drawdown/buildup is the most reliable means of predicting future behavior at the tested rate and temperature.

Prediction of drawdown and buildup at rates and fluid temperatures other than those tested is less reliable. The method used is to calculate initially a kH_a (apparent intrinsic permeability-thickness product) at the fluid temperature known during testing. The value obtained is accepted as the best available fluid-free conductance parameter. This is then used to calculate a value for s_{10} with fluid viscosities anticipated at the desired temperatures. The following relationship is used: (Allman et al, 1979).

$$kH_a = \frac{5759 \dot{Q} u}{s_{10}}$$

where: kH_a is in md-ft

Q/s_{10} is in gpm/psi/cycle

u is in centipoises

Early buildup behavior is influenced by density changes in the borehole column and inefficiency at the wellbore face. Each of these factors is estimated to arrive at early buildup pressure.

The influence of fluid density change in the wellbore or wellhead pressure can be estimated using the following relationship (Petty, 1980):

$$P_{wh} = 6.895 \ \{P_{whh} - (\gamma_1 - \gamma_2)\frac{D}{144}\} \text{ kPa}$$

where: P_{wh} = desired wellhead pressure

P_{whh} = wellhead pressure, hot water

$\gamma 1$ = specific gravity, desired water temperature

$\gamma 2$ = specific gravity, hot water

D = depth to injection zone

The influence of restriction to flow at the wellbore face or skin factor has been approximated from observed behavior during the current test and the following relationship (Earlougher, 1977):

$$\Delta p_s = \frac{141.2qBu}{kH} s \text{ (psi)}$$

where: Δp_s = the pressure change due to skin effect

q = the flow in ST B/D (standard barrels per day)

B = the formation volume factor for water RB/STB (ratio per standard barrel)

u = the viscosity in centipoises

kH = the permeability thickness product in md-ft

s = the "skin factor"

The information from the present test provides a value for the skin factor, s=3.42, this is used to derive initial pressure increases for other rates and temperatures. The predictive equation to describe total buildup pressure combining all three elements is:

$$P = P_{wh} + \Delta p_s + S_{10} \log t.$$

5.3 Predicted Well Behavior

At a producing rate of 37.8 lps, the bubbler pressure in RRGE-2 would be reduced to 240 kPa after five years of sustained pumping. This assumes no further hydrologic boundaries will be encountered, no interference influences from other pumping/injection centers, and relatively constant fluid temperature of approximately 140°C. With the present pump setting of 245 m, 37.8 lps represents the approximate rate that the well can be safely pumped.

It is interpreted from the buildup behavior of RRGI-6 that hydrologic boundaries were intersected. The boundary influences have the effect of increasing injectability. From the behavior of Monitor Well 4, it is further interpreted that the hydrologic boundary effects represent leakage to the overlying shallow aquifer complex. By permitting this leakage to occur, the injectability of RRGI-6 is improved. In predicting future wellhead buildup in RRGI-6, the "effective" hydraulic property calculated from post boundary response is used, i.e. Q/s_{10} = 83 lps/kPa/log cycle. Predicted wellhead buildup at selected times is summarized in Table 3 and presented graphically in Figure 10. The predictions assume 65°C fluid, no further hydrologic boundaries and no interference.

5.4 Interference Effects

The buildup at RRGI-7 is accepted as response to injection at RRGI-6. This response indicates an interference buildup of approximately 124 kPa after 5 years injection to RRGI-6 of 133°C fluid at 37.8 lps. Using the hydraulic properties obtained in this test (kH_a= 88.2 m^2/day, S=0.0082) the potential buildup at other rates of injection is shown on Figure 6. It is assumed in this prediction that the response at RRGI-7 will be dependent only on the rate of injection to RRGI-6 and will not be influenced by the temperature of the injected fluid.

The apparent responses in Wells RRGE-3 and RRGP-4 are not viewed with confidence as justifiable interference drawdowns for the following reasons:

1. Fluid level did not recover satisfactorily in either well.
2. Fluctuations in wellhead pressure at RRGP-4 prior to testing were recorded over a range equivalent to or greater than the apparent drawdown.

In view of the low degree of confidence in these responses, no estimate of possible interference was attempted.

Response in the shallow aquifer system to injection at RRGI-6 should be anticipated. Predicted interference at Monitor Well 4 is assumed to be dependent only on the rate of injection to RRGI-6, regardless of the characteristics and temperature of the fluid injected. Using the apparent properites from best-fit, non-leaky curve-matching, the predicted increase in fluid level of Monitor Well 4 is summarized in Table 4.

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3. R. C. Earlougher Jr. Advances in Well Test Analysis, The Society of Petroleum Engineers of AIME, Monograph Volume 5, 1977.

4. S. Petty , "Predicted Pressures for Cold Water Injection To RRGI-6 and RRGI-7," Interoffice Correspondence, EG&G Idaho, Inc., 1980.

5. C. V. Theis , "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage," Trans. American Geophys. Union, Volume 2, pp 519-524, 1935.

TABLE 1

SUMMARY OF HYDRAULIC PROPERTIES - WELL RRGI-6

s_{10} (kPa/cycle)	Q/s_{10} (lps/kPa/cycle)	Apparent kH_a (md-m)	Source
107	0.35	12,904	Buildup data, imtermediate time, Sustained test
83	0.46	16,673	Buildup data, late time, Sustained test
131	0.29	10.537	Falloff data, early time, Sustained test
269	0.14	5.135	Falloff data, late time, Sustained test

TABLE 2

SUMMARY OF HYDRAULIC PROPERTIES - WELL RRGE-2

s_{10} (kPa/cycle)	Q/s_{10} (lps/kPa/cycle)	kH_a (md-m)	Source
290	0.13	4,765	Early drawdown, sustained test
421	0.09	3,281	Late drawdown, sustained test
331	0.11	4,168	Recovery data, sustained test

TABLE 3

PREDICTED WELLHEAD PRESSURES, RRGI-6 INJECTION

INJECTION RATE (lps)	TEMPERATURE (°C)	EQUATION FOR PRESSURE	WELLHEAD BUILDUP			
			1 DAY	1 YEAR	3 YEARS	5 YEARS
37.8	138	427 + 252 + 83 log t.	940	1153	1193	1211
37.8	65	76 + 545 + 186 log t.	1209	1685	1774	1815
50.4	65	76 + 727 + 248 log t.	1590	2221	2340	2395
63.0	65	76 + 909 + 310 log t.	1965	2757	2906	2975

TABLE 4

PREDICTED INTERFERENCE BUILDUP
AT MONITOR WELL 4

INJECTION RATE (lps)	ELAPSED TIME (years)	BUILDUP (m)
37.8	3	6
50.4	3	9
63.0	3	11

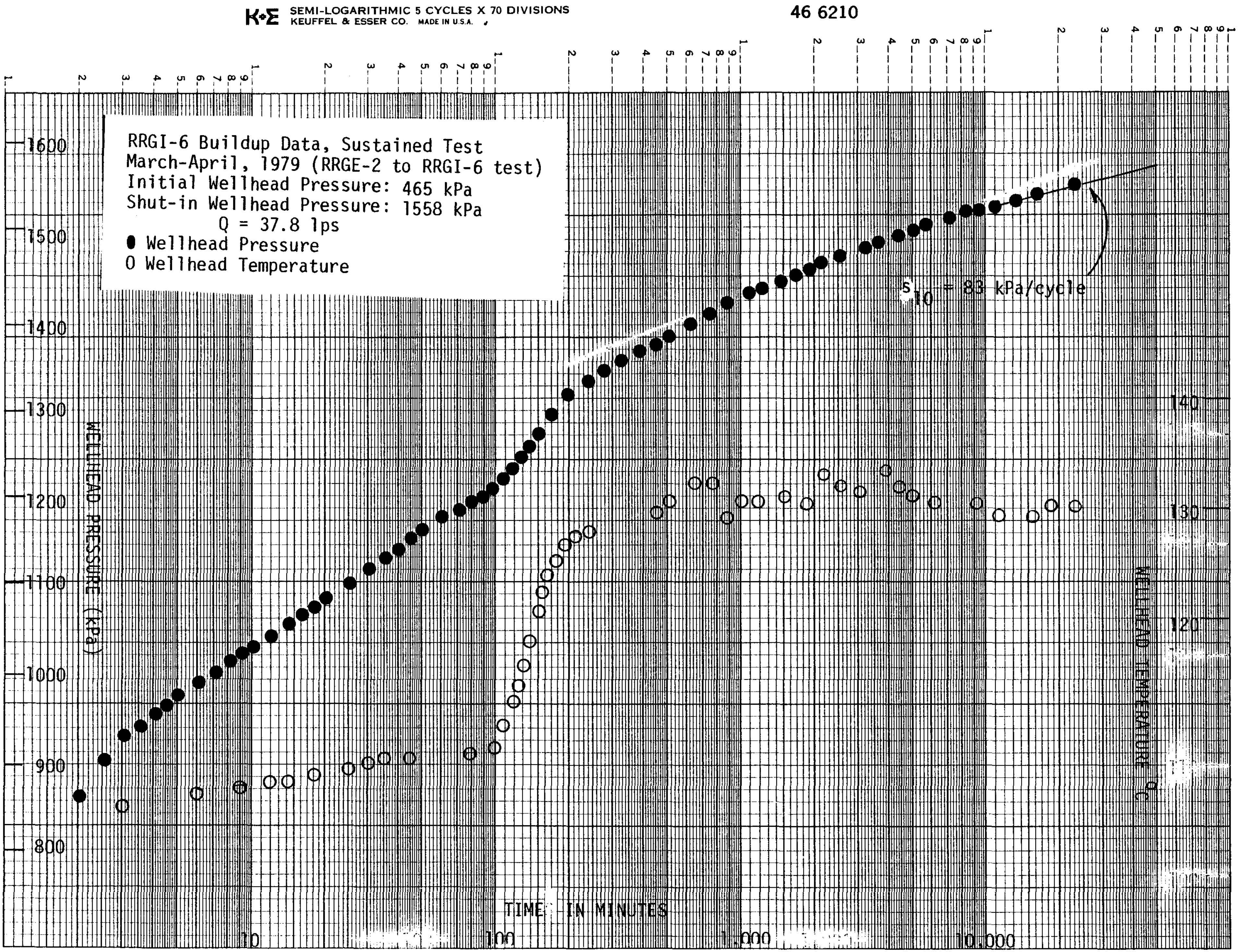

K•Σ SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
RRGI-6 Buildup Data, Sustained Test
March-April, 1979 (RRGE-2 to RRGI-6 test)
Initial Wellhead Pressure: 465 kPa
Shut-in Wellhead Pressure: 1558 kPa
Q = 37.8 lps
● Wellhead Pressure
O Wellhead Temperature
s10 = 83 kPa/cycle
WELLHEAD PRESSURE (kPa)
WELLHEAD TEMPERATURE °C
TIME IN MINUTES
1600
1500
1400
1300
1200
1100
1000
900
800
140
130
120
10
100
1,000
10,000

FIGURE 1

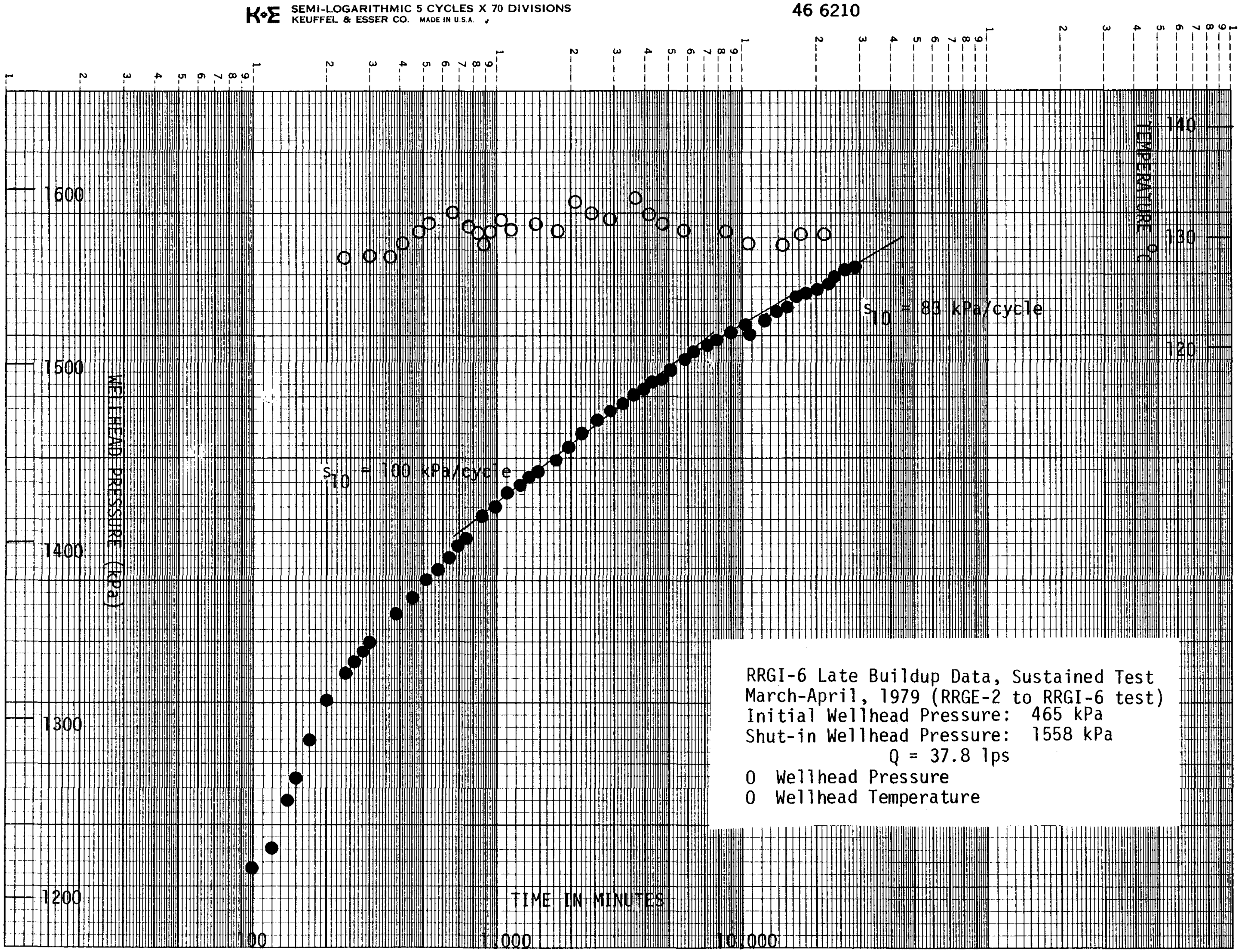
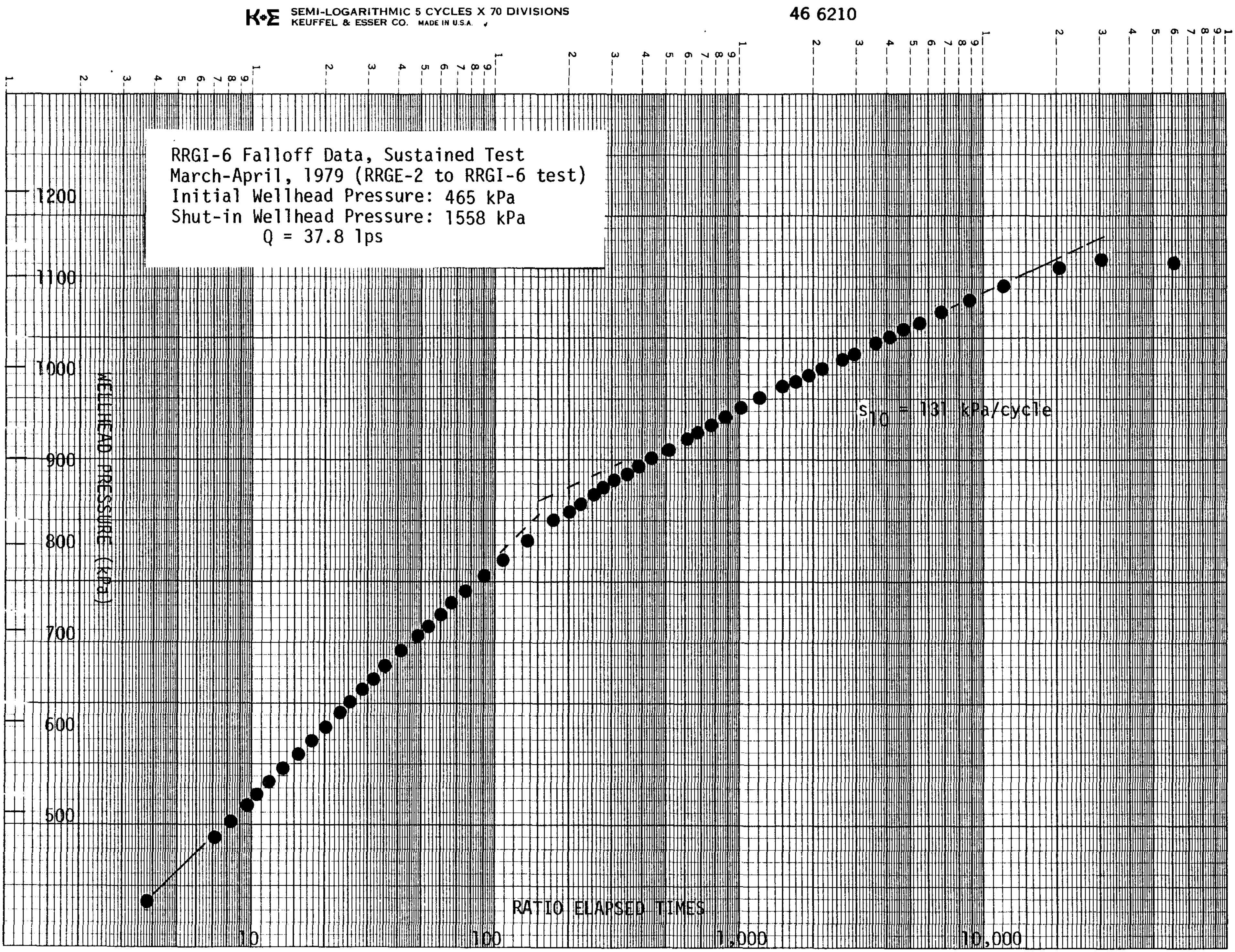

K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
WELLHEAD PRESSURE (kPa)
TEMPERATURE °C
1600
1500
1400
1300
1200
140
130
120
S_{10} = 100 kPa/cycle
S_{10} = 83 kPa/cycle
TIME IN MINUTES
100
1,000
10,000
RRGI-6 Late Buildup Data, Sustained Test
March-April, 1979 (RRGE-2 to RRGI-6 test)
Initial Wellhead Pressure: 465 kPa
Shut-in Wellhead Pressure: 1558 kPa
Q = 37.8 lps
0 Wellhead Pressure
0 Wellhead Temperature

FIGURE 2



K•Σ SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
RRGI-6 Falloff Data, Sustained Test
March-April, 1979 (RRGE-2 to RRGI-6 test)
Initial Wellhead Pressure: 465 kPa
Shut-in Wellhead Pressure: 1558 kPa
Q = 37.8 lps
S10 = 131 kPa/cycle
WELLHEAD PRESSURE (kPa)
1200
1100
1000
900
800
700
600
500
RATIO ELAPSED TIMES
10
100
1,000
10,000

FIGURE 3

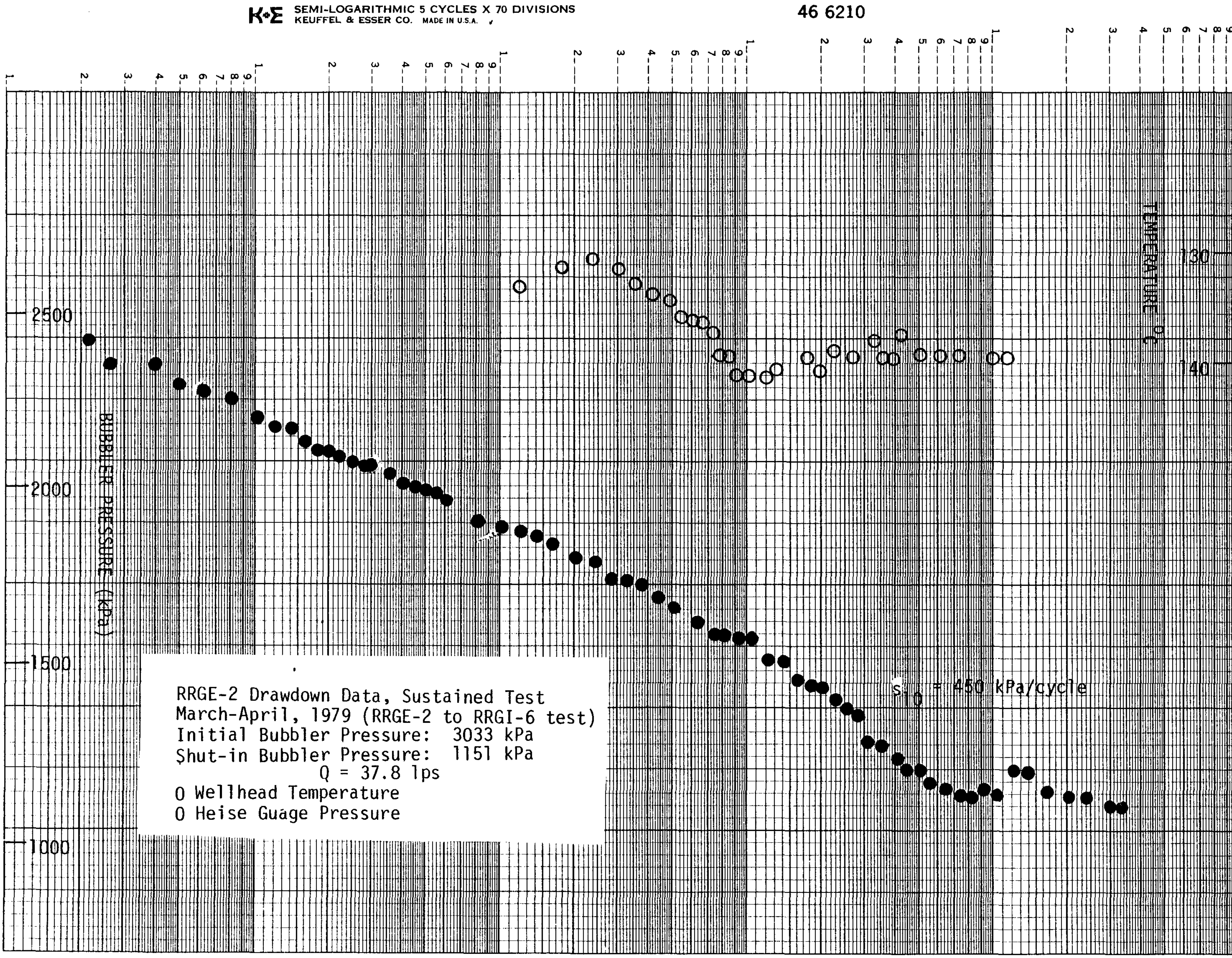

K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
BUBBLER PRESSURE (kPa)
2500
2000
1500
1000
TEMPERATURE °C
130
140
S_{10} = 450 kPa/cycle
RRGE-2 Drawdown Data, Sustained Test
March-April, 1979 (RRGE-2 to RRGI-6 test)
Initial Bubbler Pressure: 3033 kPa
Shut-in Bubbler Pressure: 1151 kPa
Q = 37.8 lps
O Wellhead Temperature
O Heise Guage Pressure

FIGURE 4

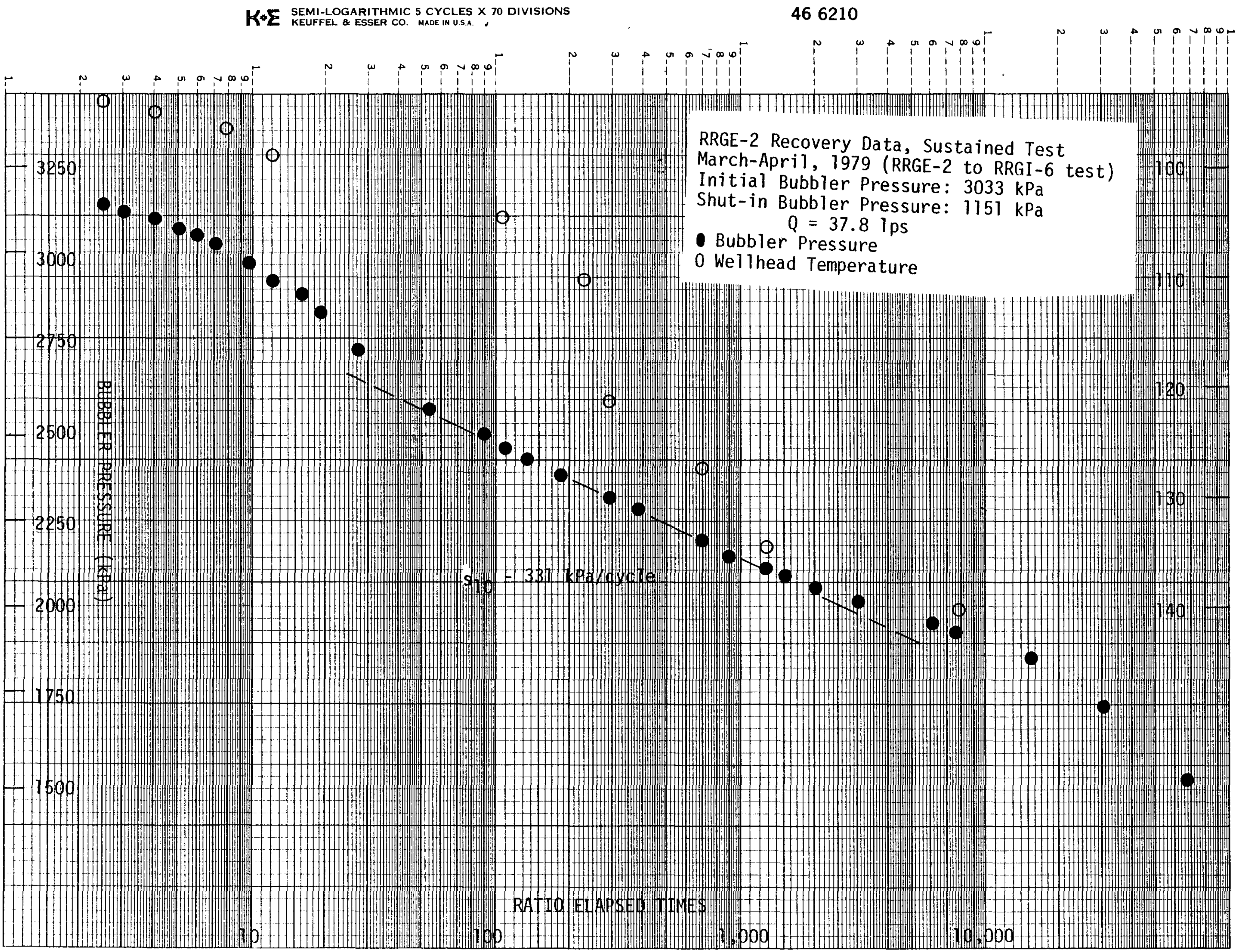
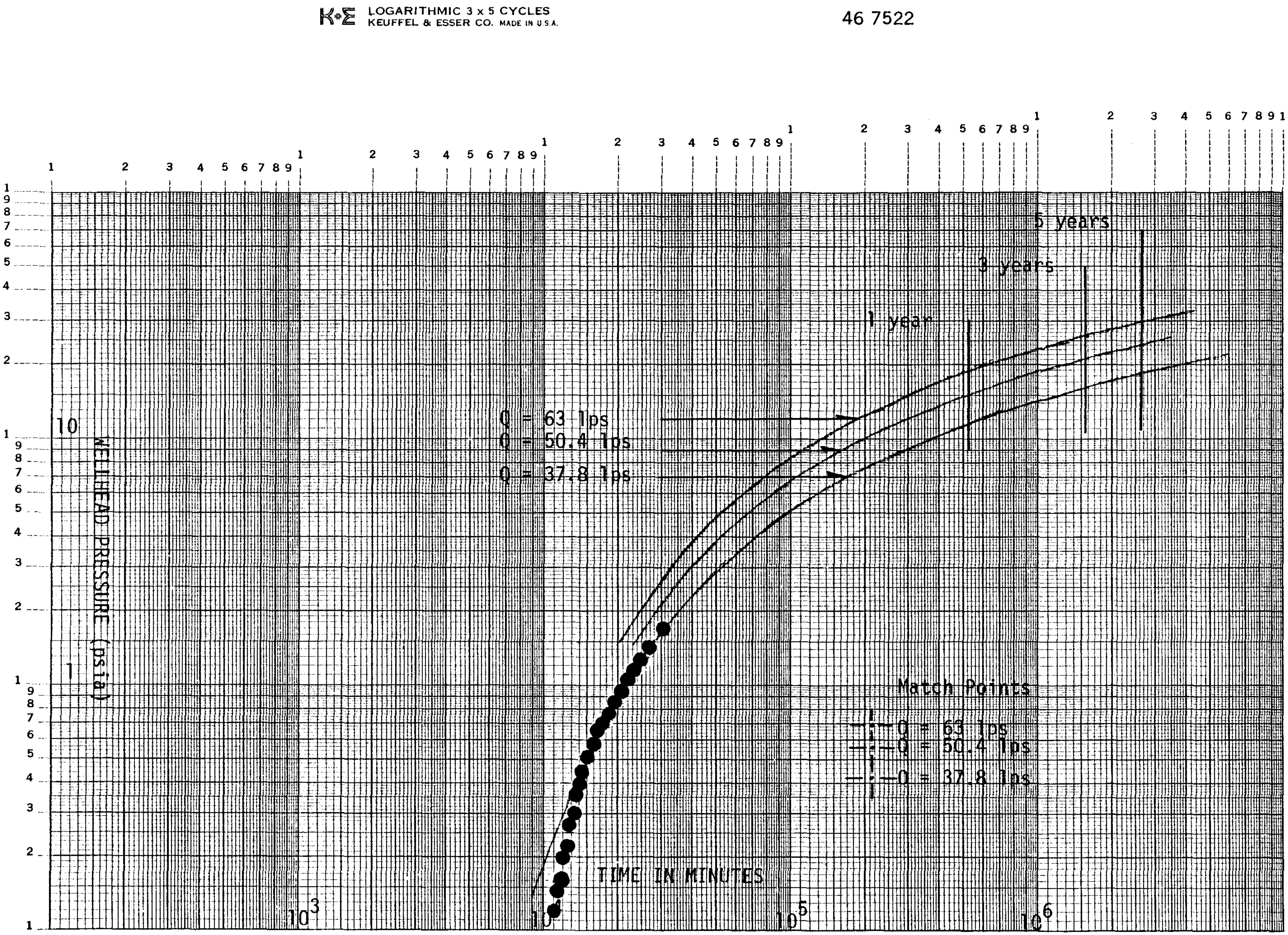
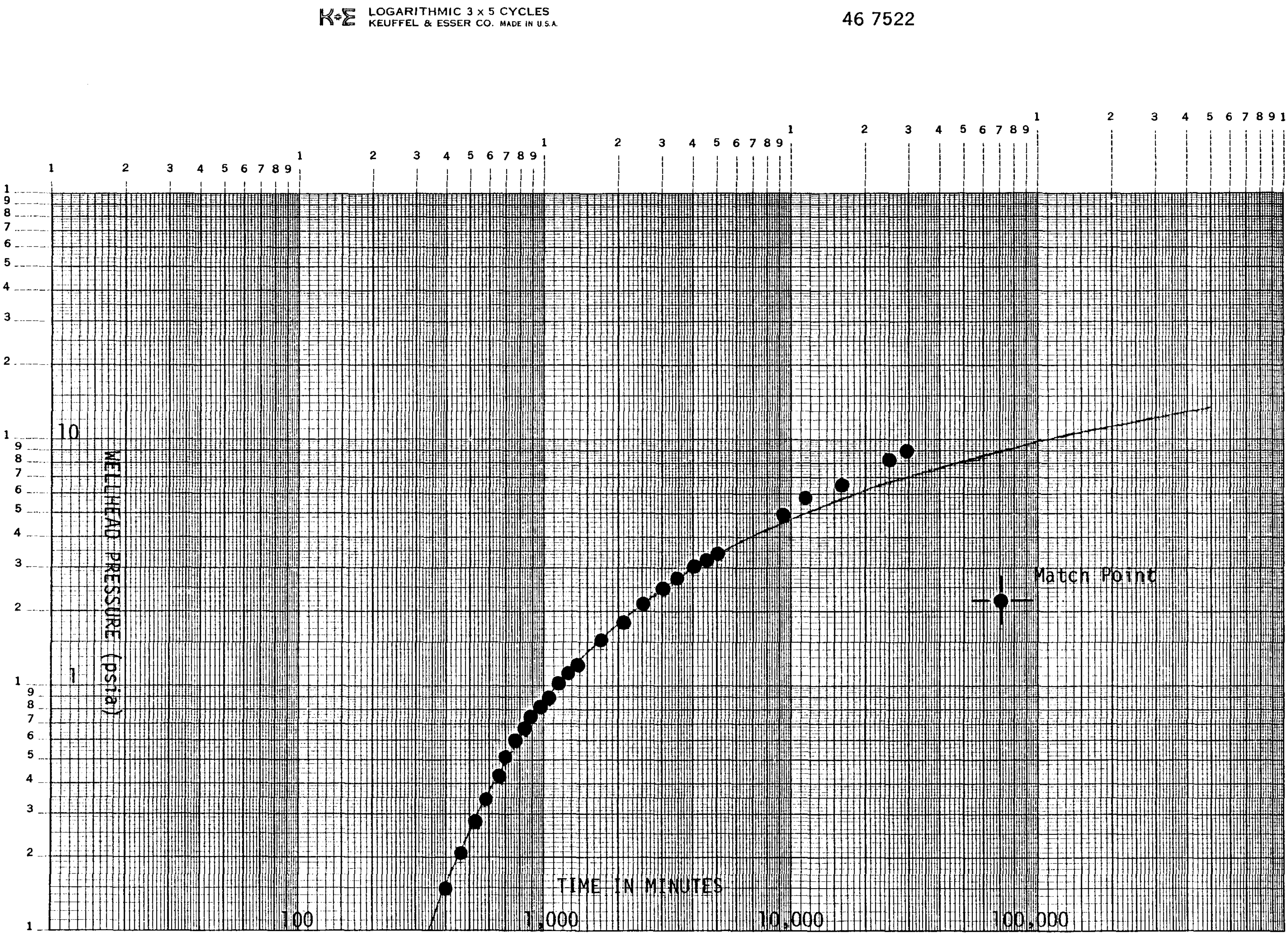

K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
RRGE-2 Recovery Data, Sustained Test
March-April, 1979 (RRGE-2 to RRGI-6 test)
Initial Bubbler Pressure: 3033 kPa
Shut-in Bubbler Pressure: 1151 kPa
Q = 37.8 lps
● Bubbler Pressure
O Wellhead Temperature
BUBBLER PRESSURE (kPa)
3250
3000
2750
2500
2250
2000
1750
1500
100
110
120
130
140
s10 = 331 kPa/cycle
RATIO ELAPSED TIMES
10
100
1,000
10,000

FIGURE 5



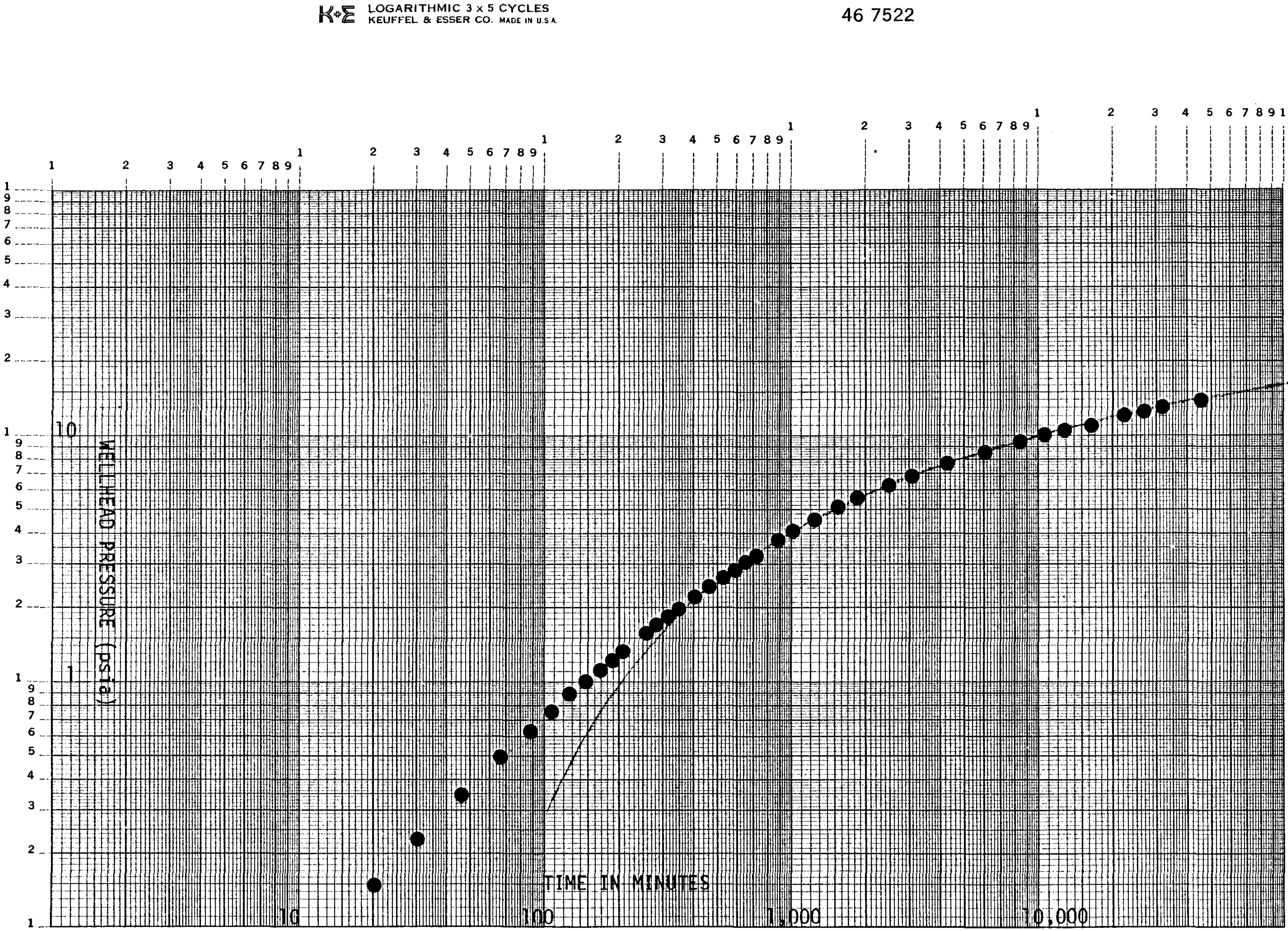
RRGI-7 BUILDUP (RRGE-2 TO RRGI-6 TEST, MARCH-APRIL, 1969)
SHOWING PREDICTED BUILDUP AT OTHER RATES

FIGURE 6



RRGP-4 DRAWDOWN (RRGE-2 TO RRGI-6 TEST, MARCH-APRIL, 1969)

FIGURE 7



RRGE-3 DRAWDOWN (RRGE-2 TO RRGI-6 TEST, MARCH-April, 1969)

FIGURE 8

MONITOR WELL HYDROGRAPHS
January-June, 1979

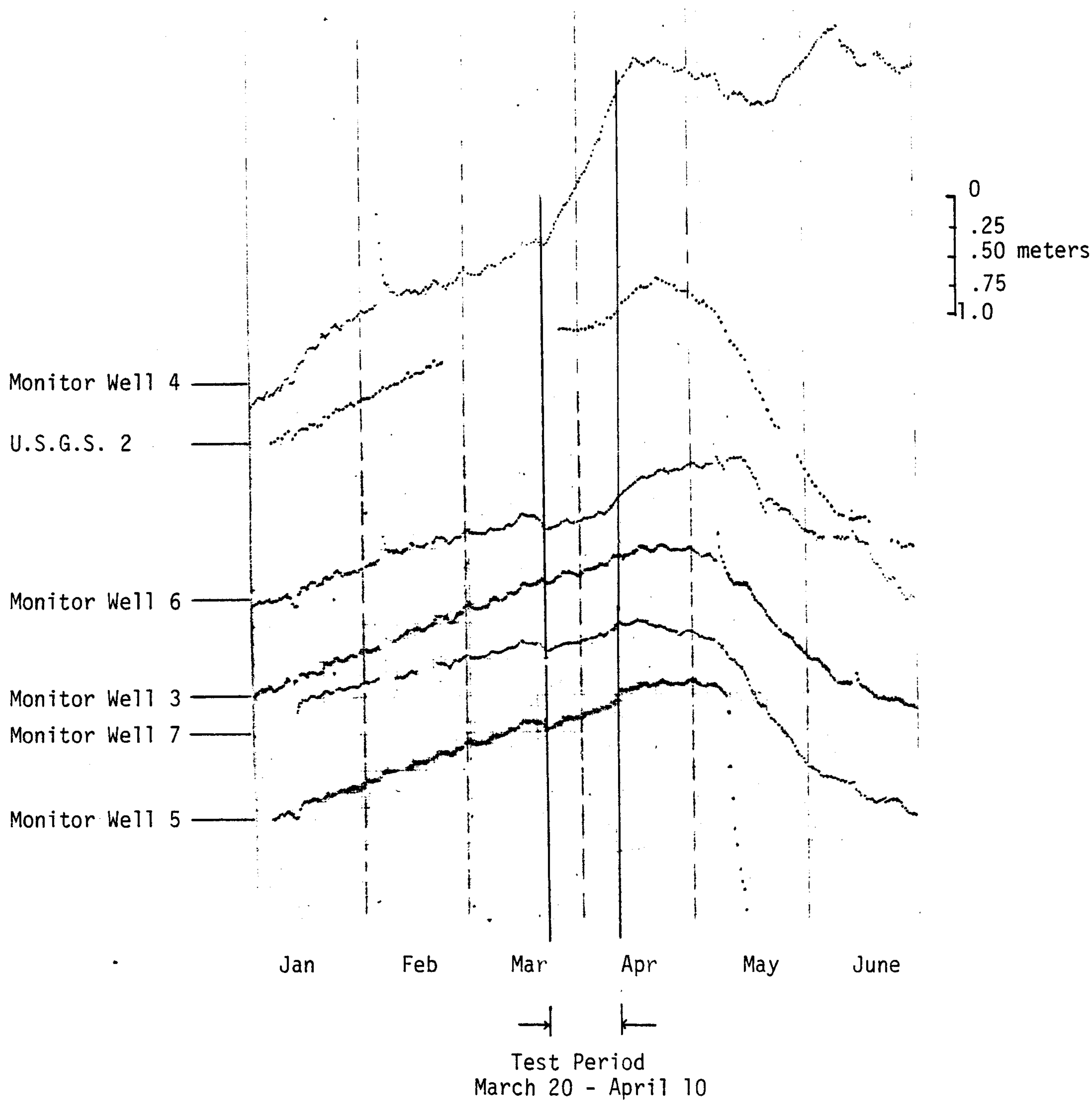


FIGURE 9

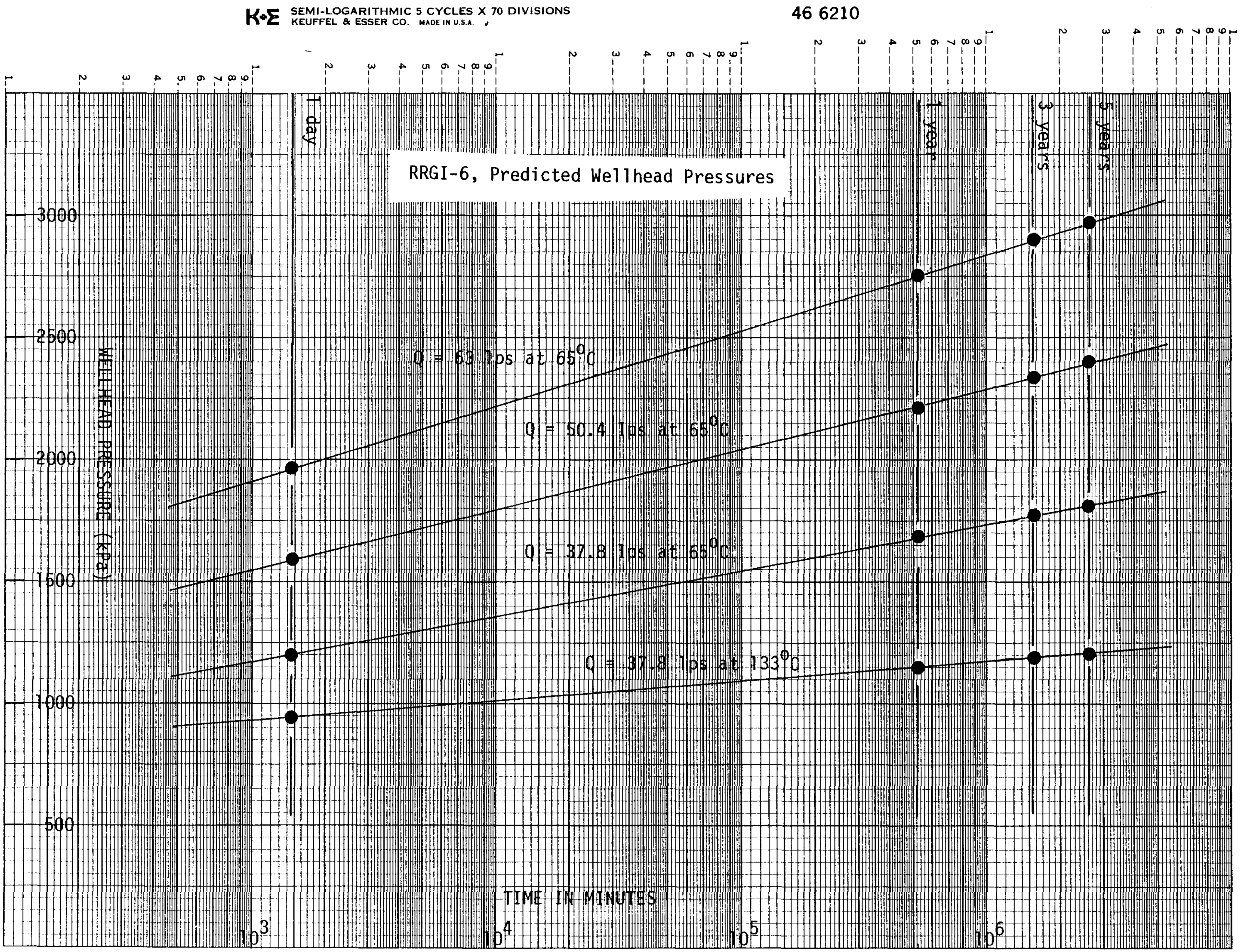

K•Σ SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
RRGI-6, Predicted Wellhead Pressures
1 day
1 year
3 years
5 years
Q = 63 lps at 65°C
Q = 50.4 lps at 65°C
Q = 37.8 lps at 65°C
Q = 37.8 lps at 133°C
WELLHEAD PRESSURE (kPa)
3000
2500
2000
1500
1000
500
TIME IN MINUTES
10^3
10^4
10^5
10^6

FIGURE 10