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GASBUGGY POSTSHOT HYDROLOGIC INVESTIGATIONS IN GB-3

J. A. Korver

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Abstract

The Gasbuggy postshot well GB-3 was drilled, logged and cored to investigate the effects of the nuclear explosion on the Ojo Alamo aquifer. Postshot investigations in other wells (GB-ER, GB2-RS, and 10-36) indicated that hydraulic communication had been established between the aquifer and the gas reservoir.

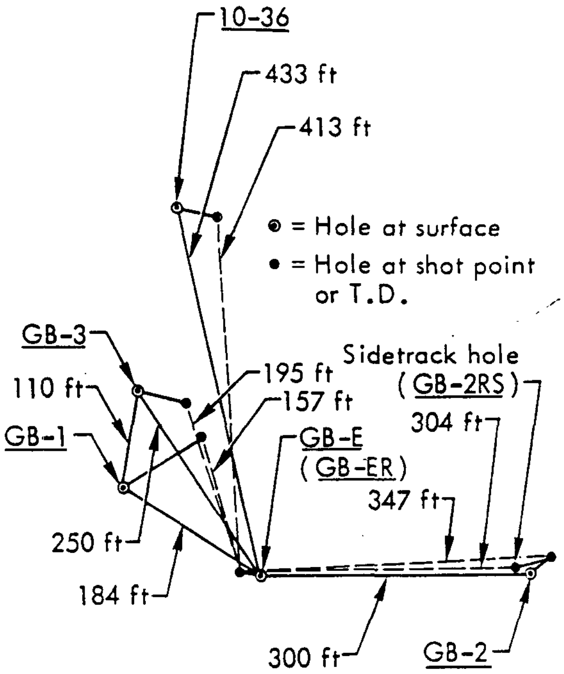
Hydrologic tests in GB-3 indicated that the permeability of the aquifer was increased by factors of 2 to 4 over preshot values at a radial distance of about 630 ft from the shot point. Investigations of the aquifer response to pressure changes in the reservoir, water levels in wells 10-36, GB-3 and the tubing annulus in GB-ER suggest that the main, if not only, point of hydraulic communication between aquifer and reservoir is through casing breaks in GB-ER.

Introduction

One of the objectives to be accomplished during the drilling, coring, and logging of the Gasbuggy postshot well GB-3 (250 ft NE of the emplacement hole) was to investigate the effects of the nuclear explosion on the Ojo Alamo aquifer. Preshot predictions as to the behavior of the aquifer were made in the event that the chimney or fractures extending from the chimney intersected the aquifer.[1] It was expected that some postshot investigation would be undertaken to determine whether hydraulic communication was established, and if so, what effect this might have on the aquifer and the reservoir.

Postshot Hydrologic Studies

Postshot investigations in GB-ER[2] and GB-2RS[3] indicated that possible effects on the aquifer had taken place, although the programs for these holes did not allow for detailed investigations. (See Fig. 1 for a layout of the Gasbuggy holes.) Later reentry drilling in well 10-36 (a preexisting gas well) revealed a casing offset in the lower part of the Ojo Alamo formation which prevented further drilling. It was decided then to perforate the casing in the interval of the aquifer to determine if the elevation of the hydrostatic head differed from that measured preshot. No change in the head was observed after perforation on October 15, 1968, but since



Well	Elevation	Total depth
GB-1	7203.6	4306
GB-2	7201.7	4247
GB-2RS	7201.7	4600
GB-E	7202.1	4350
10-36	7190.6	4210
GB-3	7200.4	4809

Fig. 1. Plan view of tops and bottoms of holes at Gasbuggy site.

production tests in GB-ER were due to begin shortly, a surface-recording pressure transducer was installed in the well by the U. S. Geological Survey.

During the second 30-day production test in GB-ER (December 10, 1968 to January 8, 1969), where the bottom hole pressure (BHP) was held at approximately 700 psig, a noticeable drop in the hydrostatic head in well 10-36 was observed. Subsequent production tests in GB-ER at lower BHP's resulted in correspondingly lower values of the hydrostatic head in well 10-36. Apparently, hydraulic communication of some sort had occurred between the Pictured Cliffs gas reservoir and the Ojo Alamo aquifer which had not existed before the nuclear explosion. Figure 2 is a plot of the BHP history in GB-ER during the production tests, along with the water level history in well 10-36. Also seen is the water level response to the hydrologic tests in well GB-3, and the response to the final flushing experiment in GB-ER, which took place after GB-3 was completed. A suggested explanation of this last response will be discussed later.

An attempt was then made to determine the distance between well 10-36, where the observations were made, and the sink, or point of communication with the gas reservoir.[4] This assumed, of course, that there was only one point of communication. It was also assumed, since no data to the contrary were then available, that the aquifer permeability and porosity were unchanged from preshot values. The results from this analysis indicated that the sink was located at a distance somewhere between 175 to 225 ft from well 10-36.

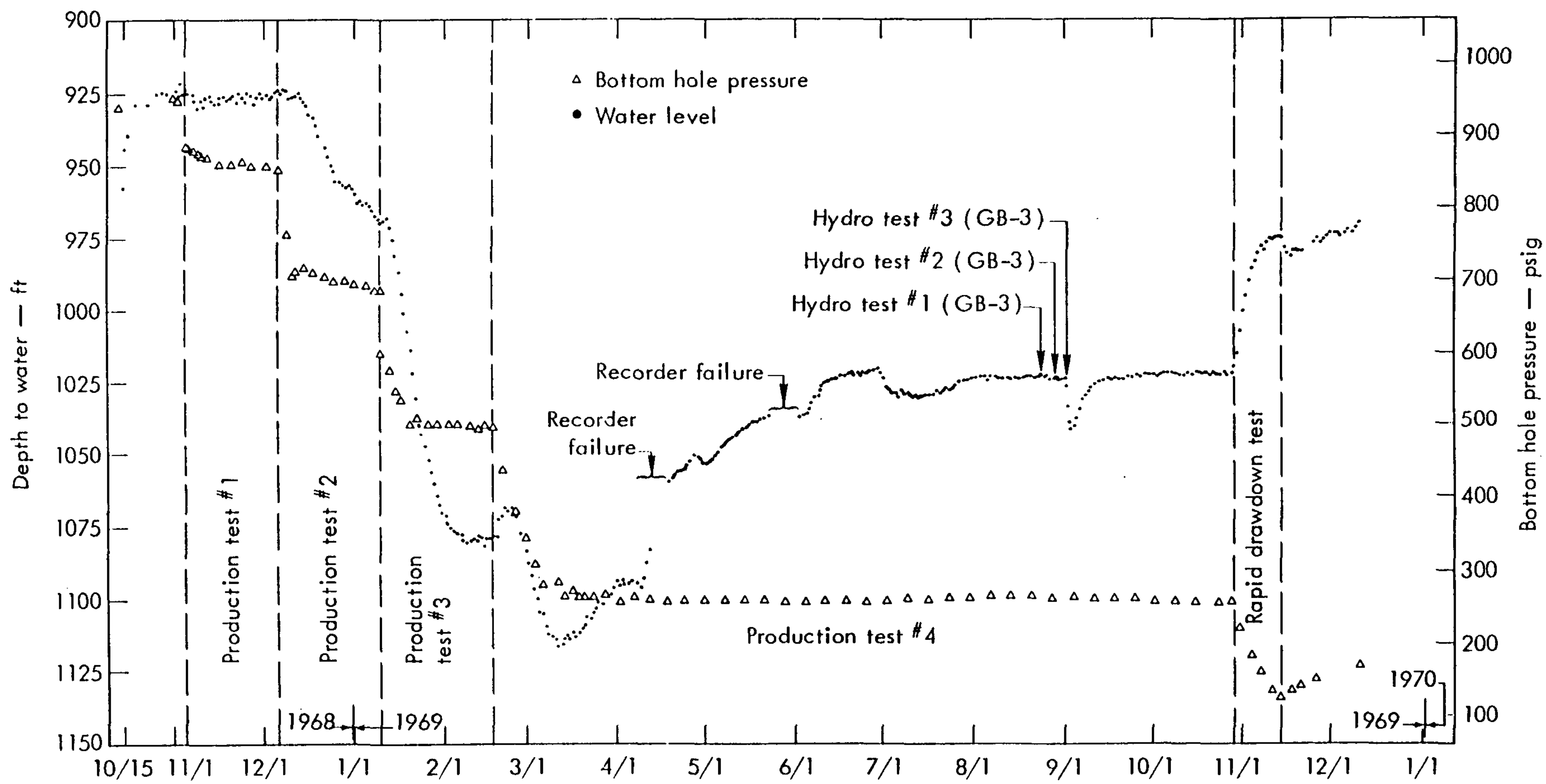


Fig. 2. Depth to water in well 10-36; bottom hole pressure in well GB-ER.

GB-3 Hydrologic Tests

The hydrologic testing program for GB-3 was designed essentially to reproduce the procedures used for hydrologically testing preshot well GB-1, which is 110 ft from GB-3. The purpose of this was to make the results of the GB-1 and GB-3 tests as directly comparable as possible. The relatively small distance between these two holes (40 to 50 ft in the Ojo Alamo formation) also makes the results more comparable.

The first hydrologic test began on August 24, 1969, after the hole had been drilled and cored to 3575 ft (KB measurement). A Lynes inflatable packer was set at 3476 to 3481 ft, and 2-3/8 in. tubing was run through the packer. Swabbing through the tubing began at 2153 hours, and ceased at 0700 hours on August 25. Results of the swab test (shown in Table 1) indicate that, although the packer seat was apparently good, bypass of annulus fluid (mud) took place throughout the test. The consensus is that the formation was fractured in the interval where the packer was set.

The hole was then deepened (cored) from 3575 to 3647 ft and logged (3-arm caliper, density, and formation gamma logs). On the basis of the logs it was decided to attempt a second swab test with the top of the packer set at 3471 ft, or 5 ft higher than the first seat. Swabbing began at 1418 hours on August 29 and continued until 1950 hours. The swab test was again unsuccessful in that the swabbed fluid was mostly drilling mud (see Table 2). As a result, further attempts to test the upper part of the Ojo Alamo aquifer were abandoned. After discussions with El Paso Natural Gas personnel in El Paso it was decided to go back to coring and cut another 60 ft of core, run gamma-density-caliper logs, and on the basis of these logs and the core, pick a new packer seat and attempt to test the lower part of the Ojo Alamo aquifer.

Coring began at 3647 ft on August 31 and continued to 3699 ft on the morning of September 1. This core, which consisted of shale with interbedded fine sandstones of the Kirtland and upper Fruitland formations, was severely broken with randomly oriented fractures. A packer seat was picked at 3576 to 3581 ft from an examination of the logs which were run following the coring.

The third swab test started at 1431 hours on September 1 and ended at 2034 hours. This time the test appeared to be successful, in that conductivity and pH tests indicated that most of the fluid swabbed was formation water (see Table 3).

Measurements of the aquifer recovery began at 2152 hours, using the USGS "Iron Horse" probe. The recovery was followed until 0624 hours (September 2) at which time approximately 100 gal of makeup water was injected in the hole. The water level decline was then measured until 0844 hours, thus concluding the recovery test (Table 4).

Table 1. GB-3 swab test No. 1.

Date: 8/24-25/69
Interval tested: 3480.76 to 3575 ft

Run No.	Clock time	$\sum \Delta t$ (min)	Staff gauge (ft)	Δq (gal)	$\Delta q/\Delta t$ (gal/min)	$\sum \frac{\Delta q}{\Delta t}$ (gal/min)	Swab depth (ft)	Water level (ft)	kH (md-ft)
1	2153	0					600		
2	2157	4					900		
3	2205	12					1500		
4	2213	20					1700		
5	2221	28					2000	700	
6	2230	37					2200	1000	
7	2243	50					2500	1200	
8	2256	63					2800	1200	
9	2308	75					2900	1200	
10	2328	95					2900		
11	2348	115					2700	800-900	
12	0004	131					2500	900-1000	
13	0027	154					2500	1000	
14	0048	0	0.0	0	0	0	2500	1050	0
15	0102	14	0.14	82.3	5.90	5.90	2500	1050	14.5
16	0126	38	0.40	153.0	5.62	11.52	2500	1050	29.7
17	0147	59	0.70	177.0	7.35	18.87	1800	750	41.4
18	0307	139	0.75	29.4	1.40	20.27	2500	800	51.0
19	0327	159	1.14	172.6	2.16	22.43	2500	800	54.7
20	0343	175	1.48	226.0	13.82	36.25	2500	800	89.1
21	0358	190	1.85	217.5	12.25	48.50	2500	900	119.5
22	0428	220	2.16	183.0	12.15	60.65	2500	900	148.5
23	0452	244	2.78	365.0	12.04	72.69	2500	1000	178.0
24	0512	264	3.27	288.0	10.30	87.99	2500	1050	203.0
25	0530	282	3.62	207.0	11.75	94.74	2500	1100	232.0
26	0548	300	3.98	212.0	9.80	104.54	2500	1100	256.0
27	0606	318	4.28	176.5	9.45	113.99	2500	1100	279.0
28	0624	336	4.57	170.5	[a]9.15	123.14	2500	1100	302.0
29	0647	359	4.85	164.0					
	0697								

Table 2. GB-3 swab test No. 2.

Date: 8/29/69
Interval tested: 3475.42 to 3647 ft

Run No.	Clock time	$\sum \Delta t$ (min)	Staff gauge (ft)	Δq (gal)	$\Delta q/\Delta t$ (gal/ min)	$\sum \frac{\Delta q}{\Delta t}$ (gal/min)	Swab depth (ft)	Water level (ft)	kH (md-ft)
1	1418	0					1200	0	
2	1427	9					1400	300	
3	1436	18					1500	350	
4	1446	28					1600	400	
5	1456	38					1700	450	
6	1507	49					1750	500	
7	1524	66					1750	550	
8	1537	79					2100	650	
9	1548	0	0	0	0	0	2200	750	
10	1601	13	0.07	29.4	22.60	22.6	2300	800	63.3
11	1615	27	0.19	67.1	12.57	35.17	2300	900	98.5
12	1630	42	0.49	176.0	5.33	50.50	2300	900	141.2
13	1645	57	0.88	230.0	9.80	60.30	2300	950	168.9
14	1700	72	1.13	147.0	8.88	66.18	2400	1000	185.3
15	1725	97	1.28	88.2	7.06	73.94	2400	1050	207.0
16	1740	112	1.58	176.4	13.82	87.66	2400	1050	245.5
17	1756	128	1.93	205.8	14.70	103.36	2400	700	290.3
18	1813	145	2.53	235.2	5.19	108.55	2000	800	390.5
19	1837	169	2.68	88.2	3.68	112.23	2400	800	314.2
20	1851	183	2.88	117.6	8.47	120.70	2400	900	336.2
21	1904	196	3.08	117.6	9.05	129.75	2400	900	363.3
22	1919	211	3.23	88.2	9.80	139.55	2400	800	390.7
23	1934	226	3.58	147.0	5.88	145.43	2400	700	407.2
24	1950	242	3.73	88.2			1700	500	

Table 3. GB-3 swab test No. 3.

Date: 9/1/69
Interval tested: 3580 to 3699 ft

Run No.	Clock time	$\sum \Delta t$ (min)	Staff gauge (ft)	Δq (gal)	$\Delta q/\Delta t$ (gal/min)	$\sum \frac{\Delta q}{\Delta t}$ (gal/min)	Swab depth (ft)	Water level (ft)	kH[a] (md-ft)
1	1431	0					1200	0	
2	1439	8					1500	300	
3	1453	22					1800	400	
4	1504	33					1900	550	
5	1515	44					2000	700	
6	1535	64					2100	900	
7	1546	75					2200	1000	
8	1600	89					2200	1100	
9	1613	102					2400	1200	
10	1628	117					2500	1300	
11	1638	127					2600	1500	
12	1650	139					2600	1500	
13	1715	0	0.83	0	0	0	2700	1600	
14	1730	15	1.02	111.7	7.44	7.44	2700	1650	
15	1745	30	1.28	152.9	10.19	17.63	2700	1650	
16	1800	45	1.52	141.1	9.02	26.65	2700	1700	
17	1815	60	1.75	135.2	7.84	34.49	2700	1750	
18	1830	75	1.95	117.6	5.88	40.37	2700		
19	1848	93	2.10	88.2	4.90	45.27	2700	1800	
20	1858	103	2.29	117.7	11.17	56.44	2700	1800	
21	1908	113	2.47	105.8	8.23	64.67	2700	1800	
22	1920	125	2.61	82.3	7.06	71.73	2700	1800	
23	1930	135	2.73	70.6	7.06	78.79	2700	1800	
24	1941	146	2.85	70.6	6.41	85.20	2700	1800	
25	1952	157	3.00	88.2	8.02	93.22	2700	1800	
26	2002	167	3.10	58.8	5.88	99.10	2700		
27	2013	178	3.25	88.2	8.02	107.12	2700	1800	
28	2033	188	3.36	64.7	6.47	113.59	2700		
29	2034	199	3.45	52.9	4.81	118.40	2700		

[a]Values given in Table 6.

Table 4. GB-3 recovery test.

Date: 9/1-9/2/69
t_0 = 199 min

Clock time	Δt (min)	Water level (ft)	$\frac{t_0 + \Delta t}{\Delta t}$	Clock time	Δt (min)	Water level (ft)	$\frac{t_0 + \Delta t}{\Delta t}$
2152	78	1912	3.550	0400	446	1246	1.446
2204	90	1847	3.210	0500	506	1221	1.394
2206	92	1837	3.163	0550	556	1206	1.358
2209	95	1821	3.095	0624	590	1198	1.337
2213	99	1804	3.001	Injected 100 gal water			
2221	107	1771	2.860	0701	627	1083	1.314
2229	115	1738	2.731	0704	630	1084	1.313
2238	124	1706	2.605	0707	633	1085	1.313
2248	134	1673	2.486	0710	636	1086	1.312
2258	144	1641	2.382	0713	639	1087	1.311
2309	155	1607	2.284	0716	642	1089	1.310
2321	167	1575	2.192	0719	645	1090	1.308
2334	180	1542	2.105	0724	650	1092	1.306
2348	194	1509	2.027	0731	657	1094	1.303
0005	211	1476	1.943	0738	664	1096	1.300
0023	229	1442	1.869	0743	669	1097	1.297
0043	249	1410	1.799	0753	679	1100	1.293
0108	274	1378	1.726	0804	690	1104	1.289
0137	303	1345	1.657	0824	710	1108	1.280
0213	339	1312	1.587	0844	730	1112	1.273
0300	386	1279	1.516				

Hydrologic Data Analysis

Only the data from the third swab and recovery tests are considered to be valid. The analyses, then, are based on these data.

In conjunction with each of the swab tests, pressure recorders and maximum recording temperature thermometers were run below the packer. Comparison of these data (Table 5) with the water levels and swabbing depths on each swab run reported by the swab line operator show that the two do not agree. Considering that the operator counted turns on the line spool to determine the depths, it is felt by the author that the pressure recorders are more accurate. Table 6 presents the data from the third swab test, along with the kH products calculated from both sets of data. The kH values in Table 6 were computed by using the following equation[5];

$$kH = \frac{\mu \sum \frac{\Delta q}{\Delta t}}{1.791 \times 10^{-4} \Delta H}$$

where

kH is the permeability-thickness product (md-ft),

μ is the fluid viscosity (cp),

$\sum(\Delta q/\Delta t)$ is the summation of the production rates (gal/min),

ΔH is the drawdown from the static head (ft), and

1.791×10^{-4} is a unit conversion factor.

The viscosity μ is determined from the maximum temperature which was reported as 124°F. This corresponds to a viscosity of 0.54 cp. The static head was determined from an extrapolation of the water level to $[(t_0 + \Delta t)/\Delta t] = 1$ in Fig. 3 (t_0 is the elapsed time after swabbing started and Δt is the elapsed time after swabbing stopped). This value is 1148 ft below the surface.

The final kH products from the swab test (Table 6) are:

$$kH_{(oper)} = 247.9 \text{ md-ft}$$

$$kH_{(bomb)} = 257.9 \text{ md-ft}$$

where the subscripts

(oper) = swab line operator's data and

(bomb) = pressure bomb data.

The kH product can also be determined from a graphical construction on the recovery curve and the equation[5]

$$kH = \frac{1.151 (\overline{\Delta q}/\Delta t)\mu}{8.953 \times 10^{-5} \Delta H_{10}}$$

where

1.151 is the slope of dimensionless pressure over dimensionless time for time sufficiently large,

$\overline{\Delta q}/\Delta t$ is the average production rate during swabbing (gal/min),

ΔH_{10} is the change in head over one log cycle,

μ is the fluid viscosity (cp), and

8.953×10^{-5} is a unit conversion factor.

Substitution of the appropriate values in the above equation results in

$$kH = 162.1 \text{ md-ft}.$$

Table 5. GB-3 pressure bomb data.

Date: 9/1/69

		High			Low		
Run No.	Clock time	Pressure (psig)	Equiv. head (ft)	Depth to water (ft)	Pressure (psig)	Equiv. head (ft)	Depth to water (ft)
1	1431	1561	3630	-50	1424	3310	270
2	1439	1462	3400	180	1336	3108	472
3	1453	1367	3178	402	1194	2776	804
4	1504	1235	2873	709	1080	2513	1067
5	1515	1124	2615	965	993	2309	1271
6	1535	1053	2449	1131	916	2160	1420
7	1546	963	2239	1341	844	1963	1617
8	1600	904	2102	1478	801	1862	1718
9	1613	872	2028	1552	750	1745	1835
10	1628	832	1935	1645	701	1630	1950
11	1638	783	1821	1759	655	1523	2057
12	1650	740	1720	1860	611	1421	2159
13	1715	740	1720	1860	590	1372	2208
14	1730	678	1576	2004	534	1242	2338
15	1745	616	1432	2148	496	1153	2427
16	1800	584	1358	2222	467	1086	2494
17	1815	564	1311	2269	468	1088	2492
18	1830	569	1323	2257	468	1088	2492
19	1848	551	1281	2301	451	1048	2532
20	1858	546	1270	2310	442	1028	2552
21	1908	541	1257	2323	432	1000	2580
22	1920	530	1233	2347	432	1000	2580
23	1930	530	1233	2347	432	1000	2580
24	1941	530	1233	2347	432	1000	2580
25	1952	530	1233	2347	432	1000	2580
26	2002	530	1233	2347	432	1000	2580
27	2013	530	1233	2347	432	1000	2580
28	2023	530	1233	2347	432	1000	2580
29	2034	544	1265	2315	449	1044	2536

Table 6. GB-3 swab test No. 3.

Date: 9/1/69
Interval tested: 3580-3699 ft

Run No.	Clock time	Δt (min)	Staff gauge (ft)	Δq (gal)	Δq/Δt (gal/min)	$\sum \frac{\Delta q}{\Delta t}$ (gal/min)	Water level (ft) (oper)	Water level (ft) (bomb)	Swab depth (ft) (oper)	Swab depth (ft) (bomb)	kH (md-ft) (oper)	kH (md-ft) (bomb)
13	1715	0	0.83	0.72	0	0	1600	1860	2700	2208		
14	1730	15	1.02	111.72	7.44	7.44	1650	2004	2700	2338	14.53	18.92
15	1795	30	1.28	152.88	10.19	17.63	1650	2148	2700	2427	34.45	41.70
16	1800	45	1.52	141.12	9.02	26.65	1700	2222	2700	2494	52.10	59.90
17	1815	60	1.75	135.24	7.84	34.49	1750	2269	2700	2492	67.40	77.65
18	1830	75	1.95	117.60	5.88	40.37		2257	2700	2492	78.90	101.0
19	1848	93	2.10	88.20	4.90	45.27	1800	2301	2700	2532	88.45	110.1
20	1858	103	2.29	117.72	11.17	56.44	1800	2310	2700	2552	110.3	121.7
21	1908	113	2.47	105.84	8.23	64.67	1800	2323	2700	2580	126.3	136.6
22	1920	125	2.61	82.32	7.06	71.73	1800	2347	2700	2580	140.1	151.5
23	1930	135	2.73	70.56	7.06	78.79	1800	2347	2700	2580	153.9	166.5
24	1941	146	2.85	70.56	6.41	85.20	1800	2347	2700	2580	166.5	180.0
25	1952	157	3.00	88.20	8.02	93.22	1800	2347	2700	2580	182.1	197.0
26	2002	167	3.10	58.80	5.88	99.10		2347	2700	2580	193.7	209.5
27	2013	178	3.25	88.20	8.02	107.12	1800	2347	2700	2580	209.3	226.3
28	2023	188	3.36	64.68	6.47	113.59		2347	2700	2580	237.9	240.0
29	2034	199	3.45	52.90	4.81	118.40		2315	2700	2536	247.9	257.9
30	2041		3.52									
						End Test						

An examination of the density log (Fig. 4) and the core lab measured permeabilities (Table 7) in the interval of the swab test provides a method for determining an approximate permeability of the lower part of the Ojo Alamo from the kH values. It is assumed that only those portions of the aquifer where the measured porosities and permeabilities are relatively high are water-producing. The effective producing interval, then, is 54 ft thick. Using this value of H,

$$k_{(oper)} = 247.9/54 = 4.59 \text{ md}$$

$$k_{(bomb)} = 257.9/54 = 4.78 \text{ md}$$

$$k_{(recovery)} = 162.1/54 = 3.01 \text{ md}.$$

During each of the three swab tests, the pressure recorder in well 10-36 was monitored to determine if any response to the tests was observable. No response was noted during the first two unsuccessful tests, but after the third test the water level in 10-36 dropped rapidly, and then slowly recovered (see Fig. 2). This response afforded another method of

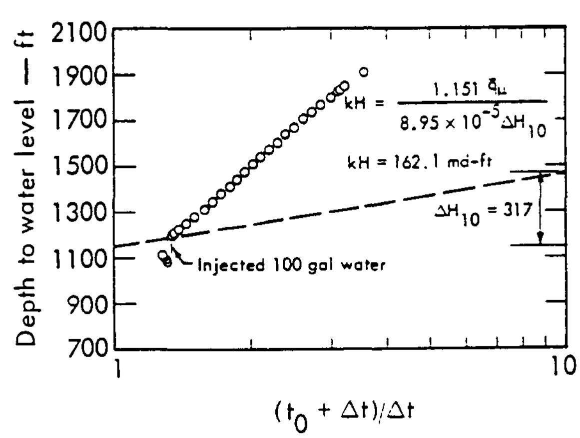


Fig. 3. GB-3 water level recovery (September 2, 1969).

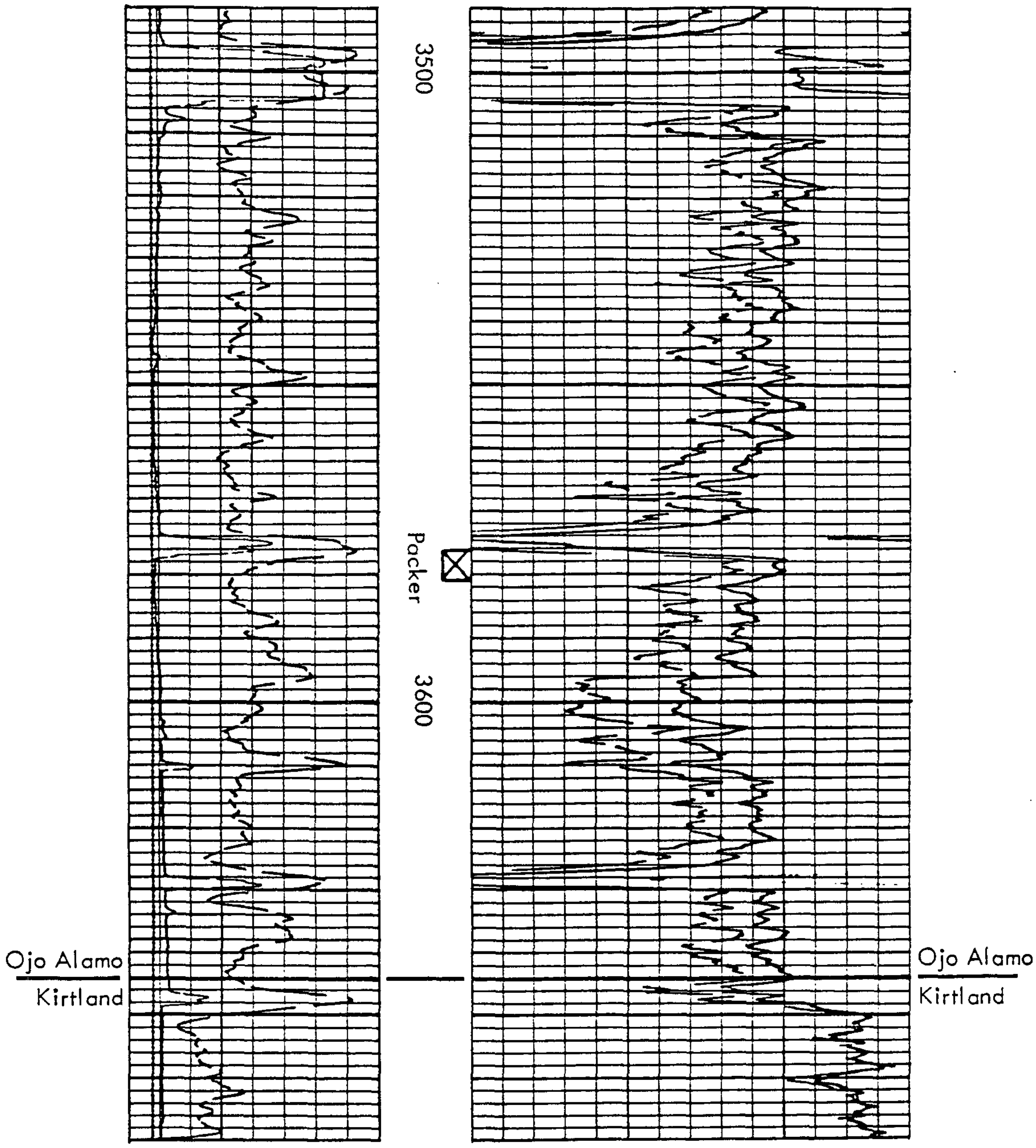


Fig. 4. Density log for well GB-3.

determining the permeability of the Ojo Alamo aquifer.

An examination of the strip chart of the pressure in 10-36 (Fig. 5) shows that the pressure transient from the swab test in GB-3 was felt at 10-36 about five hours after swabbing was begun. This transit time can be used to determine an approximate permeability of the aquifer between GB-3 and 10-36 by the relation[6]

$$k = \frac{0.04 \, \mu \, c \, \phi \, r_e^2}{\Delta t}$$

where

$\mu = 0.54$ cp,

$c = 3.31 \times 10^{-6}\ psi^{-1}$,

$\phi = 0.13$,

$r_e^2 = (222.5)^2\ ft^2 = 4.95 \times 10^4\ ft^2$, and

$t = 300\ min = 2.085 \times 10^{-1}\ day$.

Then,

$$k = \frac{4 \times 10^{-2} \times 3.31 \times 10^{-6} \times 1.3 \times 10^{-1} \times 5.4 \times 10^{-1} \times 4.95 \times 10^{4}}{2.085 \times 10^{-1}}$$

$k = 2.21 \times 10^{-3}$ darcies = 2.21 md.

Table 7. Core analysis results.

Date: 8/28/69

Sample No.	Depth (ft)	Permeability (md)		Porosity (%)	Residual saturation % pore		Sample[a] description and remarks
		Horiz.	Vert.		Oil	Total water	
10	3576-77	0.05	0.04	10.7	0.0	85.9	Wh, fine-med, very slightly calcareous
11	3578-79	0.32	0.19	11.6	0.0	81.0	Wh, fine-med, very slightly calcareous
12	3580-81	1.2	1.1	12.1	0.0	84.3	Wh, med-coarse, very slightly calcareous
13	3582-83	1.24	1.04	13.7	0.0	85.4	Wh, med-course, very slightly calcareous
14	3584-85	1.24	0.41	13.7	0.0	81.7	Wh, med-coarse, very slightly calcareous
15	3586-87	0.55	0.17	12.1	0.0	76.0	Wh, med-coarse, very slightly calcareous
16	3588-89	28	2.1	15.8	0.0	86.1	Wh, med-coarse, very slightly calcareous
17	3590-91	4.8	2.6	13.3	0.0	81.2	Wh. coarse, very slightly calcareous, carb
18	3592-93	9.0	2.1	15.3	0.0	86.3	Wh, med-coarse, slightly calcareous
19	3594-95	20	13.00	17.7	0.0	85.3	Wh, coarse, slightly calcareous, vertically fractured
20	3596-97	27	26.00	20.2	0.0	87.6	Wh, med-coarse, slightly calcareous
21	3598-99	35	21.00	17.9	0.0	86.5	Wh, med-coarse, slightly calcareous
22	3600-01	25	21.00	19.1	0.0	85.4	Wh, med, very slightly calcareous
23	3602-03	57	43.00	19.8	0.0	81.3	Wh, fine-med, very slightly calcareous
24	3604-05	51	23.00	21.5	0.0	82.4	Wh, med-coarse, slightly calcareous
25	3606-07	46	30.00	18.3	0.0	83.6	Gry, fine-med, slightly calcareous
26	3608-09	5.6	2.1	16.5	0.0	85.5	Gry, fine-med, slightly calcareous
27	3610-11	1.4	1.2	12.0	0.0	69.1	Gry, fine-med, slightly calcareous
28	3612-13	0.6	0.47	13.0	0.0	78.4	Gry, fine-med, slightly calcareous
29	3614-15	0.07	0.05	9.5	0.0	72.7	Gry, fine-med, slightly calcareous
30	3616-17	0.66	0.47	12.7	0.0	78.6	Gry, fine-med, slightly calcareous
31	3618-19	0.66	0.47	12.2	0.0	77.1	Gry, fine-med, slightly calcareous
32	3620-21	0.66	0.39	12.3	0.0	61.0	Gry, fine-med, slightly calcareous
33	3622-23	1.4	0.75	12.5	0.0	66.3	Gry, fine-med, slightly calcareous
34	3624-25	1.3	0.99	13.4	0.0	80.7	Gry, fine-med. slightly calcareous
35	3626-27	2.7	1.2	14.1	0.0	78.7	Gry, fine-med, slightly calcareous
36	3628-29	20	4.8	15.9	0.0	69.8	Gry, fine, calcareous
37	3632-33	0.45	0.45	10.8	0.0	73.1	Gry, fine, slightly calcareous
38	3634-35	0.14	0.07	12.6	0.0	73.0	Gry, fine, slightly calcareous
39	3636-37	0.02	0.01	9.0	0.0	77.7	Gry, fine, slightly calcareous, shaly
40	3638-39	0.04	0.02	9.1	0.0	78.0	Gry, fine
41	3640-41	0.07	0.07	8.3	0.0	47.0	Gry, fine-med, interval badly broken
42	3642-43	0.07	0.07	9.9	0.0	57.6	Gry, fine-med. interval badly broken
43	3644-45	0.07	0.04	10.8	0.0	52.8	Gry, fine-med

[a]All samples were sandstone.

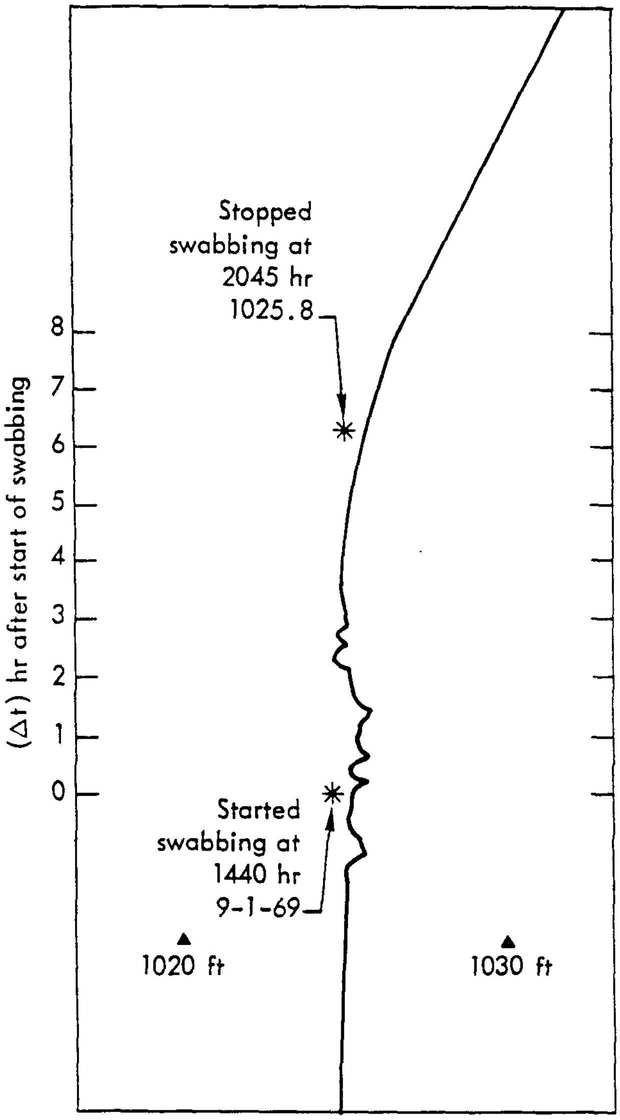


Fig. 5. Pressure response in well 10-36.

Shortly after the completion of the hydrologic tests in GB-3 (on Sept. 4) a Birdwell Nuclear Annulus Investigation Log (NAIL) was run in GB-ER. This log was used to determine if a water level existed in the annulus between the 2-7/8 in. production tubing and the 7 in. drill pipe. The results showed that the fluid level was 1237 ft below the surface. On this date the fluid level in 10-36 was 1041 ft below the surface. Since drilling and coring operations were continuing at this time in GB-3, no water level measurement was possible. Figure 6 is a plot of the three water level measurements in GB-ER, GB-3, and 10-36.

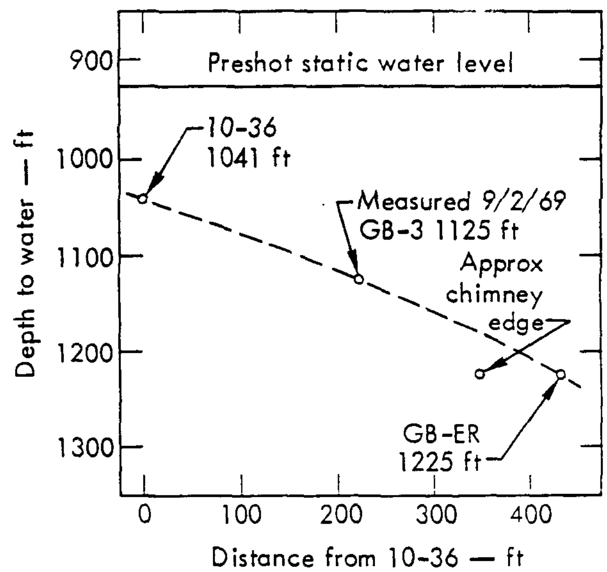


Fig. 6. Gasbuggy postshot water levels (September 4, 1969).

Discussions and Conclusions

When the preshot analysis was made of the possible effects of the Gasbuggy detonation on the Ojo Alamo aquifer, it was assumed that the probability of observable effects was small. Postshot investigations, however, have shown that this assumption was faulty. The fact that the aquifer has responded to the detonation is undeniable. The nature of this response and its implications to the objectives of the experiment are only beginning to be understood. Further exploration and analysis will be necessary to completely assess the effects.

Nevertheless, from the evidence presently available, the following conclusions can be made:

- Hydraulic communication has been established between the Ojo Alamo aquifer and the Pictured Cliffs gas reservoir. This is demonstrated by the aquifer response to the gas production tests, and the fact that the water produced in the gas stream near the end of the six-month test period had the same chemistry as that of the Ojo Alamo water.

- The most probable point of communication, although it cannot be demonstrated that it is the only point of communication, is at the emplacement hole, GB-ER. The evidence for this is that the lowest point measured on the aquifer drawdown occurs at GB-ER. This is not to say that we have seen the lowest point of drawdown, but it seems likely that it would occur here.

- The hydrologic tests in GB-3 are believed to be valid, and show that the effective permeability of the aquifer is higher than those permeabilities measured in either GB-1 or GB-2. The kH product from the swab tests for the lower part of the Ojo Alamo formation in GB-1 was 105.3 md-ft. The weighted average kH product for GB-1 was 73.3 md-ft and that for GB-2 was 76.5 md-ft, indicating that the aquifer was reasonably homogeneous between these holes. On the other hand, the kH product from the swab test for the lower part of the Ojo Alamo formation in GB-3 (lateral distance to GB-1: ≈45 ft) is 257.9 md-ft. Taken together, the hydrologic tests in GB-3 show an increase in aquifer permeability on the order of 3 to 5 times.

- Although somewhat subjective, examination of the cores from GB-1 and GB-3 suggests that the GB-3 cores in the lower part of the Ojo Alamo formation show a higher frequency of fracturing than the GB-1 cores. The interval from 3640 to 3647 ft is severely shattered, and a series of closely spaced, parallel near-vertical fractures exists from 3650 to 3670 ft, just below the Ojo Alamo—Kirtland contact. Moreover, although it was not cored, the interval from 3470 to 3480 ft where the packer was set for the first two swabbing attempts may also be fractured, since fluid bypass took place on both occasions.

- It is reasonable to assume that the flow of Ojo Alamo water into the Pictured Cliffs reservoir is having some effect on the production characteristics of the gas. This effect is most likely adverse, but its magnitude, in light of present data, can only be qualitatively evaluated.

Since the nature of the communication between the aquifer and the reservoir has not been defined, it is difficult or impossible to determine the total amount of water which has entered the reservoir. Some indication of the quantity may be deduced from the chimney volume calculations which were made during the production tests in mid-1968 and again during the rapid flushing experiment in October-November 1969. The earlier calculations gave a chimney volume of 2.8×10^6 to 3.1×10^6 ft^3 of void volume. Calculations from the more recent tests give a void volume of 2.5×10^6 to 2.7×10^6 ft^3. This drop of some two to three hundred thousand cubic feet may be the result of an equivalent amount of water influx. It must be recognized, however, that this amount is of the same order of magnitude as the uncertainty of measurement. Nevertheless, there appears to be a real decrease in volume. If this difference is real, it would indicate that the chimney is approximately 10% filled with water. For a chimney porosity of 20% and a radius of 85 ft, this amount of water would fill the chimney to a height of 44 to 66 ft. For a 25% porosity, the numbers are 35 to 53 ft.

It is also quite possible that some of this water, whatever its amount, is not in the chimney, but is filling some of the reservoir porosity around the chimney. The effect in this case would be to restrict the flow of gas into the chimney.

- The water level history in well 10-36, following the rapid drawdown for the long-term production test, requires some explanation. Indeed, the observed fluctuations in the water level may provide a clue to the nature of the communication between aquifer and reservoir. These fluctuations, which at times are quite large, are apparently independent of the BHP in GB-ER.

It is believed that the fluctuations are caused by intermittent partial plugging and, in some cases, unplugging at the points of communication between the aquifer and the reservoir. On two occasions (once in early April and again in late October) blockage appeared to be almost complete. On the latter occasion, in fact, the point(s) of communication may have become completely sealed since the present water level is very close to the preshot level.

Further evidence that blockage has occurred is given by two other facts.[7] First, no increase in entrained water in the gas stream was experienced during this last lowering of the BHP, whereas during the fourth production test, such large quantities of water were produced in the gas stream that it was not possible to lower the pressure for this test to the intended 200 psig. Second, the tritium concentration in the entrained water during the last test was about an order of magnitude higher than that experienced during the fourth production test, which would indicate that no dilution of the Pictured Cliffs water with Ojo Alamo water was taking place.

Assuming, then, that blockage has occurred, this behavior suggests that *communication between the aquifer and* reservoir exists at a single point, probably GB-ER. It is difficult to imagine that, if the communication consisted of more than one point, stoppage could occur as abruptly as is indicated.

In conclusion, the presence of an unknown, but significant, amount of Ojo Alamo water in the reservoir raises some questions about the interpretation of the Gasbuggy production tests as they relate to nuclear stimulation of gas reservoirs. Moreover, if dynamic effects of the Gasbuggy experiment are truly discernible at distances as far away as the Ojo Alamo aquifer in GB-3 (about 700 ft), application of nuclear explosives to gas and oil stimulation projects or to the development of storage facilities will have to take cognizance of effects at least to these scaled distances.

References

1. D. E. Rawson and J. A. Korver, Acceptability of the Gasbuggy Site, Lawrence Radiation Laboratory, Livermore, Rept. UCID-15132 (1967).
2. J. A. Korver and D. E. Rawson, Gasbuggy Postshot Investigations in GB-ER, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-50452 (1968).
3. D. E. Rawson, J. A Korver, R. L. Pritchard, and W. Martin, Gasbuggy Postshot Geologic Investigations, USAEC Rept. PNE 6-11 (1969). Available from Clearinghouse for Scientific and Technical Information, Springfield, Va.
4. J. A. Korver, Gasbuggy-Postshot Effects on the Ojo Alamo Aquifer, Lawrence Radiation Laboratory Internal Memorandum, SDK 69-16 (1969).
5. P. A. Witherspoon, I. Javandel, S. P. Neuman, and R. A. Freeze, Interpretation of Aquifer Gas Storage Conditions From Water Pumping Tests, American Gas Association Monograph NS-38, Chap. 1 (1967).
6. B. C. Craft, and M. F. Hawkins, Applied Petroleum Reservoir Engineering (Prentiss-Hall Publ. Co., New York, 1959).
7. P. D. Randolph, private communication (12/21/69).

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