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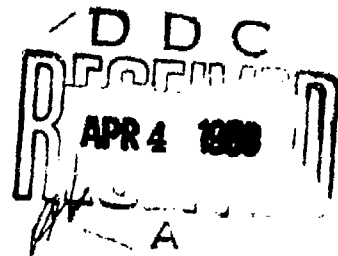
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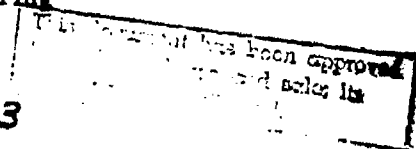
INITIAL FLUID INJECTION CHARACTERISTICS
PRE-CAMBRIAN INTERVAL
PRESSURE INJECTION DISPOSAL WELL
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Prepared for
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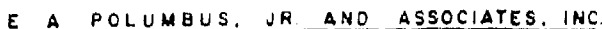
Signed and Sealed

E. A. Pulmbus, Jr.

Released March 15, 1962

ROCKY MOUNTAIN ARSENAL

LEGEND



E A POLUMBUS, JR. AND ASSOCIATES, INC.

TABLE OF CONTENTS

	<u>Page No.</u>
I. Introduction	1
II. Objectives of Initial Injection Tests	4
III. Results of Initial Injection Tests	6
IV. Conclusions	11
V. Recommendations Concerning the Continuous Injection Period	12

TABLES

	<u>Table No.</u>
<u>Drill Stem Tests</u>	
DST No. 13	1
DST No. 14	2
<u>Injection Tests Through 4 1/2-inch Drill Pipe</u>	
Test No. I	3
Test No. II	4
Test No. III	5
Test No. IV	6
Test No. V	7
<u>Reservoir Fluid Sampling</u>	
Chloride Content vs. Cumulative Volume Pumped	8
<u>Injection Tests Through 5 1/2-inch Tubing</u>	
Test No. 1	9
Test No. 2	10
Test No. 3	11
Test No. 4	12
<u>Summary of Pressure Test Results</u>	13
<u>Core Description</u>	
Core No. 28	14

FIGURES

	<u>Figure No.</u>
Casing and Hole Details	1
Graphical Representation of Formation Evaluation Data	2
Pre-Fountain Geologic Column	3
Pressure and Cumulative Volume Histogram	4
Injection Tests Through 4 1/2-inch Drill Pipe of Interval 11,975 feet - 12,045 feet	5-6
Produced Water vs. Chloride Content	7
Injection Tests Through 5 1/2-inch Tubing of Interval 11,975 feet - 12,045 feet	8-11
Composite Graph Injection Rates vs. Injection Pressures Pre-Cambrian Interval 11,975 feet - 12,045 feet	12

INTRODUCTION

The accumulating waste effluent from chemical plants at the Rocky Mountain Arsenal, Denver, Colorado presented the problem of finding a permanent solution for disposal in such a manner as to protect shallow fresh water aquifers from contamination. The Chemical Corps of the United States Army considered various methods for handling these waste fluids and decided upon the drilling of a deep pressure injection disposal well in the search for a subsurface formation reservoir capable of accepting fluid at rates up to 800 gallons per minute under a maximum of 2,000 psi surface injection pressure for a number of years.

The site selected for the well on the Arsenal grounds was near storage Pond F in Section 26, Township 2 South, Range 67 West, Adams County, Colorado. The responsibility for designing and drilling the well was vested in the Department of the Army, U. S. Army Engineer District, Omaha, Corps of Engineers. The petroleum engineering consulting firm of E. A. Polumbus, Jr., and Associates, Inc., was engaged to design the drilling program, manage the drilling and testing, provide engineering and geological services, and conduct the initial injection tests.

Reference to the following two reports prepared by Polumbus and Associates will provide adequate background details concerning the design and drilling of the injection well:

"Final Design Analysis, Pressure Injection Disposal Well,
Rocky Mountain Arsenal (July 5, 1960)"

"Final Report on Drilling, Rocky Mountain Arsenal Pressure
Injection Disposal Well (November 30, 1961)"

The latter report presents the drilling history and details of the formation evaluation program followed in the disposal well which was spudded March 10, 1961 and penetrated into Pre-Cambrian granite to a final total depth of 12,045 feet.

Prior to drilling the injection well eight zones were considered to offer potentialities as injection reservoirs. These consisted of the Hygiene, Codel, "J", Dakota, and Lakota sandstones, the Morrison, Lyons and Fountain formations. Two of these now appear to offer potential injection reservoirs; namely, fractured intervals of the Lyons and Fountain formations. Additionally, the Pre-Cambrian granite hornblende gneiss (Figure 3) containing fractures within the interval 11,975 to 12,045 feet constituted an initially unsuspected potential injection reservoir. The core No. 28 (Table 14), drill stem test Nos. 13 and 14 (Tables 1 and 2 and Figure 2), and the behavior of lost circulation encountered while penetrating this section indicated a zone of sufficient merit to warrant completing the well with 5 1/2-inch liner cemented at 11,975 feet (Figure 1) and proceeding first to evaluate this open hole interval for an injection reservoir.

This report, "Initial Fluid Injection Characteristics, Pre-Cambrian Interval, Rocky Mountain Arsenal Pressure Injection Disposal Well,"

constitutes a sequel to the Final Report on Drilling. It presents the results of initial injection tests using City of Denver potable water to evaluate the Pre-Cambrian interval 11,975 feet to total depth 12,045 feet for an injection reservoir.

OBJECTIVES OF INITIAL INJECTION TESTS

Predictions of injection performance may be made on zones of interest by conducting drill stem tests as drilling proceeds and without the necessity of completing the well. From the results of these tests, decisions may be made whether or not to conduct further tests. In the Rocky Mountain Arsenal Disposal well, every effort was extended to thoroughly examine promising zones whenever conditions were permissible. Such a zone exists in the Pre-Cambrian interval 11,975 to 12,045 feet wherein the fractured granite encountered caused considerable drilling fluid to be lost to the formation.

Before attempts are made to inject disposal fluid into a formation, it is prudent first to examine various reservoir parameters which will be useful in diagnosing problems that may arise during continuous injection operations. The important parameters are as follows:

1. Reservoir capacity to accept fluid.
2. Drainage radius.
3. Total reservoir pore volume.
4. Reservoir pressure and temperature.
5. Well damage or skin effect.
6. Compatibility of injection fluid with reservoir fluid and matrix material.

Numerous techniques may be employed in evaluating these properties, all of which were utilized in the Rocky Mountain Arsenal well whenever conditions permitted.

Ordinary means of volumetric computations are impractical for two important reasons. First, horizontal limits of the reservoir are unknown. Second, fracture porosity evidently accounts for a substantial portion of the total void space. The results of the tests conducted to date give strong evidence that the "effective" reservoir is expanding as injection continues, but it is impractical to attempt to identify the drainage radius or effective reservoir volume, because the necessary parameters cannot be accurately defined at this time.

Additional injection tests with potable water are considered unnecessary, and injection of treated Pond F water is now recommended. It is advisable to continue to conduct periodic pressure fall-off tests as proposed herein for the purpose of better defining the parameters mentioned above.

Included in the testing program was a determination of friction factors of the tubing string under various flowing rates. These factors are required in subsequent calculations of reservoir performance where pressure losses due to friction are significant.

RESULTS OF INITIAL INJECTION TESTS

Injection tests included in the study incorporate considerations of mud losses into the formation while drilling and completing, brief injection tests with potable water through 4 1/2-inch drill pipe while the rig was on location and injection tests with City of Denver water through 5 1/2-inch tubing using surface plant pumping facilities. The results of all tests are shown graphically in Figure 12, which relates rates of injection to wellhead injection pressures. It may be noted that in the reservoir conditions that existed during the time of these initial injection tests, a definite relationship exists which can be extrapolated to indicate an injection rate of 800 gallons per minute at a wellhead pressure of approximately 865 psig.

The chronology of tests conducted on the initial injection interval is presented graphically in Figure 4. Details of individual tests are presented graphically in Figures 5, 6, and 8 to 11. In Figure 4, values of reservoir pressure and cumulative differential volume injected or removed from the formation are plotted as a function of time. The summary of calculations of important pressure tests are also included in this figure. It may be pointed out that the results of each test were evaluated and utilized in making a decision on subsequent test procedures. Because of the complex nature of the Pre-Cambrian interval tested, dependable results were not always obtainable.

Introduced into the equations from which calculation of injectivity characteristics were made are certain physical constants for which measured values are unobtainable. In such cases, it was necessary to use assumed values for expediency in completing the calculations. It is believed that computations for all parameters are reasonable except possibly drainage radius. Nevertheless, calculations of drainage radius are significant in that it appears to be increasing with volume injected. This feature is not entirely unexpected in view of the prevailing fracture system, and it may very well prove to be a valuable asset in fulfilling the initial objectives of the disposal well.

The values of various physical constants used in evaluating pressure tests are as follows:

Datum depth (Z_d)	12,000	ft
Temperature at 12,000 ft (T_f)	240	$^{\circ}\text{F}$
Viscosity of water at 240°F (μ)	0.28	cp
Compressibility of water (C_w)	3×10^{-7}	/psi
Effective compressibility (C_{we})	8.8×10^{-6}	/psi
Porosity (Fractures only) (ϕ)	3.0	%
Density formation water (ρ_{fw})	1.05	gm/cc
Density fresh water (ρ_w)	1.00	gm/cc
Density drilling fluid (ρ_m)	1.08	gm/cc
Density muddy water (ρ_{mw})	1.06	gm/cc

The tabulation of results of each pressure test conducted in this interval are included in Tables 1 through 12 excluding Table 8. The

calculated values of important parameters for all tests are summarized in Table 13. In addition to the symbols given previously, the following definitions of symbols apply to Table 13.

ΔV	Barrels fluid injected or withdrawn.
$\Sigma \Delta V$	Cumulative differential volume.
Fluid	Fluid in hole during pressure test.
ρ fluid	Density of fluid.
Z_b	Position of pressure bomb.
$Z_d - Z_b$	Distance between bomb depth and datum.
ΔP_{cor}	Pressure correction = $0.433 (\rho \text{ fluid}) (Z_d - Z_b)$.
P_s	Static pressure at 12,000 ft.
P^*	Extrapolated pressure at 12,000 ft.
P_m	Maximum or minimum pressure at 12,000 ft.
Kh	Formation capacity in millidarcy-feet.
F.E.	Flowing efficiency (accounts for well damage)
r_e	Apparent drainage radius in ft.

An attempt was made to secure a representative formation fluid sample in order to determine compatibility and other characteristics of this fluid. Because of the loss of drilling fluid into the fractures during drilling and coring, it was very questionable whether either drill stem test No. 13 or 14 provided uncontaminated formation fluid samples. The best sample analyzed indicated a chloride content of 46,400 ppm.

Normally it is possible to produce a well for a short time to clean out the contaminated fluid and then secure a bottom-hole sample which should very nearly reflect true formation fluid characteristics. Initial

injection tests through the drill pipe, while the rig was still on location, indicated that the interval below 11,975 feet would accept fluid at sufficient rates to warrant further investigation. Before the drilling rig was moved efforts were made to obtain a formation fluid sample through 4 1/2 inch drill pipe by air lift which is a high capacity lifting method. This proved to be uneconomical because of the low rate of fluid entry. Upon removal of the rig from the location, rods, tubing and pump were run as a more economical means of obtaining the desired sample. Figure 7 presents graphically the chloride content of the produced fluid as a function of cumulative volume withdrawn.

After several days of pumping the well pumped down, and the recovery became so small that continuance of the effort to gain a representative sample was unwarranted. It should be noted that after producing 1,100 barrels fluid in excess of the injected volume, the chloride content was considerably lower than that obtained from the drill stem test No. 14. The significance of this behavior is that either a limited reservoir volume is implied, or during production the fractures possibly were being squeezed together by compression forces which resulted in restricting fluid entry into the wellbore. This factor supports the suggestion given above that the effective reservoir is expanding when the pressure is restored by injection and may continue to do so during the continuous injection period to follow. The composite graph (Figure 12) showing

Injection rates versus injection pressures for all injection tests in the Pre-Cambrian interval 11,975 feet to 12,045 feet lends support to this interpretation.

CONCLUSIONS

1. The rates, with corresponding injection pressures at which the Pre-Cambrian interval (11,975 to 12,045 feet) accepted fluid during tests, are shown graphically on Figure 12. Extrapolation of the rate vs. pressure trend indicates an injection pressure of approximately 865 psig at an injection rate of 800 gallons per minute. The maximum actual injection rate through 5 1/2-inch tubing with available surface plant facilities was 400 gallons per minute at 650 psig wellhead pressure with no observed pressure rise during test.
2. The reservoir consists of fractures which apparently expand as additional volumes of fluid are injected.
3. Extension of effective reservoir boundaries is indicated for the period of testing discussed herein.
4. Continued injection of fluid and the contemporaneous recording of pressure and injected volume data, plus periodic pressure fall-off tests are essential to a more positive evaluation of the Pre-Cambrian reservoir.

RECOMMENDATIONS CONCERNING
THE CONTINUOUS INJECTION PERIOD

1. It is recommended that the following data be collected for each day of injection operations.
 - a. Injection Rate
 - b. Daily Injected Volume
 - c. Tubing Pressure
 - d. Annulus Pressure
 - e. Solids content and chemical characteristics of injected fluid
2. Periodic observations of tubing pressure should be made throughout the day during the initial injection period. Significant increases should be studied without delay as related to reservoir performance. If the tubing pressure reaches 2,000 psi, the injection rate should be reduced.
3. During the first 90 days of operation, a 24-hour fall-off test is recommended at the end of each 30-day period. Every effort should be exercised to maintain a constant injection rate for approximately 10 days prior to shutting in the well for these tests.
4. Future test requirements should be evaluated after examining the results of the 30-day fall-off tests.
5. A water storage pressure chamber should be connected to the 8 5/8-inch - 5 1/2-inch annulus to provide for variations in the annular volume requirements due to subsurface temperature variations as influenced by well operations.

6. Corrosion test coupons should be placed in the injection stream as near the wellhead as possible in order to evaluate the severity of corrosion in the water injection path. Some oilfield operators consider the upper limit of corrosive activity to be 1.0 MPY (0.001 inches per year) for subsurface conditions. This however requires individual economic analysis involving casing design specifications, cost of replacement, cost of corrosion inhibition, possible irreparable reservoir damage due to the end products of corrosion, and damage to the permanent installation in the wellbore.

It should be mentioned that coupons do not necessarily evaluate the entire injection path. Before extensive or costly corrosion inhibition programs are initiated based upon coupon tests alone, additional corroboration should be obtained from other sources; such as caliper surveys in the 5 1/2-inch tubing, periodic visual inspection of the casing head, pumps and other surface appurtenances.

Table 1

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
DRILL STEM TEST NO. 13

September 5, 1961

<u>Time Minutes</u>	<u>Shut-in Pressure, psi At 9,645 Feet</u>	<u>Time Minutes</u>	<u>Shut-in Pressure, psi At 9,645 Feet</u>
0	2,565	50	3,732
1	2,981	54	3,732
2	3,111	58	3,732
3	3,211	62	3,732
4	3,274	66	3,732
5	3,335	70	3,732
6	3,393	74	3,732
7	3,436	78	3,732
8	3,477	82	3,732
9	3,515	86	3,732
10	3,548	90	3,732
14	3,634	94	3,732
18	3,673	98	3,732
22	3,692	102	3,732
26	3,703	106	3,732
30	3,712	110	3,732
34	3,719	114	3,732
38	3,727	118	3,732
42	3,727	122	3,732
46	3,732		

Formation	Early Paleozoic
Interval Tested	9,660-11,985
Flow Periods	3 and 60 minutes
Closed-in Times	30 and 122 minutes
Gauge Depth	9,645
Initial Flow Pressure	856-1,117
Initial Shut-in Pressure	3,868
Final Flow Pressure	925-2,565
Final Shut-in Pressure	3,732
Recovery	5,330 feet mud (no water cushion)

Table 2

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
DRILL STEM TEST NO. 14

September 6, 1961

<u>Time Minutes</u>	<u>Shut-in Pressure, psi At 11,007 Feet</u>
0	3,508
9.3	3,782
18.6	3,910
27.9	4,000
37.2	5,059
46.5	4,093
55.8	4,116
65.1	4,129
74.4	4,138
83.7	4,148
93.0	4,155
Formation	Early Paleozoic
Interval Tested	11,020-11,985
Flow Periods	6 and 156 minutes
Closed-in Times	none and 93 minutes
Gauge Depth	11,007 feet
Initial Flow Pressure	1,684-1,844
Initial Shut-in Pressure	none (bypassed and reopened)
Final Flow Pressure	1,692-3,508
Final Shut-in Pressure	5,155
Recovery	2,000 feet water cushion 5,400 feet salt water

Table 3

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL NO. 1
INJECTION AND FALL-OFF TESTS

TEST NO. 1 (September 20, 1961)

<u>Time</u>	<u>Surface Pressure</u>	<u>Pressure at 11,975' K. B.</u>	<u>Remarks</u>
0 min. - 45 min.	975 psi	6170 psi	Injected 16,200 gallons at 385 GPM.
45 min. - 0 sec.	850	6045	Instantaneous shut-in pressure.
45 min. - 10 sec.	825	6020	Shut-in 10 sec.
45 min. - 20 sec.	525	5720	Shut-in 20 sec.
45 min. - 30 sec.	250	5445	Shut-in 30 sec.
45 min. - 40 sec.	225	520	Shut-in 40 sec.
45 min. - 50 sec.	220	5415	Shut-in 50 sec.
45 min. - 60 sec.	210	5405	Shut-in 60 sec.
46 min. - 10 sec.	205	5400	Shut-in 70 sec.
46 min. - 40 sec.	190	5385	Shut-in 100 sec.
47 min. - 10 sec.	175	5370	Shut-in 130 sec.
47 min. - 40 sec.	125	5320	Shut-in 160 sec.
48 min. - 10 sec.	125	5320	Shut-in 190 sec.
48 min. - 40 sec.	110	5305	Shut-in 220 sec.
49 min. - 10 sec.	110	5305	Shut-in 250 sec.
53 min. - 0 sec.	75	5270	Shut-in 480 sec.
56 min. - 0 sec.	50	5245	Shut-in 660 sec.
58 min. - 0 sec.	0	5195	Shut-in 780 sec.

Injection test through 10,700 feet of 4 1/2-inch drill pipe.
5 1/2-inch liner set at 11,975 feet.
Injection interval 11,975-12,045 feet.

Table 4

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL NO. 1
INJECTION AND FALL-OFF TESTS

TEST NO. 11 (September 20, 1961)

<u>Time</u>	<u>Surface Pressure</u>	<u>Pressure at 11,975' K.B.</u>	<u>Remarks</u>
0 min. - 5 min.	250 psi	5445 psi	Injected 1008 gallons at 216 GPM
5 min. - 0 sec.	250	5445	Instantaneous shut-in pressure
5 min. -10 sec.	175	5370	Shut-in 10 sec.
5 min. -20 sec.	90	5285	Shut-in 20 sec.
5 min. -30 sec.	25	5220	Shut-in 30 sec.
5 min. -40 sec.	0	5195	Shut-in 40 sec.

Injection test through 10,700 feet of 4 1/2-inch drill pipe.
5 1/2-inch liner set at 11,975 feet.
Injection interval 11,975-12,045 feet.

Table 5

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL NO. 1
INJECTION AND FALL-OFF TESTS

TEST NO. III (September 29, 1961)

<u>Time</u>	<u>Surface Pressure</u>	<u>Pressure at 11,975' KB</u>	<u>Remarks</u>
0 min. - 15 min.	1475 psi	6670 psi	Injected 8232 gallons at 538 GPM
15 min. - 0 sec.	1475	6670	Instantaneous shut-in pressure
15 min. - 10 sec.	225	5420	Shut-in 10 sec.
15 min. - 20 sec.	225	5420	Shut-in 20 sec.
15 min. - 30 sec.	210	5405	Shut-in 30 sec.
15 min. - 40 sec.	190	5385	Shut-in 40 sec.
15 min. - 50 sec.	175	5370	Shut-in 50 sec.
16 min. - 0 sec.	160	5355	Shut-in 60 sec.
16 min. - 30 sec.	110	5305	Shut-in 90 sec.
17 min. - 0 sec.	100	5295	Shut-in 120 sec.
17 min. - 30 sec.	80	5275	Shut-in 150 sec.
18 min. - 0 sec.	75	5270	Shut-in 180 sec.
18 min. - 30 sec.	50	5245	Shut-in 210 sec.
20 min. - 0 sec.	0	5195	Shut-in 300 sec.

Injection test through 10,700 feet of 4 1/2-inch drill pipe.
5 1/2-inch liner set at 11,975 feet.
Injection interval 11,975-12,045 feet.

Table 6

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL NO. 1
INJECTION AND FALL-OFF TESTS

TEST NO. IV (September 20, 1961)

<u>Time, min.</u>	<u>Surface Pressure</u>	<u>Pressure at 6,000' K.B.</u>	<u>Pressure at 11,975' K.B.</u>	<u>Remarks</u>
0-136	700 psi	3182 psi	5775 psi	Injected 20,916 at average rate of 250 GPM
137	200			Shut-in 1 min.
146	100	2864	5457	Shut-in 10 min.
156	0	2713	5306	Shut-in 20 min.
176		2652	5245	Shut-in 40 min.
196		2618	5211	Shut-in 60 min.
216		2592	5185	Shut-in 80 min.
236		2577	5170	Shut-in 100 min.
256		2551	5144	Shut-in 120 min.
276		2543	5136	Shut-in 140 min.
296		2524	5117	Shut-in 160 min.
316		2515	5108	Shut-in 180 min.
336		2506	5099	Shut-in 200 min.
356		2498	5091	Shut-in 220 min.
376		2491	5084	Shut-in 240 min.
531		2432	5025	Shut-in 395 min.
546		2432	5025	Shut-in 410 min.
561		2428	5021	Shut-in 425 min.
639		2413	5006	Shut-in 503 min.

Injection test through 10,700 feet of 4 1/2-inch drill pipe.
5 1/2-inch liner set at 11,975 feet.
Injection interval 11,975-12,045 feet.

Table 7

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL NO. 1
INJECTION AND FALL-OFF TESTS

TEST NO. V (September 20-21, 1961)

<u>Time, min.</u>	<u>Surface Pressure, psi</u>	<u>Pressure at 5,000', psi</u>	<u>Pressure at 11,975', psi</u>	<u>Remarks</u>
0	1120	2991	6018	Begin injection at 263 GPM
2	1120	2991	6018	" "
30	1120	2991	6018	" "
60	1120	2991	6018	" "
120	1120	2991	6018	" "
142	1120	2991	6018	Stop injection after 37,346 gallons
144		2807	5834	Shut-in 2 min.
152		2783	5810	Shut-in 10 min.
162		2525	5552	Shut-in 20 min.
172		2390	5417	Shut-in 30 min.
182		2287	5314	Shut-in 40 min.
202		2202	5229	Shut-in 60 min.
262		2143	5170	Shut-in 120 min.
322		2116	5143	Shut-in 180 min.
382		2105	5132	Shut-in 240 min.
442		2090	5117	Shut-in 300 min.
502		2084	5111	Shut-in 360 min.
562		2073	5100	Shut-in 420 min.
682		2052	5077	Shut-in 540 min.
802		2027	5054	Shut-in 660 min.

Injection test through 10,700 feet of 4 1/2-inch drill pipe.
5 1/2-inch liner set at 11,975 feet.
Injection interval 11,975-12,045 feet.

Table 8

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
PRE-CAMBRIAN INTERVAL, 11,975 TO 12,045'
CUMULATIVE WATER PRODUCED BY AIR LIFTING AND PUMPING
VERSUS CHLORIDE CONTENT OF WATER SAMPLE

Cumulative Production Barrels	Chloride Content ppm	Cumulative Production Barrels	Chloride Content ppm
650	1,600	4,453	33,500
2,035	4,000	4,465	28,400
2,090	13,000	4,483	24,600
2,517	13,000	4,530	27,000
2,624	12,000	4,670	26,000
2,966	15,000	4,699	27,000
3,330	15,000	4,744	26,000
3,580	18,000	4,790	31,000
3,920	26,000	4,870	32,500
3,975	25,000	4,896	31,500
4,011	21,000	4,920	32,000
4,200	28,000	4,934	31,000
4,211	32,000	4,956	33,000
4,321	29,500	4,982	31,250
4,417	33,500	5,001	32,500

Table 9

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
INJECTIVITY TESTS THROUGH 5 1/2-INCH TUBING
PRE-CAMBRIAN INTERVAL 11,975-12,045'

TEST NO. 1
January 3, 1962

<u>Shut-in Time</u>	<u>Wellhead Pressure, psi</u>
0	280
10 Seconds	120
20 Seconds	110
30 Seconds	105
40 Seconds	95
50 Seconds	95
60 Seconds	92
2 Minutes	75
3 Minutes	62
4 Minutes	54
5 Minutes	48
6 Minutes	42
7 Minutes	35
8 Minutes	29
9 Minutes	25
10 Minutes	21
11 Minutes	17
12 Minutes	13
13 Minutes	9
14 Minutes	6
15 Minutes	3
16 Minutes	0
Effective Injection Time	856 minutes
Average Injection Rate	206 GPM
Volume of Denver City Water Injected	4,200 barrels

The bottom-hole pressure was not recorded since the clock in the Amerada pressure bomb malfunctioned.

Table 10

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
INJECTIVITY TESTS THROUGH 5 1/2-INCH TUBING
PRE-CAMBRIAN INTERVAL 11,975-12,045'

TEST NO. 2
January 5, 1962

Shut-in Time Minutes	Wellhead Pressure psi	Pressure At 3,000' psi	Shut-in Time Minutes	Wellhead Pressure psi	Pressure At 3,000' psi
0	335	1,630	480	29	1,347
1	190		540	25	1,340
5	138		600	20	1,339
10	112		840	12	1,322
15	102	1,401	1080	9	1,314
30	87	1,388	1,235	line drained	1,306
45	80	1,386	1,295		1,305
60	76	1,383	1,355		1,303
75	72	1,381	1,415		1,301
90	68	1,378	1,475		1,300
120	64	1,371	1,535		1,293
150	60	1,370	1,595		1,290
180	56	1,370	1,655		1,288
210	52	1,370	1,715		1,287
240	48	1,368	1,820		1,285
300	43	1,363	1,880		1,282
360	39	1,353	1,940		1,279
420	34	1,352			

Effective Injection Time 682 minutes
Average Injection Rate 208 GPM
Volume of Denver City Water Injected 3,380 barrels

The bottom-hole pressure was not recorded since the Amerada pressure bomb was dropped in the hole when the wire line broke at 9,000 feet.

Table 11

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
INJECTIVITY TESTS THROUGH 5 1/2-INCH TUBING
PRE-CAMBRIAN INTERVAL 11,975-12,045'

TEST NO. 3
January 22, 1962

<u>Shut-in Time</u>	<u>Wellhead Pressure psi</u>	<u>Pressure at 7500' psi</u>
0	535	3,666
1 min.	335	3,596
5 min.	270	
10 min.	245	
15 min.	232	
30 min.	210	3,437
1 hr.	202	3,416
2 hrs.		3,391
2 hrs. 30 min.		3,388
3 hrs.		3,385
4 hrs.		3,382
6 hrs.		3,354
8 hrs. 30 min.		3,353
9 hrs.		3,290
12 hrs.		3,211
15 hrs.		3,186
18 hrs.		3,174
20 hrs.		3,171
26 hrs.		3,164
30 hrs.		3,161
36 hrs.		3,158

Effective Injection Time 424 min.
Injection Rates 10 min. at 104 GPM
10 min. at 208 GPM
324 min. at 312 GPM
80 min. at 416 GPM

Volume of Denver City Water Injected 3,450 bbls.

The Amerada pressure bomb was set at 7,500' for safety precautions.

Table 12

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
INJECTIVITY TESTS THROUGH 5 1/2-INCH TUBING
PRE-CAMBRIAN INTERVAL 11,975-12,045'

TEST NO. 4
January 25, 1962

Shut-in Time	Wellhead Pressure psi	Pressure At 8,000' psi	Shut-in Time	Wellhead Pressure psi	Pressure At 8,000' psi
0	630	3,997	16 hrs.	160	3,642
1 min.	380	3,884	18 hrs.	150	3,633
5 min.	335		20 hrs.	141	3,627
15 min.	290		22 hrs.	132	3,618
30 min.	260	3,755	24 hrs.	123	3,608
1 hr.	240	3,725	26 hrs.	115	3,605
2 hrs.	230	3,712	28 hrs.	107	3,602
4 hrs.	220	3,691	30 hrs.	99	3,599
6 hrs.	210	3,688	32 hrs.	91	3,587
8 hrs.	200	3,682	34 hrs.	83	3,587
10 hrs.	190	3,666	36 hrs.	75	3,587
12 hrs.	180	3,663	46 hrs.	35	
14 hrs.	170	3,660			

Effective Injection Time

373 min.

Injection Rates

59 min. at 196 GPM

314 min. at 392 GPM

Volume of Domestic City Water Injected 3,240 bbls.

The Amerada bomb was set at 8,000' for safety precautions.

ROCKY MOUNTAIN
PRESSURE INJECTION
SUMMARY OF PRESSURE

Date	Operation	ΔV barrels	$\Sigma \Delta V$ barrels	Fluid	ρ fluid	Z _b ft	Z _f
9-3-61	Coring	450	450				
9-5-61	DST #13	75	375	Muddy formation water	1.06	9,645	2.
9-6-61	DST #14	75	300	Formation water	1.05	11,007	
9-8-61	Injection Test	190	490	Fresh water	1.00		
9-10-61	Drilling	477	967				
9-12-61	Drilling	270	1,187				
9-14-61	Drilling	72	1,259				
9-18-61	Injection Test	401	1,660	Fresh water	1.00	11,975	
9-19-61	Injection Test	692	2,352	Fresh water	1.00	11,975	
9-20-61	Injection Test	1,574	3,926	Fresh water	1.00	11,975	
9-21-61	P _s Test						
9-22-61	Air Lift	-1,100	2,826				
9-23-61	Air Lift	-795	2,031				
9-25-61	Air Lift	-509	1,522				
10-6-61	Fluid Level						
10-11-61	Pumping	-79	1,443				
10-12-61	Pumping	-267	1,176				
10-13-61	Pumping	-188	988				
10-19-61	Pumping	-342	646				
10-20-61	Pumping	-285	361				
10-21-61	Pumping	-220	121				
10-23-61	Pumping	-424	-303				
11-1-61	Pumping	-185	-488				
11-3-61	P _s Test						
11-8-61	Pumping	-256	-744				
11-16-61	Pumping	-143	-887				
11-22-61	Pumping	-353	-1,240				
11-27-61	End Pumping	-202	-1,402				
12-1-61	P _s Test	0	-1,402	Formation water		12,000	
12-21-61	P _s Test	0	-1,402	Formation water		12,000	
1-3-62	lnj. Test #1	4,534	3,132	Fresh water	1.00	0	12.
1-5-62	lnj. Test #2	3,380	6,180	Fresh water	1.00	3,000	9.0
1-17-62	P _s Test	0	6,180	Fresh water	1.00	8,500	3.2
1-22-62	lnj. Test #3	3,450	9,630	Fresh water	1.00	7,500	4.3
1-25-62	lnj. Test #4	3,240	12,870	Fresh water	1.00	8,000	4.0

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Table 13

Y MOUNTAIN ARSENAL
INJECTION DISPOSAL WELL
PRESSURE TEST RESULTS

<u>Z_b</u> <u>ft</u>	<u>Z_d-Z_b</u> <u>ft</u>	<u>ΔP cor</u> <u>psi</u>	<u>P_s</u> <u>psi</u>	<u>P*</u> <u>psi</u>	<u>P_m</u> <u>psi</u>	<u>Kh</u> <u>md-ft</u>	<u>F.E.</u> <u>%</u>	<u>r_e</u> <u>ft</u>
9,645	2,355	1,082	4,968	4,910	4,814	431	44	302
11,007	997	459		4,694	4,522	173	87	177
11,975	25	11						
11,975	25	11						
11,975	25	11	4,943					
			5,024					
			4,359					
			3,040					
2,000	0	0	2,125?					
2,000	0	0	2,613					
12,000		5,196	2,714	5,174	5,196	3,390	52	768
9,000		3,897	4,756	5,244	5,180	11,260	53	1,522
8,500	3,500	1,516	4,824					
7,500	4,500	1,949	5,114	5,282	5,109	6,110	78	3,980
8,000	4,000	1,732	5,143	5,389	5,291	8,700	68	6,200

B

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
CORE DESCRIPTION

Core No. 28

Interval:	Pre-Cambrian
Depth:	11,976-11,985'
Cut 9':	Recovered 6.7'
6.0':	Biotite, hornblende, granite gneiss, fractured
0.7':	Biotite, hornblende, granite gneiss, and pegmatite

CASING AND HOLE DETAILS

FIGURE 1

PRESSURE INJECTION DISPOSAL WELL
ROCKY MOUNTAIN ARSENAL
SECTION 26, T2S-R67W
ADAMS COUNTY, COLORADO.

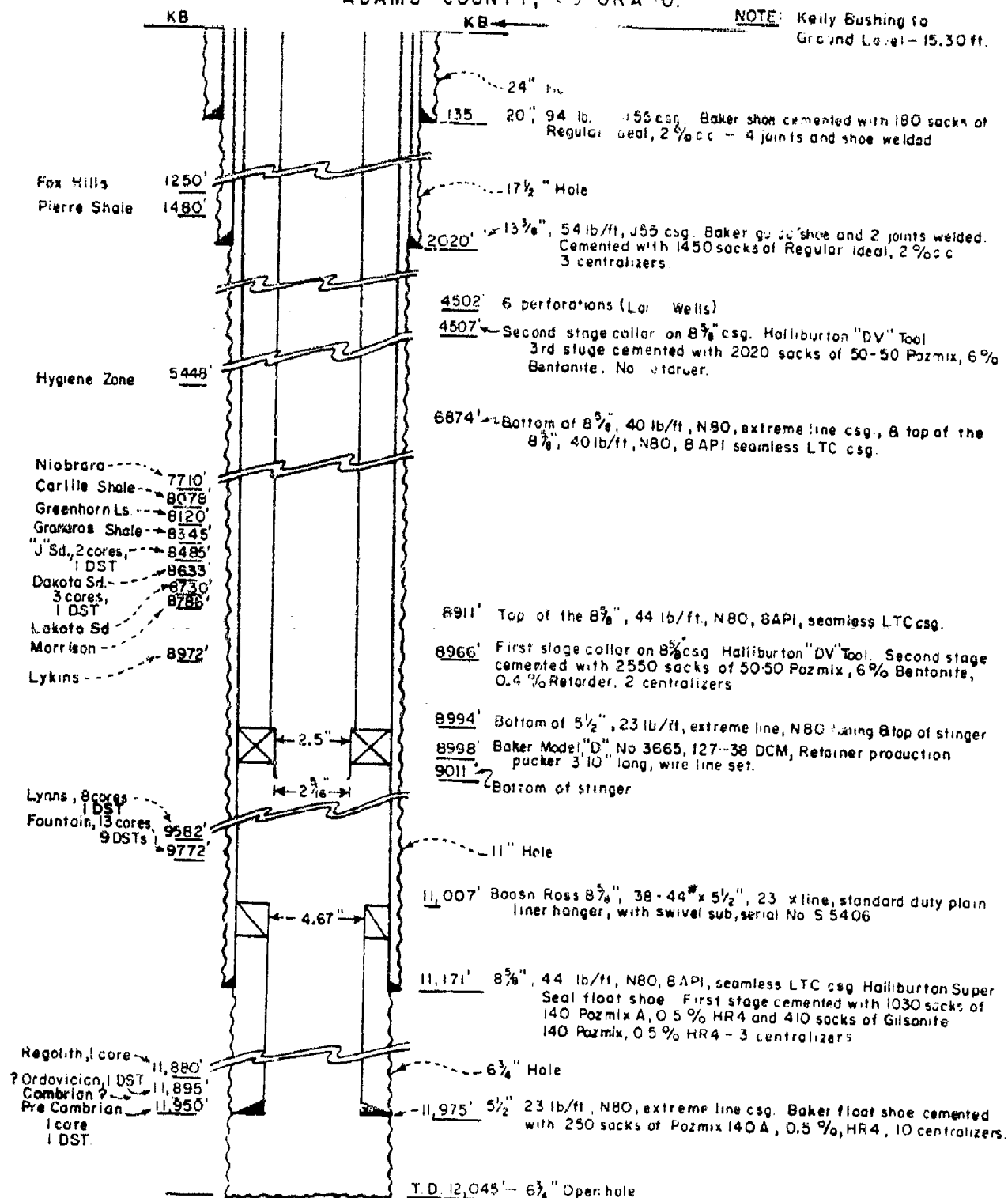
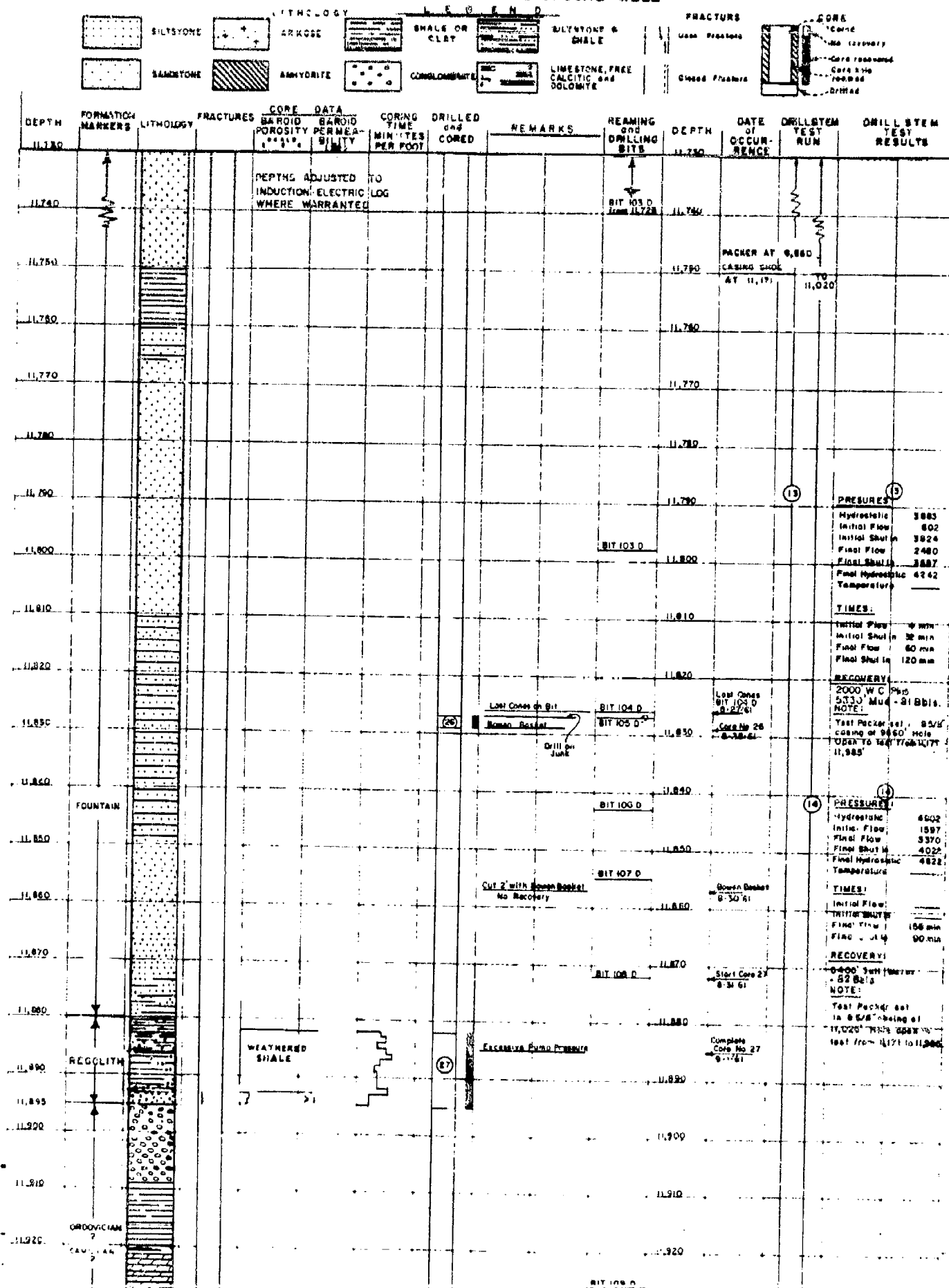
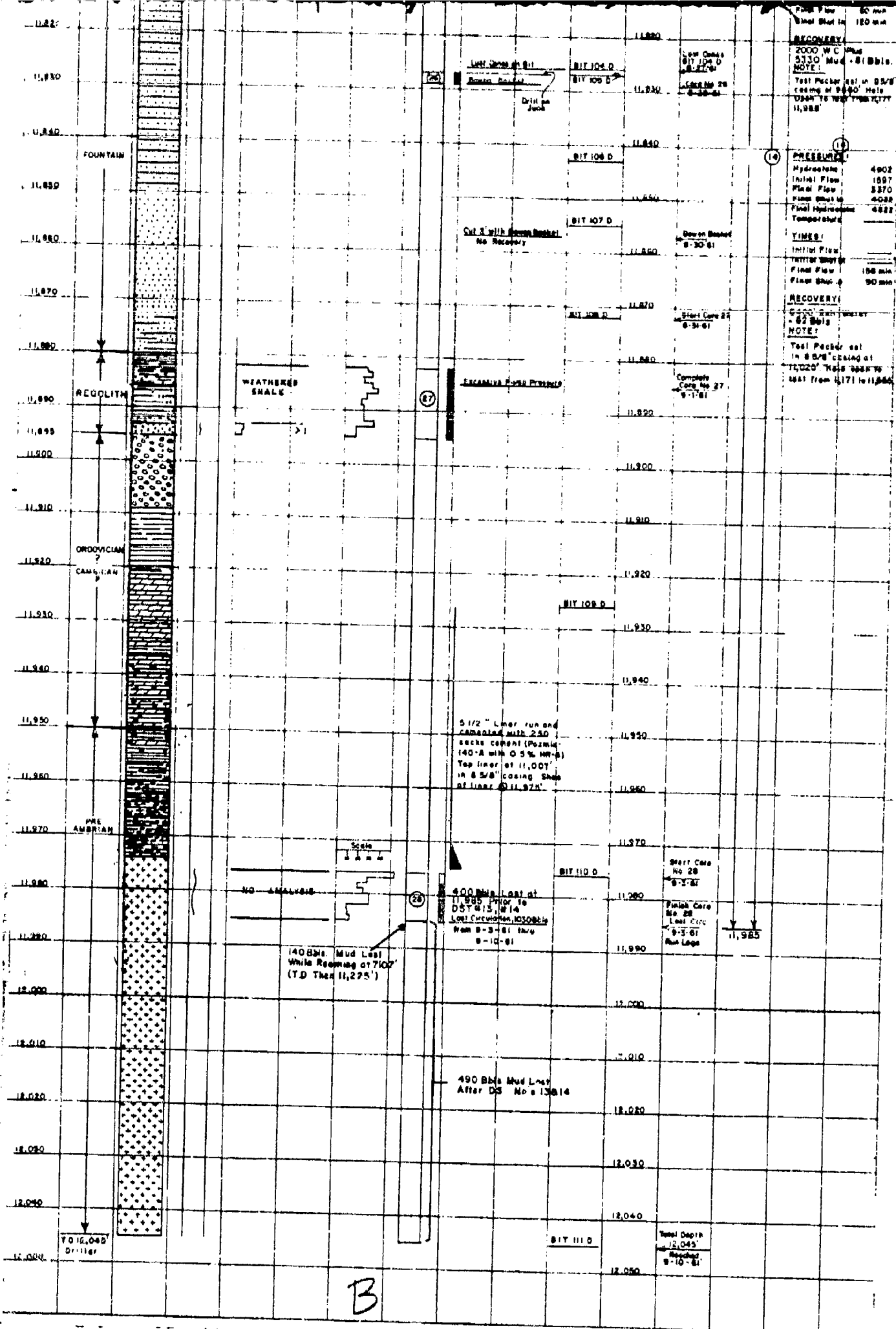


FIG 2

NO 12
INTERVAL 11.720 - 12.000'





RECOVERY:
2000 W.C. Mud
5330' Mud - 81 Bbls.
NOTE:
Test Packer set in 8 5/8" casing at 9490' Hole Open 78 hrs from 7:17 11,988'

PRESSURE:
Hydrostatic 4902
Initial Flow 1597
Final Flow 3870
Flow Shut in 4088
Final Hydrostatic 4822

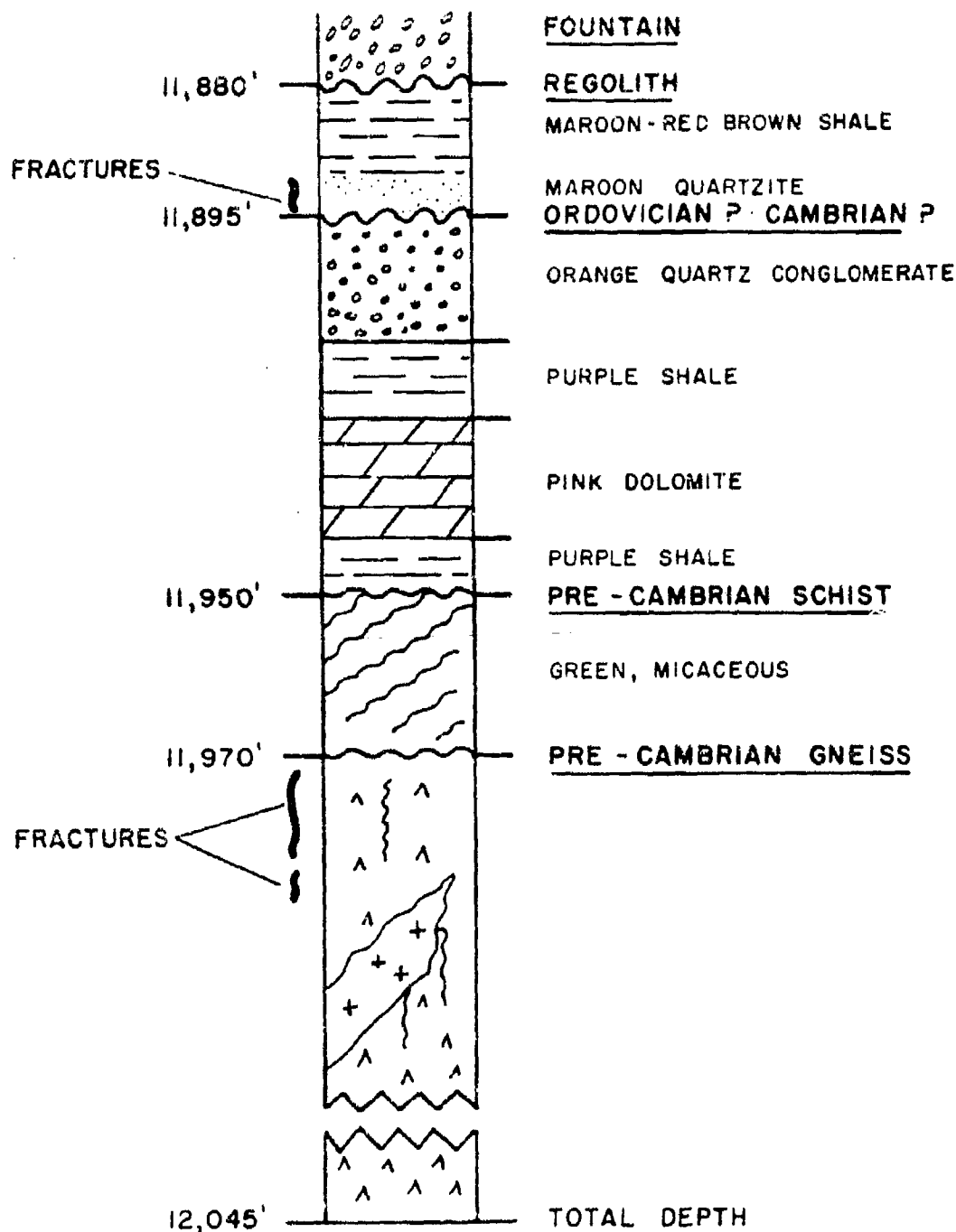
TIME:
Initial Flow
Packer Set 100 min
Flow Shut in 90 min

RECOVERY:
5000' Test Water
- 82 Bbls
NOTE:
Test Packer set in 8 5/8" casing at 11,020' Hole Open 78 test from 11:17 to 11:56

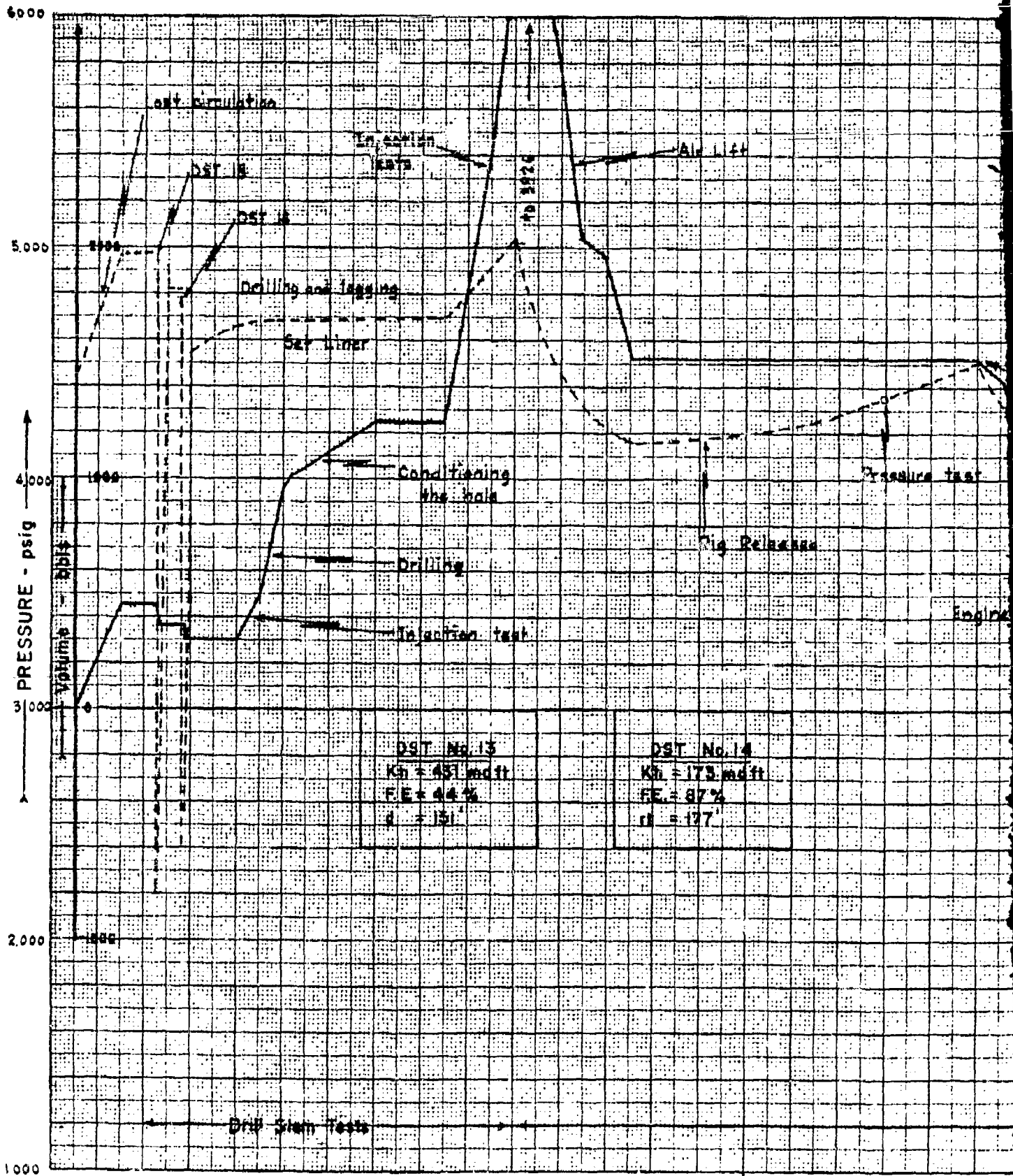
FIGURE 3

ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

PRE - FOUNTAIN GEOLOGIC COLUMN



K-2
 FEDERAL BUREAU OF INVESTIGATION
 100-101011-1000 320-147



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10/1/61

ROCKY MOUNTAIN ARSENAL

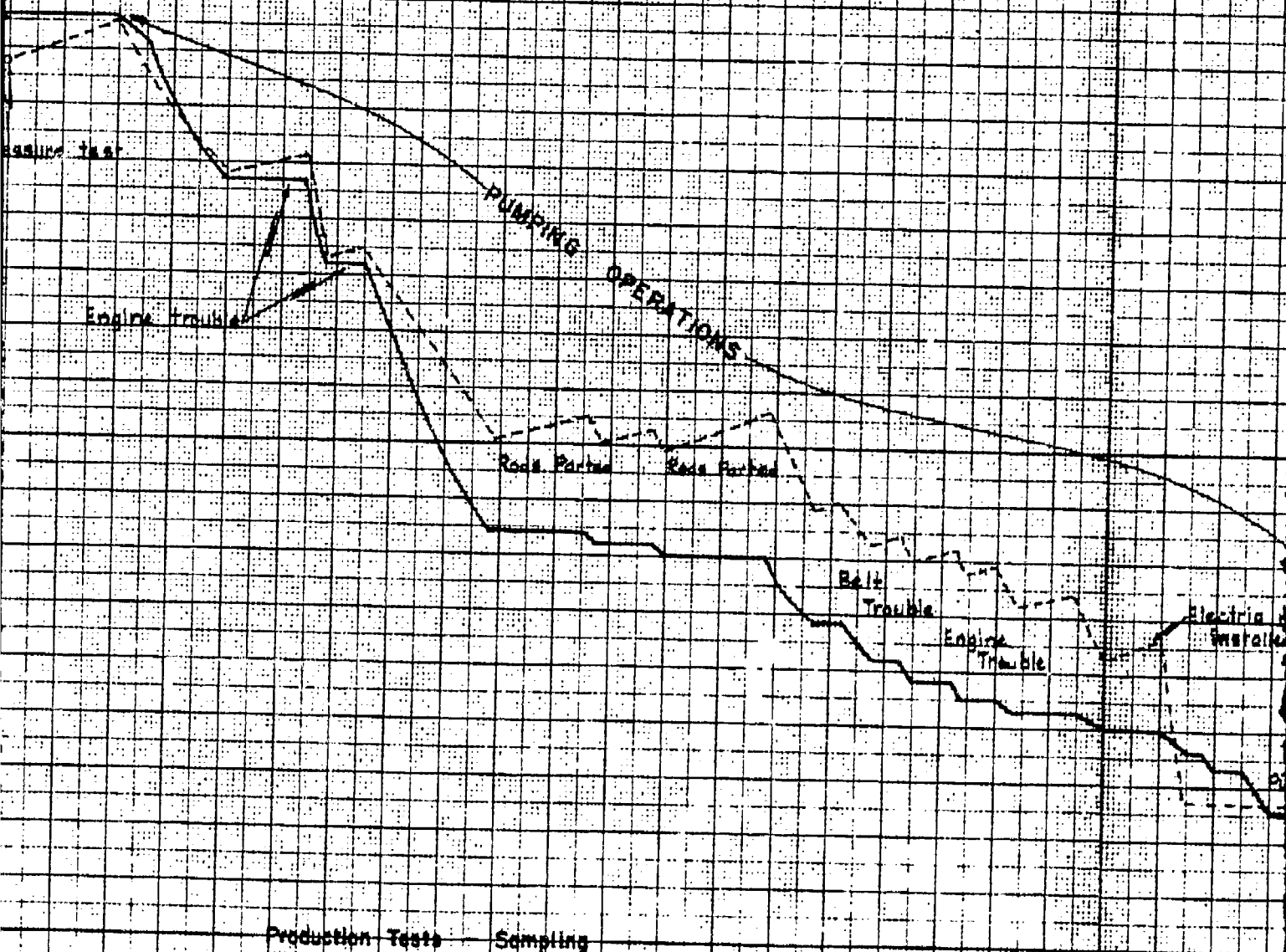
PRESSURE INJECTION DISPOSAL WELL

PRE-CAMBRIAN INTERVAL 11,975 - 12,046

PRESSURE AND CUMULATIVE VOLUME HISTOGRAM

FROM SEPTEMBER 1, 1961 TO JANUARY 27, 1962

———— Cumulative Volume, bbls
----- Pressure, psig



B

11/1/61

TIME

E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

Inj. Test No. 1
 Kh = 3390
 FE = 52%
 d = 384

Inj. Test No. 2
 Kh = 11260
 FE = 53%
 d = 781

Inj. Test No. 3
 Kh = 6110
 FE = 70%
 d = 1890

Inj. Test No. 4
 Kh = 9700
 FE = 60%
 d = 3100

Test #

ZERO CUMULATIVE VOLUME DIFFERENTIAL

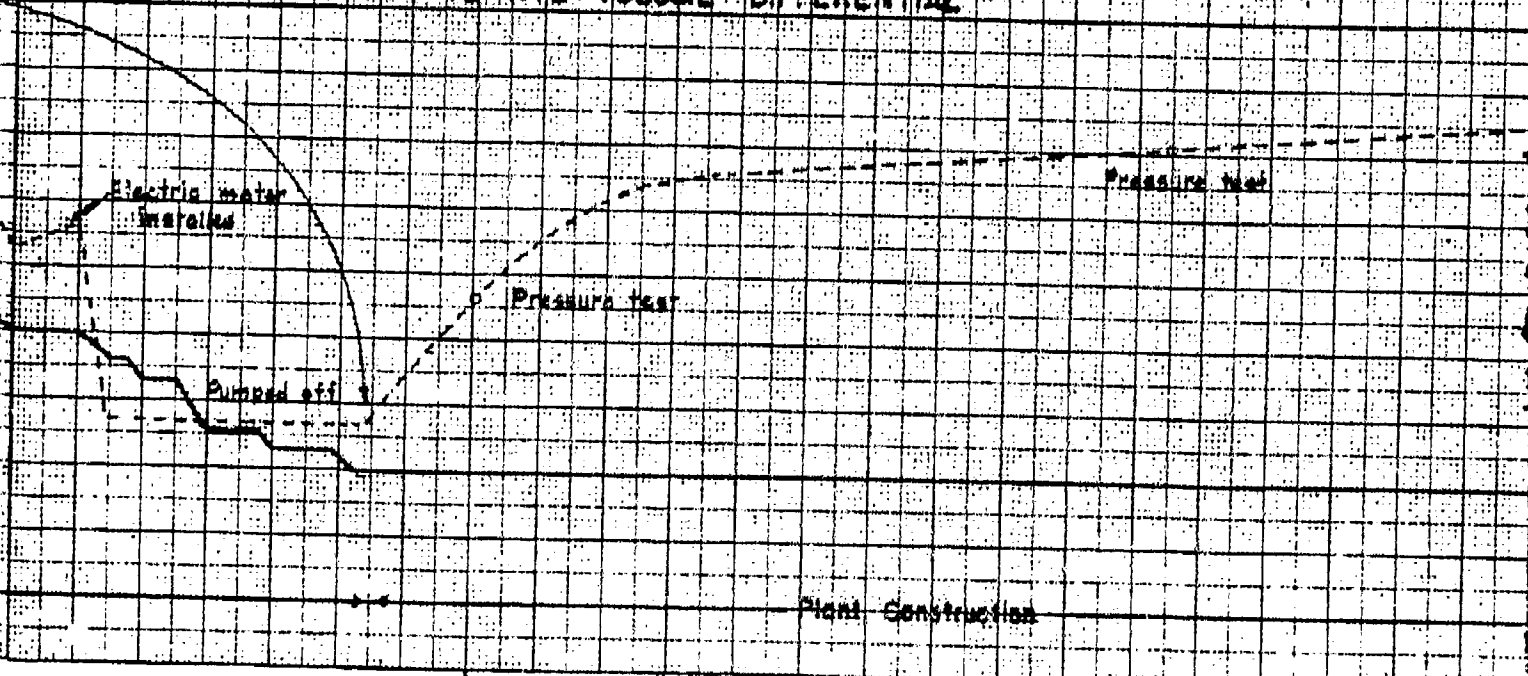
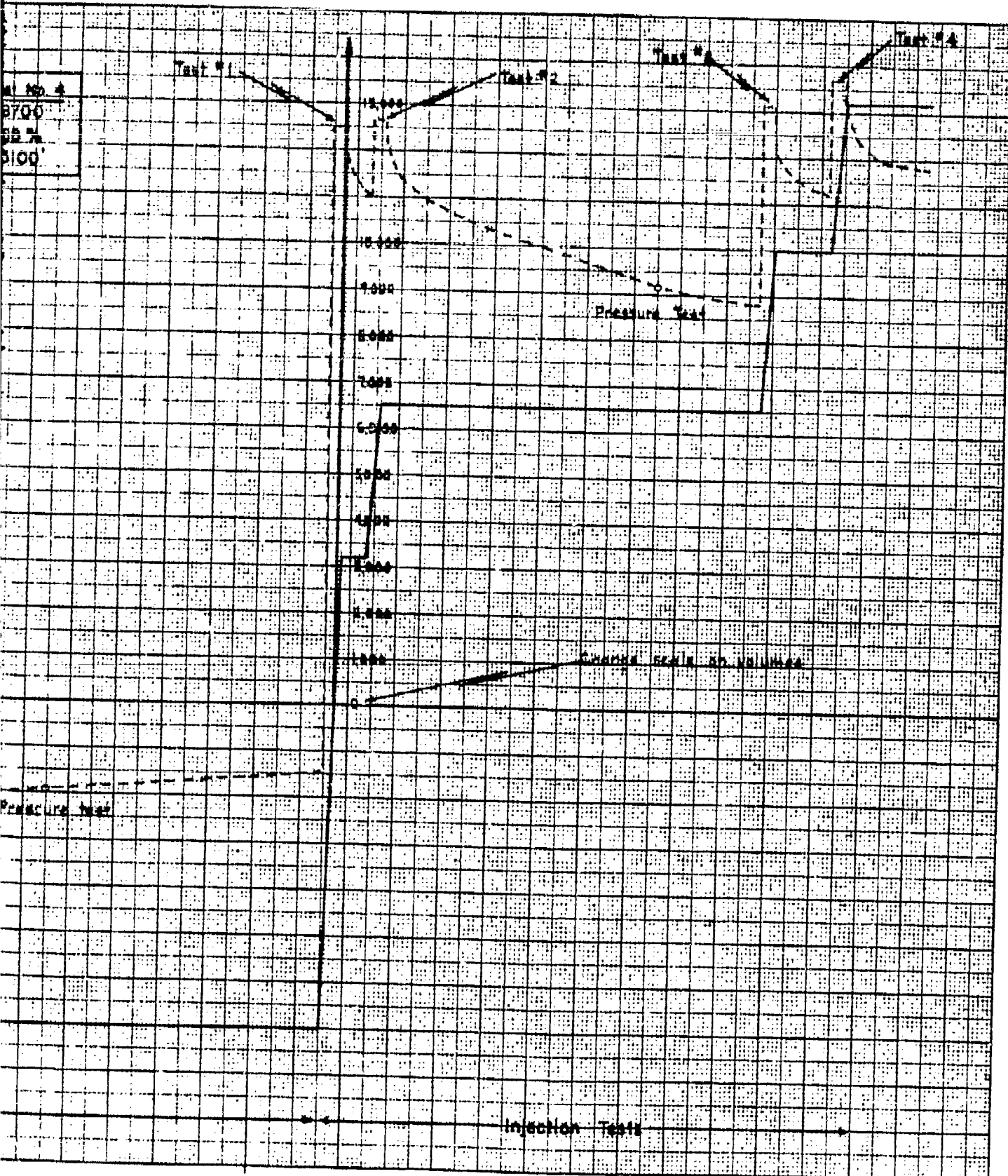
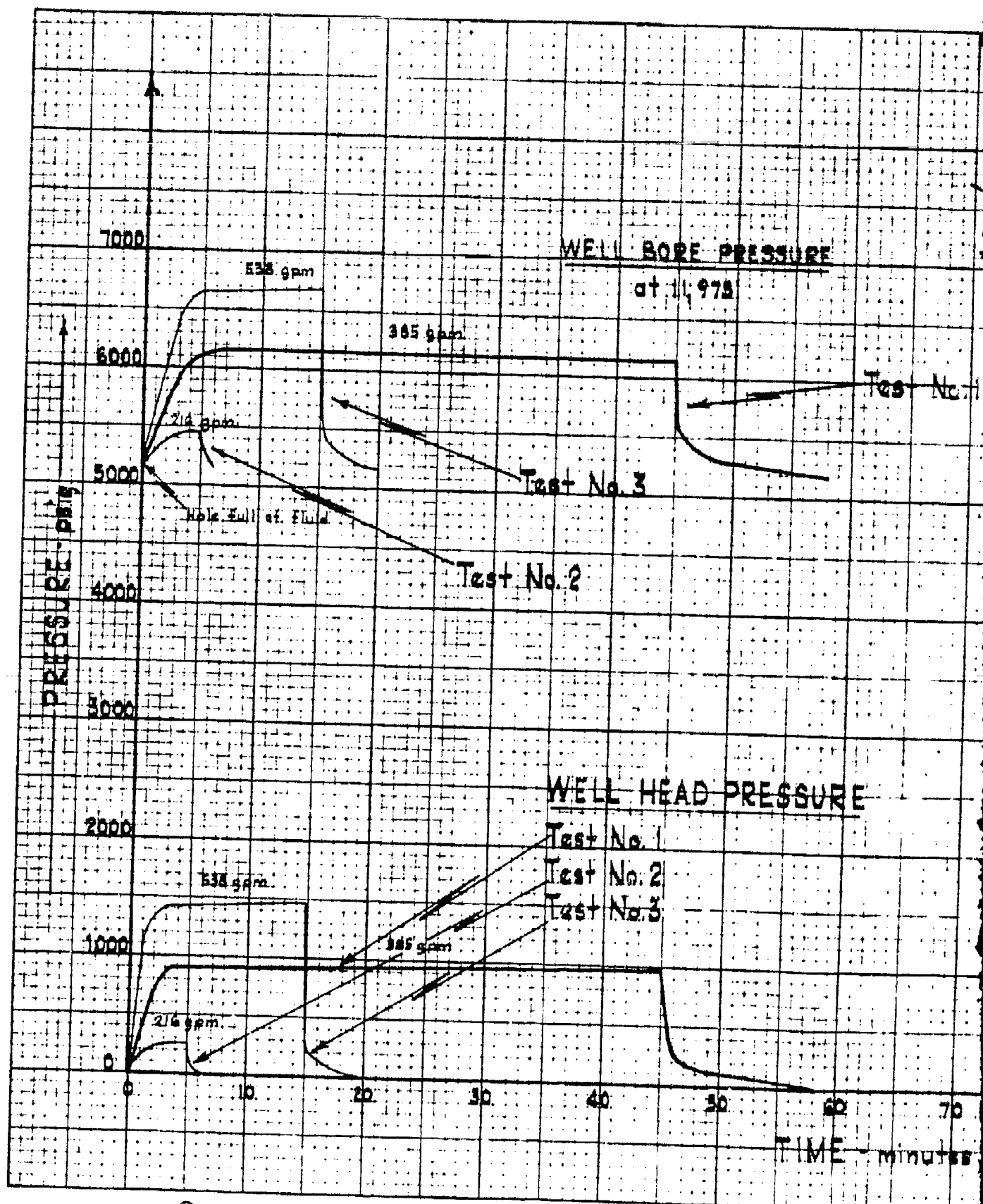


FIGURE 4

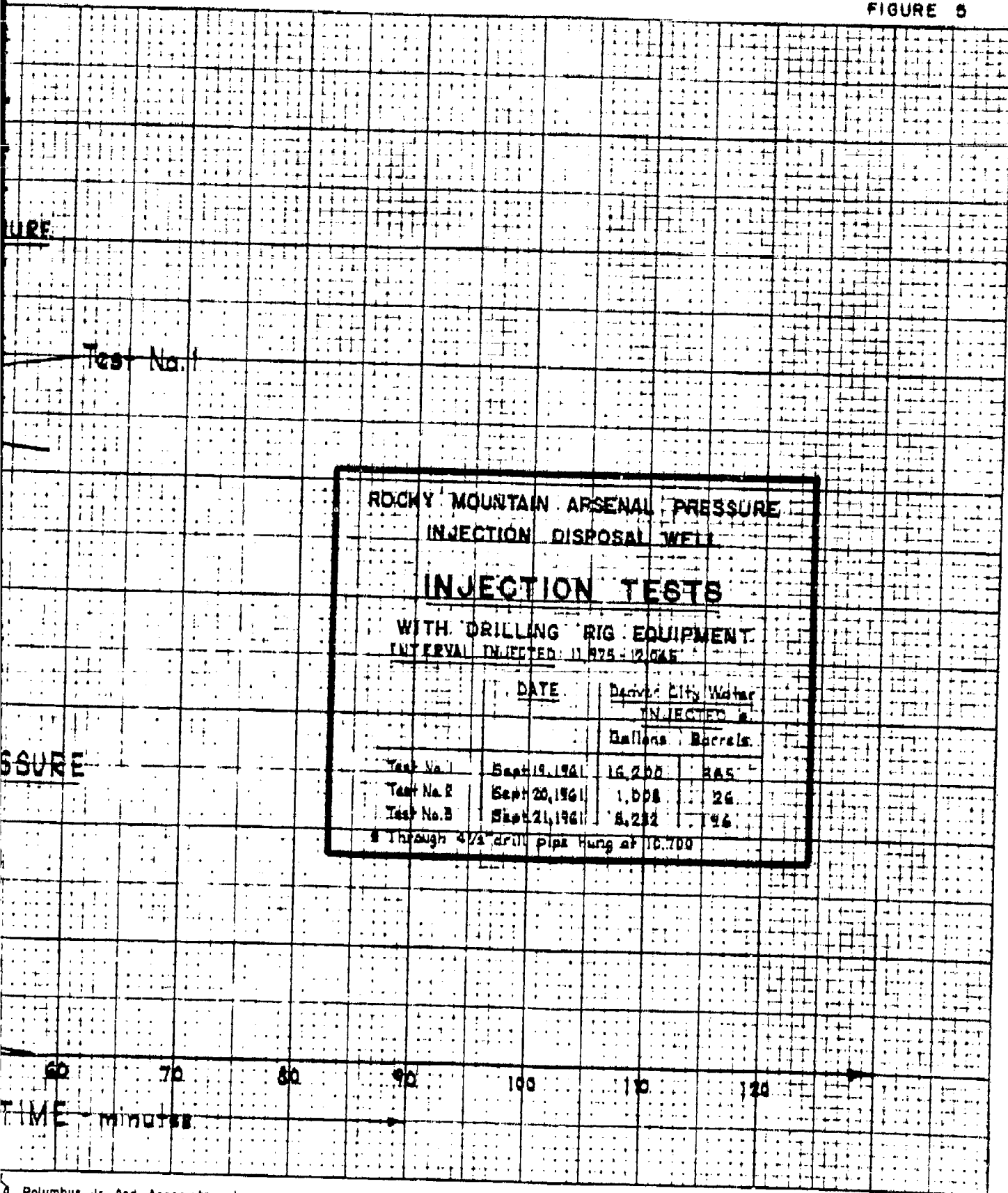


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FIGURE 5



B

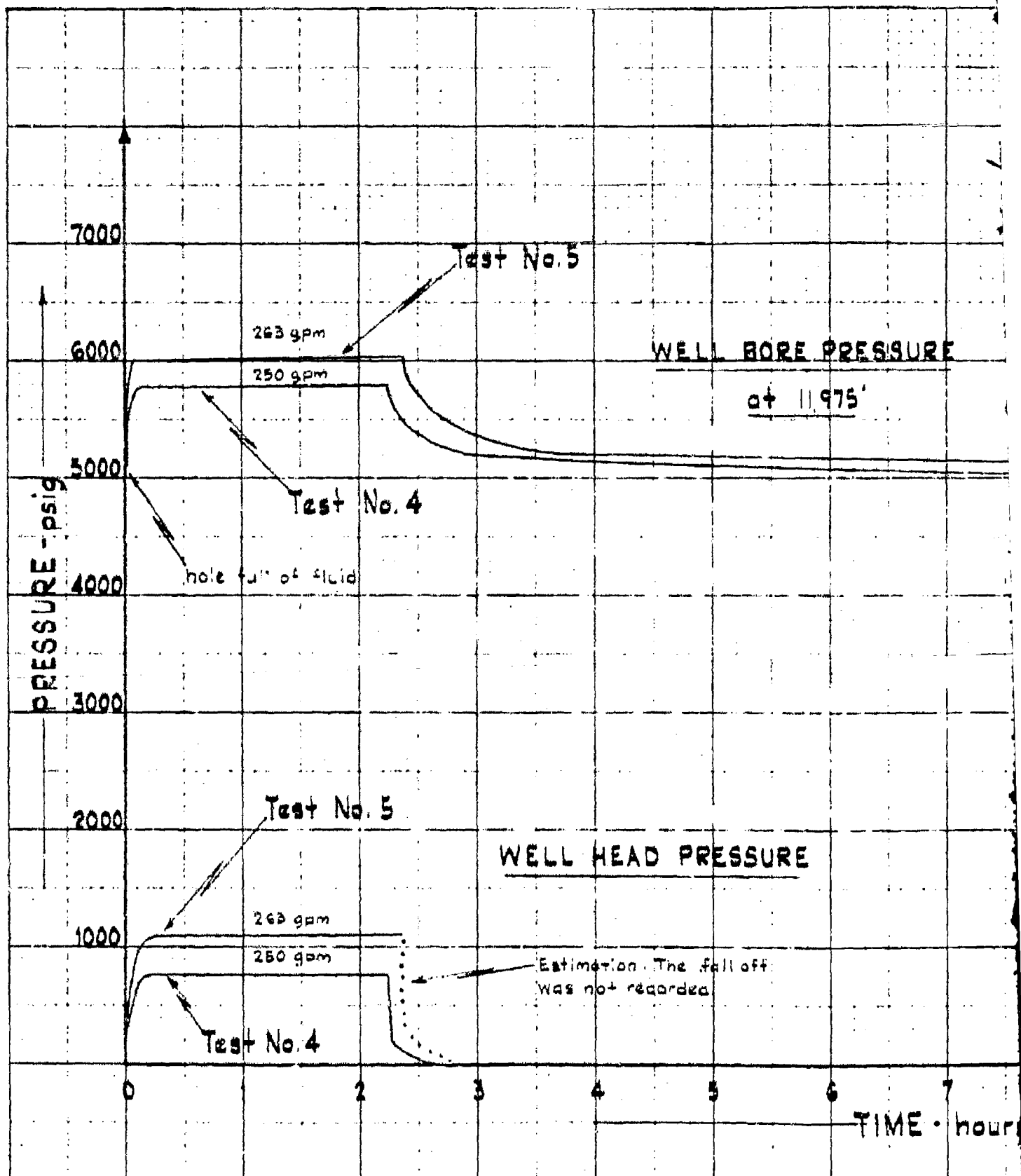


FIGURE 6

ORE PRESSURE

+ 11,975'

RE

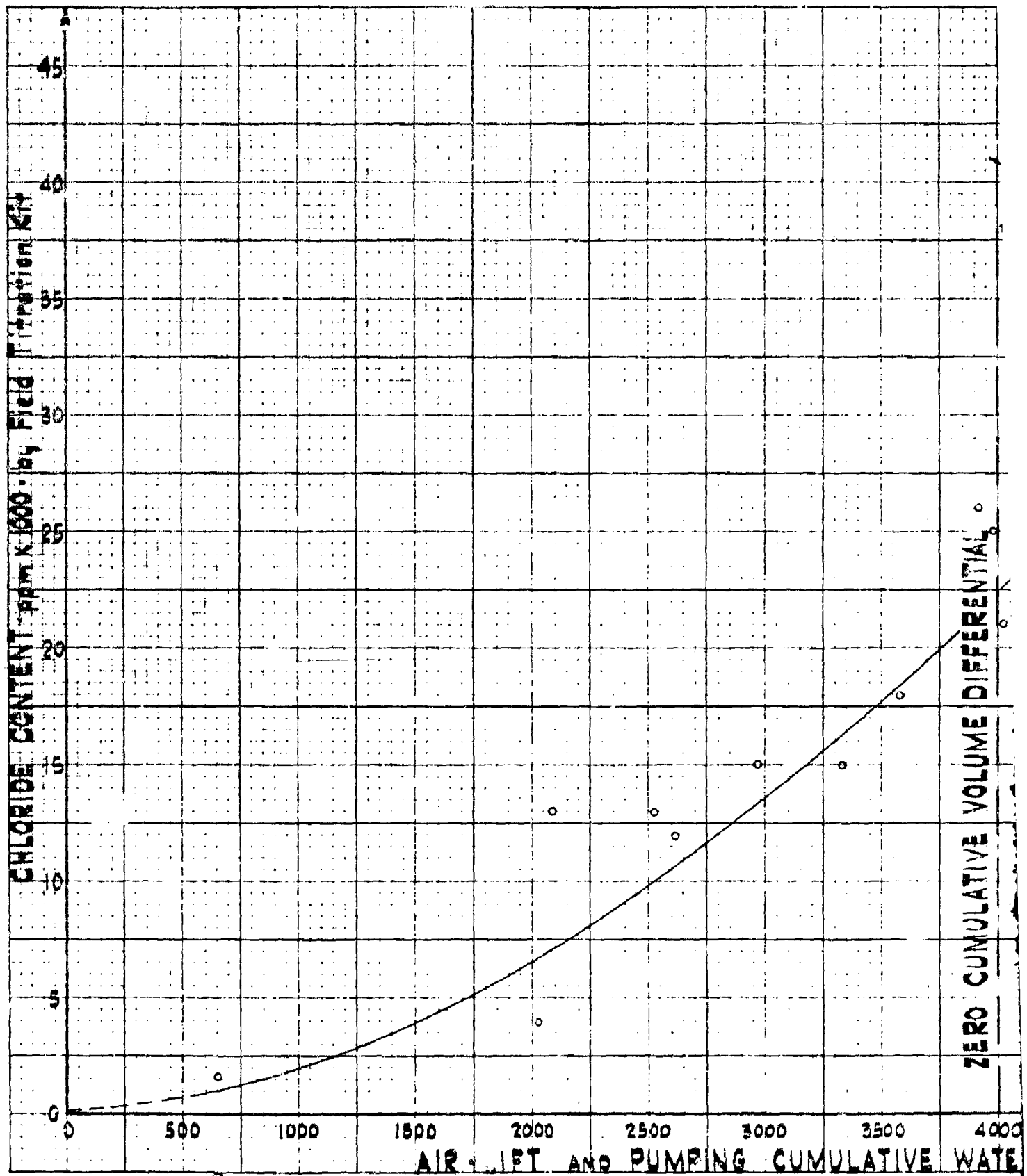
ROCKY MOUNTAIN ARSENAL PRESSURE
INJECTION DISPOSAL WELL
INJECTION TESTS

WITH DRILLING RIG EQUIPMENT
INTERVAL INJECTED: 11,975' - 12,045'

	DATE	Denver City Water	
		INJECTED	
		Gallons	Barrels
Test No. 4	Sep. 20, 1961	20,916	498
Test No. 5	Sep. 21, 1961	57,344	889
* Through 4 1/2" drill pipe hung at 10,700'			

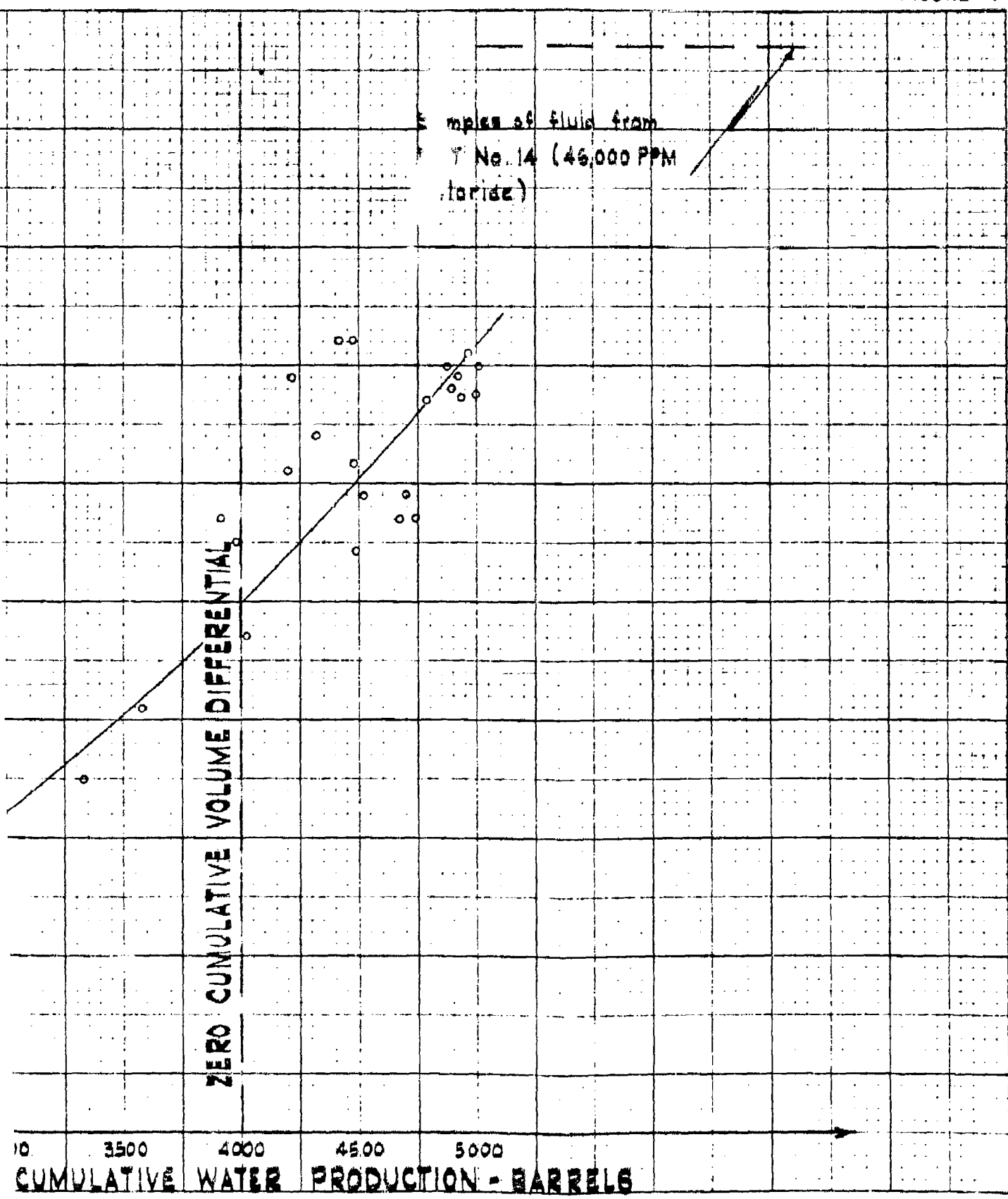
6 7 8 9 10 11 12 13

TIME - hours



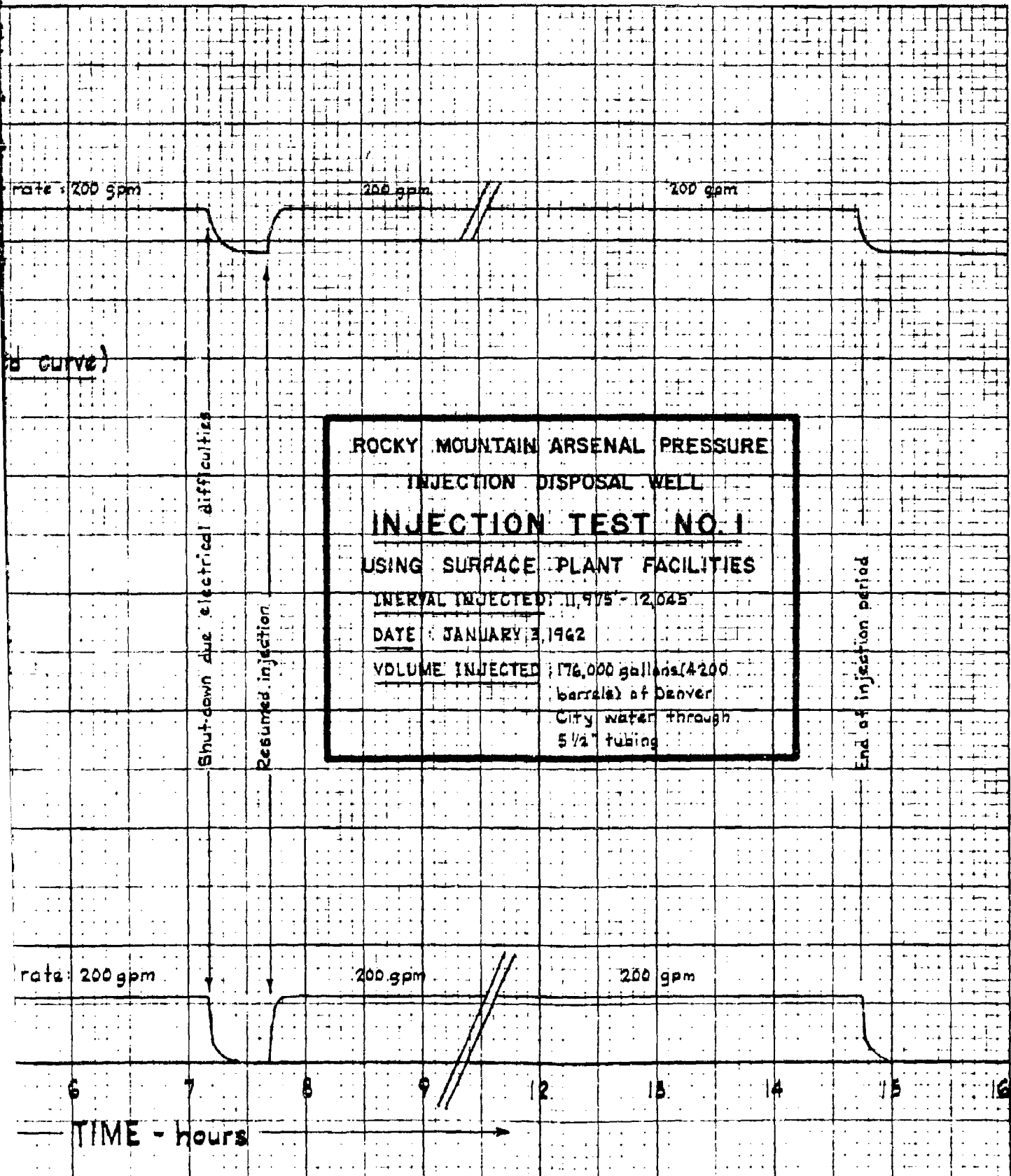
A

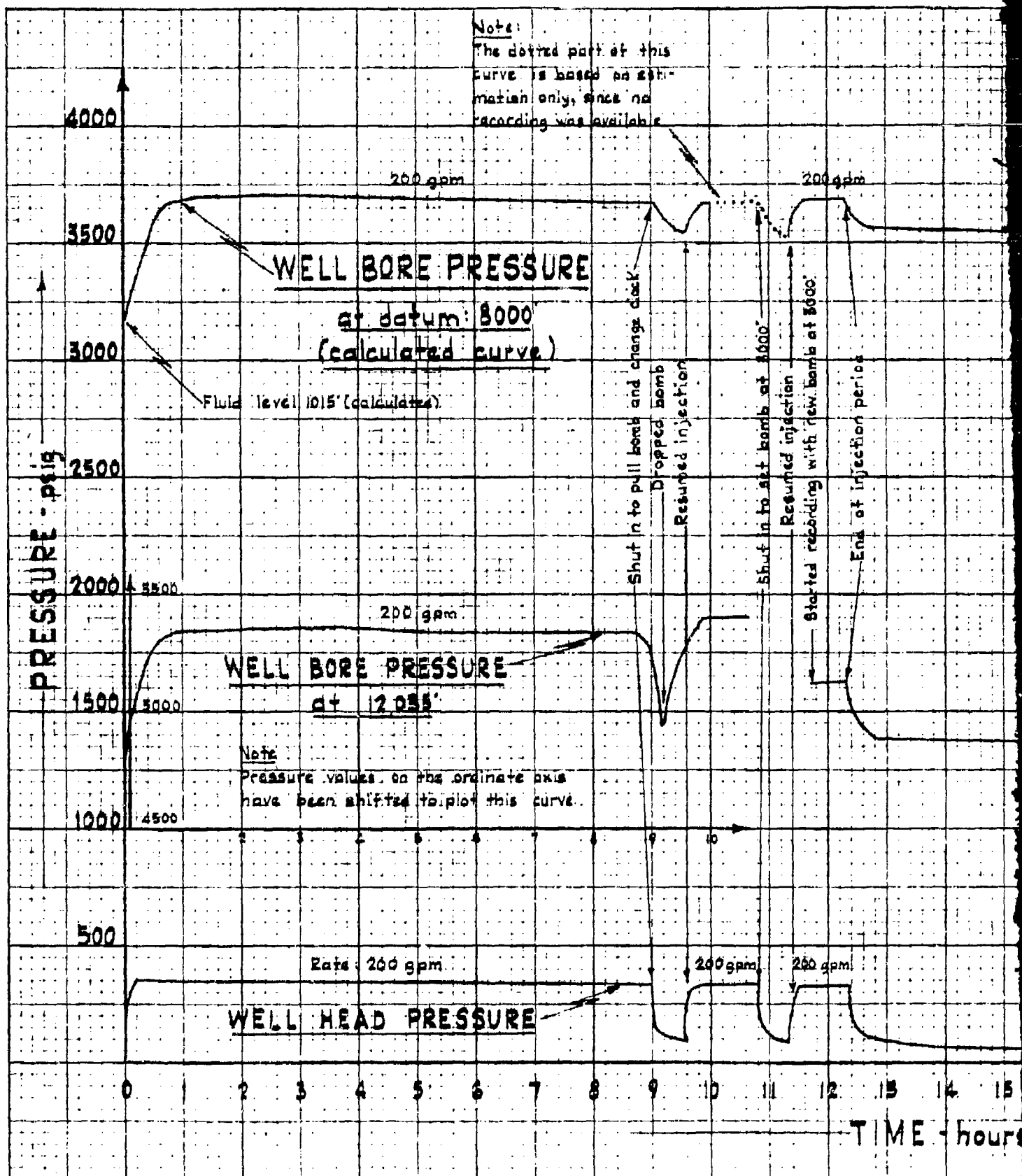
FIGURE 7



B

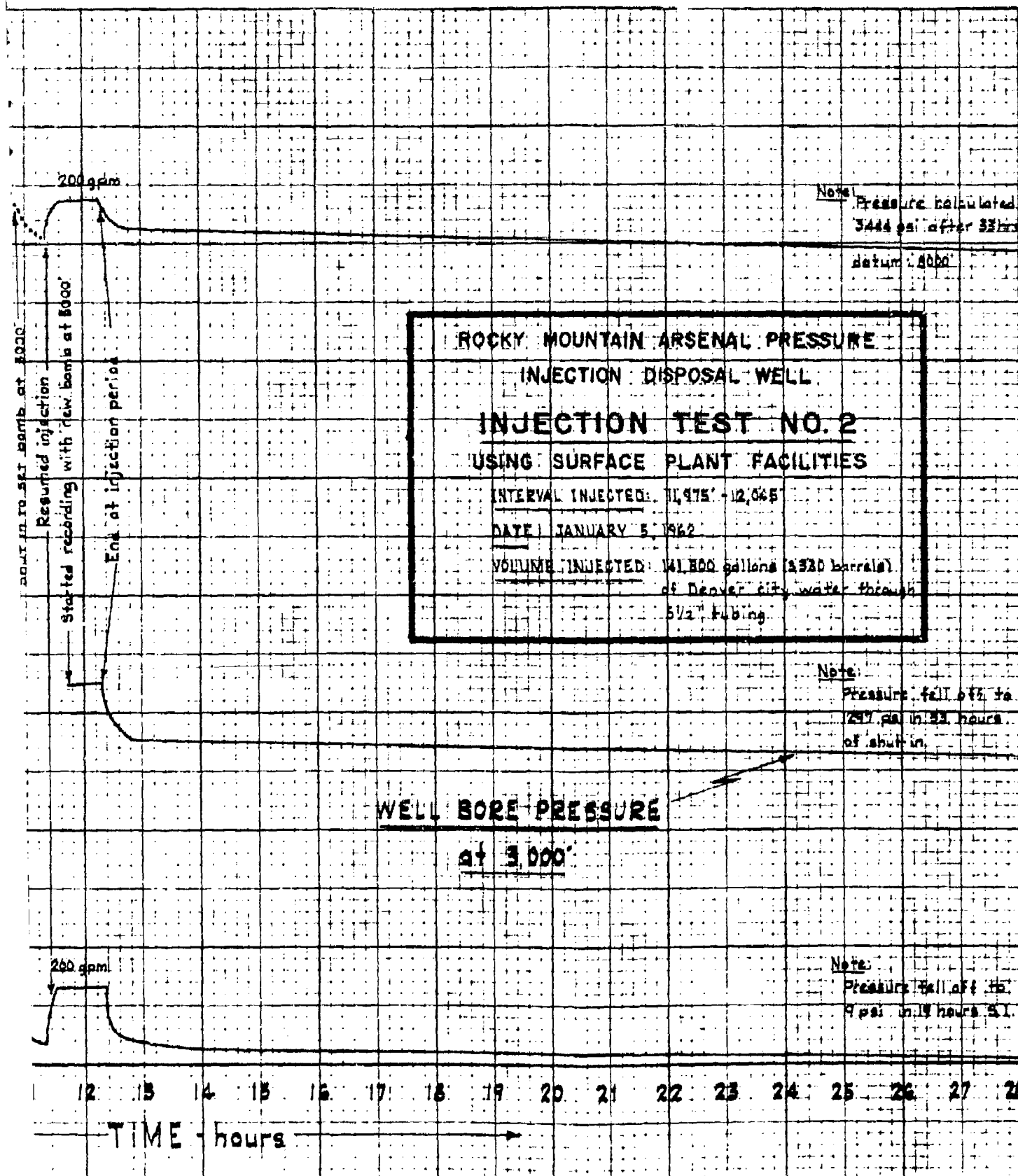
FIGURE 8

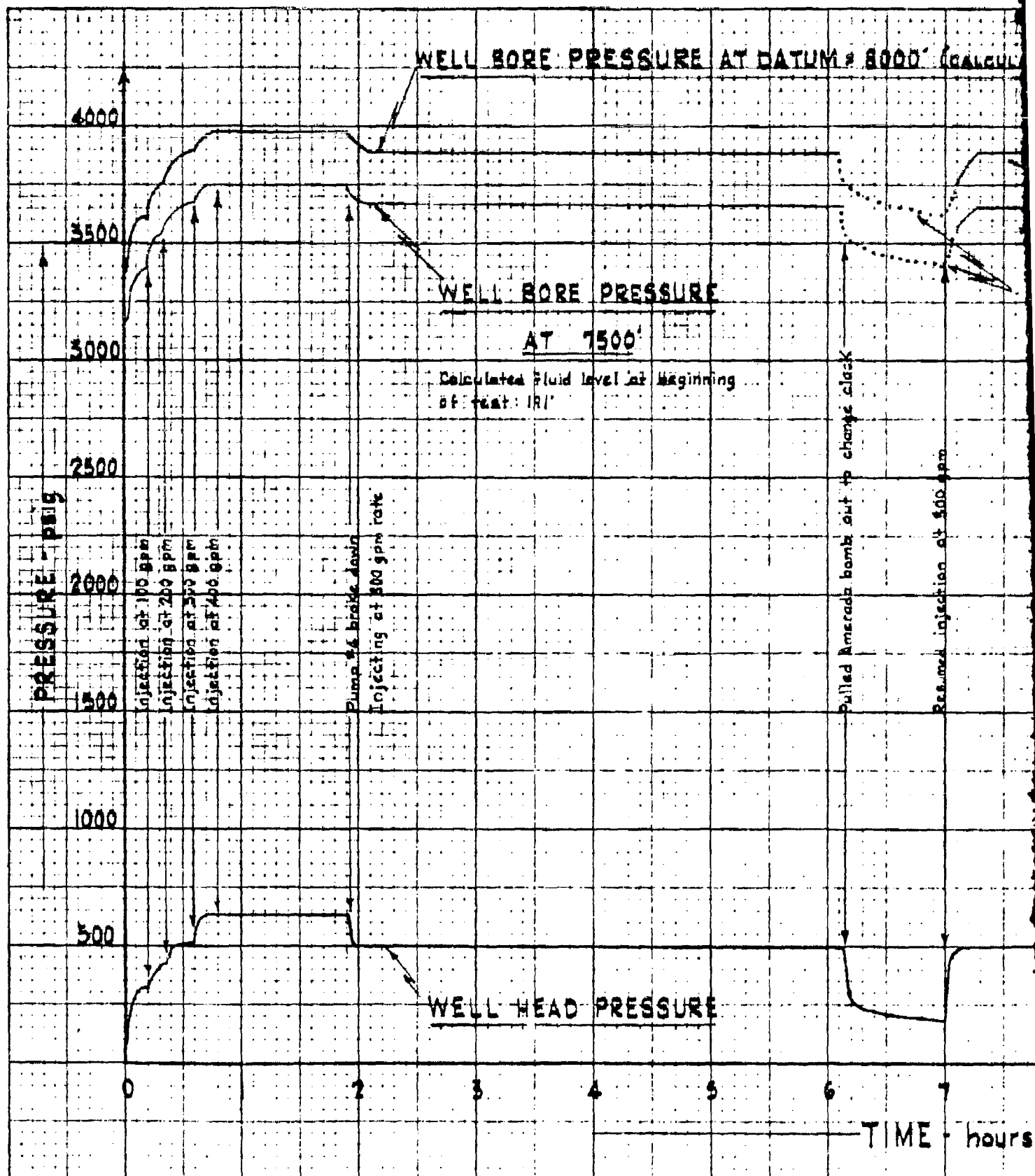




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FIGURE 9





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FIGURE 10

DATUM = 8000' (CALCULATED CURVE)

Note:
Pressure calculated
3416 psi after 36 hours
datum 8000'

Note:
Pressure fall off to
3198 psi in 36 hours
of shut in

Estimated part of the curve

Pulled Amerasia bomb out to change clock

Resumed injection at 800 ppm

End of injection period

ROCKY MOUNTAIN ARSENAL PRESSURE
INJECTION DISPOSAL WELL

INJECTION TEST NO. 3

USING SURFACE PLANT FACILITIES

INTERVAL INJECTED: 11.975 - 2.045

DATE: JANUARY 22, 1962

VOLUME INJECTED: 137,800 gallons (3280
barrels) of Denver
City water through
5 1/2" tubing.

Note:
Pressure fall off to
30 psi after 36 hours
of shut in

TIME - hours

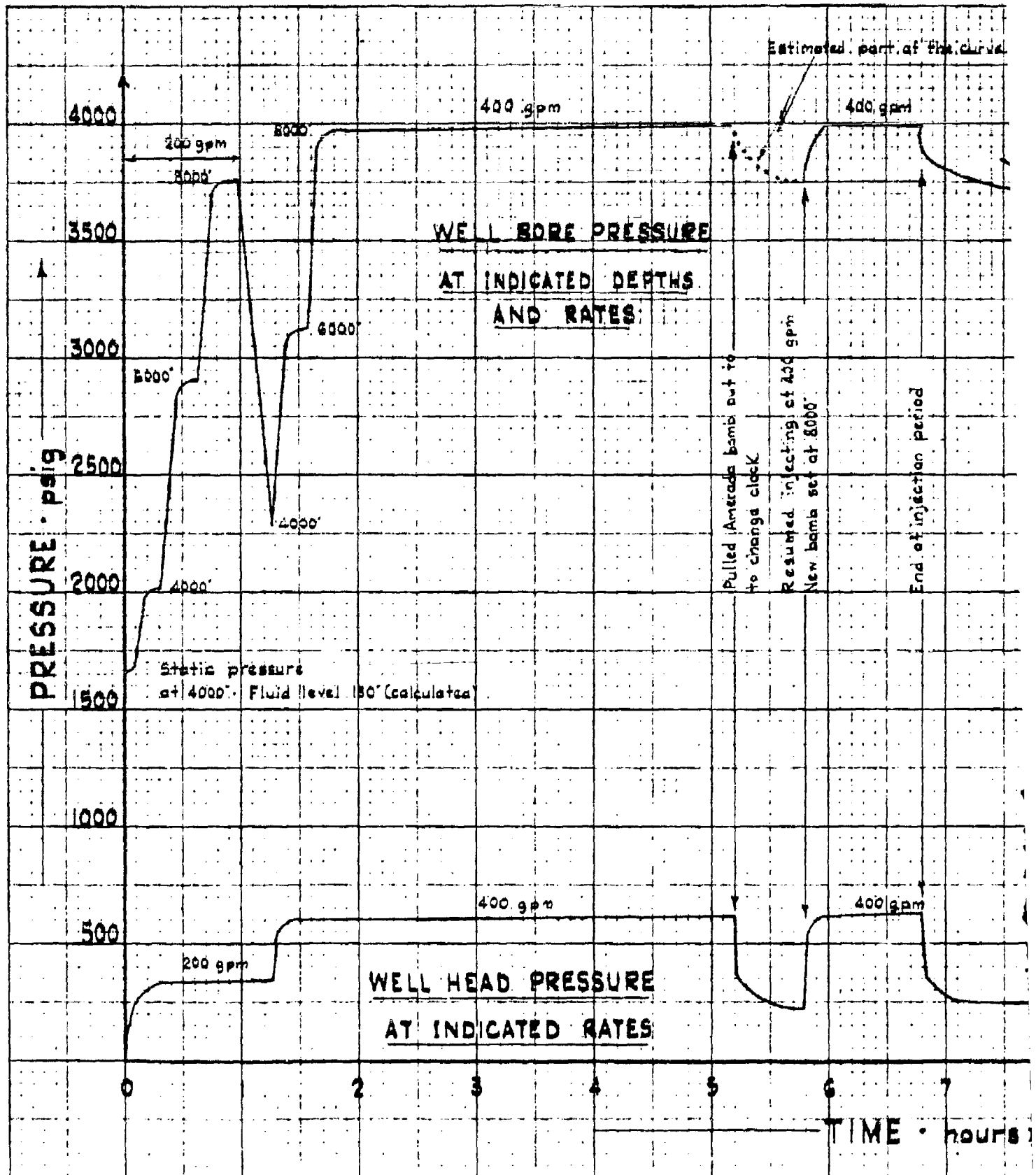
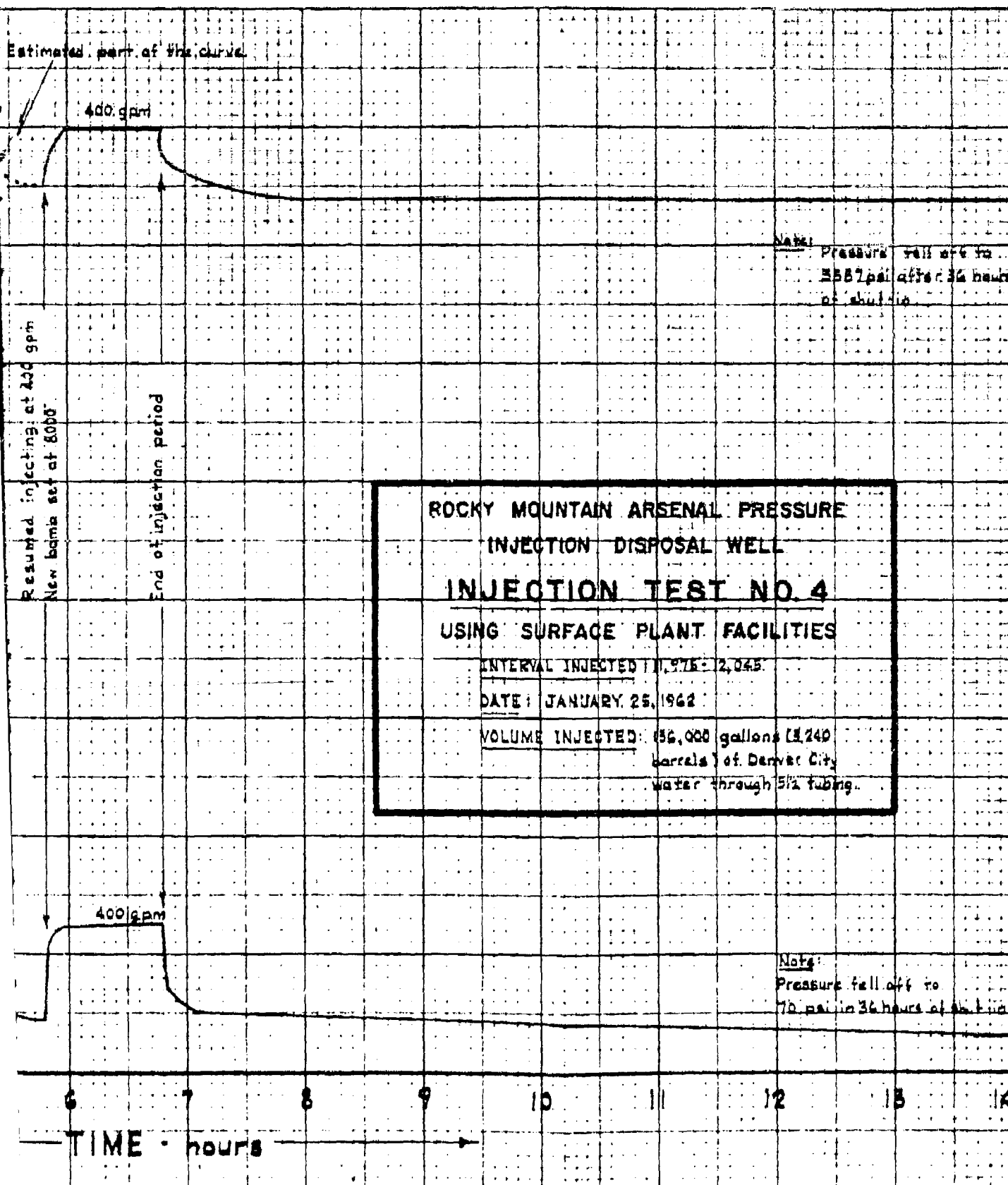
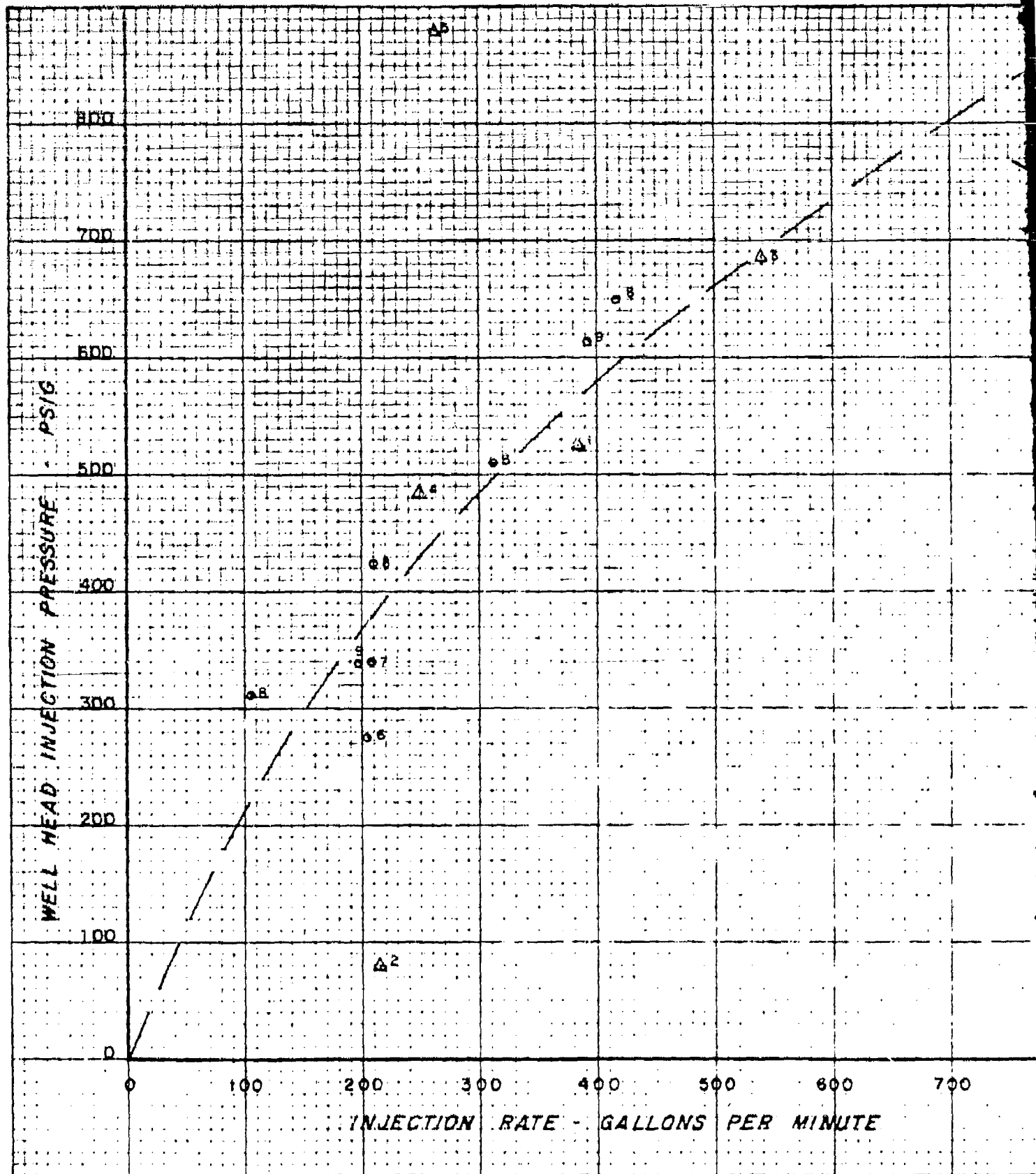


FIGURE 11



ROCKY MOUNTAIN ARSENAL PRESSURE
INJECTION DISPOSAL WELL
INJECTION TEST NO. 4
USING SURFACE PLANT FACILITIES
INTERVAL INJECTED 1,975 - 2,045
DATE: JANUARY 25, 1962
VOLUME INJECTED: 156,000 gallons (1,240
barrels) of Denver City
water through 5 1/2 tubing.



A

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
COMPOSITE GRAPH
INJECTION RATES VS. PRESSURES
PRE-CAMBRIAN INTERVAL 11,975-12,045

LEGEND

Identification	Injection Test No.	Corresponding Figure No. in Report	Injection String	Net Cumulative Injected Volume (Bbls)
Δ^1	1	5	4 7/8" dp*	1635
Δ^2	2	5	"	1660
Δ^3	3	5	"	1800
Δ^4	4	6	"	2352
Δ^5	5	6	"	3926
ϕ^6	1	8	5 1/2" Tubing	3132
ϕ^7	2	9	"	6180
ϕ^8	3	10	"	9630
ϕ^9	4	11	"	12,870

NOTE: The irregularity of points Δ^2 and Δ^5 may be related to the inaccuracy of the volume measurements using rig equipment.

* Pressure values converted to equivalent through 5 1/2" Tubing.

600

700

800

MINUTE

END

5-16-68