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ANALYSIS AND LEAK TESTS OF WELLS FOR NEW SOLUTION MINED CAVERNS AT THE BRYAN MOUND DOE-SPR STORAGE SITE

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Abstract

An analysis is presented of factors important to leak tests of wells to be used in developing solution mined caverns in salt domes. Results of leak tests of 30 wells are presented. Leak rates of 26 of the wells met the DOE leak rate criterion of no more than 100 barrels per year per cavern.

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Introduction

The Strategic Petroleum Reserve is a national program involving the underground storage of crude oil in salt dome cavities located in the Texas-Louisiana gulf coast area. To achieve the required storage capacity, construction of a number of new underground caverns is currently being implemented at DOE sites at the Bryan Mound salt dome in Texas and at the West Backberry and Bayou Choctaw salt domes in Louisiana. Such caverns are cavities in the salt dome leached away by the circulation of raw water through wells. Wells for new caverns are nearing completion and leaching of new caverns is well underway at the Bryan Mound site.

DOE has established a criterion of 100 barrels per year maximum leak rate from each cavern. A procedure is required for tests of new cavern construction wells to determine whether this leakage criterion is met. Leakage from the completed caverns is expected to equal or exceed the leakage from the construction wells, which are parts 'of the completed cavern storage systems. Thus, the well tests can be expected to indicate unacceptable leak rates for the completed caverns, but conversely, cannot insure acceptable leak rates.

Tests for well leaks are usually pressure tests. This paper includes an analysis of leak determination from pressure tests of brine filled wells in salt domes. Interpretation of pressure test results in terms of leak rates requires consideration of: compressibility of fluid in the well; thermal expansion of fluid in the well; leaching of salt from. the borehole walls; elasticity of the borehole boundary materials; salt creep; and gas escape' from the salt. These factors are addressed herein. Results of Well tests are also included.

Description of Wells

A schematic of typical well construction is shown in Figure 1 along with details for both the Bryan Mound and West Hackberry wells. A production casing is cemented into the salt at a point somewhat above the planned top of the storage cavern. Two concentric casing strings are hung inside the production casing; the larger diameter "first" string to a depth somewhat below the bottom of the production casing; and the smaller diameter "second" string to a depth near the bottom of the well. Leaching of the salt from the uncased walls of the borehole is accomplished by flowing raw water to the bottom of the well through the small hanging string and removing the brine through the annulus between the two hanging strings until a sump volume adequate to accommodate the insolubles in the salt i's created, then the flow is reversed. The outer annulus is filled with oil to a depth below the casing seat to protect salt near the casing seat from being leached away.

Three different well designs being used are as indicated in the figure. At Bryan Mound, six caverns are planned using three 13 3/8" diameter wells and the remaining six have two 16" diameter wells. At West Hackberry sixteen caverns are planned using single 20" diameter wells. At Bayou Choctaw, a single cavern is planned using two 14" diameter wells (not shown).

Compressibility and Thermal Expansion of Brine

Volumetric properties of aqueous sodium chloride solutions, as determined from the literature, are presented in Reference 1. Brine compressibility values derived from Reference 1 are presented in Figure 2. It is shown that there is a significant effect of temperature on brine compressibility in the temperature range of interest (70°-120°F). The effect of salt content in solutions near saturation is significant but less than the effect of temperature. The data was not adequate to establish an effect of pressure on compressibility in the range of interest (atmospheric to 3000 psi). At the mean temperature of interest, about 100°F, Figure 2 indicates brine compressibility between 2.15 and 2.3 x 10^{-6} volume change per unit volume per psi pressure change.

Brine thermal expansion values derived from Reference 1 are presented in Figure 3. It is shown that there is a significant effect of pressure onthermal expansion in the pressure range of interest. The effect of salt content is smaller, does not appear consistent, and probably is insignificant. At the mean pressure of interest, about 1500 psi, Figure 3 indicates a brine thermal expansion of about 2.7 x 10^{-4} volume change per unit volume per °F temperature change.

When brine in a well has a changing temperature, heat to affect the change has to flow to or from the surrounding material, causing thermal expansion or contraction of the surrounding material. For the open hole portion of a well in salt, increasing brine temperature would correspond to decreasing temperature and contraction of salt adjacent to the borehole. Contraction of the salt adjacent to the borehole, which is part of a very large salt block, would result in an increased borehole cross-section. Thus, while increasing brine temperature causes a thermal expansion, the corresponding decreasing salt temperature creates additional hole volume to partially accommodate the expansion. For the exposed salt portion of the well, assuming 100 atmospheres pressure and 25-percent weight fraction of salt in solution, the increased volume of the borehole would be 51-percent of the increased volume of brine due to thermal expansion. In other words, the effective thermal expansion of brine in the uncased portion of the well would be about half the values indicated by Figure 3. No comparable analysis can reasonably be made for the cased portion of the well with one to three casing strings cemented into salt and overburden materials..

These above results illustrate one very important consideration. The volumetric thermal expansion due to 1°F temperature change is equivalent to the volumetric compressibility due to about 120 psi pressure change. While the effective value may be only half this great, a very precise

knowledge of time-temperature history of brine in a well would be required for interpreting pressure changes in terms of leak rates. In fact, it appears unlikely that average brine temperatures in a well can be measured to the required accuracy under field conditions. It is therefore essential that average brine temperature in the well be stabilized before leak tests are made.

A thermal analysis was made[2] to provide an estimate of the time required for brine temperature stabilization in a typical Bryan Mound 13 3/8-inch cavern well filled with 70°F brine. The analysis indicates large pressure change rates immediately after filling with cool brine, Figure 4, but that thermal affects are probably insignificant after about five days.

Leaching

When a well is filled with unsaturated brine, or with saturated brine at a temperature below formation temperatures, leaching of the salt walls of the borehole will occur. Any such leaching will cause additional volume in the well. The effect of this increased well volume will be offset to a large extent by increased volume of the solution as the salt content increases. An analysis of brine properties data indicates that brine volume increase will be around 85-percent of the volume of salt added for brines with values of weight fraction of salt in solution between 0.17 and 0.25. This result corresponds to the following relation:

$$\frac{AV}{V_o} = 0.085 \times \Delta R$$

where AV difference between volume of salt dissolved and increase in solution volume

V_o initial brine volume

AR increase in weight fraction of salt in solution

The above equation indicates that 0.01 increase of weight fraction of salt in solution would correspond to a value of 8.5 x 10^{-4} for $\Delta V/V_o$ which is equal to the effect of brine compressibility due to a pressure change of about 380 psi. It is thus extremely important to avoid significant leaching during the pressure test. This can be accomplished by using fully saturated brine, to fill the well initially and then allowing an extended period of well stabilization before beginning the test.

If saturated brine at 700F is put in the well and then heated to 100°F, the increase of weight fraction of salt in solution at saturation would be 0.0022, corresponding to an effective increase in well volume equal to the effect of brine compressibility with a pressure change of 83 psi. This would correspond to an average pressure change rate of 0.25 psi/hr. over a two week period. Since actual leaching rate should decay assymptotically as saturation is approached, the actual pressure change rate at the end of a two week period would be considerably less than that for the above assumed constant leaching rate. It is thus concluded that if the fill brine is fully saturated, two weeks for stabilization is adequate.

Elasticity of Borehole Boundary Materials

Elasticity of the partially cased and partially open boreholes can possibly have a significant effect on the interpretation of pressure test results in terms of leak rates. If the well were a rigid container, a decrease in pressure would indicate the loss of a certain volume of fluid, depending on the fluid compressibility and the pressure decay. However, elasticity of the well results in a well volume decrease corresponding to the pressure decay. Thus, the fluid volume loss corresponding to a given pressure decay will include the sum of losses due to compressibility, the decreased well volume and any leak.

The well configuration shown in Figure 1 is a complex elastic structure including a section of uncased hole in the salt, single and double cased sections in the salt, and triple and quadruple cased sections in the overburden above the salt. Casing wall thickness sometimes varies with depth in the casing string. In addition to configuration complexity, the elastic properties of the salt, cement, and overburden are not well known. Calculations for the cased portion of the borehole using assumed material properties[3], together with more straight forward calculations for salt elasticity in the open borehole, were used to estimate elasticity of the complete well. These estimations, while subject to considerable question, indicate well elasticities, $(\Delta V/V)/psi$, approaching half the value of brine compressibility.

Fortunately, it is not necessary to rely on crude assumptions such as the above for determining the effects of well elasticity, as these effects can be obtained directly from the well leak tests. The only requirement is measurement of brine volume required to pressurize the well and the brine volume recovered during depressurization. These incremental volumes per unit pressure change include effects of both well elasticity and brine compressibility and in fact, are equal to leakage volume per unit pressure decay when only well elasticity and brine compressibility are considered, i.e., a well at thermal and salinity equilbrium. When this experimental method is used for defining total elasticity it is important that the well be completely filled with brine before pressurization is begun. Any gas pocket remaining in the well at the beginning of pressurization will cause the total elasticity to be abnormally high because of the normal high compressibility of gas.

Salt Creep

Borehole closure due to salt creep could result in decreased well volume and an increase in well pressure. Borehole closure is the subject of considerable analytical effort[4], is highly variable, and is not readily predictable. For example, in the study of Reference 4, 9-inch boreholes 5000 ft. deep were drilled into two separate salt domes. During a 90 day period, one borehole was found to have decreased in diameter by 1.75-inches near the bottom and lesser amounts with decreasing depth, while the other had no measureable closure. Two months later, neither borehole indicated a change from the 90 day measurements. In addition to not being predictable, borehole closure of amounts important to interpeting pressure results, are too small for measurement by existing techniques.

For a borehole, salt creep is generally considered to be in a direction to cause the hole to close. However; as will be seen in data presented later, test results from several Bryan Mound wells appear to indicate creep, on a relatively short time basis, in the opposite direction. After pressurizing and shutting the well in, there was in many cases a relatively rapid pressure decay during the first few hours with a continuous decrease in decay rate to a much lower rate which was near constant toward the end of a 24-hour test. The pressure time history is not characteristic of a simple leak but could be explained by reverse salt creep during the early hours of the test.

Normally, salt creep is in a direction to cause borehole closure because lithostatic pressure in the salt formation is higher than borehole pressure. A possible explanation for creep in the opposite direction could be as follows. Over a period of time, salt in the vicinity of the borehole has relaxed to the point where horizontal stresses at the edge of the borehole are in equilibrium with brine head pressures in the borehole, and there is a zone in the salt for transition between these stresses and stresses due to lithostatic pressure. With such a stress field, an abrupt increase of brine pressure in the borehole might cause local salt to creep away from the borehole on a short term basis.

From the borehole closure results of[4], and also from the Bryan Mound well test results if they do indeed indicate reverse salt creep, it is apparent that salt creep in the vicinity of a well cannot be adequately predicted. Therefore, the effects of any salt creep during tests to determine well leakage cannot be interpreted in terms of leak rates. However,

indications of the Bryan Mound well test results are that salt creep will not be an important factor after the first several hours of a pressure test. If leak tests indicate important short term reverse salt creep, it is possible that increasing the test time will result in creep decay rate to a point unimportant to the leak test.

Gassy Wells

It is not unusual to find gas in salt domes and gas has been encountered in several of the Bryan Mound new cavern wells. Gas in a salt dome may be entrapped at the crystalline grain boundaries, where it has caused outbursts during mining operations[5], or it may be in porous cavities in impurities in the salt. Gas entrapped at the grain boundaries would be expected to be released only during the leaching process and is not expected to be a problem during leak tests. On the other hand with gas in a formation, satisfactory leak tests are probably not possible unless the gas can be prevented from entering the well cavity while the test is being made. If the gas bearing formation is not too extensive and its permeability is high enough so that gas pressures can be reduced below well test pressures, it may be possible to block the gas in the formation and compress it to well test pressures. If this can be done, a satisfactory test may be possible, but will be difficult because of abnormally high values of total well elasticity.

Aside from the leak test problems, gassy wells present an operational problem during leaching. Also, they are a major concern regarding cavern integrity because the direction and distance which the gas formations extend cannot be determined.

Test Procedures

The test procedures required that all wells be flushed free of drilling muds and filled with clean saturated brine at least two weeks before beginning the test. The actual stabilization period was considerably longer in all cases.

The wellhead was equipped with blind flanges or skillets to prevent undetected leakage through valves and into pipe ng connected to the wellhead.

All gas at the wellhead was bled off. For wells with the hanging strings installed, this included bleed off at the brine string and at the two annuli. Saturated brine was added at the wellhead until the well was full.

An accurate pressure transducer with digital printout of readings was installed at the wellhead. Pressure readings were normally recorded at intervals of about 10 minutes early in the test and at 30 minute intervals thereafter. The pressure transducer was calibrated with a dead weight tester before and after the test.

A pump truck was used to pump saturated brine from a tank into the well. Generally, no more than 3 or 4 barrels of brine was required to pressurize the wells which were not gassy. The wells which were very gassy required considerably more brine. Pumping rates were quite low to avoid high rates of pressurization. A pressurization rate up to 25 psi/minute was considered acceptable. Brine was pumped from small tanks into the wells and pumped volumes were determined by measuring depths in the tanks. Following test completion, brine was withdrawn from the wells into the same tanks or into drums, and recovered volumes were.determined by measuring depths. Volumes determined in this manner were quite crude and the use of flow meters for volume determination is highly recommended.

Volumes measured were divided by the corresponding pressure increase during pressurization and by the corresponding pressure decrease during depressurization, to obtain values of change in volume per unit pressure change, called total well elasticity. For gassy wells requiring repeated pressurization to reach a stable condition, values of elasticity were obtained only during depressurization. For these wells, the rate of bleed off was considerably reduced in an effort to avoid pressure non-equilibrium between brine and gas.

In some cases where the pressure dropped more than 16 psi/hr during the first two hours of shut in following pressurization, the well was repressurized and shut .in again. For non-gassy wells, this was done in only a few cases. However, for gassy wells it was repeated many times. For the gassy wells, it was

theorized that brine had to be driven into a permeable gas formation and that significant time was required for brine to flow through the formation and pressurize the gas. For the most gassy wells, this pressure drop-repressurization cycle was continued for 2 to 3 days before a fairly stable condition was achieved.

The maximum brine pressure at the wellhead during these tests was about 650 psi. This was based on a maximum allowable test gradient of 0.85 psi per foot of depth to the casing seat. Subsequent to these tests, a maximum allowable test gradient of 0.82 psi/ft was established by DOE for the Bryan Mound site6. Lowering of the allowable gradient was a result of lithostatic pressures obtained from density logs being lower than the usually expected value; 0.92 psi/ft as opposed to the ususal value of 1.0 psi/ft.

The final shut in period of the pressure test was 24 hours in most cases, though longer times were allowed for some of the gassy wells.

Pressure decay rates were obtained by linear regression of pressure versus time data for the last several hours of the tests where the rates of decay appeared near constant.

Leak rate calculated was the product of experimental total well elasticity (bbls/psi) and experimental pressure decay rate (psi/hr).

Test Results

Pressure-time histories of the well tests are presented in Figures 5 to 38. For many of the wells, the previously noted rapid pressure decay immediately following pressurization and shut in is shown. The majority of wells for which this characteristic is absent or less pronounced were wells which were repressurized before beginning the 24 hour shu in period, typically for wells with gas.

No data are included for well 104-C. Digital data obtained during the test was lost. However, a circular chart pressure record of much lower pressure resolution indicated about 20 psi pressure loss during the 24 hour shut in. On this basis well 104-C was determined to meet the leak rate criterion.

A summary of the leak test results is included in Table I. The table includes pressure decay rate for the last several hours of the tests, total well elasticities determined from measured brine volumes injected during pressurization and/or measured brine volumes withdrawn during depressurization, and calculated well leak rates.

The leak rate shown for well 108-C is excessive. One repair of this well has been attempted and a second repair attempt is being implemented.

Results of three tests of well 109-A are shown. Two of the tests resulted in leak rates 1 1/2 to 2 times the single well criterion. Following these tests, the well was repaired and the leak rate determined from the third test was below the criterion.

Well 109-C was tested twice. This well is very gassy and the relatively large pressure decay rate during the first test was believed due in part to brine moving into a gas formation during the test period. Prior to the second test, brine was pumped into the well for an extended time before starting the test period in an effort to achieve equilibrium between brine and formation gas. Total well elasticity was obtained by bleeding a small volume of brine (2 gallons) at a low rate of 300 bbls/yr, in an effort to maintain equilibrium between gas and brine and thus obtain a reasonable value of elasticity. The bleed off results are shown in Figure 38. The leak rate indicated for this well in Table I is 76.9 bbls/yr, over twice the single well criterion. However', the combined leak rate indicated for the three wells of the 109 cavern is 124.6 bbls/yr. It was decided that no attempt would be made to repair the well.

Well 111-A is a very gassy well. Brine was pumped into this well and gas was bled from the wellhead for an extended period until it appeared that the brine and gas were in equilibrium. However, shortly after shutting the well in, the pressure began to rise at a significant rate, Figure 34, because of gas entering the well and rising to the wellhead. It was decided that no satisfactory leak test of this well is possible with the gas problem as it exists.

Well 112A is also a very gassy well. It is believed that some of the pressure decay indicated in Figure 36 is due to brine entering the gas formation during the test period. Also, inadequate well elasticity data were obtained to define a leak rate. During a second attempt to test this well with equilibrium between brine and gas pressures, the well began to lose pressure rapidly. Some months following the test, there were indications of communication between wells 112A and 112C, in which leaching had begun. It appears that future tests of 112A will be possible only together with 112C.

It is noted in Table I that brine compressibility alone should contribute 0.00236 bbls/psi to total elasticity of a typical 13 3/8-inch well and 0.00266 bbls/psi to total elasticity of a typical 16-inch well. Five experimental values of well total elasticity are less than the contribution of brine compressibility by as much as 30-percent. This result could be due to well volumes somewhat less than typical, but is more likely due to relatively crude volume measurements. Of these five apparently low values of total elasticity, only one appears of importance. Doubling the experimental value for well 105B for use in the leak rate calculation would result in a cavern 105 leak rate of 108 bbls/yr.

Eight experimental values of well total elasticity are greater than 1.5 times the contribution of brine compressibility. At least five of these higher values can be explained by significant gas in the wells. The remaining 19 experimental values lie between 1 and 1 1/2 times the contribution of brine compressibility, a range considered reasonable based on rough calculations of borehole boundary material elasticities.

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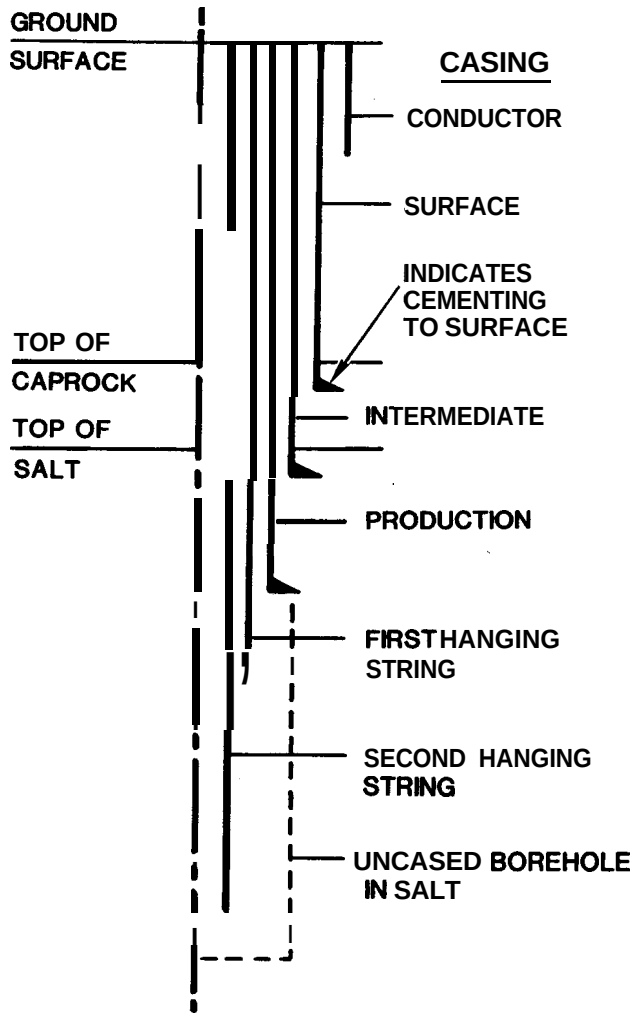
TABLE I - SUMMARY OF LEAK TEST RESULTS

Well	Test Date	Pressure Decay Rate psi/hr	Total Well Elasticity bbls/psi	Leak Rate bbls/yr
101A	7/3/80	1.153	0.00369	37.3
101C	7/7/80	.439	.00343	13.2
102B	7/9/80	.723	.00314	19.9
102C	7/9/80	2.028	.00286	50.8
103B	7/6/80	-.038	.00733	a
103C	7/6/80	1.679	.00495	72.8
104A	12/21/79	.391	.00381	13.0
104B	2/4/80	.829	.00202	14.7
104C	2/5/80	b	.01024	b
105B	6/6/80	1.434	.00190	23.9
105C	6/7/80	1.713	.00402	60.3
106A	3/5/80	.281	.00250	6.2
106B	12/18/79	1.050	.00281	25.8
106B	2/2/80	1.106	.00264	25.6
106C	2/3/80	.333	.00257	7.5
107A	2/2/80	1.554	.00512	69.7
107B	2/1/80	.691	.00357	21.6
107C	2/1/80	.278	.00312	7.6
108A	12/19/79	-.187	.00190	a
108B	1/30/80	.615	.00317	17.1
108C	1/30/80	5.871	.00226	116.2
109A	6/10/80	2.751	.00214	51.6
109A	6/20/80	2.149	.00274	51.6
109A	7/16/80	1.424	.00248	30.9
109B	2/3/80	.760	.00252	16.8
109C	6/9/80	.364	c	c
109C	7/21/80	.210	.04188	76.9
110A	12/21/79	.628	.00248	13.6
110B	1/29/80	1.084	.00243	23.1
110C	1/29/80	1.491	.00307	40.1
111A	7/14/80	-.872	c	c
111B	7/14/80	.974	.00590	50.3
112A	6/11/80	1.110	c	c
112C	7/19/80	.546	.00450	21.5

a - slight pressure increase no leak rate calculated
b - digital data lost - circular pressure chart indicated tolerable pressure decay
c - very gassy well - inadequate data obtained

Note: Fluid compressibility above corresponds to well elasticity of 0.00236 for 13 3/8-inch well with typical 1050 bbl volume and of 0.00266 for 16-inch well with typical 1180 bbl volume.



WELL CASING DIAMETERS (inches)

	BRYAN MOUND TRI-LOBE	BRYAN MOUND BI-LOBE	WEST HACKBERRY
CONDUCTOR	36	36	48
SURFACE	26	26	36
INTERMEDIATE	20	20	26
PRODUCTION	13-3/8	16	20
FIRST HANGING STRING	10-3/4	13-3/8	16
SECOND HANGING STRING	7	8-5/8	1o-314
OPEN BOREHOLE DIA	15-17-1/2	17-1/2-18-1/2	17-1/2-22

APPROXIMATE DEPTHS (feet)

	BRYAN MOUND	WEST HACKBERRY
CONDUCTOR CASING	99-i 17	100+
TOP OF CAPROCK	720-850	1560-2010
SURFACE CASING	737-944	INTO CAPROCK
TOP OF SALT	1077-1093	2030-2335
INTERMEDIATE CASING	1218-1324	2200-2450
PRODUCTION CASING	1987-2048	2450-2700
FIRST HANGING STRING	2288-2308	2800-3050
SECOND HANGING STRING	4435-4459	4935
BOTTOM OF WELL	4500-4550	5000

FIGURE 1- SCHEMATIC OF TYPICAL WELL CONSTRUCTION ANC WELL DETAILS

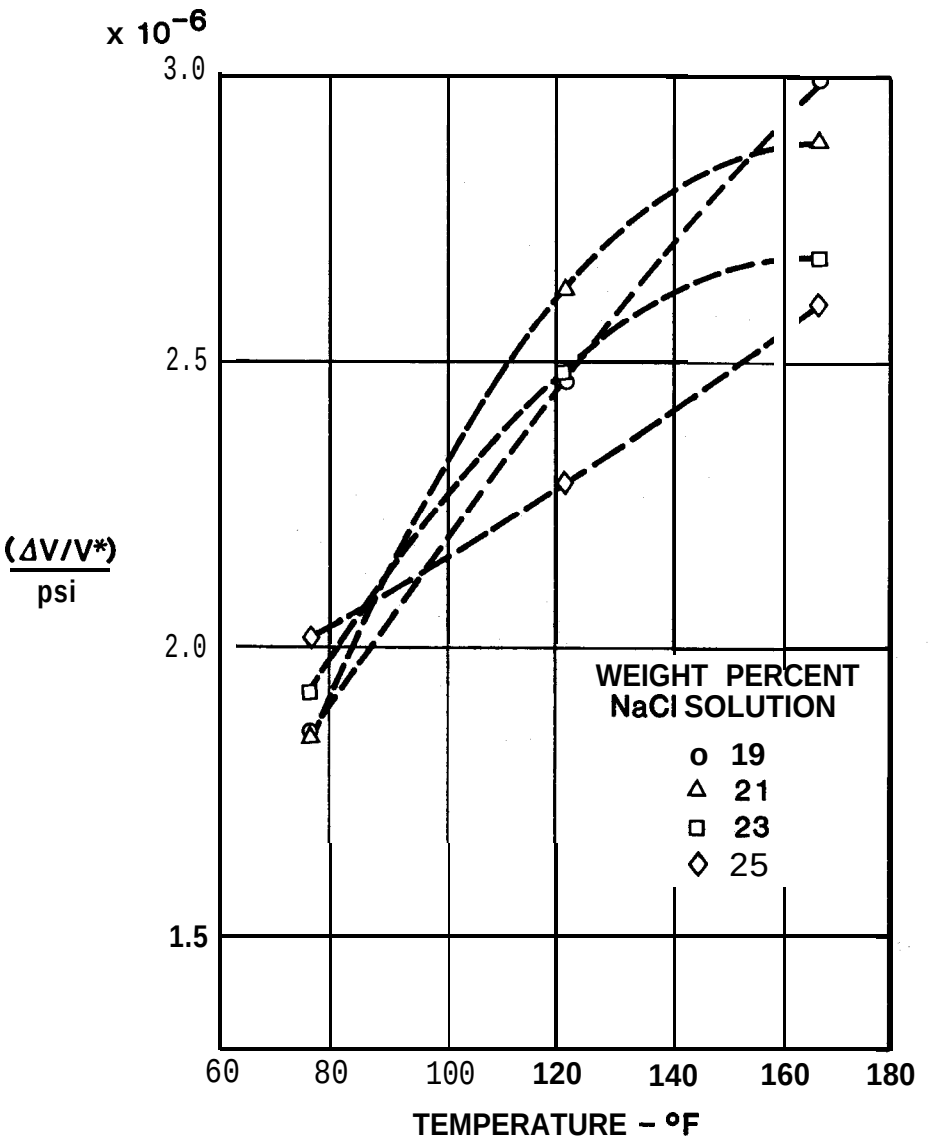


FIGURE 2 - COMPRESSIBILITY OF BRINE (V* IS VOLUME AT ATMOSPHERIC PRESSURE)

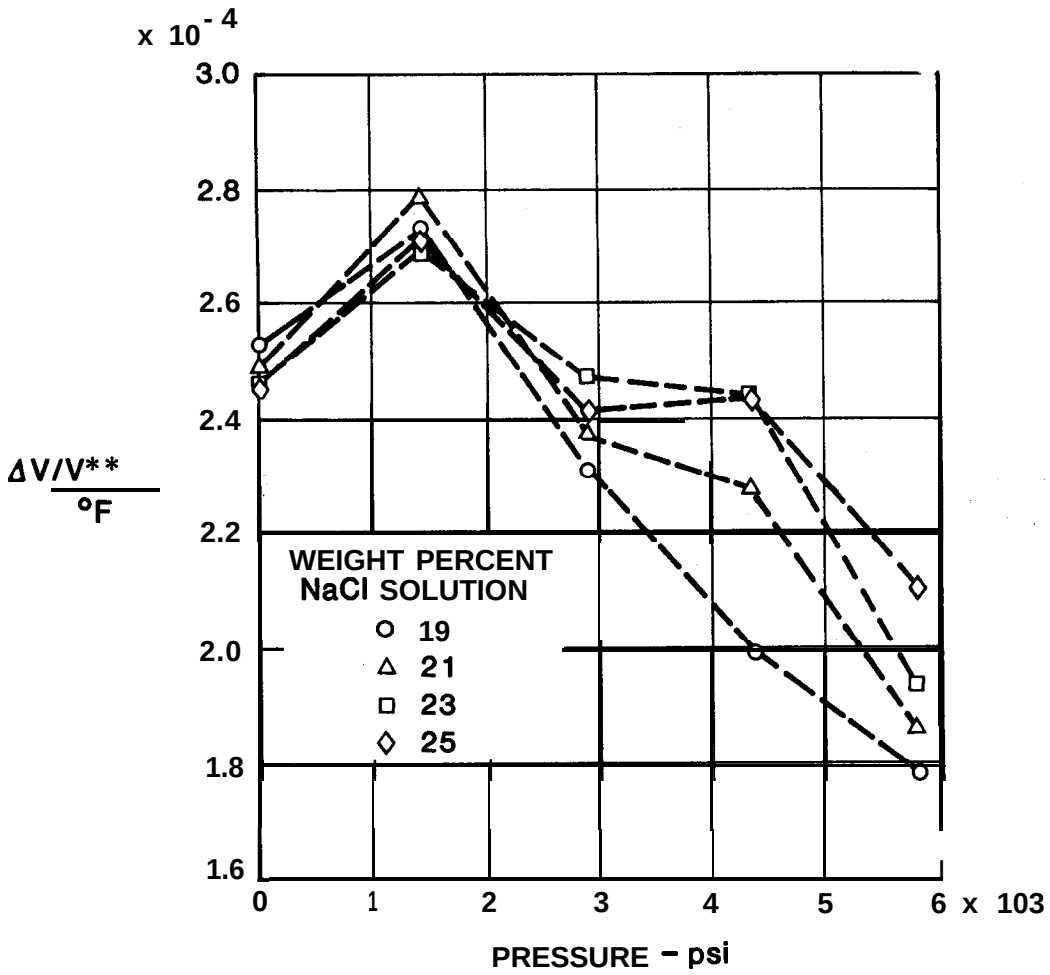


FIGURE 3 - VOLUMETRIC THERMAL EXPANSION OF BRINE (V^{**} IS VOLUME AT 32°F)

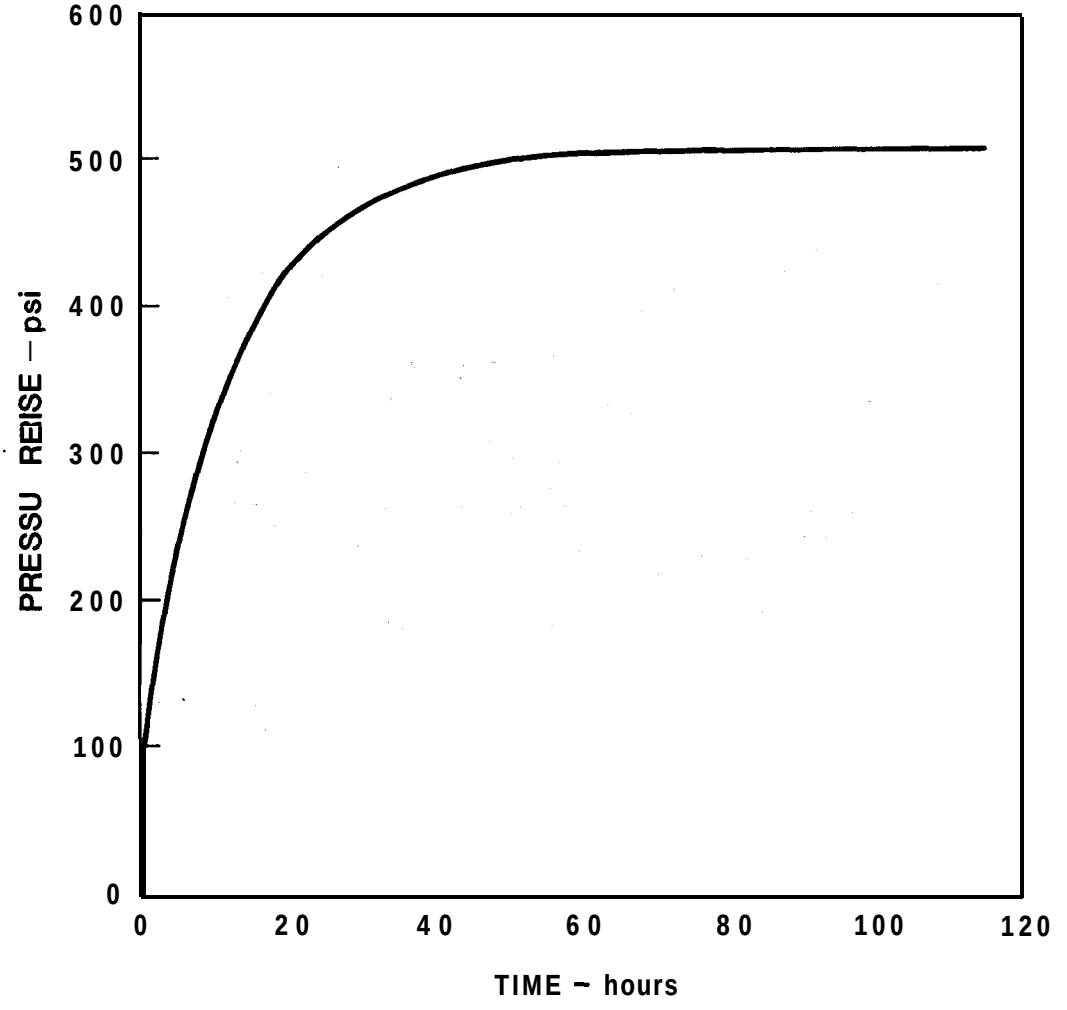


FIGURE 4 - CALCULATED PRESSURE RISE DUE TO TEMPERATURE INCREASE IN A WELL WITH 13 3/8-INCH CASING TO 2000 FEET AND WITH A 15-INCH BOREHOLE EXTENSION TO 4500 FEET. (WELL TEMPERATURE VARIES FROM 70°F AT SURFACE TO 115°F AT BOTTOM OF BOREHOLE; BRINE TEMPERATURE IN WELL 70°F AT TIME ZERO,)

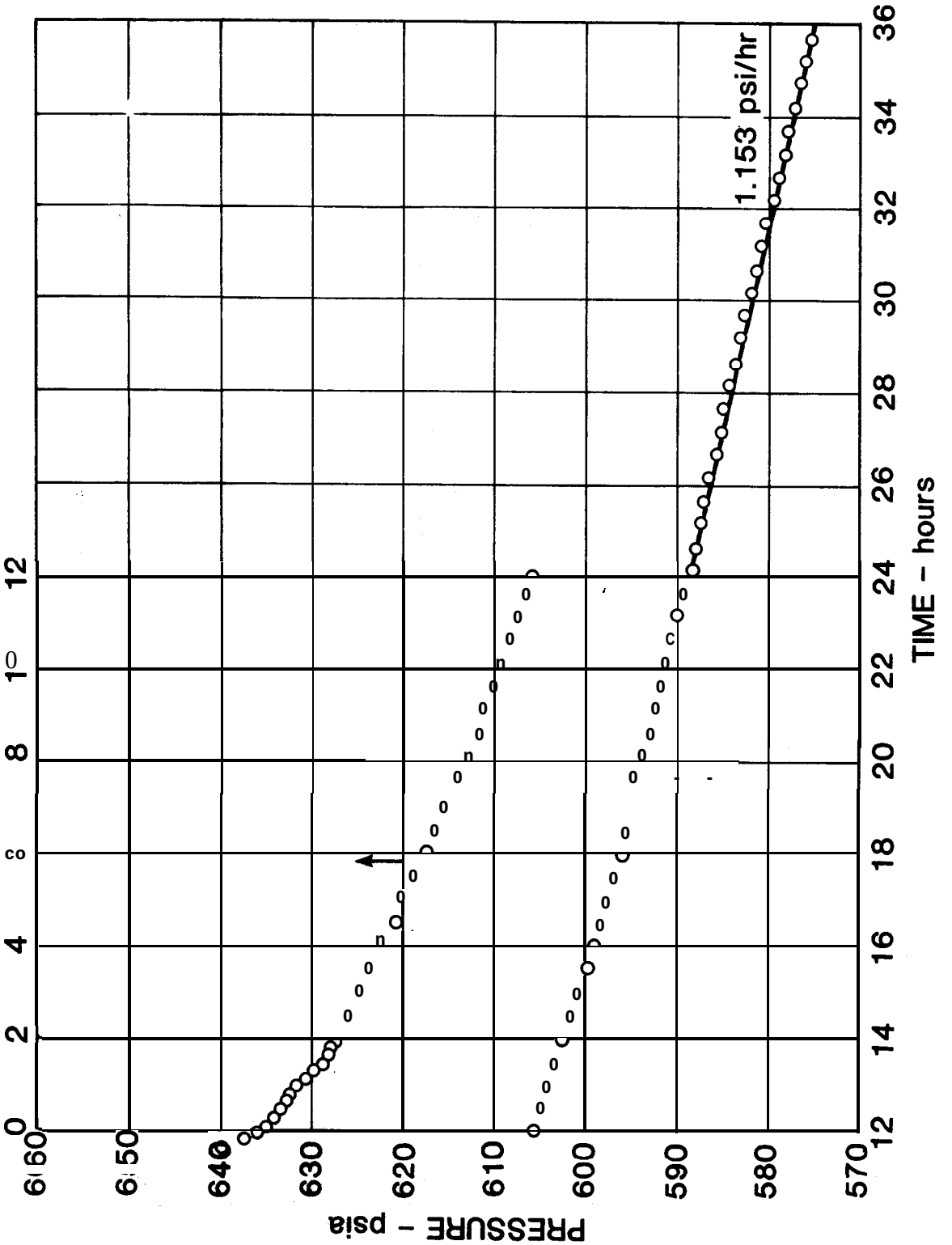


FIGURE 5 - PRESSURE TIME HISTORY FOR WELL 101A

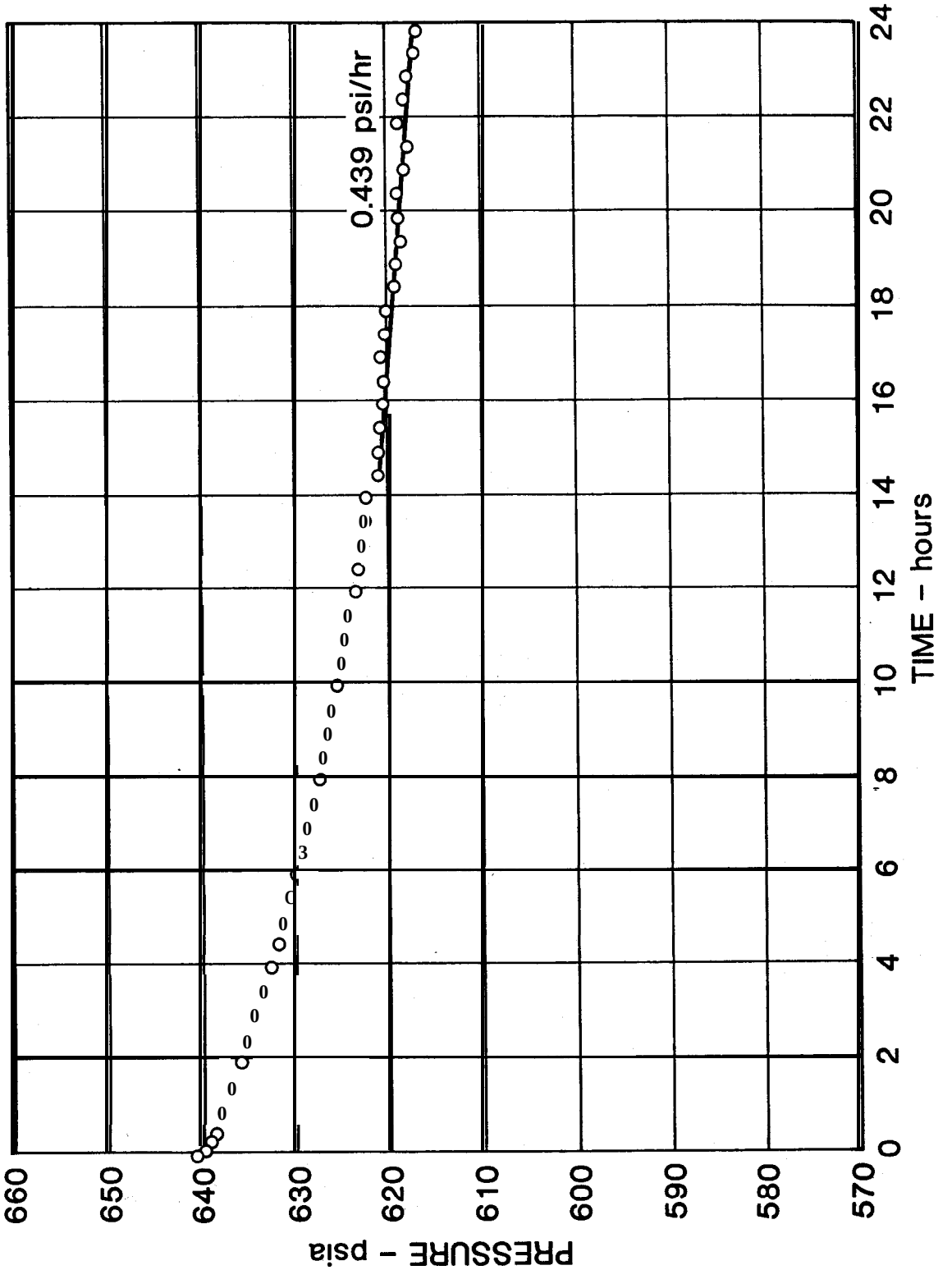


FIGURE 6 - WELL 101C

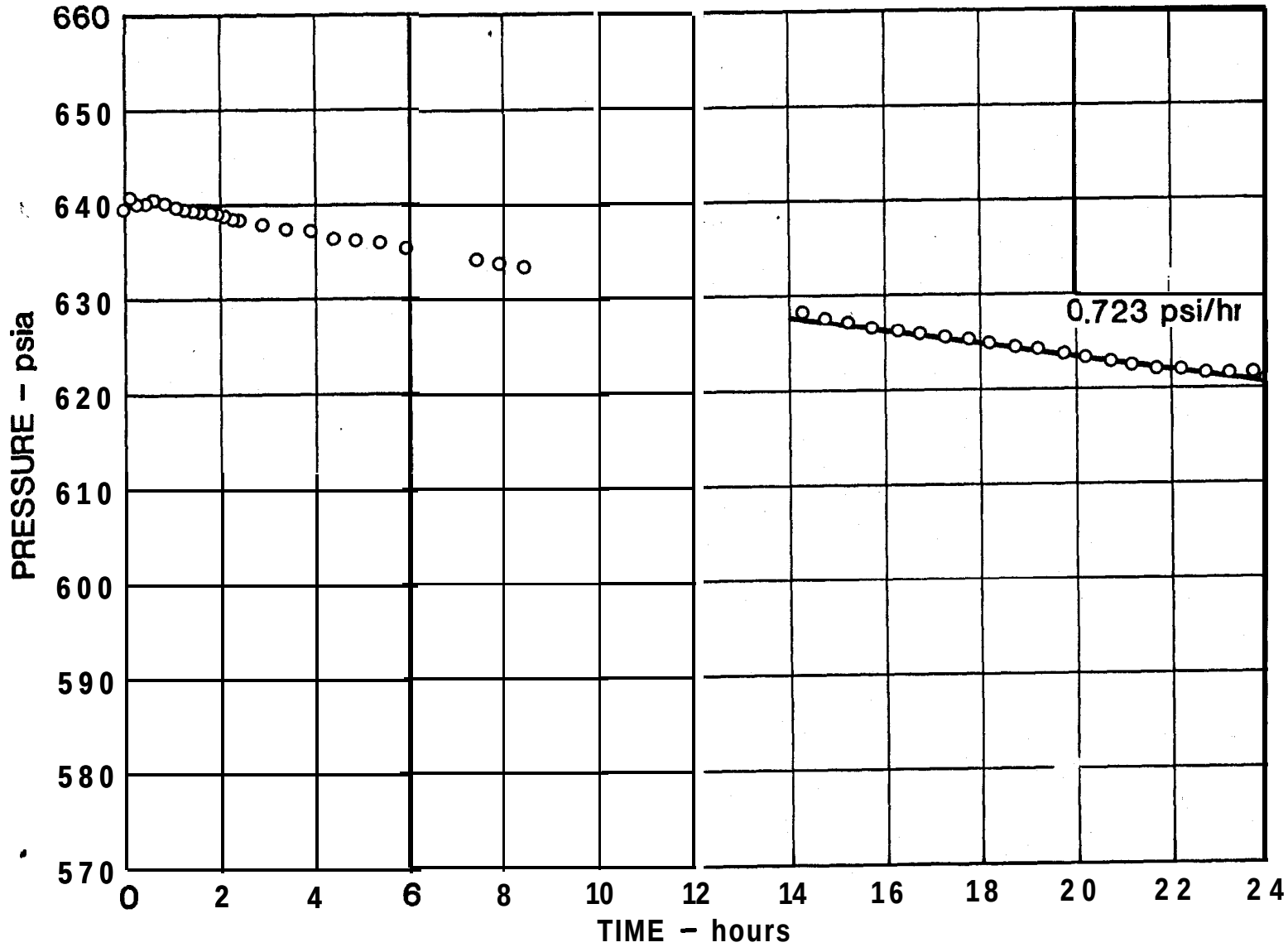


FIGURE 7 - WELL 102B

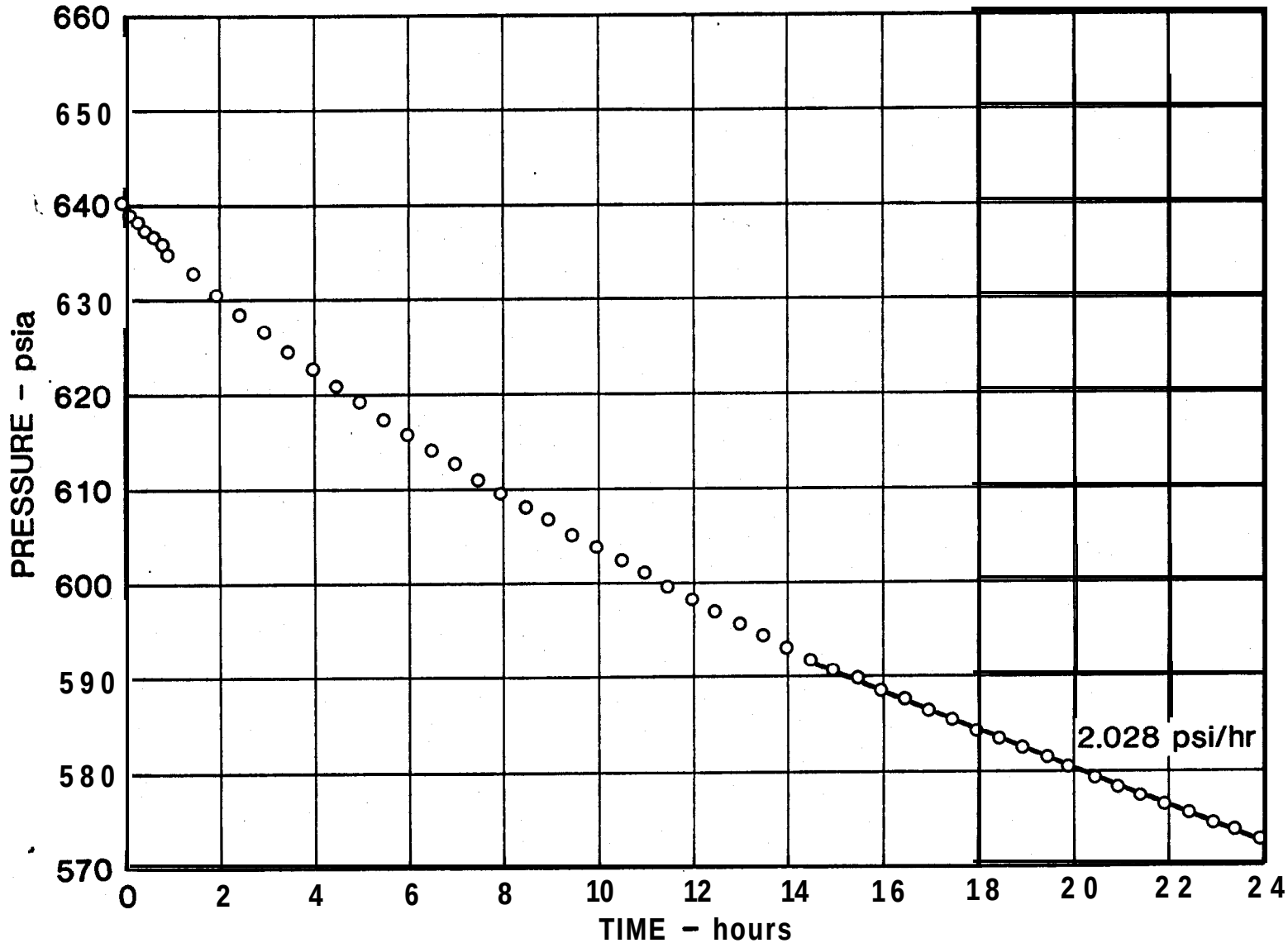


FIGURE 8 - WELL 102C

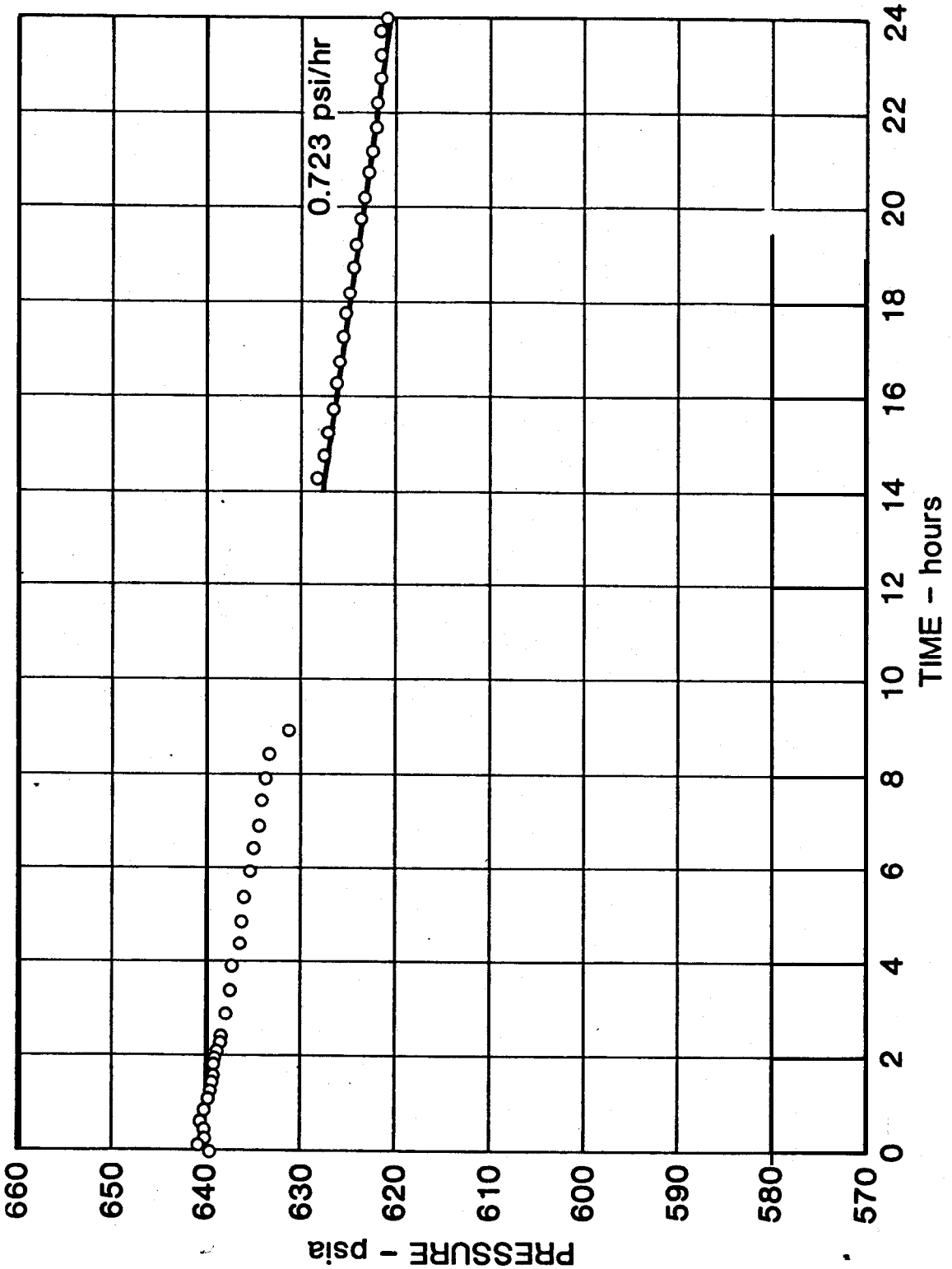


FIGURE 7 -WELL 102B

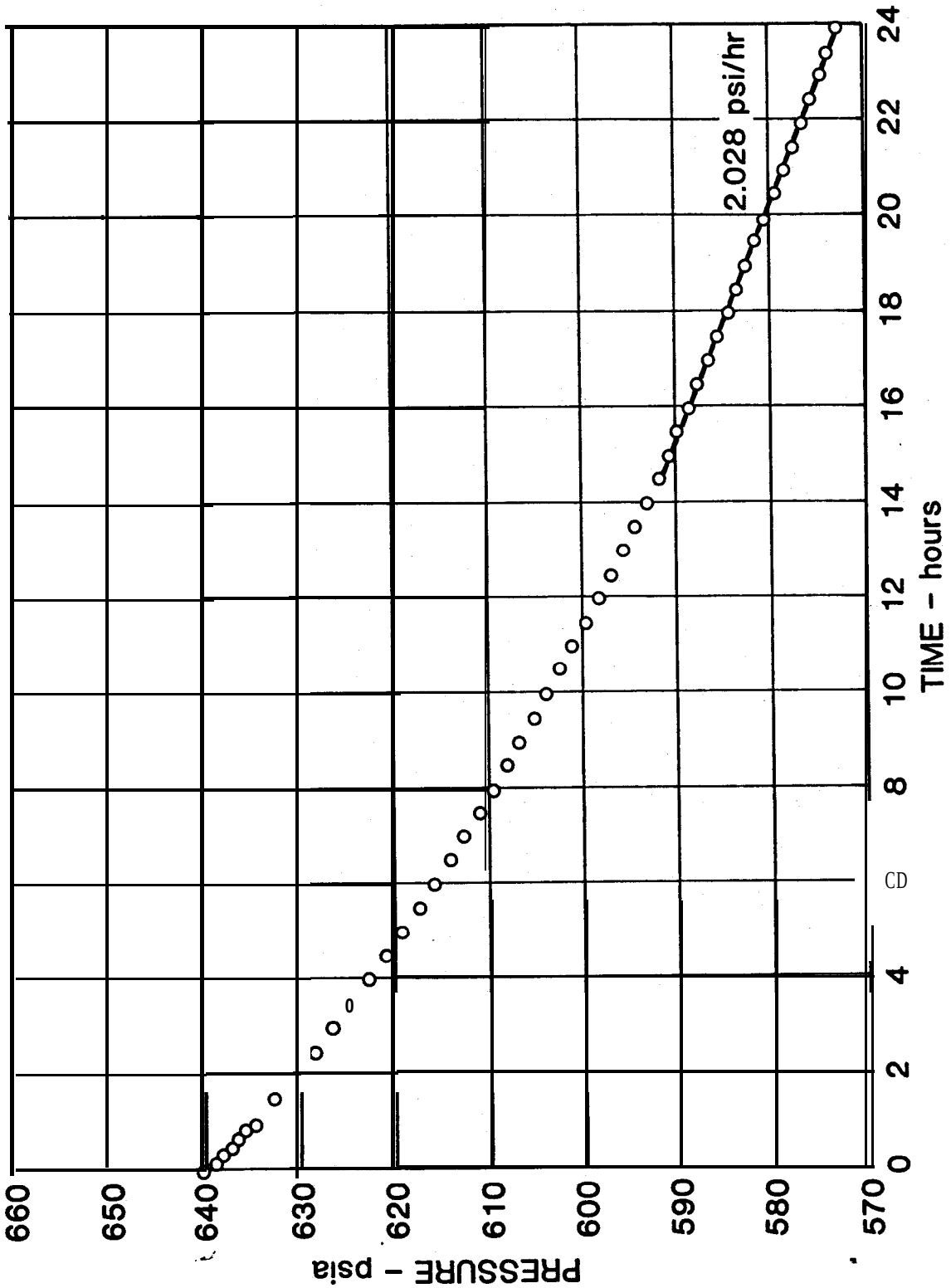


FIGURE 8 - WELL 102C

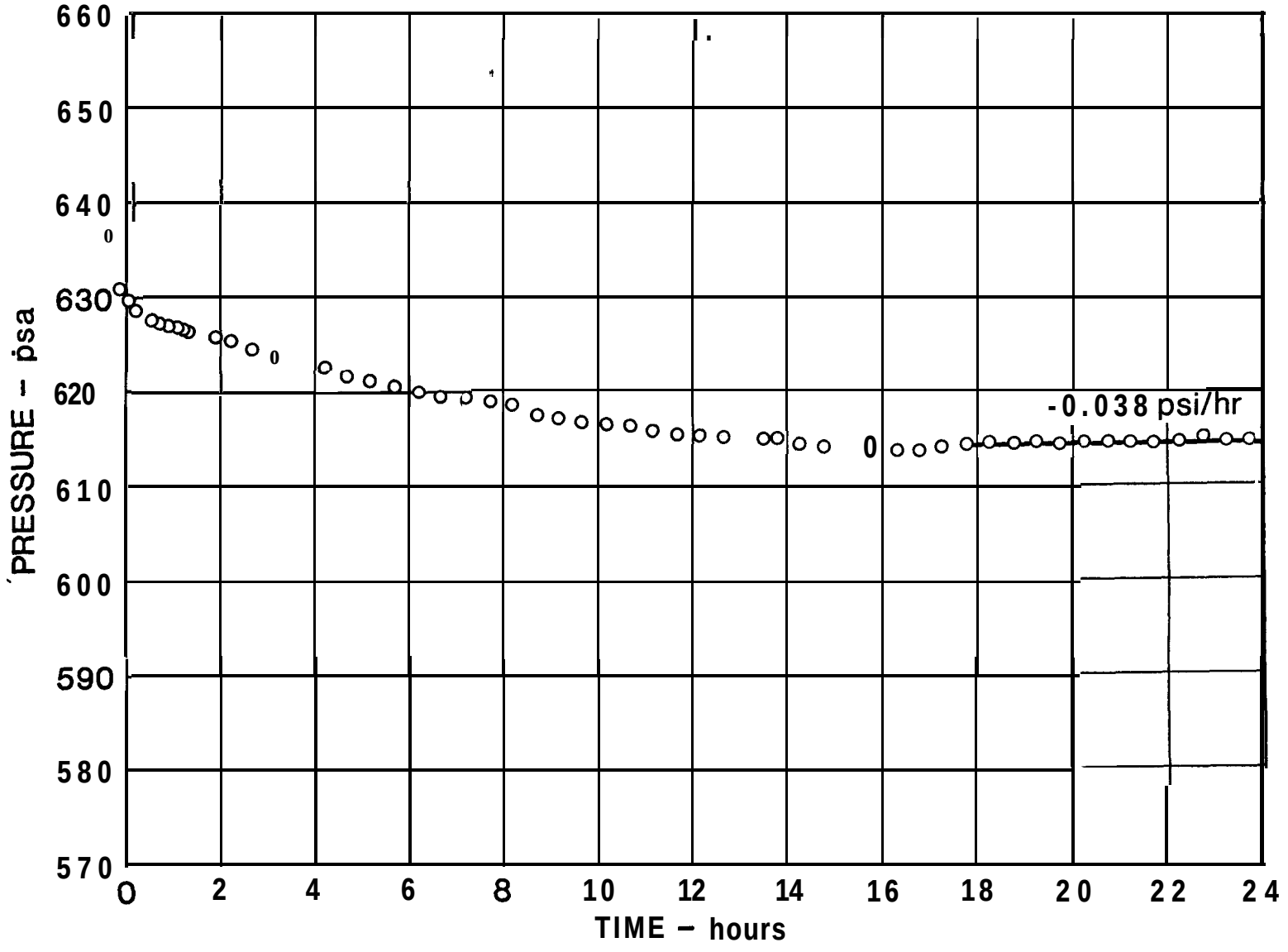


FIGURE 9 - WELL 103B

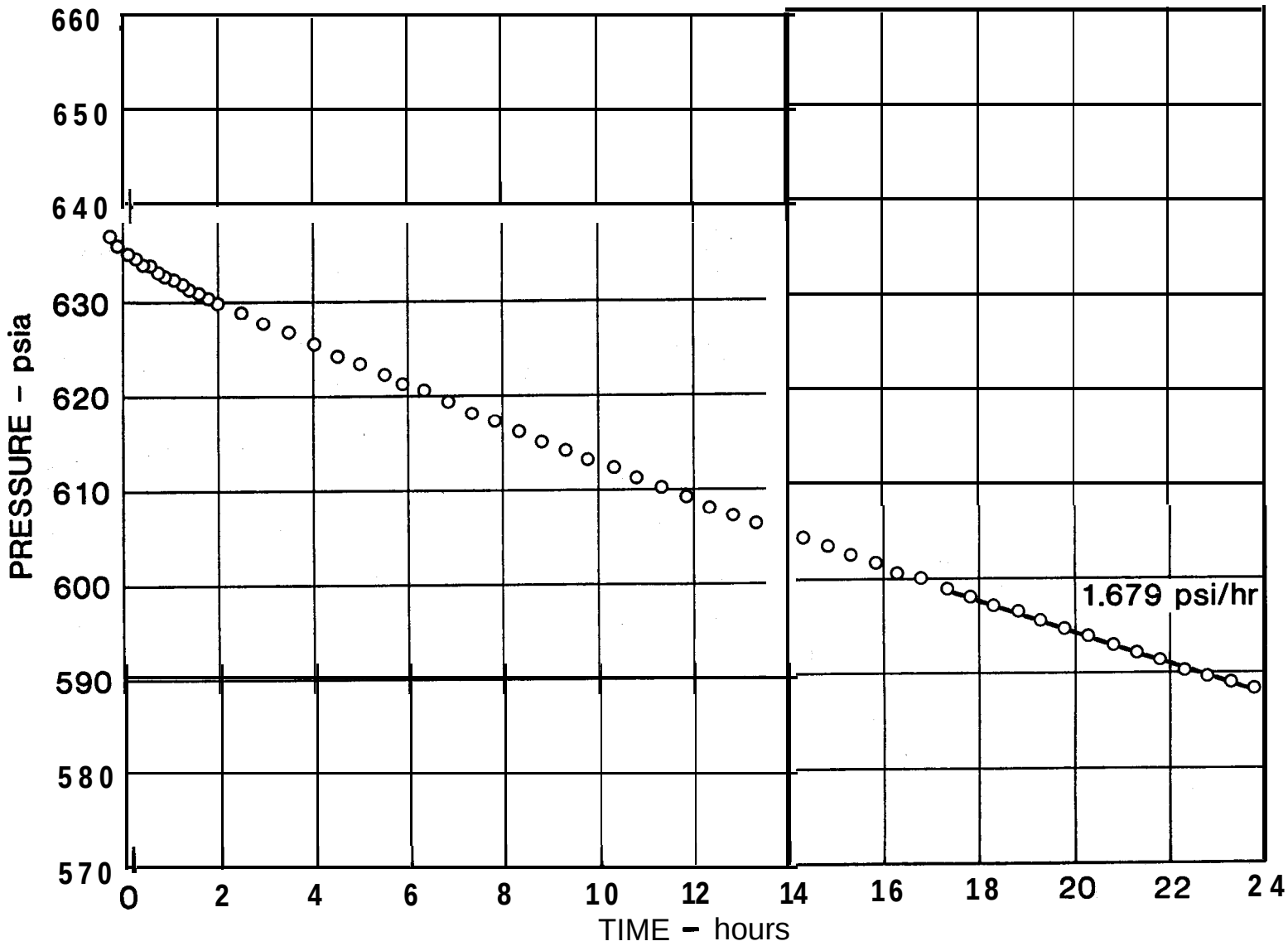


FIGURE 10 - WELL 1U3C

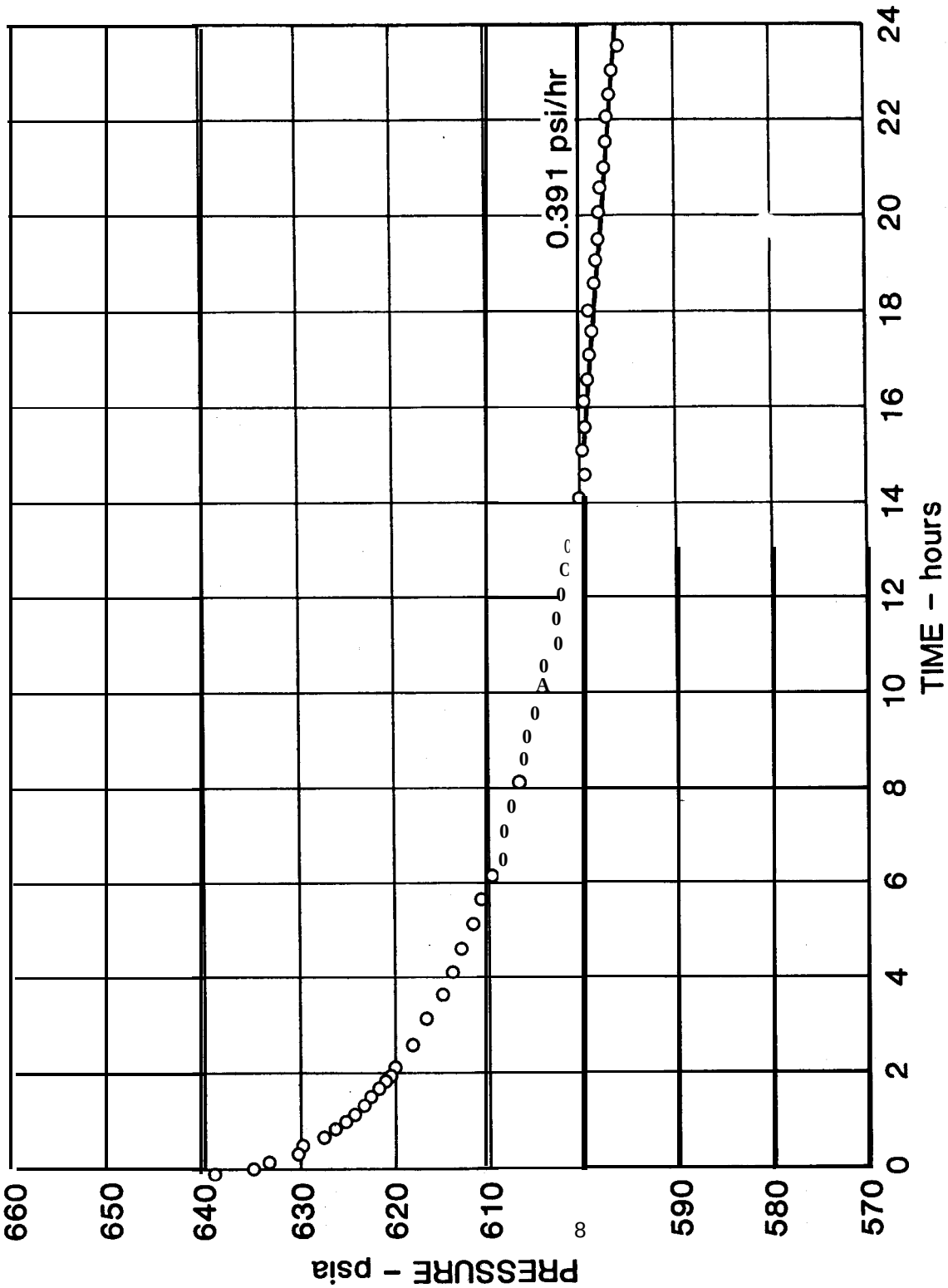


FIGURE 11 - WELL 104A

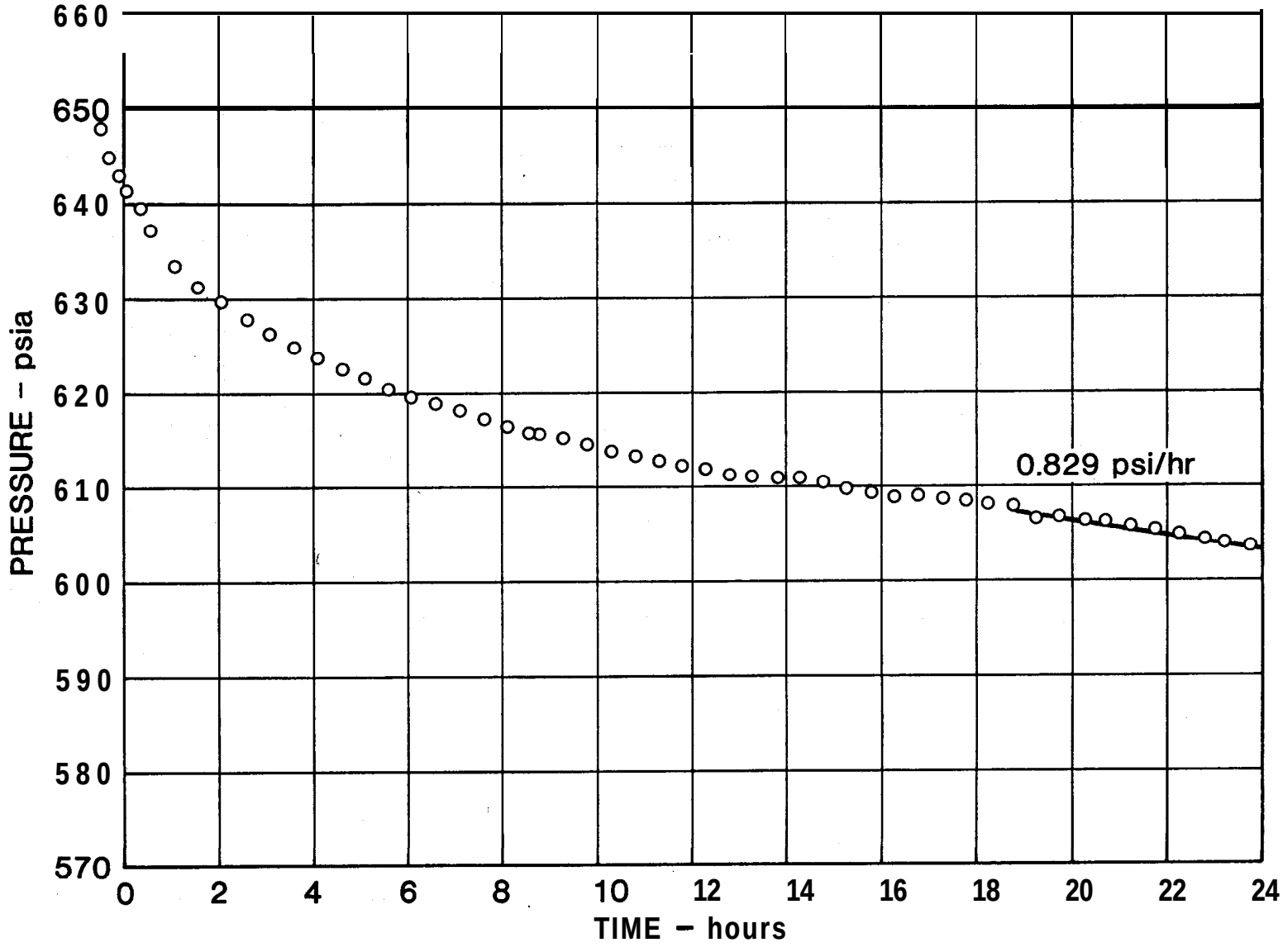


FIGURE 12 - WELL 104B

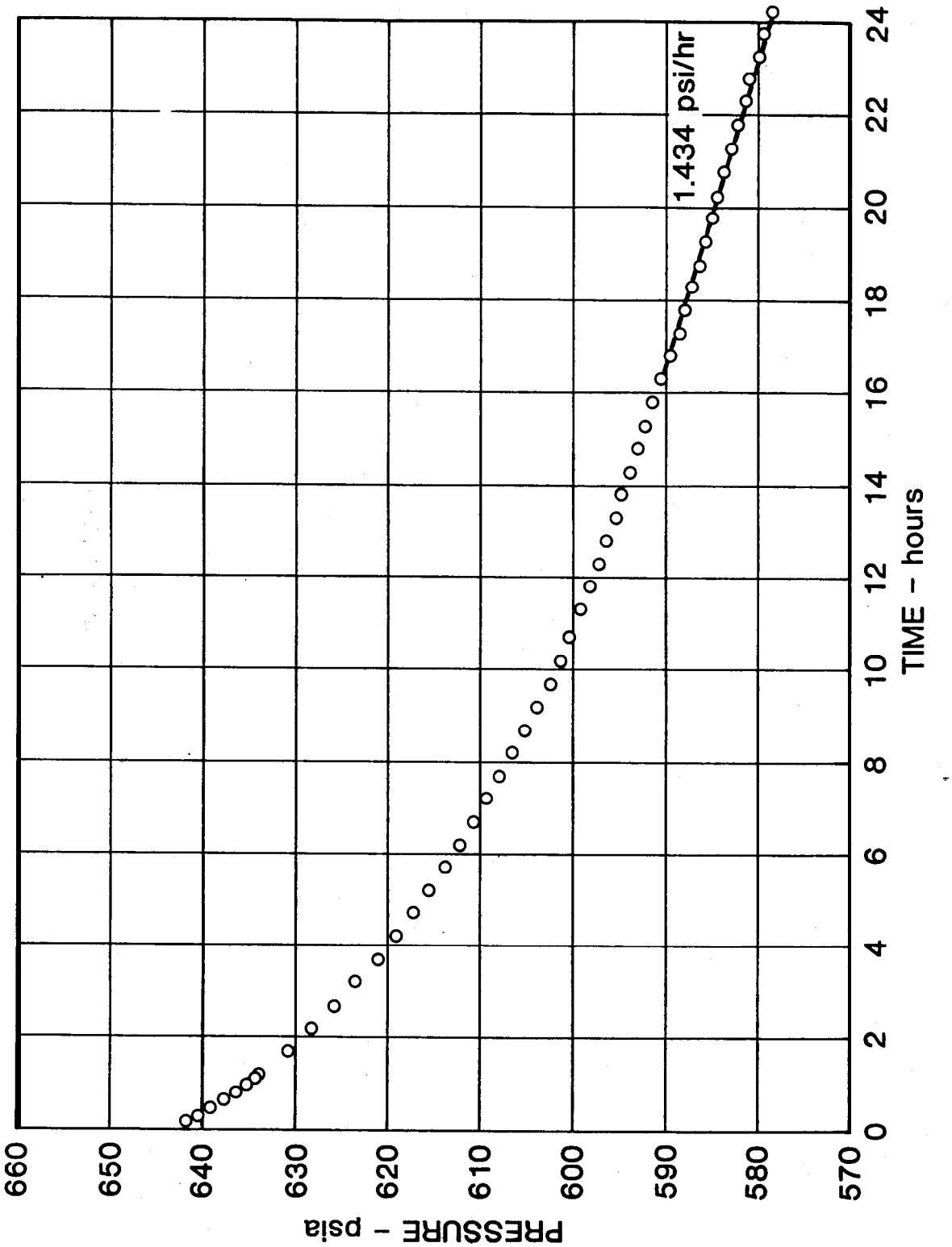


FIGURE 13 - WELL 105B

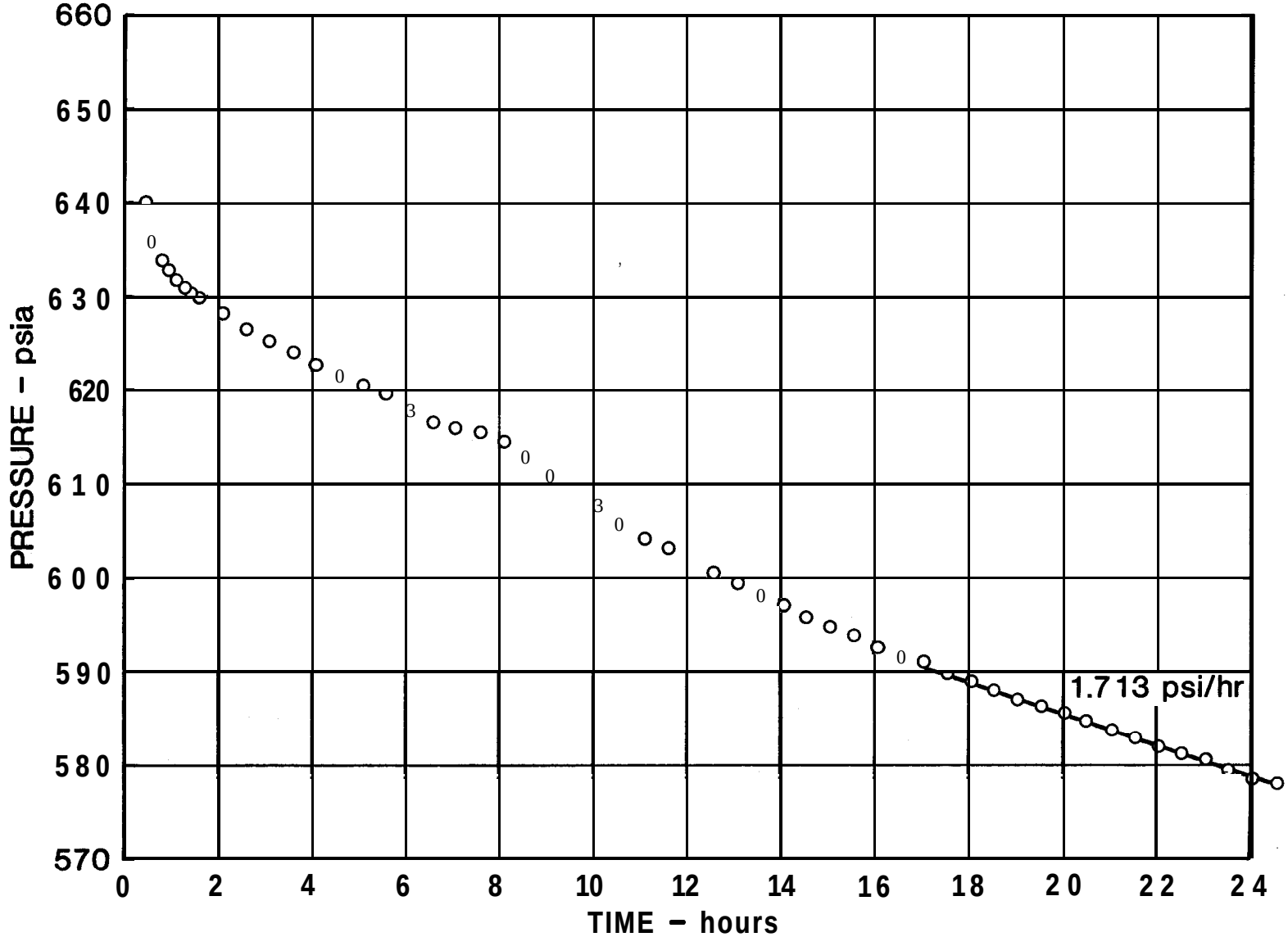


FIGURE 14 - WELL 105C

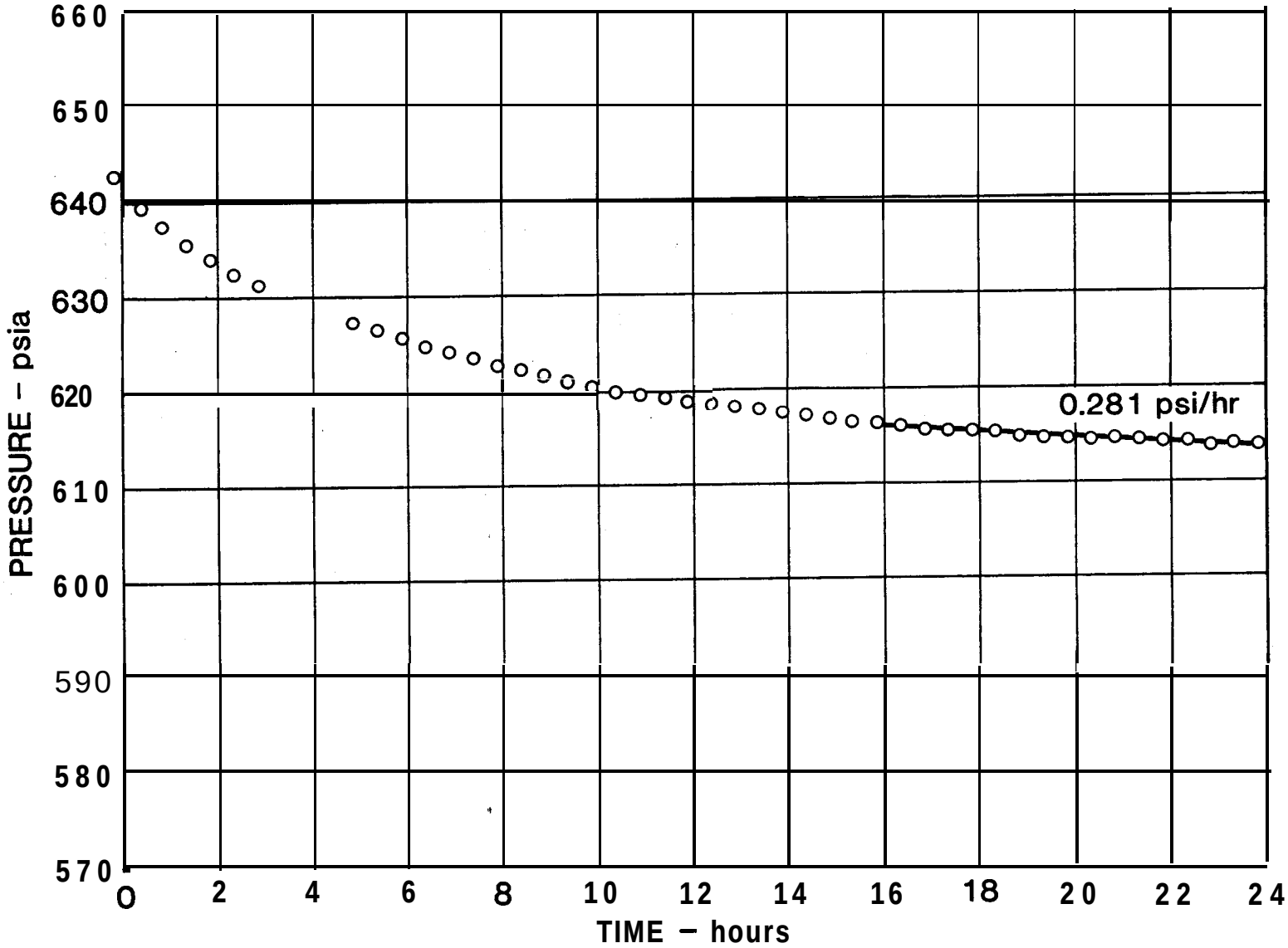


FIGURE 15 - WELL 106A

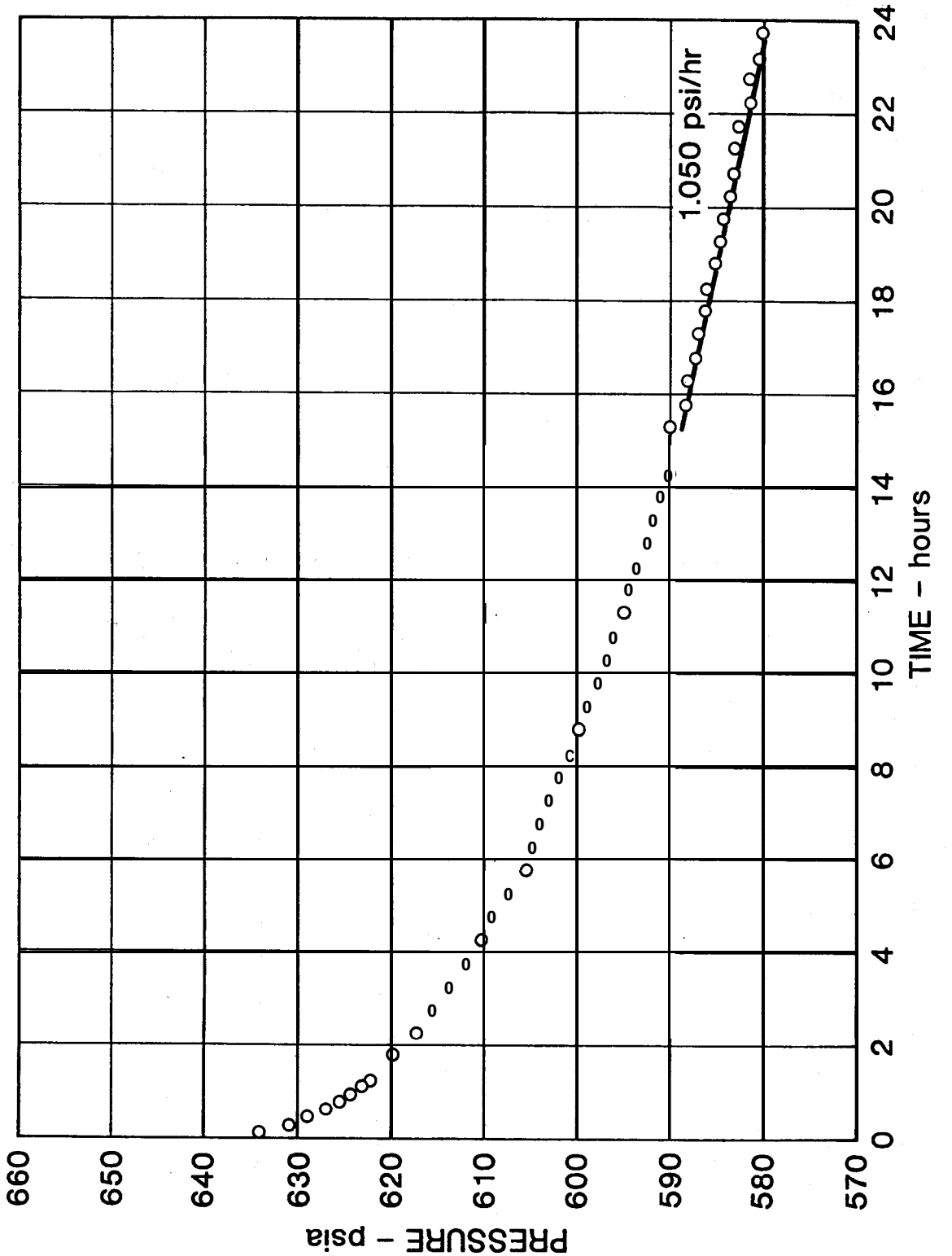


FIGURE 16 - WELL 106B

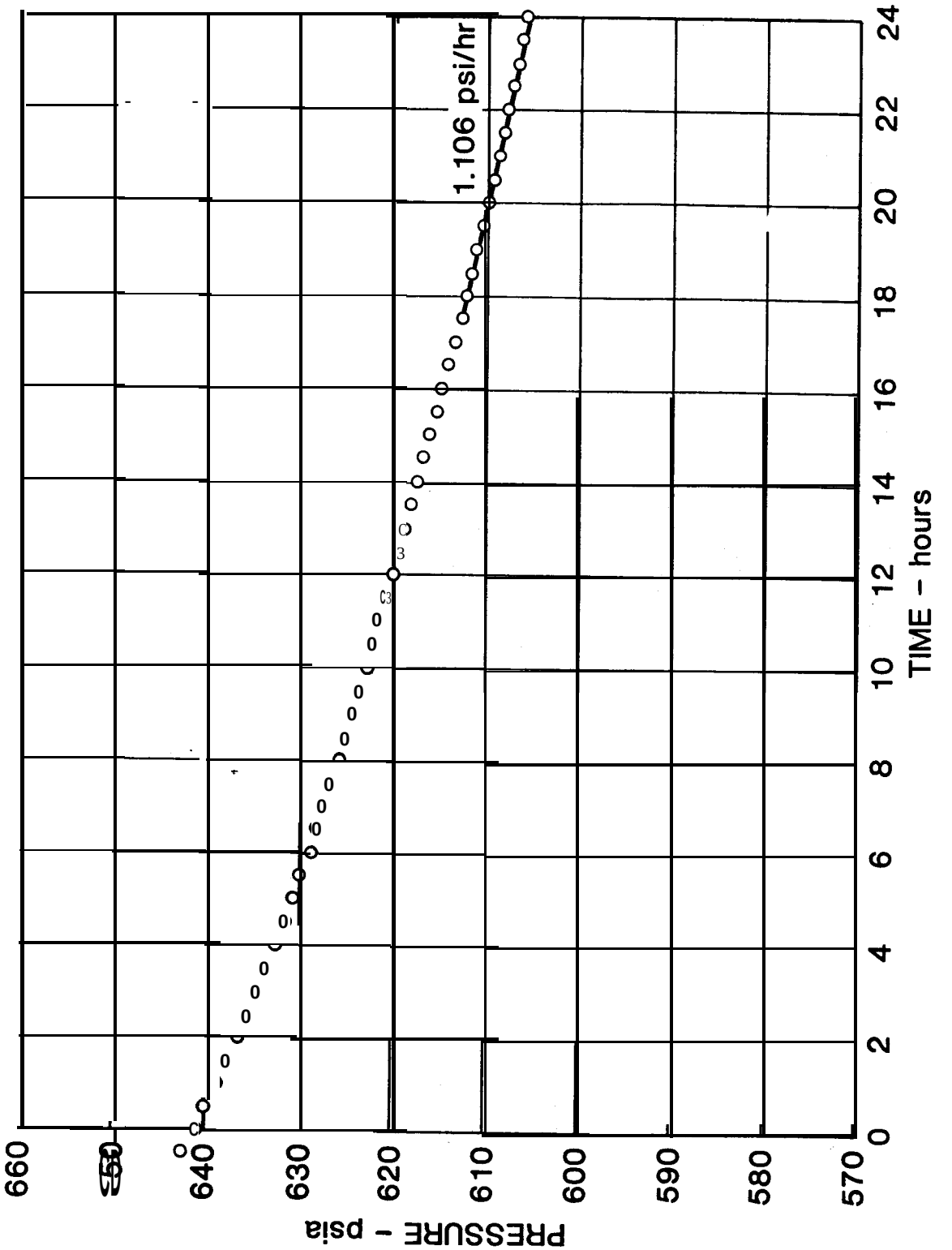


FIGURE 17 - NELL 106B

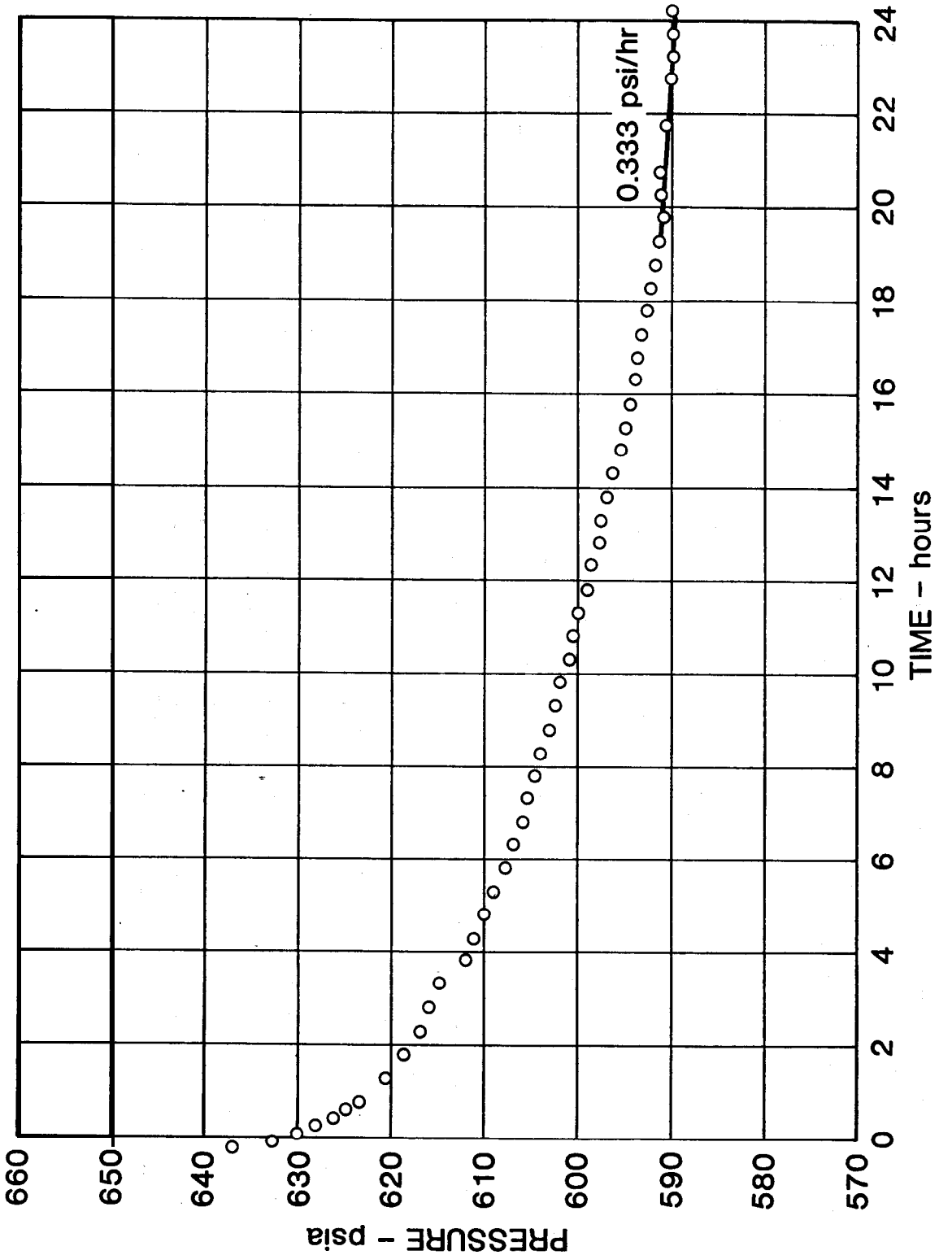


FIGURE 18-WELL 106C

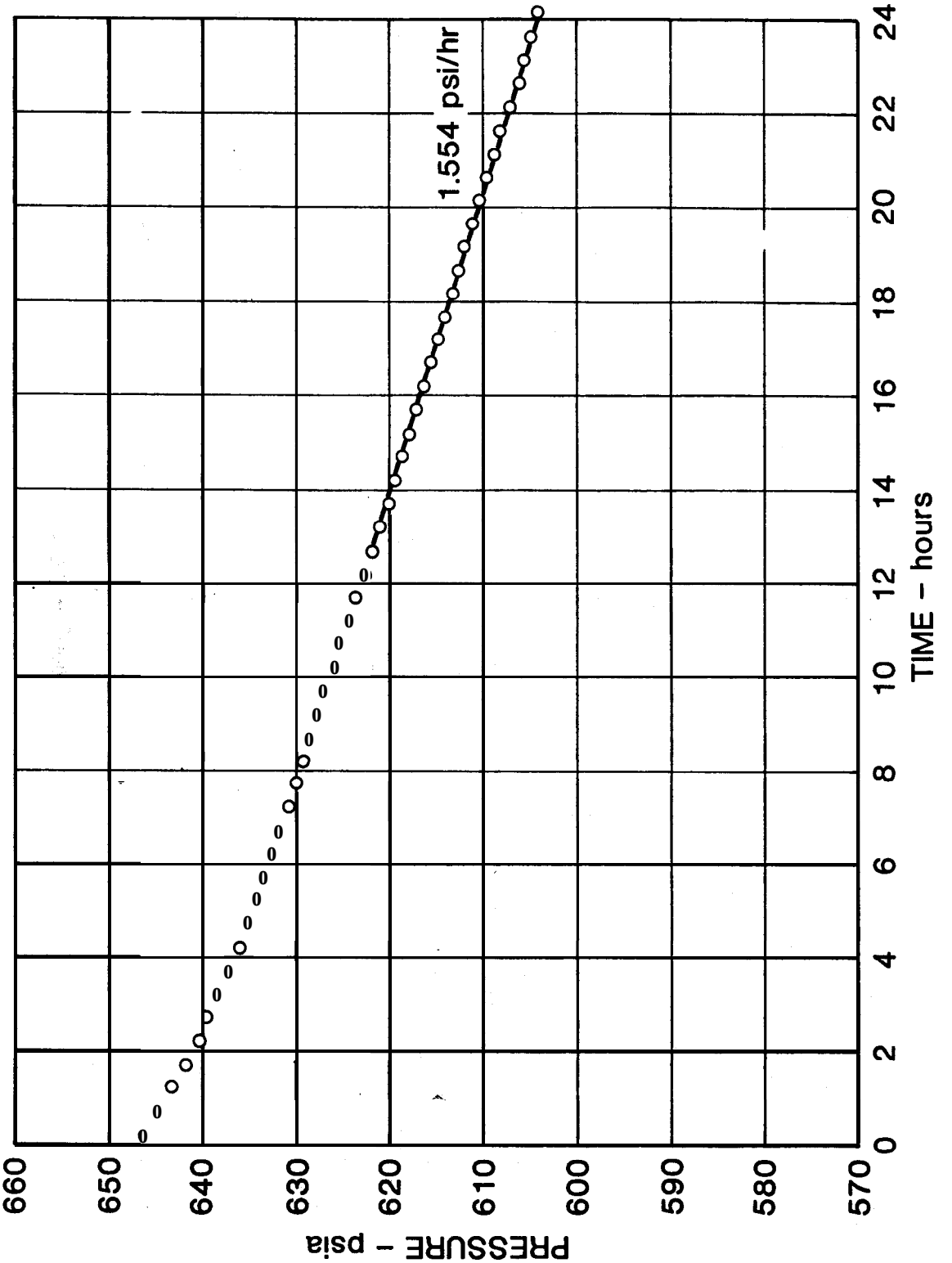


FIGURE 19 - WELL 107A

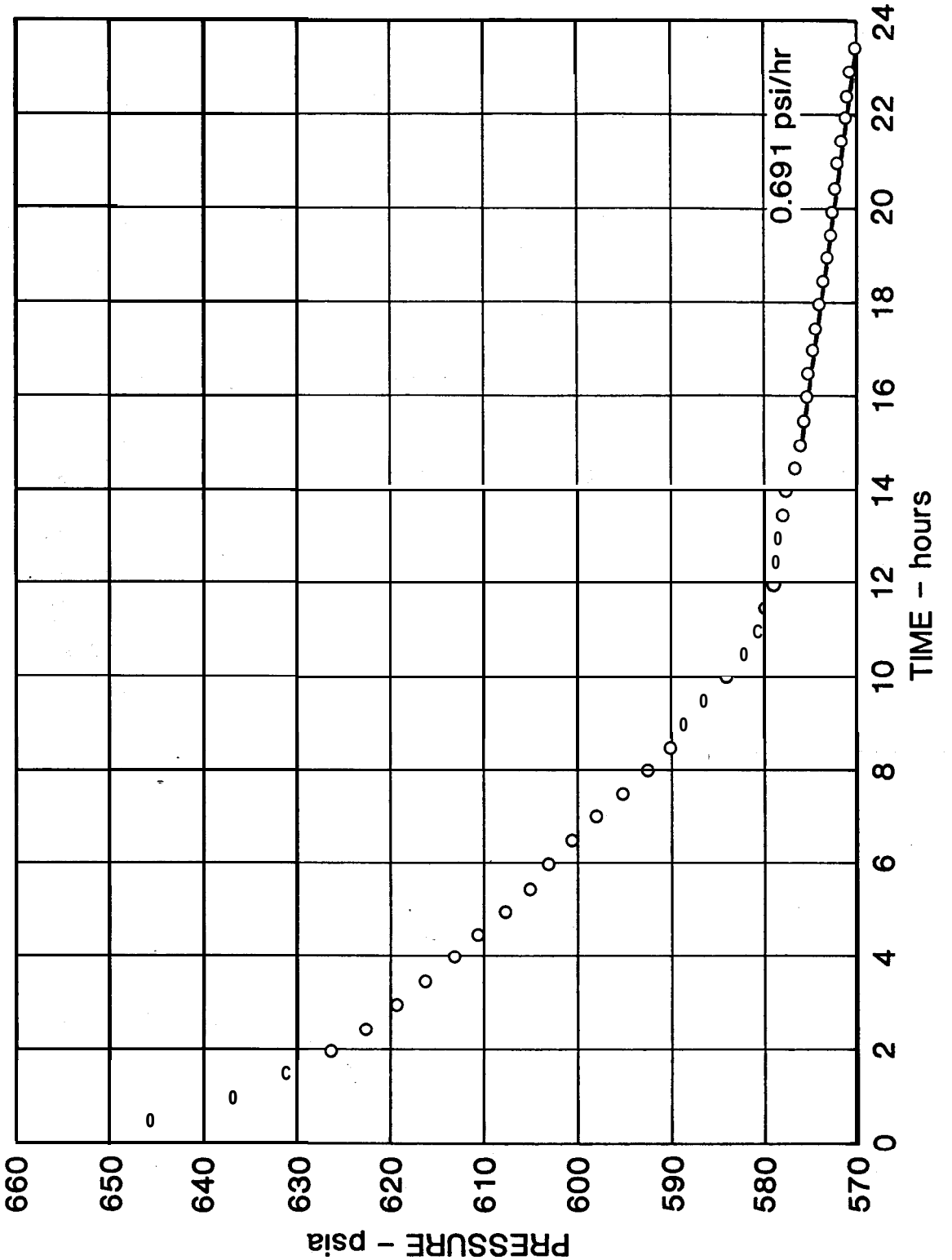


FIGURE 20 - WELL 107B

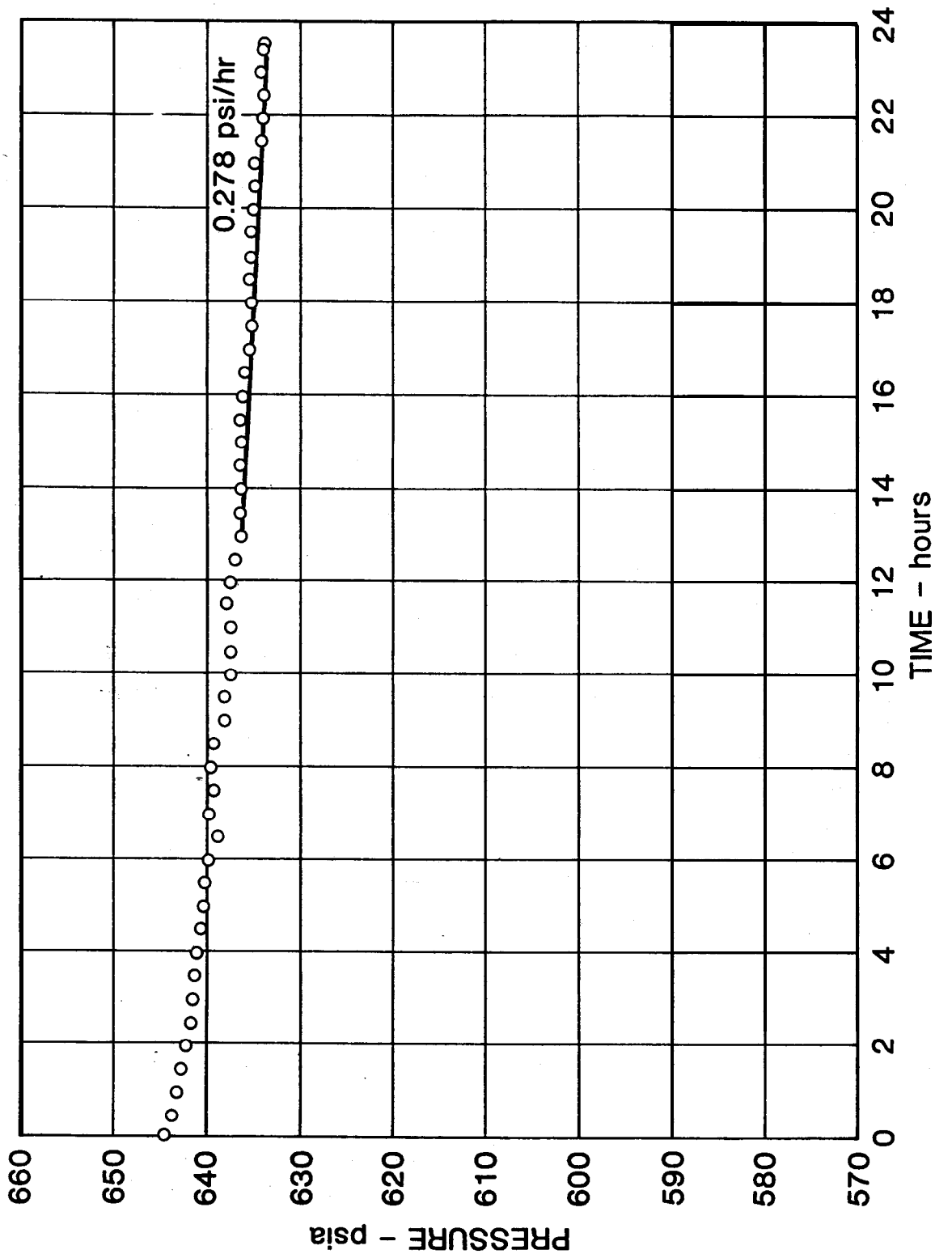


FIGURE 21 -WELL 107C

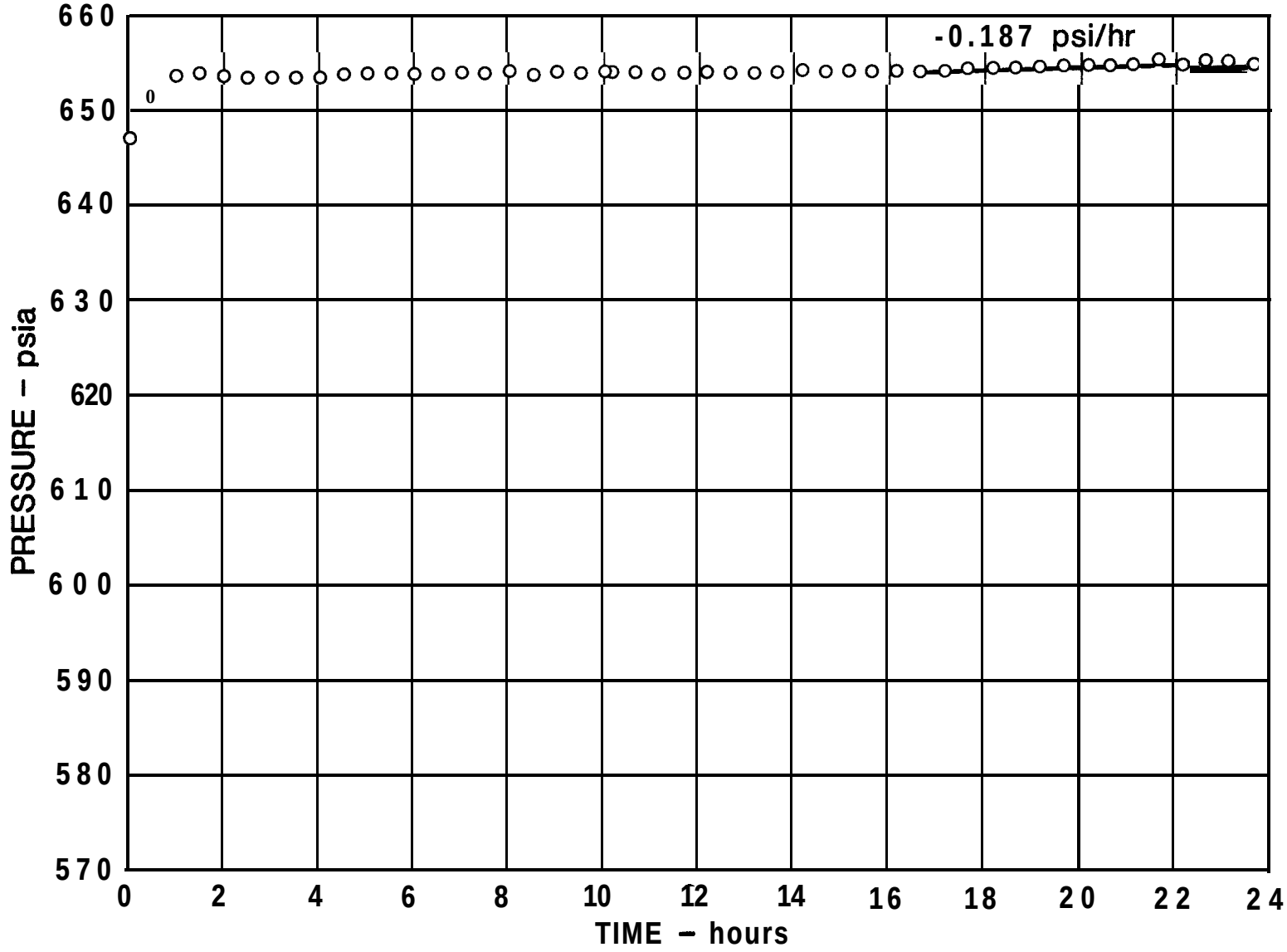
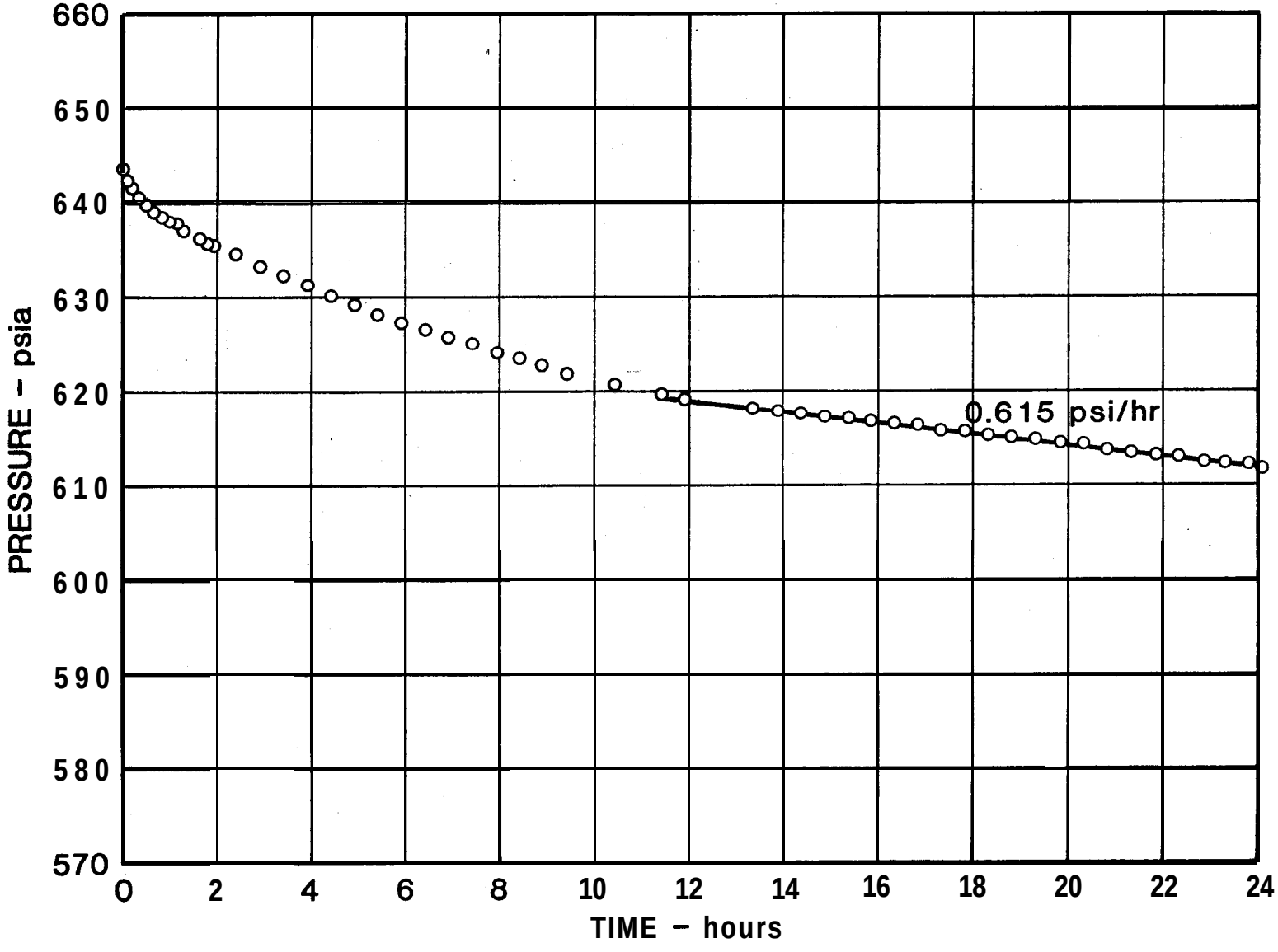
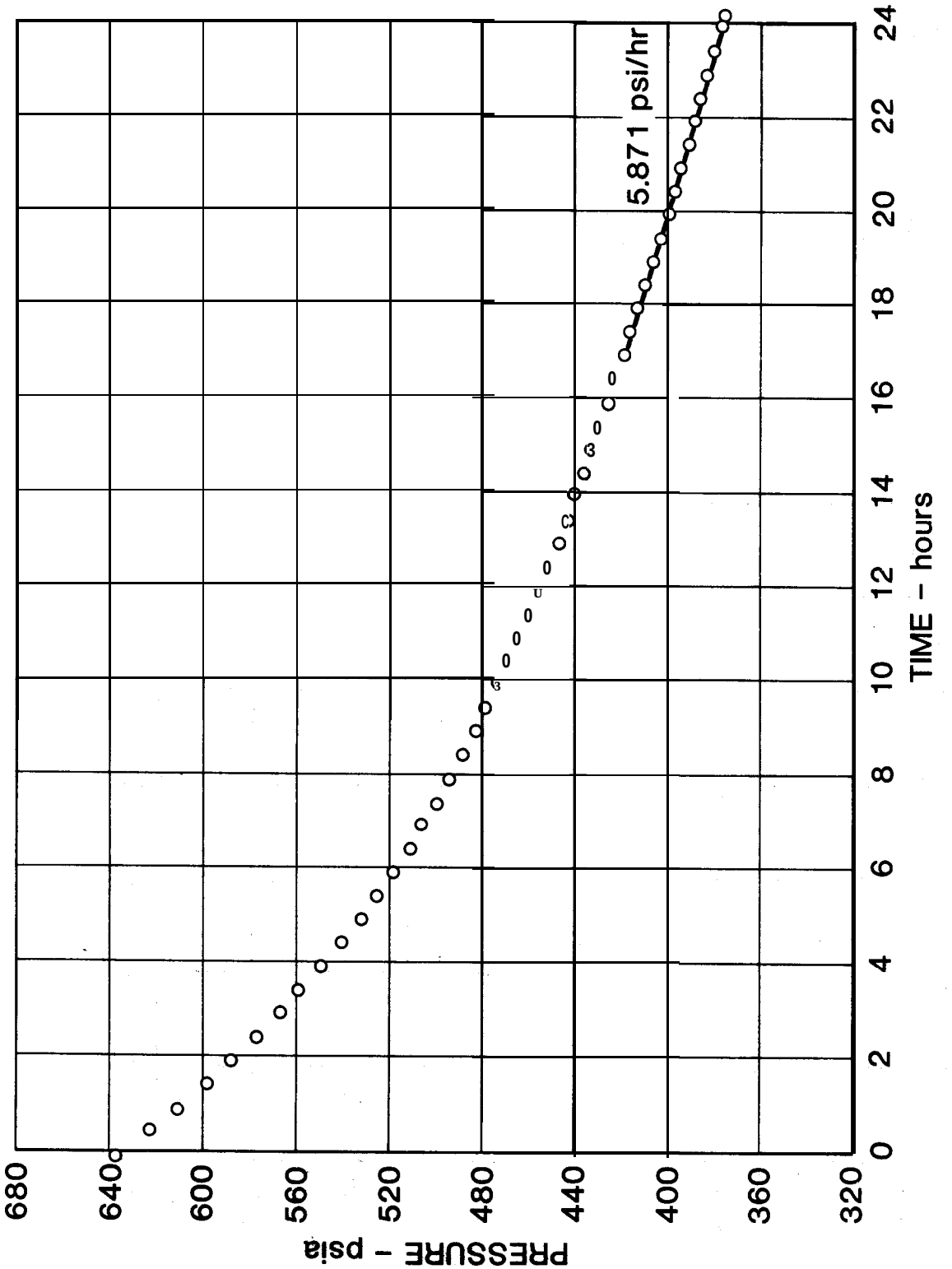


FIGURE 22 WELL 108A



GURE 23 - WELL 108B



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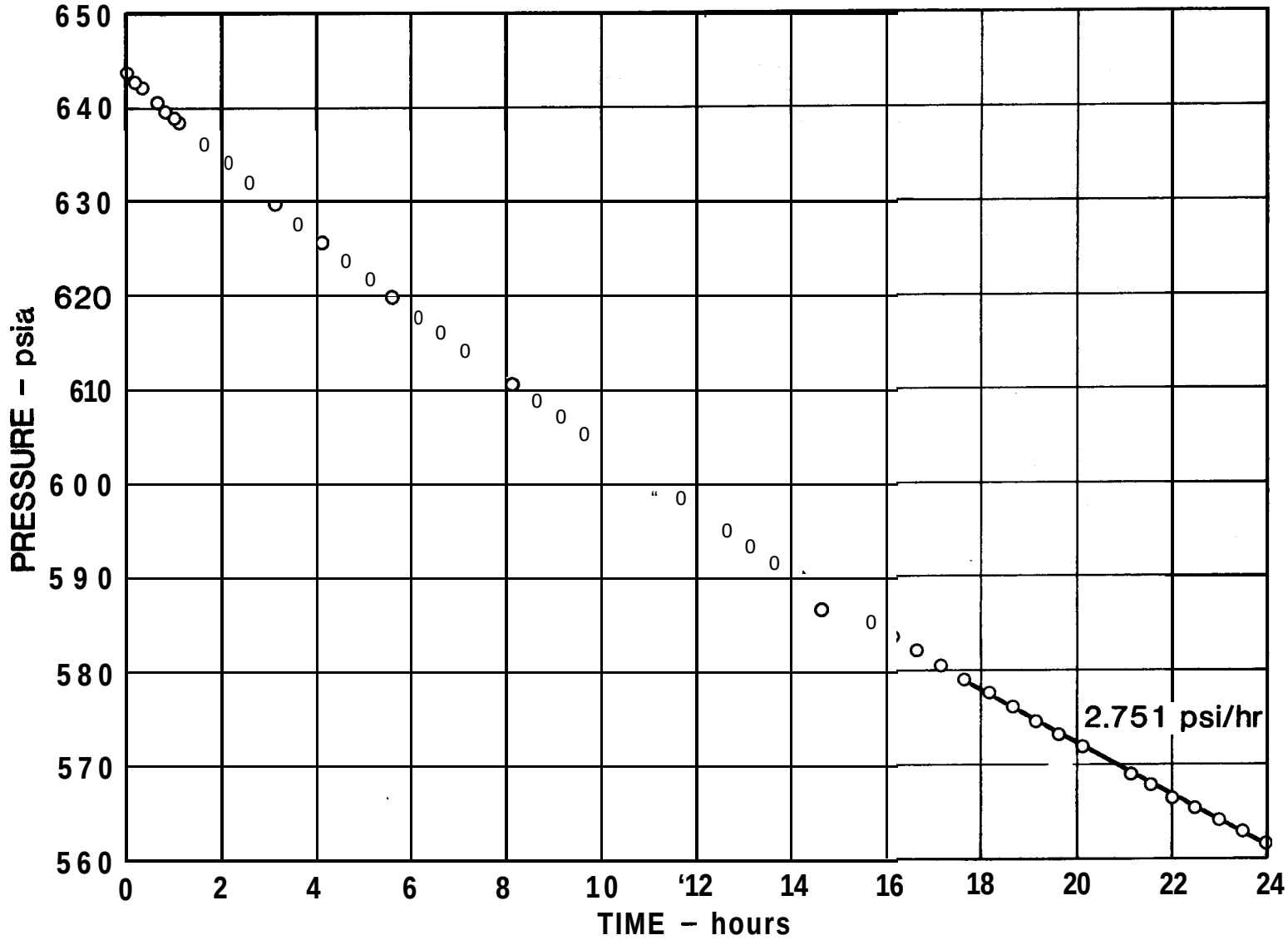

FIGURE 25 - WELL 109A

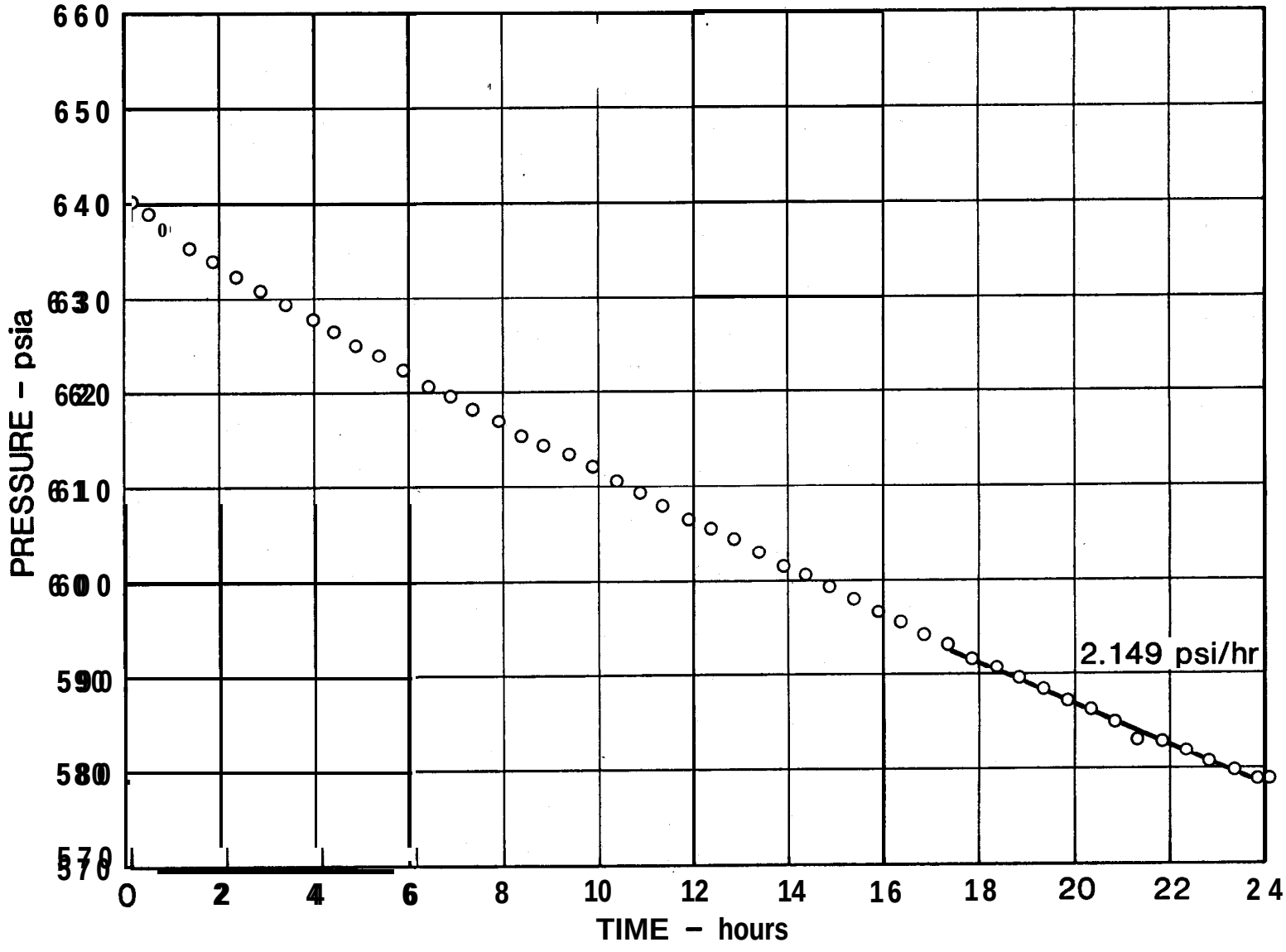

FIGURE 26 WELL 109A

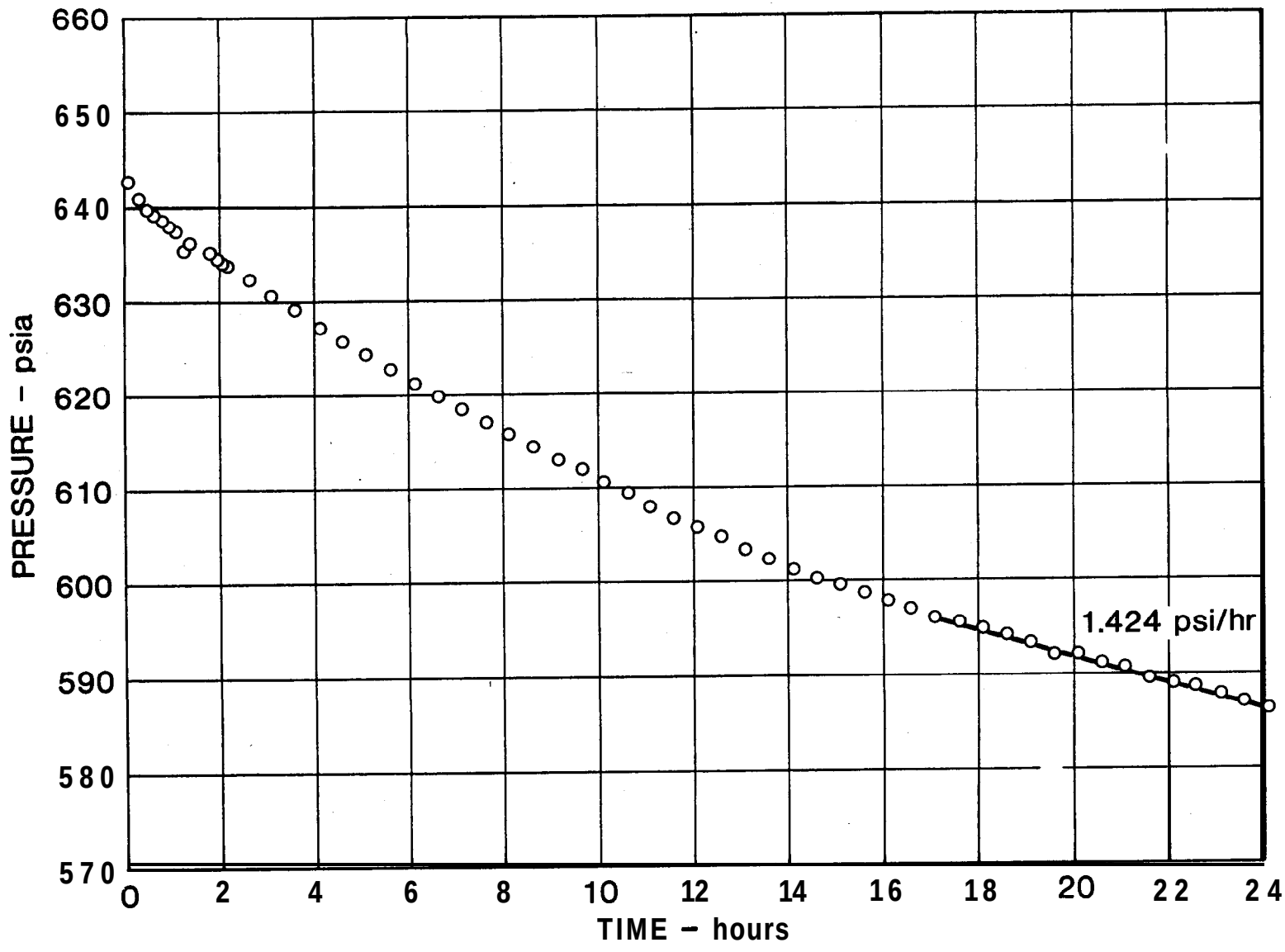

FIGURE 27 - WELL 109A

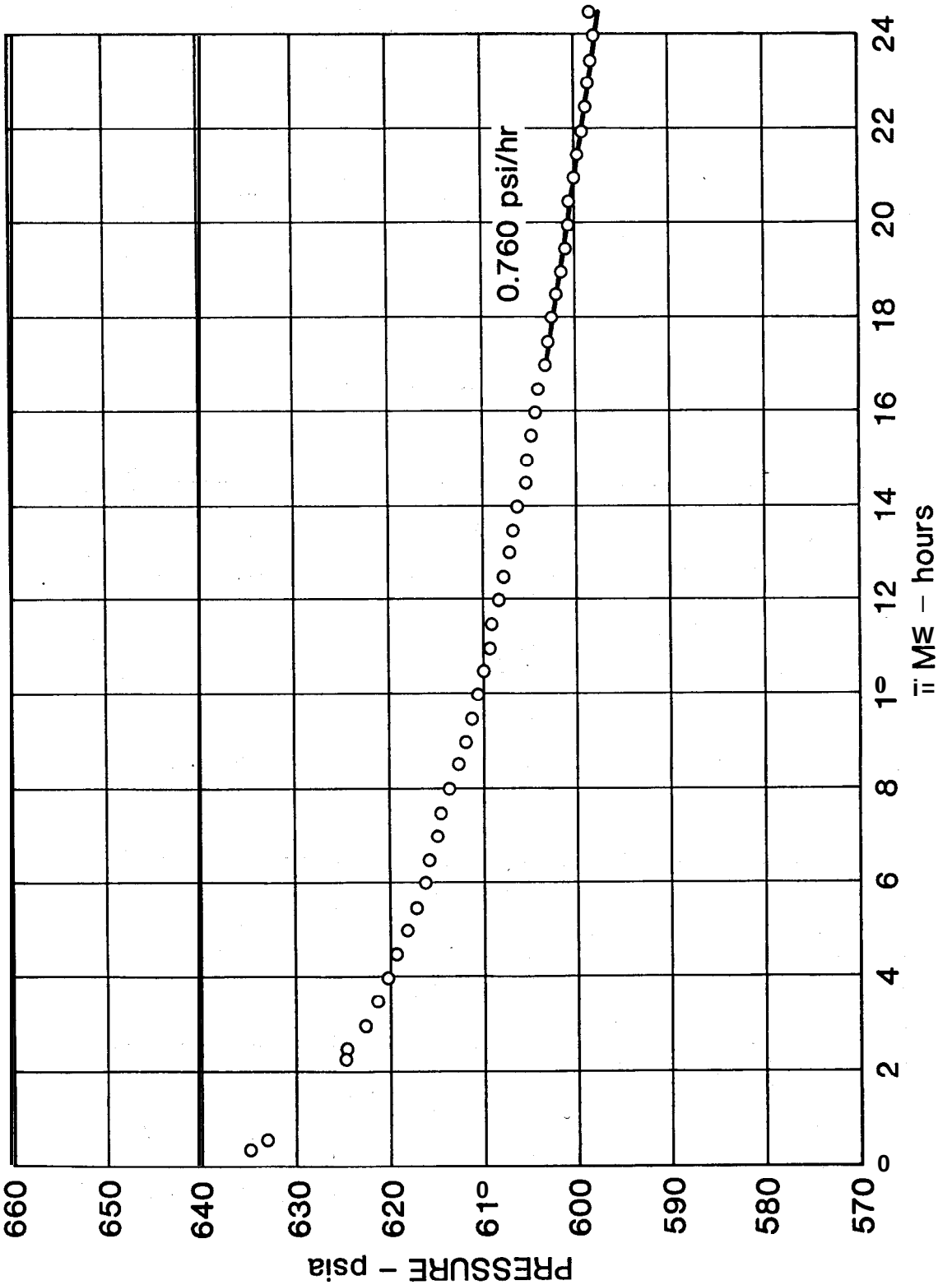

FIGURE 28 - WELL109B

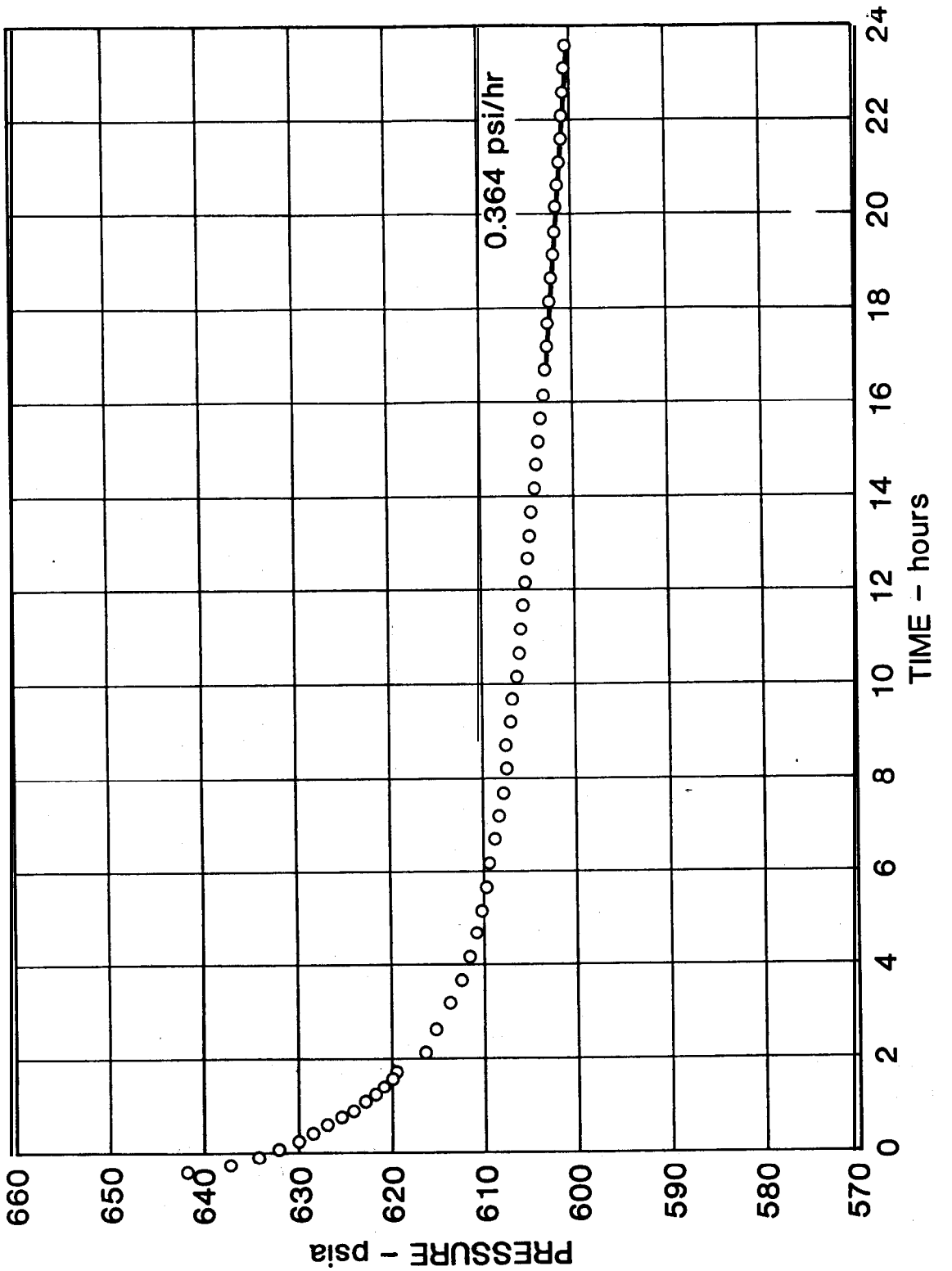

FIGURE 29 - WELL 109C

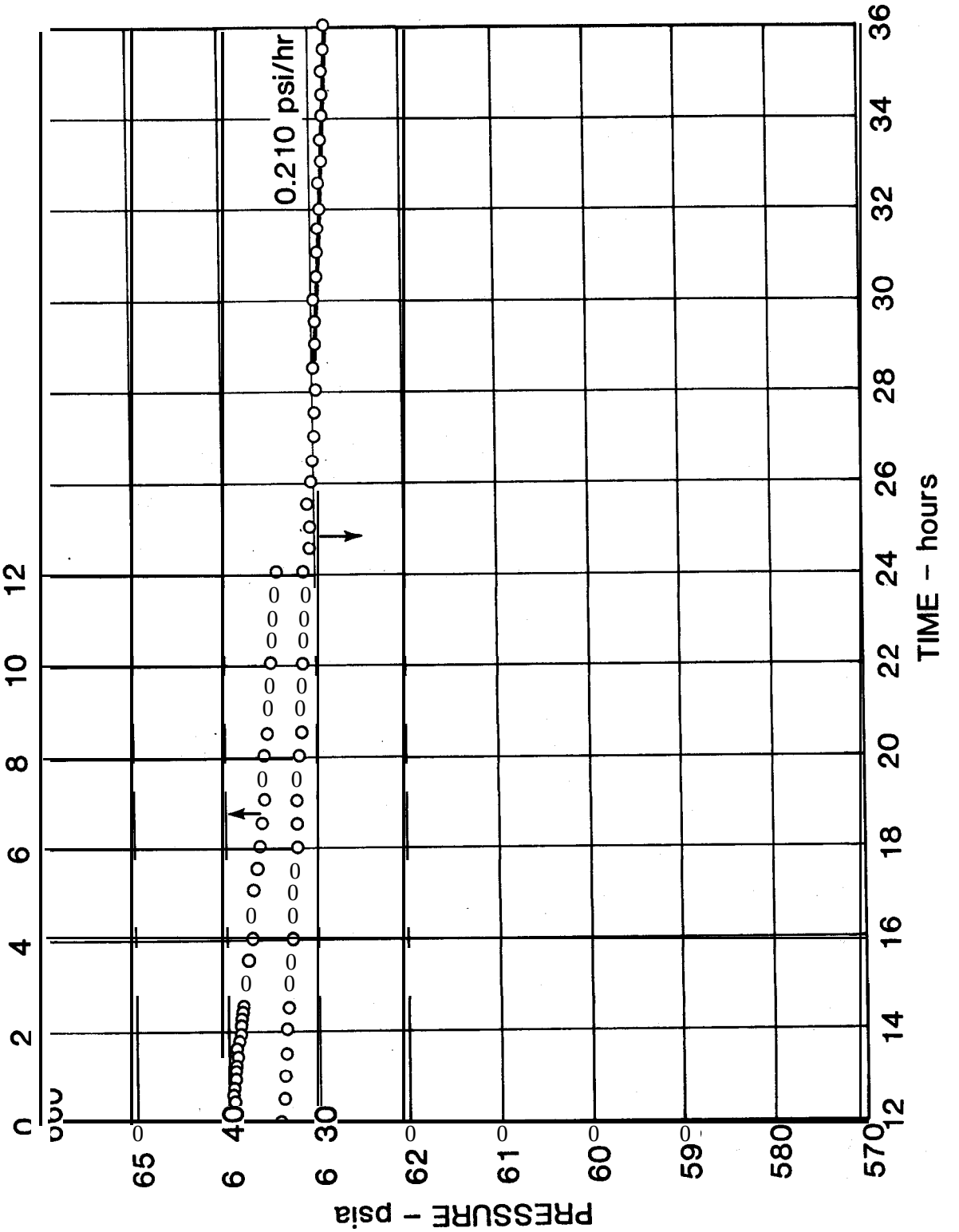

FIGURE 30 - WELL 109C

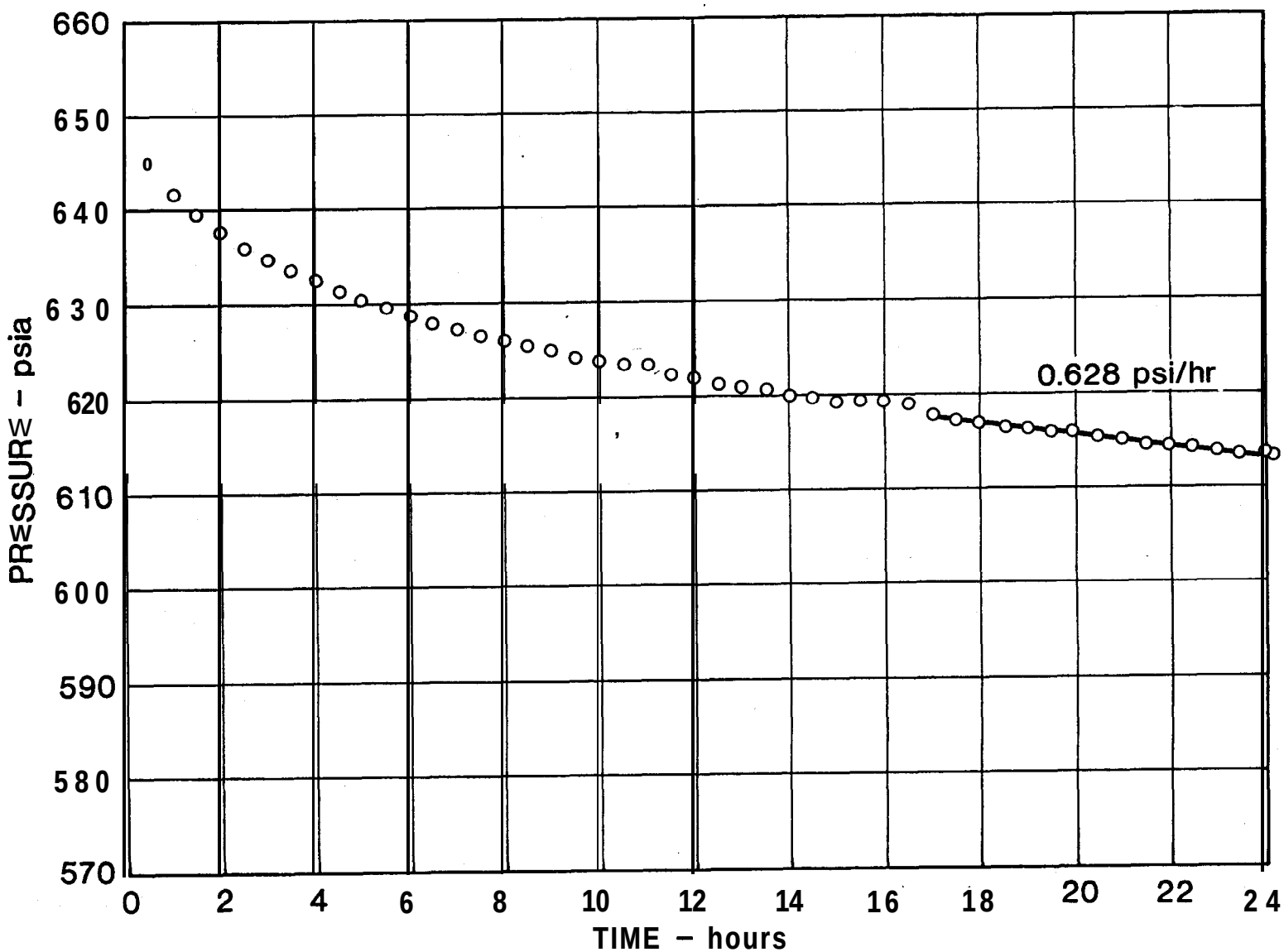

FIGURE 31 - WELL 110A

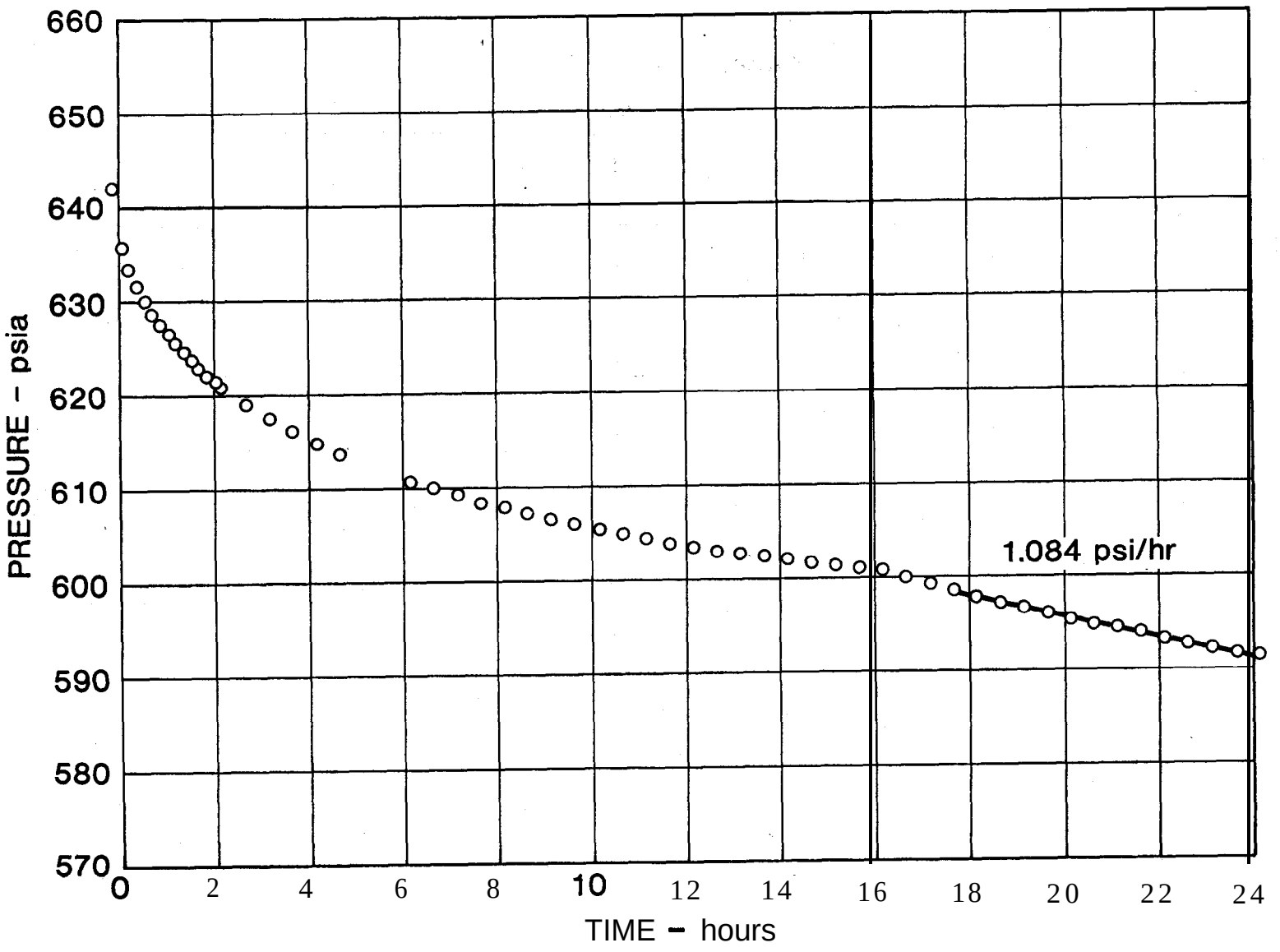

FIGURE 32 WELL 110B

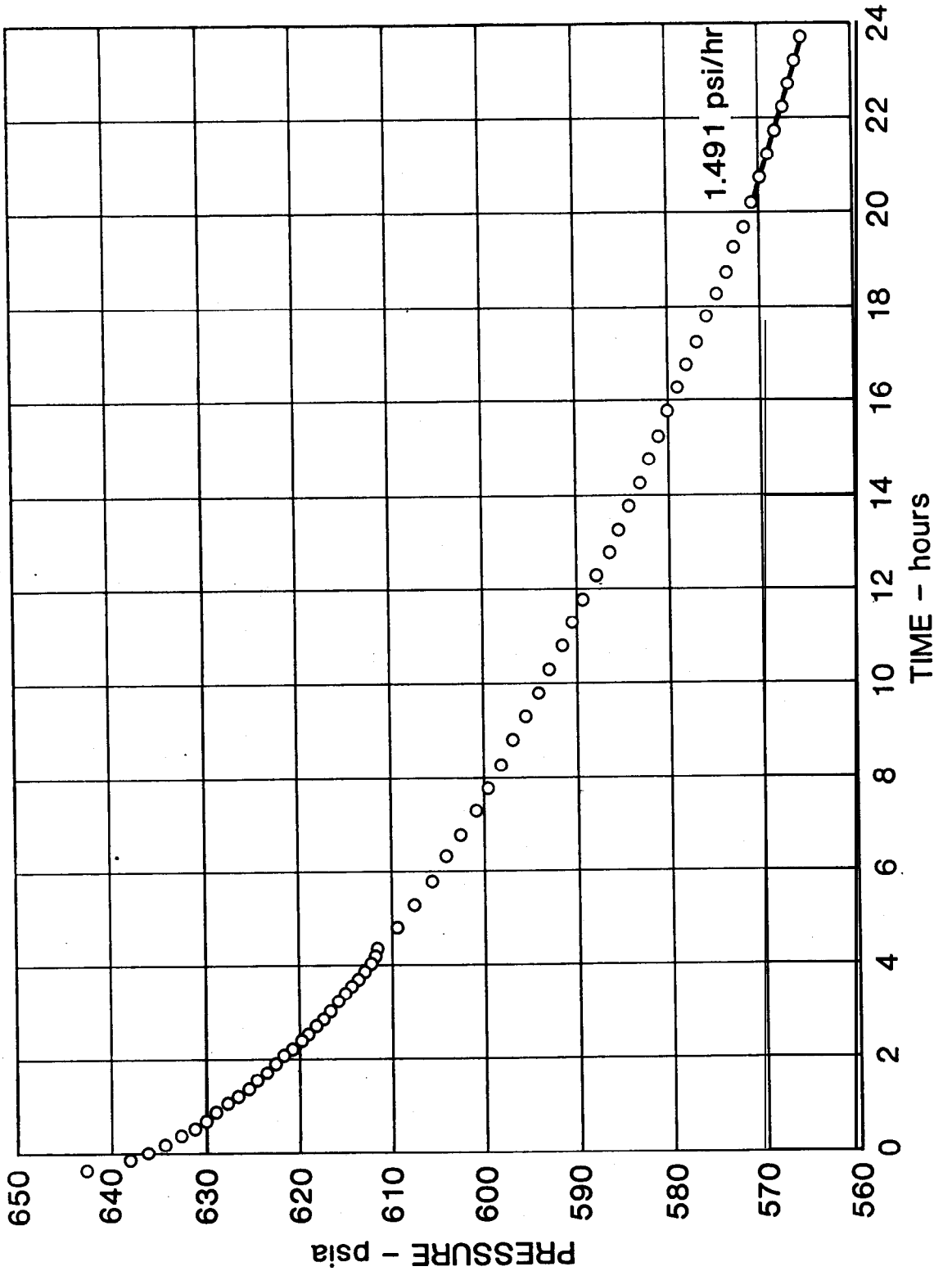

FIGURE 33 -WELL110C

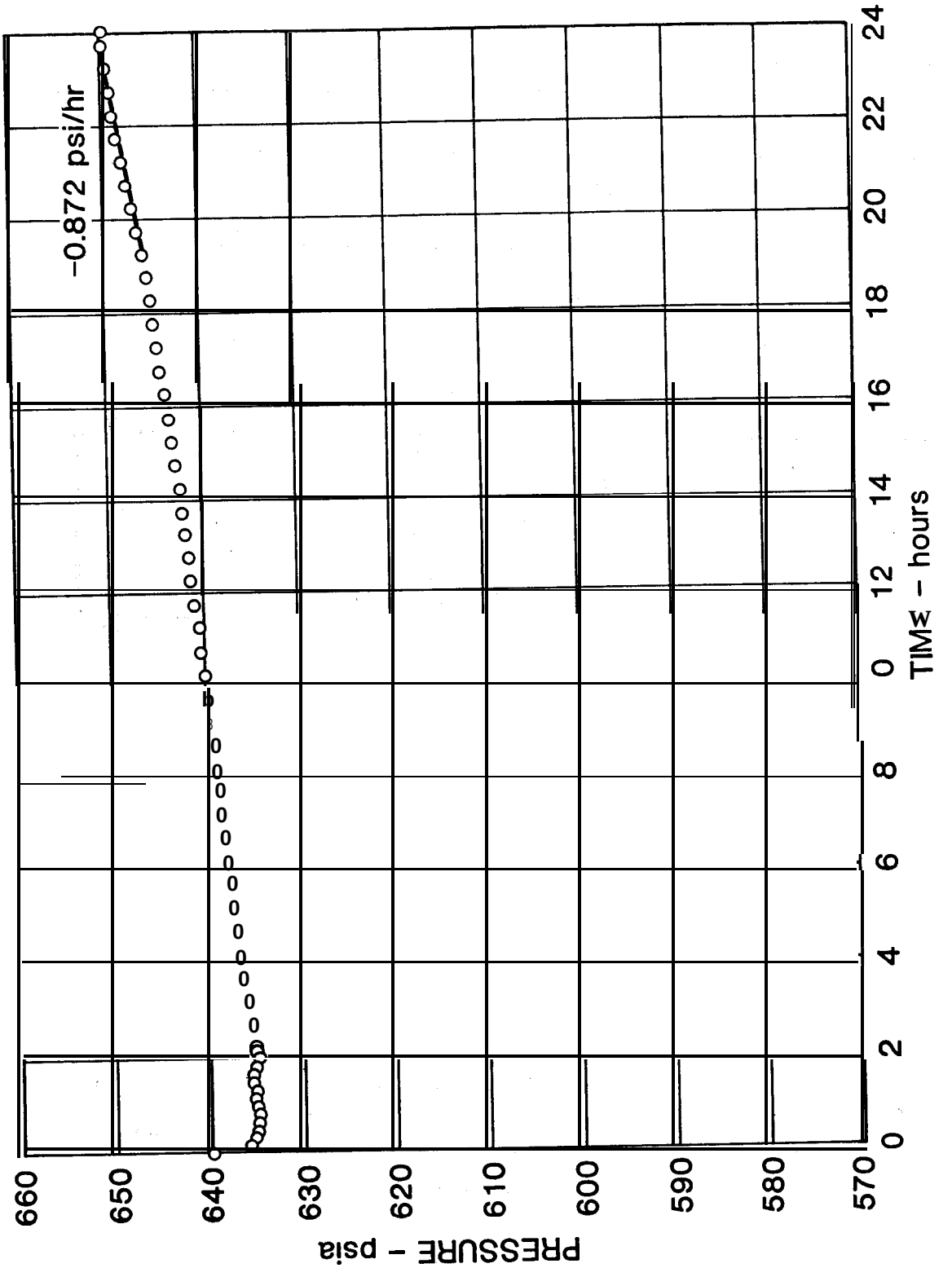

FIGURE 34 - WELL 111A

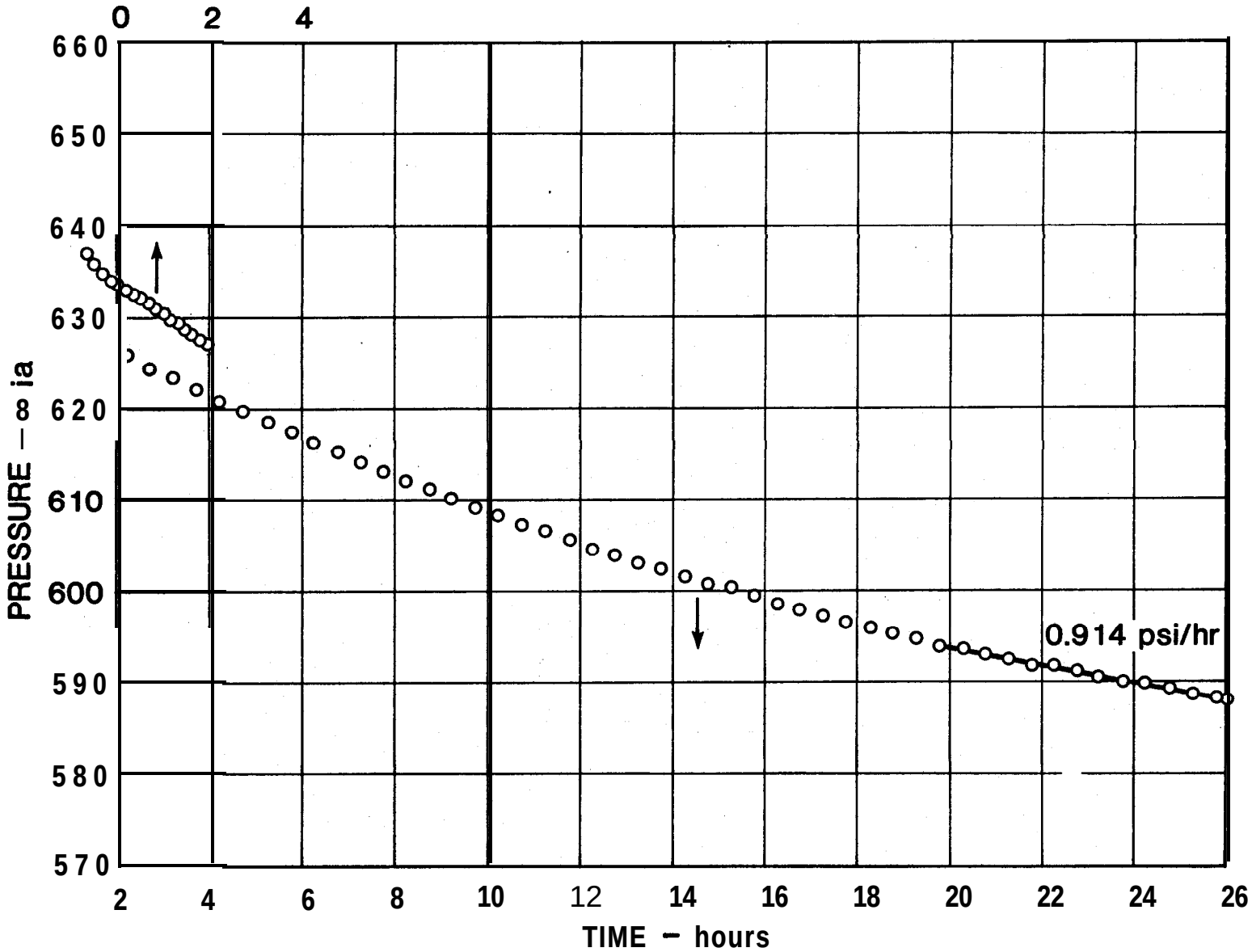

FIGURE 35 - WELL 111D

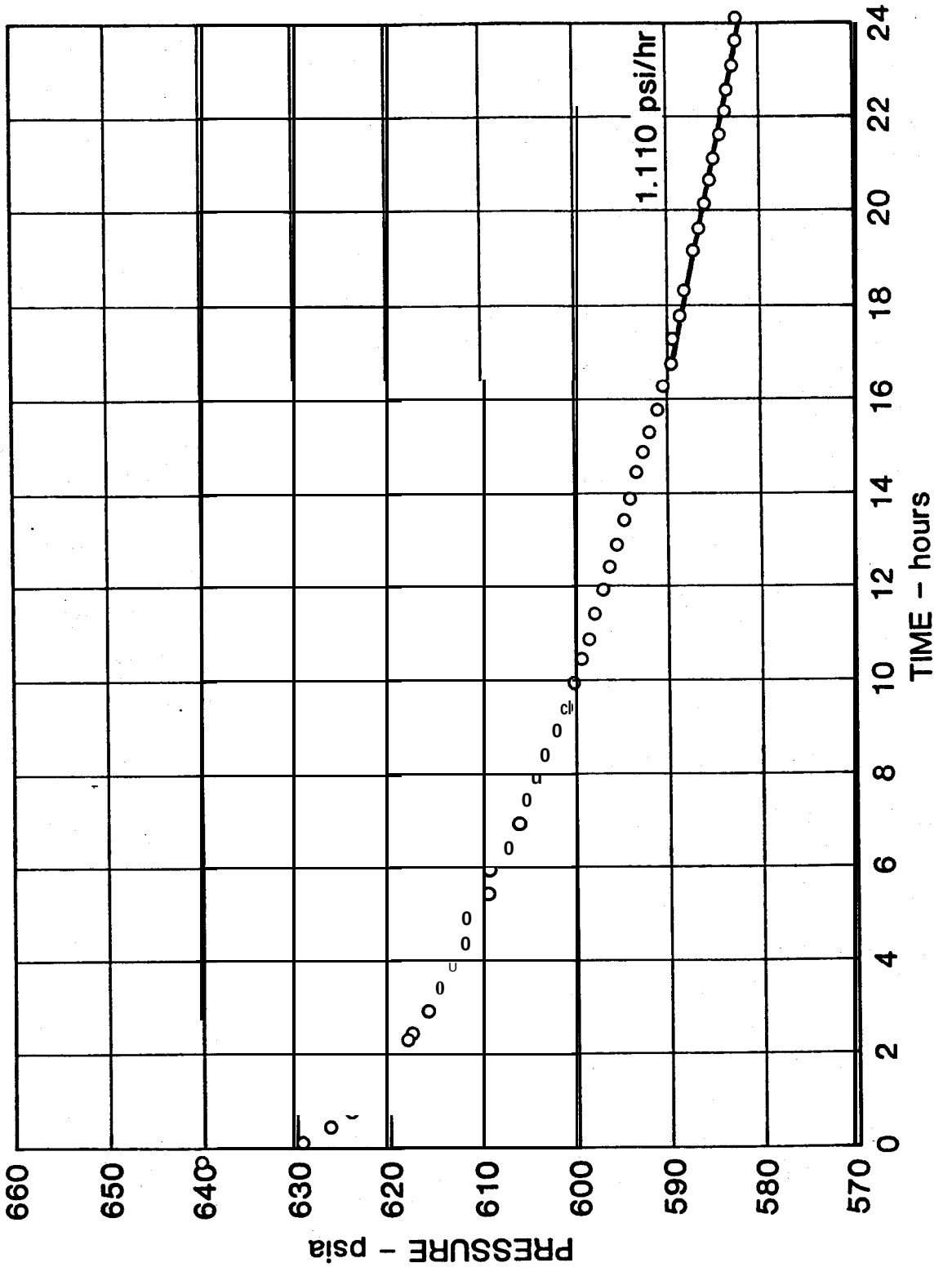

FIGURE 36 -WELL112A

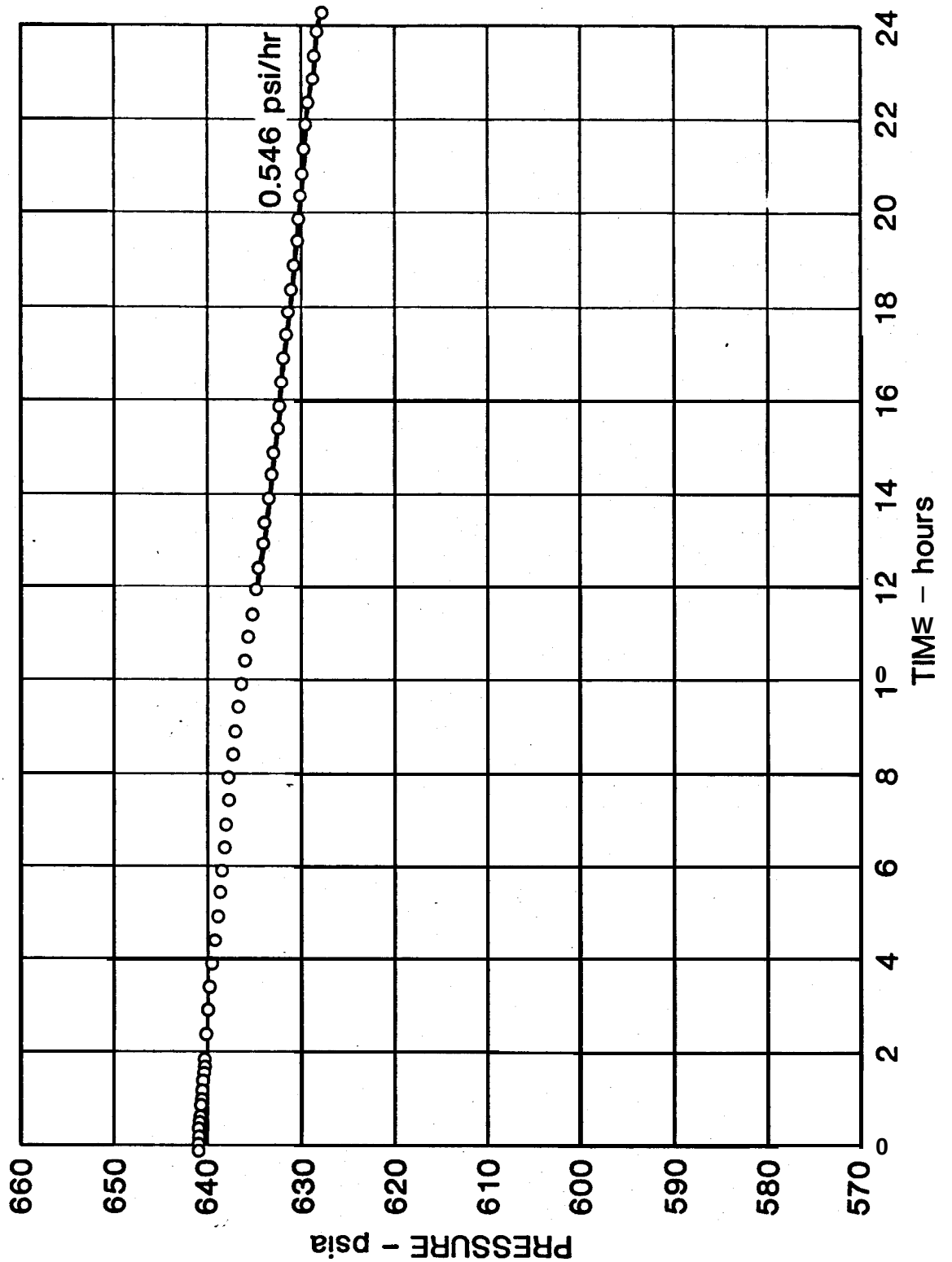

FIGURE 37 - WELL 112C

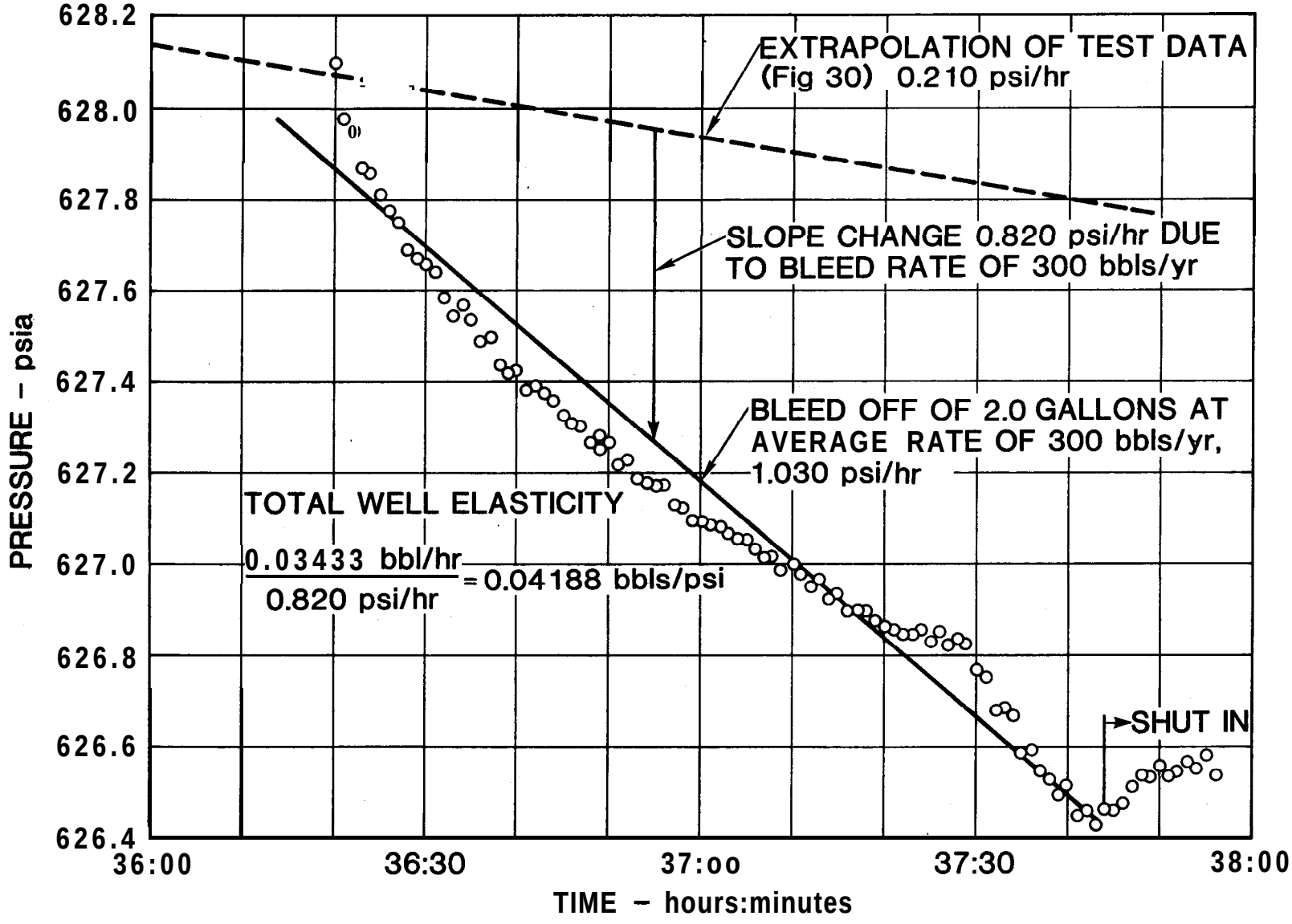

FIGURE 38 PRESSURE TIME HISTORY DURING SLOW BLEED OFF OF WELL 109C

Distribution:
US Department of Energy
Strategic Petroleum Reserve
Project Management Office
900 Commerce Road East
New Orleans, LA 70123
Attn: E. E. Chapple (5)
C. C. Johnson
G. A. Stafford
C. L. Steinkamp

US Department of Energy
Strategic Petroleum Reserve
1000 Independence Avenue SW
Washington, DC 20585
Attn: L. Pettis
R. Smith

Aerospace Corporation
880 Commerce Road West, Suite 300
New Orleans, LA 70123
Attn: K. Henrie
R. Merkle

Aerospace Corporation
P. 0. Box 92957
Los Angeles, CA 90009
Attn: G. F. Kuncir

Dravo Utility Constructors, Inc.
850 S. Clearview Pkwy.
New Orleans, LA 70123
Attn: R. Heaney (2)

Jacobs/D'Appolonia Engineers
6226 Jefferson Hwy., Suite B
New Orleans, LA 70123
Attn: H. Kubicek
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4000 A. Narath
4500 E. H. Beckner
4540 M. L. Kramm
4543 J. F. Ney
4543 K. L. Goin (5)
3141 L. J. Erickson (5)
3151 W. L. Garner (3)
3154-3 J. Hernandez (25)
For: DOE/TIC (Unlimited Release)
8214 M. A. Pound
4543 File