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HYDROFRACTURE SITE PROOF STUDY AT OAK RIDGE NATIONAL LABORATORY

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OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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OPERATIONS DIVISION

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ABSTRACT

A study was carried out in FY-74 to verify that a site proposed for a new Hydrofracture Waste Disposal Facility at the Oak Ridge National Laboratory was suitable for hydrofracture operations. An injection well and four monitoring wells were drilled and cased, and a test injection was made using a grout tagged with radioisotope tracer. The results of the study indicate that the proposed site is satisfactory.

1.0 INTRODUCTION

At Oak Ridge National Laboratory, intermediate level waste solution (waste with a specific activity of between 1.5×10^{-6} and 2.0 Ci/gal) is currently being disposed of by the shale fracturing process. In this process the waste solution is mixed with cement and injected into an impermeable shale formation at a depth of about 800 ft. Here the waste grout sets, fixing the radionuclides in the cement matrix. Subsequent injections form new grout sheets adjacent and parallel to the earlier grout sheets. This process is described in References 1 and 2.

The existing Shale Fracturing Disposal Facility was built in 1963 for a series of four experimental injections. It was modified in 1966 for the routine disposal of the Laboratory's intermediate level waste solution and has since been used for the disposal of over one million gallons of waste solution containing about 500,000 Ci of various radionuclides. This facility has worked quite well for the disposal of intermediate level waste, but cannot handle either slurries or wastes with a specific activity higher than 2 Ci/gal. The need for a disposal system for these types of waste is imminent and a new shale fracturing facility is being proposed. A part of the preliminary planning for this facility is verification of the suitability of the selected site by a demonstration that the strata are suitable, that injection pressures will not be excessive (>5000 psi) and that the fractures formed by the injection will conform to the bedding planes (be essentially horizontal). Demonstration of these criteria requires a "site proof" injection - an injection of 50,000 to 100,000 gal of water or grout tagged with a radionuclide tracer that can be detected at observation wells several hundred feet distant from the injection well. The orientation of the fracture can then be verified by the comparative depths of the injection and point of detection.

This report describes this site proof injection - the preparations, results, and conclusions.

2.0 LOCATION AND GEOLOGY OF INJECTION SITE

2.1 Location

The main operation area of Oak Ridge National Laboratory is located in Bethel Valley in the south central part of the Oak Ridge AEC reservation. Certain Laboratory operations, including all of the shale fracturing operations, are located in Melton Valley, about a mile to the southeast of the main area. The locations of the shale fracturing operations in relation to the major Laboratory facilities are shown in Fig. 1. Two experimental injections were made in 1960 at a site about 1500 ft west of HFIR. These injections were made at depths of 934 and 694 ft and demonstrated that bedding plane fractures would be formed by injections into the particular shale formation at these depths. The existing Shale Fracture Disposal Facility was built in 1963 about 3000 ft west of the experimental injection site for the injection of large volumes of a waste-cement grout into this proven formation (the Pumpkin Valley member of the Conasauga shale). Over twenty injections have been made at this site and all have had an essentially horizontal orientation. The site for the proposed new Shale Fracture Disposal Facility was chosen so that injections could be made into the same shale formation that all previous experience has indicated would be entirely satisfactory. This site is about 800 ft southwest of the existing facility. At this site the disposal zone would be expected to be about 200 ft deeper than at the existing disposal site.

2.2 Geology

Oak Ridge is located in the "Valley and Ridge" physiographic province, a belt of faulted and folded rock which lies between the "Blue Ridge" subdivision of the Appalachians to the southeast and the "Appalachian Plateau" to the northwest. It extends from Pennsylvania to Alabama where its possible

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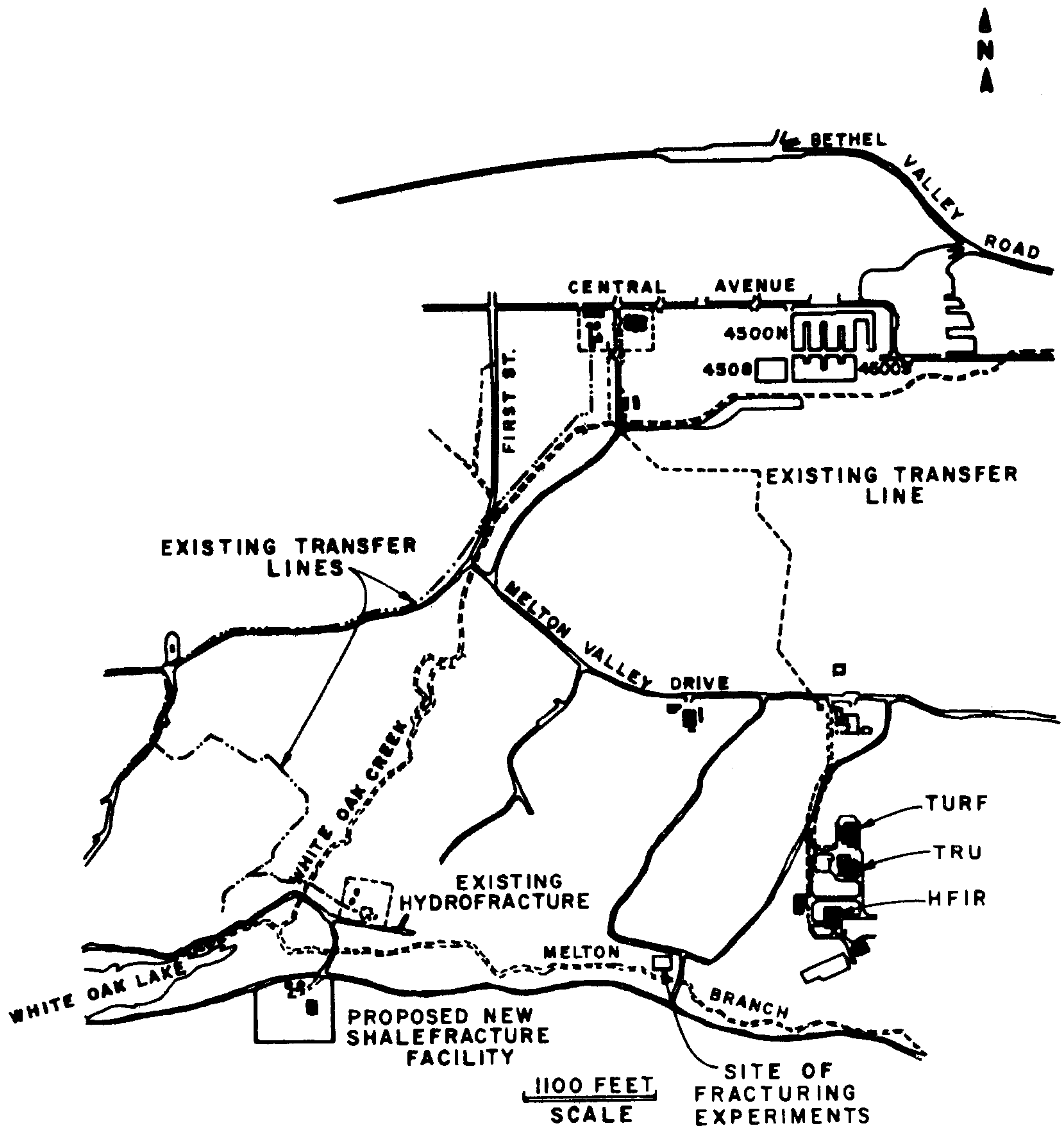

Fig. 1. Location of Shale Fracturing Operations

continuation in an arc curving to the west is obscured by a cover of younger deposits. In the Oak Ridge area the province is about 50 miles wide and is marked by a series of great overthrust faults, in each of which a layer of rock very roughly two miles thick has moved as much as several tens of miles to the northwest, overriding the similar sheet of rock in front of it and in turn overridden by the sheet behind it.

Since the latter part of the Appalachian Revolution, when the thrust sheets were formed, at least 10,000 ft of rock has been removed by erosion. The fault sheets, as presently exposed, are each bounded below by one of the major overthrust fault planes and above by a fault plane or an erosion surface, so that both the top and bottom of the original stratigraphic column are missing. A geologic section through the described formations is shown in Fig. 2.

The fault sheet of concern to this report is bounded on the northwest by the Copper Creek thrust fault which, at the surface, forms the boundary between Bethel Valley and Haw Ridge. The fault sheet extends for many miles to the northeast and to the southwest and is about four miles wide as measured from the Copper Creek fault to the next major overthrust fault to the southeast.

The fault sheet is composed of four formations. The oldest is the Rome sandstone, of lower Cambrian age, of which only the upper 350 ft is present in the Oak Ridge National Laboratory area; the lower part, perhaps as much as 1000 to 2000 ft, was left behind when the thrust sheets were formed. That part of the upper Rome present in the disposal areas is largely composed of beds of hard, brittle quartzite, 1 in. to 1 ft thick. The Rome is overlain by the Conasauga shale, about 2000 ft thick. The bottom 300 ft of the Conasauga, called the Pumpkin Valley member, is dense argillaceous shale that is very thin bedded and dominantly red. This shale breaks very easily along the bedding and is the unit into which all test and disposal injections have been made. The Pumpkin Valley is overlain by what is probably the Rutledge member of the Conasauga. The Rutledge, about 1000 ft thick, is composed of gray calcareous shale interbedded with generally thin beds or lenses or limestone. The contact between the Pumpkin Valley and the Rutledge is marked by three beds of limestone. These are

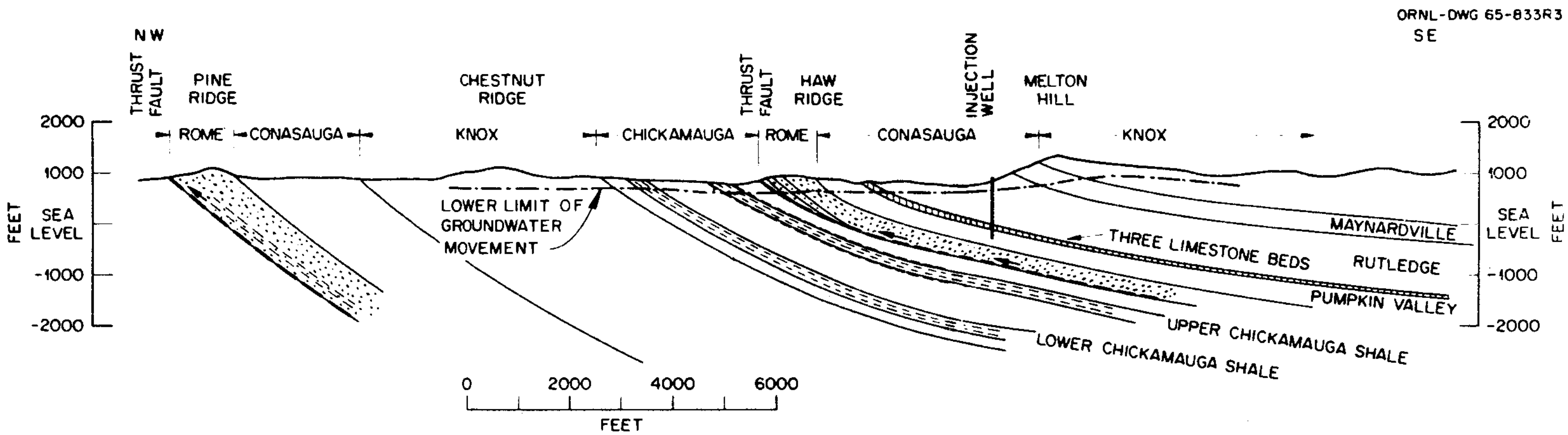

Fig. 2. Geologic Section through Area

not characteristically developed in the proposed disposal site, but the lowermost limestone beds in the Rutledge show up clearly in the gamma ray logs and serve to define the contact.

About 125 ft above the Pumpkin Valley-Rutledge contact is the lower contact of a shaley member within the Rutledge which is marked by relatively few and thin limestone beds. This member, which shows up clearly in the gamma ray logs, is about 100 ft thick and is referred to as the "shaley member." Above this, in the site studied for this report, is more normal Rutledge. The Rutledge is overlain by the Maynardville limestone member of the Conasauga, generally thinbedded and locally oolitic and fossiliferous.

The formations all dip to the southeast at 45° near the outcrops of the overthrust faults, but to the southeast of the faults the dips flatten out. At the site of the fracturing experiments, the dip of the formations was about 20°. The Rome lies at a depth of 1000 ft at this location. At the site of the present disposal plant, where the depth to the Rome is also about 1000 ft, the formations in depth were horizontal over the area explored by drilling, which reaches about 400 ft from north to south.

3.0 INJECTION AND MONITORING WELLS

3.1 Well Drilling

Four observation wells and an injection well were drilled, cased, and cemented at the site of the proposed new disposal facility, about 800 ft southwest of the existing shale fracturing site. The observation wells were located 200 ft north, south, east, and west of the injection well. Figure 3 is a plan of these wells and the closest wells of the existing facility.

Experience has shown that wells drilled by the cable-tool or churn method have straight, vertical holes in this area. Some wells drilled with rotary equipment have been straight and vertical, but others have deviated considerably from vertical. Contractor bids for drilling the five wells by each of the two methods showed that cable-tool drilling would be prohibitive in both cost and time required. Rotary drilling and

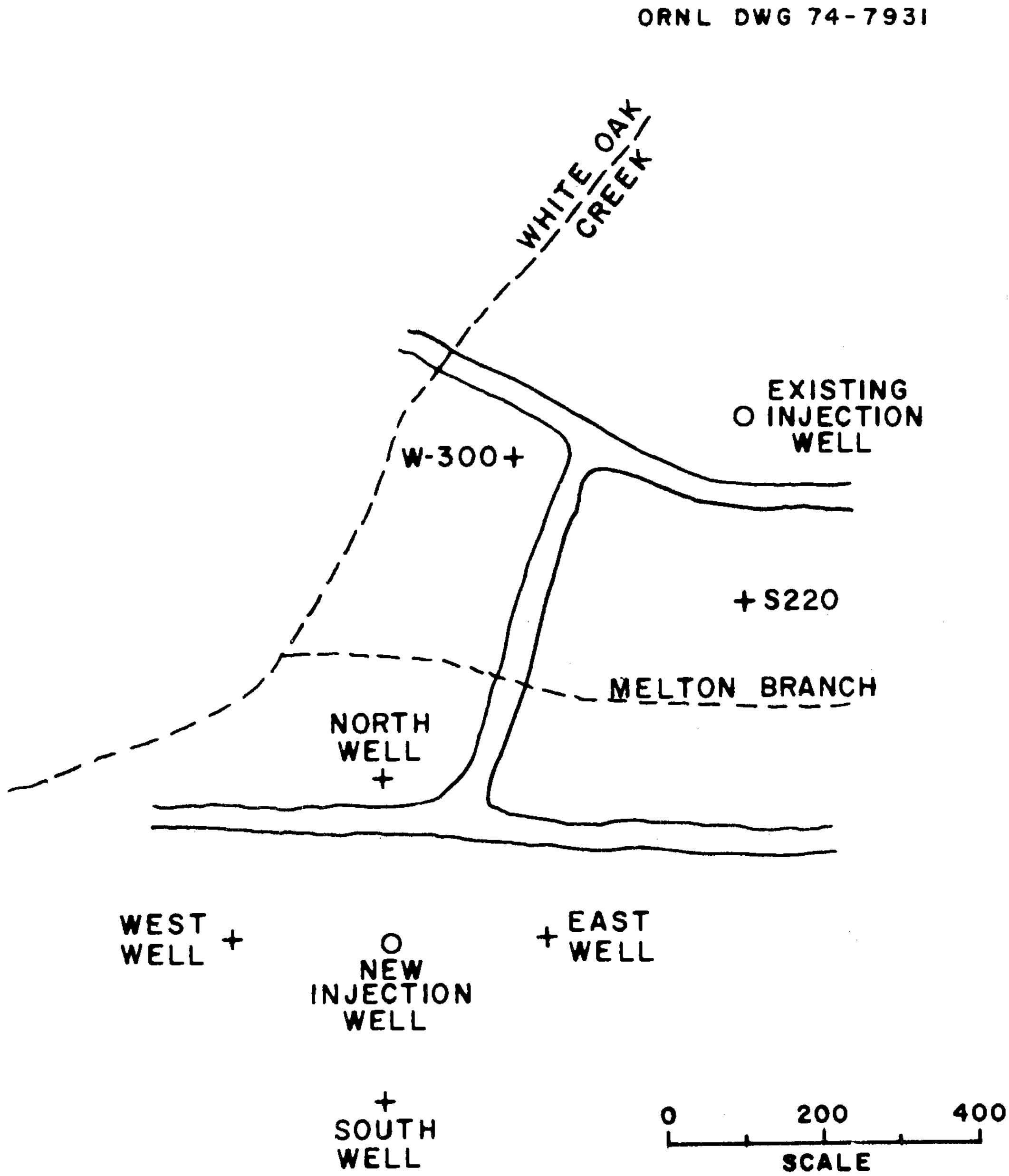

Fig. 3. Plan of New and Existing Wells

the consequent probable deviation of the well from the vertical were therefore selected. One of the monitoring wells (the south well) was to be cored from 700 ft to the top of the Rome sandstone.

A sketch of the design of the injection well and an observation well is shown in Fig. 4. The injection well consists of a 9-5/8 in. surface casing (K-55, 36 lbs/ft) 250 ft long that is cemented to the well bore throughout its length. Inside the 9-5/8 in. casing is a 5-1/2 in. casing (C-75, 23 lbs/ft) approximately 1100 ft long that is cemented to the wellbore and the 9-5/8 in. casing. Each of the observation wells consists of a 2-7/8 in. tubing string (K-55, 6.5 lbs/ft) that is cemented to the wellbore. The bottom 300 ft of each of the observation wells is cemented with a polymeric water-base gel. This is done to prevent the well tubing from being pulled apart by the stresses created by a grout sheet that passes nearby (the gel will yield and allow the tubing to move slightly, thereby relieving the stresses).

The drilling and coring was done by Jack Terry Drilling Company using Schramm rotary drilling rigs. The south observation well was drilled to 694 ft, November 27, 1973, and coring was started in this well, December 3, 1973, and coring was stopped at 1187 ft, about 17 ft below the top of the Rome. The injection well was started November 29, 1973, and the 12 in. 255 ft hole was cased with 9-5/8 in. casing and cemented January 2, 1974. An 8-3/4 in. hole was drilled through the casing to a total length of 1127 ft by February 7, 1974. The west, north, and east observation wells were drilled between December 5, 1973 and December 14, 1973. The south observation well was reamed to 6 in. diameter by January 5, 1974. The total lengths of all wells and the corresponding vertical depths are listed in Table 1. The 2-1/2 in. casings for the four observation wells and the 5-1/2 in. casing for the injection well were suspended in the holes by the drilling contractor between January 21, 1974 and January 25, 1974. The casings were cemented by Halliburton Company, February 5, 1974 and February 6, 1974.

Table 2 is a list of the sea level elevations of all of the 5-1/2 in. casing joints in the injection well.

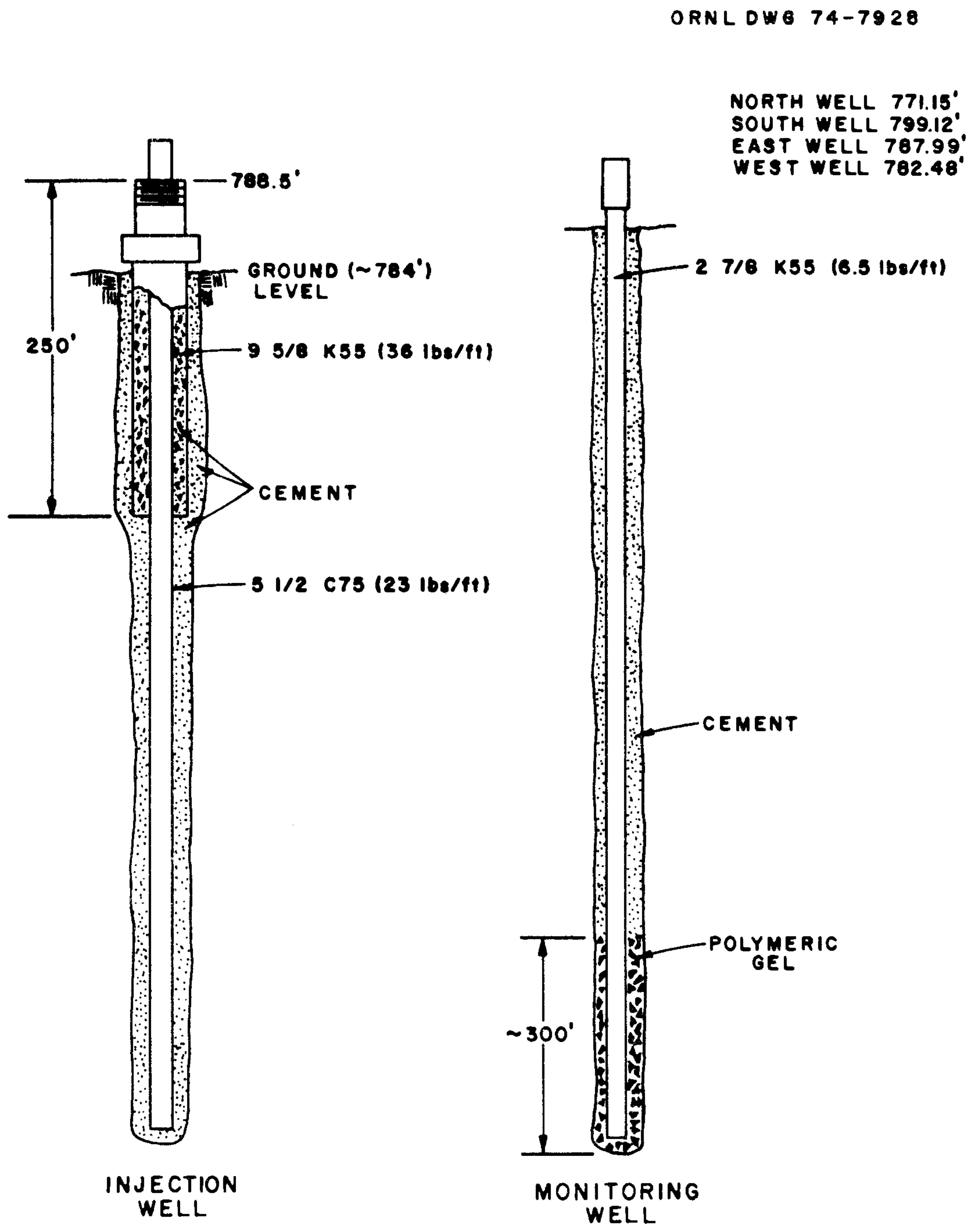

Fig. 4. Design of Injection and Observation Wells

Table 1. Statistical Resume of the Wells at the Test Site

	West (ft)	South (ft)	East (ft)	North (ft)	Injection (ft)
Coordinates	N16502.09 E27978.14	N16304.18 E28179.01	N16503.14 E28377.88	N16702.33 E28178.13	N16502.67 E28178.54
Elevation	782.48*	799.12	787.99	771.15	788.91
Length of Hole	1152	1195	1135	1120	1127
Length of Casing	1133	1158	1106	1102	1138
Depth of Hole	1127	1168	1115	1072	1102
Depth of Casing	1107	1131	1086	1051	1087
Coordinates of bottom of casing	N16681.7 E27878.7 -320.6*	N16505.6 E28070.2 -351.5	N16610.8 E28216.3 -306.0	N16935.2 E28143.3 -283.8	N16700.3 N28105.9 -303.9
Elevations of lower limestone	52.4*	-9.3	-7.4	89.7	43.6
Rome sandstone	-288.3*	-334.7	-333.7	-267.7	-298.9
Elevations of bottom of holes after cementing	-313.7*	-348.6	-303.1	-277.5	-297.5

*Mean sea level.

Table 2. Casing Joint Elevations - Injection Well (mean sea level)

Joint	Elevation	Length	Joint	Elevation	Length	Joint	Elevation	Length
1	773.39	15.52	11	397.69	391.22	21	15.74	773.17
2	737.60	51.31	12	359.31	429.60	22	-22.01	810.92
3	700.34	88.57	13	321.81	467.10	23	-59.96	848.87
4	661.92	126.99	14	284.43	504.48	24	-98.01	886.92
5	624.02	164.89	15	246.87	542.04	25	-135.56	924.47
6	586.55	202.47	16	208.06	580.85	26	-173.46	962.37
7	549.02	239.89	17	168.81	620.10	27	-211.76	1000.67
8	510.76	278.15	18	130.55	658.36	28	-249.76	1038.67
9	472.76	313.15	19	92.95	695.96	29	-288.06	1076.97
10	434.67	354.24	20	54.70	734.21	30	-325.01	1113.92

-328.09 bottom of cementing shoe

3.2 Deviation Survey

All of the wells deviate considerably from vertical, but, in general, the five wells form a parallel system that is quite suitable for determining the orientation of injected grout sheets. Each well was measured at 100 ft intervals with a photo-inclinometer and the results are listed in Tables 3 thru 7. The overall trend of the wells is to the north-northwest (local north) updip to the southeasterly dipping rocks. The configuration of the wells is illustrated by Fig. 5, a drawing of a view of the test site from above.

3.3 Interception of Grout Sheets

During the drilling of the north observation well, four thin sheets of radioactive grout were intersected. The resulting contamination of the drilling water was minor and was well contained. The grout sheets originated from injections made a number of years ago in the existing disposal well which, as measured on the surface, is some 630 ft northeast of the north observation well. Because the north well slants to the northwest the minimum distance underground is about 520 ft. These grout sheets were not intersected by the east observation well, which in the subsurface is some 670 ft southwest of the present injection well, nor in any of the other wells drilled in connection with this study.

The deepest of the grout sheets intersected by the north well was at a depth of 1021 ft, and showed only slight activity. It probably is from one of the first test injections which contained only a few curies of waste. The other three sheets were found at depths of 865 ft, 789 ft, and 778 ft, and showed much more activity, particularly the sheet at 865 ft. These probably represent injections of actual waste. Because of the distance from the present disposal well, it is not possible to correlate any of these fractures with individual injections, but the fractures appear to have followed the bedding in moving slightly down dip, and certainly did not depart far from it.

In earlier fracturing experiments grout sheets have been observed in cores obtained 500 ft distant from the injection well. No grout sheets have been observed at a greater distance. The recent test drilling has shown four grout sheets which moved 520 ft but failed to reach another well

Table 3. West Well

Hole Length	Vertical Deviation	Average Deviation	Vertical Distance Increment	Horizontal Distance Increment	Direction of Deviation True North	Direction of Deviation Local
100	1°	30'	100.0	.87	N90W	N56W
200	3°	2°	100.0	3.49	S80W	N66W
300	5°	4°	99.8	6.98	N80W	N46W
400	7° 15'	6° 8'	99.4	10.68	N85W	N51W
500	11° 30'	9° 23'	98.7	16.30	N83W	N49W
600	12° 30'	12°	97.8	20.79	N82W	N48W
700	15°	13° 45'	97.1	23.77	N72W	N38W
800	18° 45'	16° 53'	95.7	29.04	N58W	N24W
900	19° 30'	19° 8'	94.5	32.77	N58W	N24W
1000	15°	17° 15'	95.5	29.65	N55W	N21W
1100	11° 30'	13° 15'	97.3	22.92	N38W	N4W
1152	11° 30'	11° 30'	51.0	10.37	N45W	N11W
Total vertical distance - 1126.8 ft						

Table 4. South Well

Hole Length	Vertical Deviation	Average Deviation	Vertical Distance Increment	Horizontal Distance Increment	Direction of Deviation True North	Direction of Deviation Local
100	3° 30'	1° 45'	100.0	3.0	N88W	N54W
200	5° 48'	4° 39'	99.7	8.1	N60W	N26W
300	4° 30'	5° 9'	99.6	9.0	N65W	N31W
400	8° 36'	6° 33'	99.4	10.5	N65W	N31W
500	11° 12'	9° 54'	98.5	17.2	N58W	N24W
600	12° 30'	11° 51'	97.9	20.5	N58W	N24W
670	13°	12° 45'	68.3	15.4	N62W	N28W
680	13° 36'	13° 18'	9.7	2.3	N62W	N28W
700	14° 24'	14°	19.4	4.8	N63W	N29W
800	14° 36'	14° 30'	96.8	25.0	N65W	N31W
900	16°	15° 18'	96.5	26.4	N65W	N31W
1000	17° 30'	16° 45'	95.6	28.8	N62W	N28W
1100	17°	17° 15'	95.5	29.7	N62W	N28W
1195	15° 30'	16° 15'	91.2	26.6	N62W	N28W
Total vertical distance - 1168.1 ft						

Table 5. East Well

Hole Length	Vertical Deviation	Average Deviation	Vertical Distance Increment	Horizontal Distance Increment	Direction of Deviation True North	Direction of Deviation Local
100	0	0	100.0	0.0		
200	2° 30'	1° 15'	100.0	2.2	N35E	N69E
300	4° 24'	3° 27'	99.8	6.0	N85E	S61E
400	5° 36'	5°	99.6	8.7	S55E	S21E
500	2° 30'	4° 3'	99.8	7.1	S30E	S4W
600	4°	3° 15'	99.8	6.0	S80W	N66W
700	12°	8°	99.0	13.9	N60W	N26W
800	16° 42'	14° 21'	96.8	25.1	N55W	N21W
900	18° 18'	17° 30'	95.4	30.1	N58W	N24W
1000	15° 24'	16° 51'	95.7	29.0	N73W	N39W
1135	16° 30'	15° 57'	129.8	37.1	N63W	N29W

Total vertical distance - 1115.7 ft

Table 6. North Well

Hole Length	Vertical Deviation	Average Deviation	Vertical Distance Increment	Horizontal Distance Increment	Direction of Deviation True North	Direction of Deviation Local
100	3° 30'	1° 45'	100.0	3.1	S70E	S36E
200	5° 18'	4° 24'	99.7	7.7	S55E	S21E
300	2° 42'	4°	99.8	7.0	S85E	S51E
400	2° 36'	2° 39'	99.9	4.6	N35E	N69E
500	5° 36'	4° 6'	99.7	7.2	N28W	N4E
600	15° 30'	10° 33'	98.3	18.3	N35W	N1W
700	23°	19° 15'	94.4	33.0	N37W	N3W
800	25° 30'	24° 15'	91.2	41.1	N43W	N9W
900	22° 30'	24°	91.4	40.7	N48W	N14W
1000	27° 24'	24° 57'	90.7	42.2	N52W	N18W
1120	25° 12'	26° 18'	107.6	53.2	N50W	N16W

Total vertical distance - 1072.7 ft

Table 7. Injection Well

Hole Length	Vertical Deviation	Average Deviation	Vertical Distance Increment	Horizontal Distance Increment	Direction of Deviation True North	Direction of Deviation Local
100	1° 45'	53'	100.0	1.5	N30W	N4E
200	4°	2° 53'	99.9	5.0	N40W	N6W
300	8°	6°	99.5	10.4	N55W	N21W
400	9° 12'	8° 36'	98.9	15.0	N73W	N39W
500	12°	10° 36'	98.2	18.4	N72W	N38W
600	9° 48'	10° 54'	98.2	18.9	S85W	N61W
700	10° 36'	10° 12'	98.4	17.7	N72W	N38W
800	21° 30'	16° 3'	96.1	27.6	N58W	N24W
900	16°	18° 15'	95.0	31.3	N52W	N18W
1000	16° 36'	16° 18'	96.0	28.1	N35W	N1W
1127	17° 18'	16° 57'	121.5	37.0	N33W	N1E

Total vertical distance - 1101.7 ft

about 630 ft distant. This suggests that 500 ft is about the maximum distance a grout sheet will extend from an injection well. The mechanism that limits further extension of the grout sheet is probably either the preliminary gelling or the dewatering of the grout at the leading edge. Either or both of these mechanisms would result in a high grout viscosity and the consequent formation of a new grout sheet parallel to the original one as freshly injected grout seeks the path of least resistance. Such multiple grout sheets have been seen in several core samples.

3.4 Analysis of Cores and Logs

The core from the south observation well covered an interval that extended from the grey shale above the lower limestone to 17 ft below the top of the Rome sandstone. From the top of the core (694 ft) to 840 ft, the rock is interbedded grey shale and argillaceous grey to white limestones. From 840 to 970 ft the rocks are mostly red shales with variable bedding that may vary from perpendicular to the core axis to parallel to the core axis within 3 - 4 ft. The layers of shale are frequently broken

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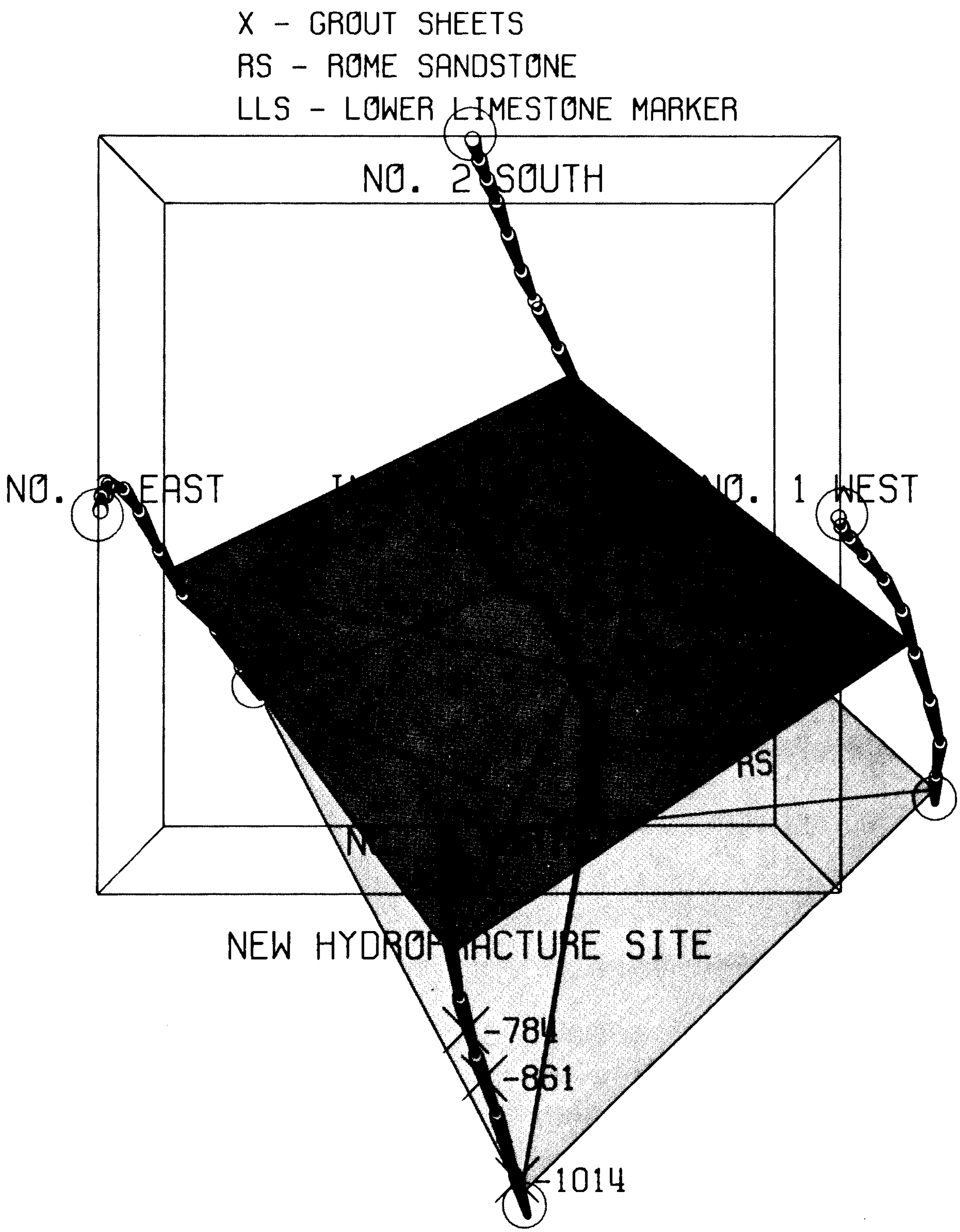

Fig. 5. Configuration of Test Wells

and either healed or filled with secondary calcite. The shale breaks readily along the bedding and pieces longer than 6 in. are rare. The permeability appears to be low or zero. From 970 to the top of the Rome sandstone the red shale becomes increasingly sandy with 1 to 6 in. thick beds of pure sandstone in the formation below 1000 ft. Appendix A contains a detailed description of the core.

After drilling, but before casing, all the wells were gamma-ray logged, and several of the wells were relogged after being cased. From these logs it was possible to locate the contacts of the Rome sandstone, the Pumpkin Valley member, the Rutledge shale member, and the so-called "Shaley Unit" within the Rutledge. These contacts could all be placed with confidence to within a foot or two. Two cross sections were prepared, using the same vertical and horizontal scales. The first started with the Joy well (W-300) on the north, extended through the new north observation well, the new injection well, and ended with the south observation well, a span of 800 ft. Over this span the upper surface of the Rome has a southerly component of dip of about 5° and was quite regular. The Pumpkin Valley member of the Conasauga varies in thickness from 300 ft to 350 ft; the lower Rutledge, between the Pumpkin Valley and the Shaley member, varies in thickness from 100 ft to 150 ft; the combined thickness of the Pumpkin Valley and the lower Rutledge is nearly constant. The Shaley member has a constant thickness of 100 ft and its upper and lower contacts have a constant southeasterly dip of 5°. This cross section is shown in Fig. 6.

The second cross section extends east and west and includes the east observation well, the injection well, and the west observation well. It has, in consequence, a span of 400 ft. The Rome sandstone has a regular component of dip to the east of 5°. The Pumpkin Valley member has a nearly uniform thickness of 335 ft, the lower Rutledge a uniform thickness of 125 ft and the Shaley member a uniform thickness of 100 ft. The several contacts within the Conasauga have a uniform component of dip to the east of about 5°. This cross section is shown in Fig. 7.

The relative positions in each of the wells of the top of the Rome sandstone and the position of the lower limestone that defines the boundary between the upper Conasauga grey shale and the lower Conasauga red shale are shown in Fig. 8. The positions of the two formations are illustrated

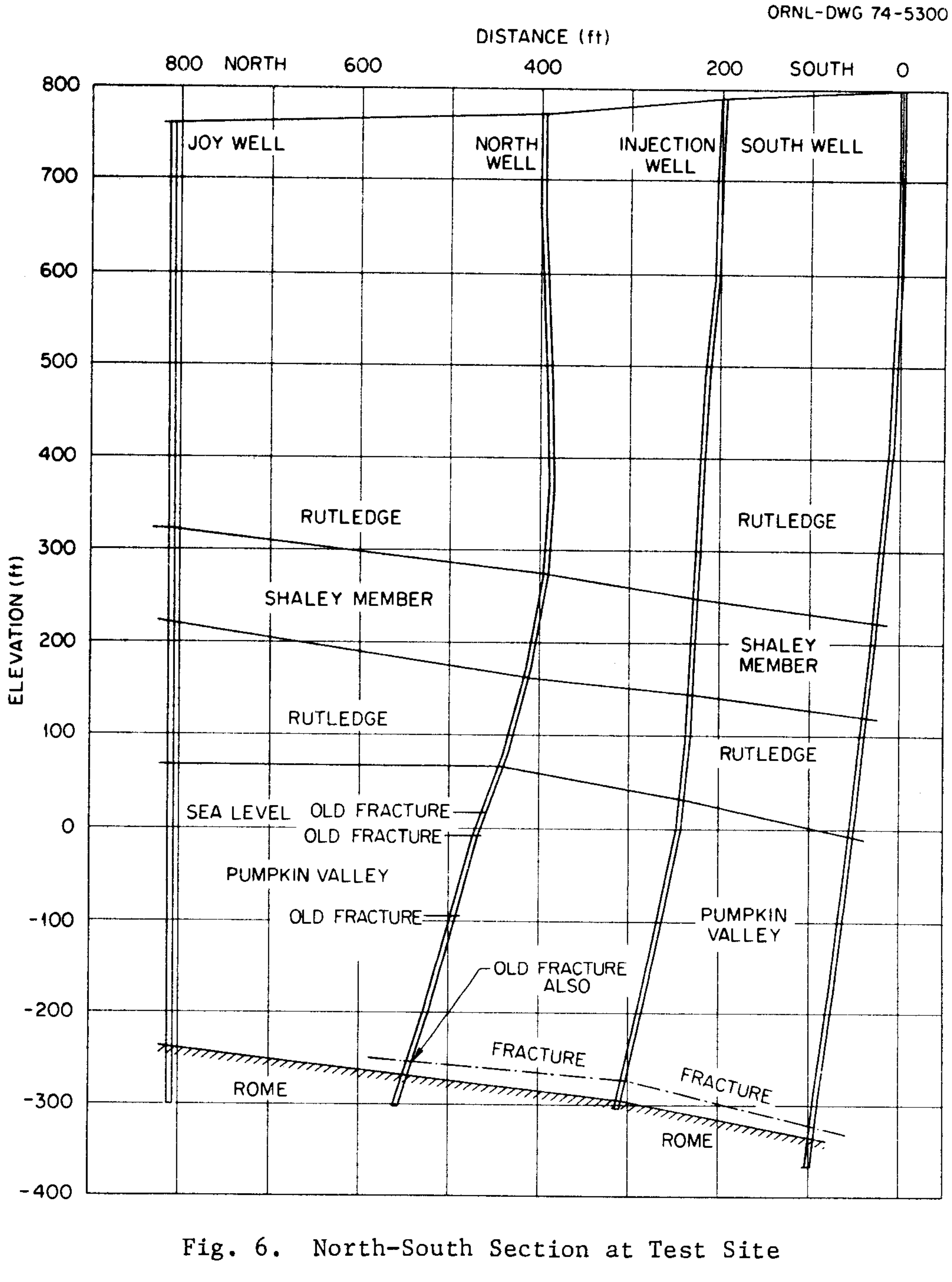

Fig. 6. North-South Section at Test Site

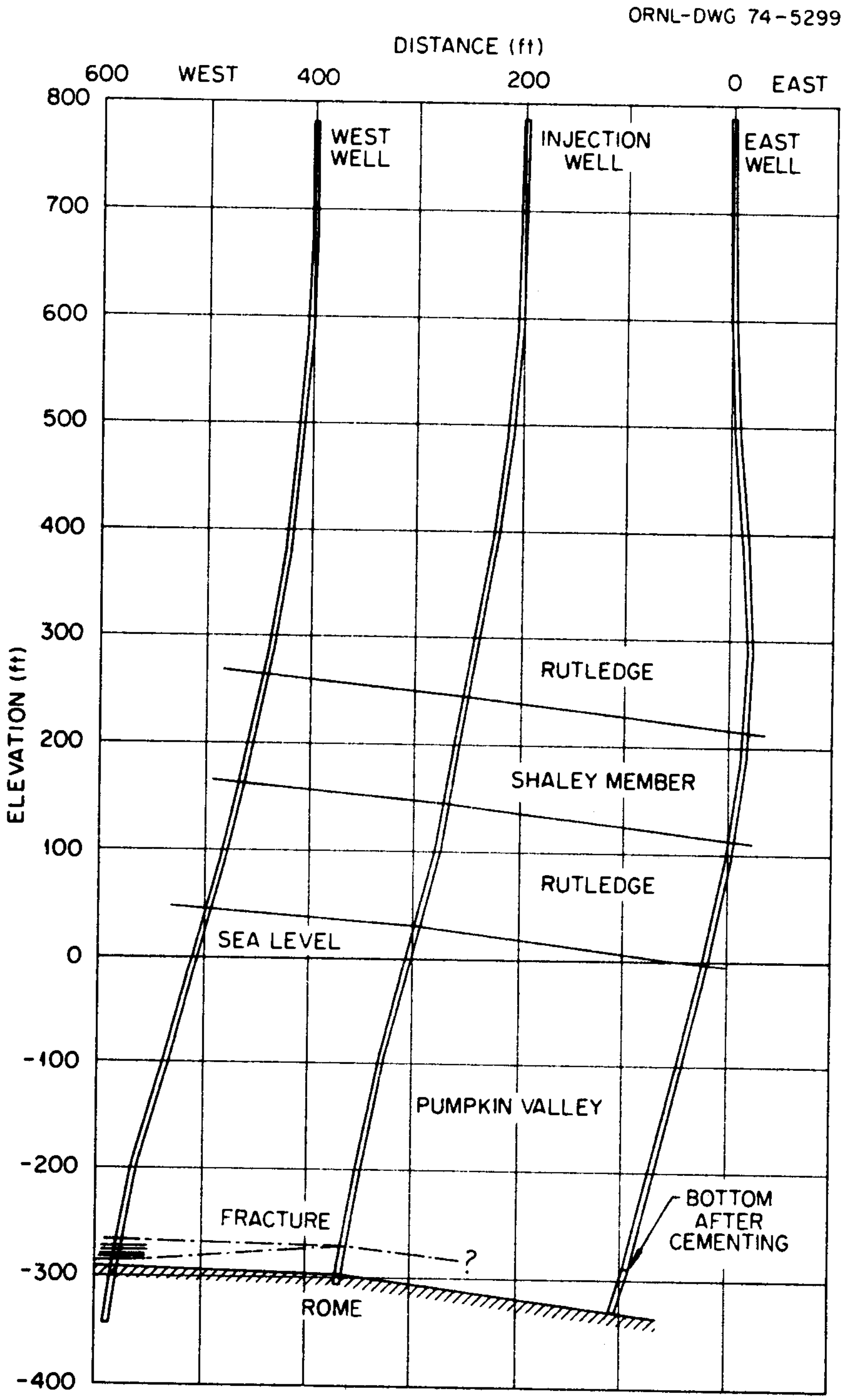

Fig. 7. East-West Section at Test Site

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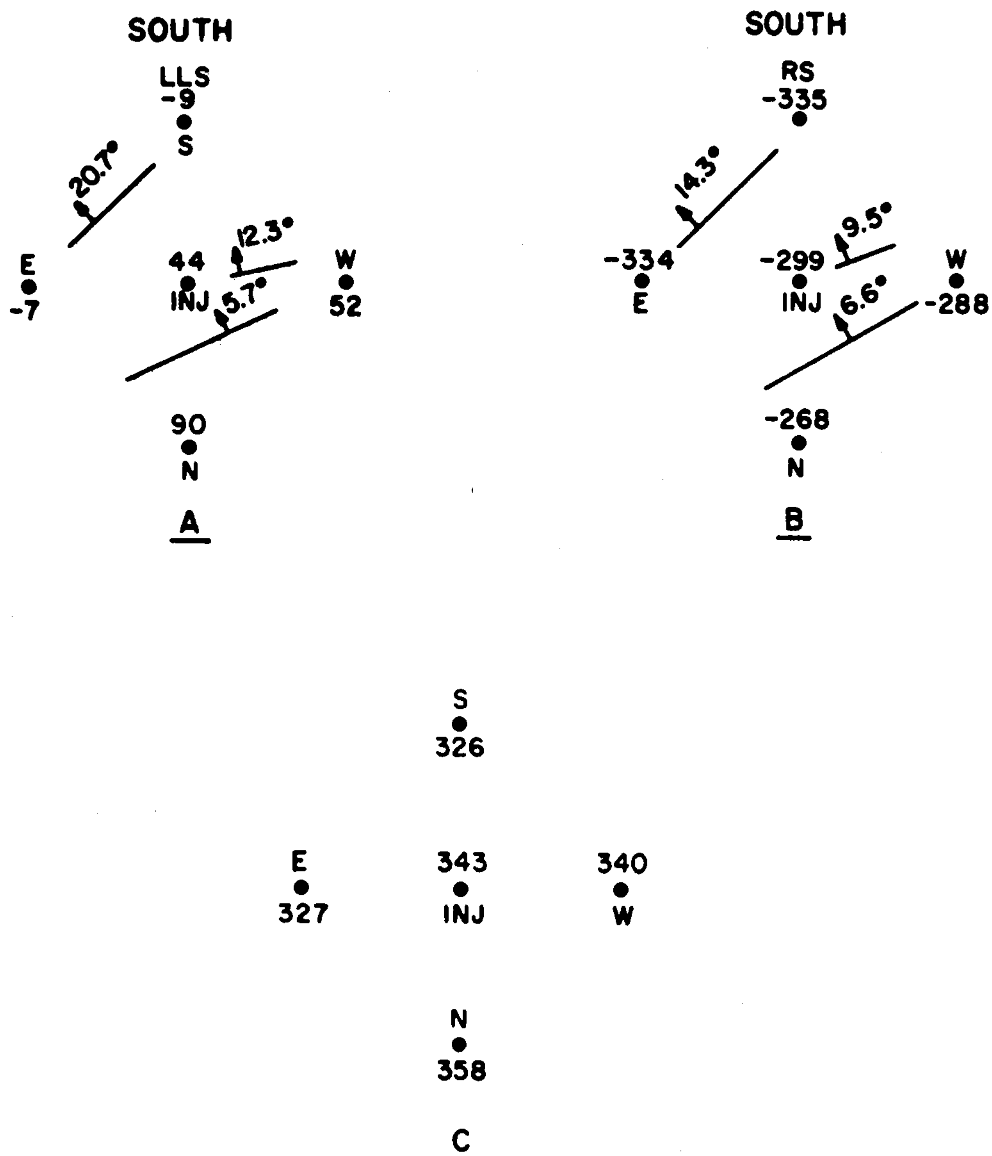

Fig. 8. Plan Views of the Lower Limestone (A) and Rome Sandstone (B) and an Isopach Map of the Lower Limestone-Rome Sandstone Interval (C).

by Fig. 8A and 8B; the elevations are mean sea level. The strike and dip is shown for each formation at three different places on the plan of the site. Fig. 8C is an isopach map of the interval between the lower limestone and the Rome; there is a minor thinning of the interval to the southeast.

It may be concluded from this that there is some deformation within the Pumpkin Valley and the lower Rutledge as shown by their variations in thickness in the north-south section, but the deformation, probably in the form of minor drag folds, does not appear to be serious and should not interfere with the use of the area for waste disposal by hydraulic fracturing. The Pumpkin Valley shale, in particular, is somewhat plastic and may be expected to show some internal deformation even when the general area is but slightly deformed.

Considering not only the two sections shown in this report but also the structure to the northeast in the present disposal area, it can be said that the general area is one of very simple, regular structure with much gentler dips than had been anticipated. In the proposed new disposal area the dips are to the southeast at about 7° to 8°. The injections into the new disposal well will probably move out in all directions, but may show a slight tendency to move preferentially to the northwest.

4.0 SITE PROOF TEST INJECTION

4.1 Criteria

The site proof test injection could have been made with either water or grout as the injected fluid. The use of water was deemed undesirable because in all previous water injection tests half or more than half of the injected water volume could not be recovered after the completion of the test; the remaining volume of water was left in the formation. A water injection at the test site would presumably result in a similar fraction of the injected water being trapped in the disposal zone and this free water could have adverse effects on future waste injections into this formation. This potential problem was avoided by making the test injection with grout in the same manner as is done with actual waste injections.

The proposed injection volume of 100,000 gal was chosen to be large enough so that the grout sheet that would be formed would have a high probability of passing by at least one of the observation wells.

Two ways of making the injection were considered - mixing and injecting the grout at the new wellhead or mixing the grout at the existing facility and pumping it overland to the new well. The second method was chosen because better control of the grout mixture could be achieved by making use of the instrumentation at the existing facility, the formidable logistical problem inherent in the first option - supplying blended solids to the mixer at a fast and constant rate - could be avoided, and recently installed modifications at the existing facility could be evaluated during an injection of essentially non-radioactive grout. A flow diagram of the equipment arrangement for the injection is shown in Fig. 9.

4.2 Preparations

4.2.1 Facility Modifications. A number of generally unrelated improvements were made to the existing Shale Fracturing Facility after the 1972 series of injections. The purpose of these modifications was to reduce the radiation exposure accumulated during operation and maintenance, improve ventilation, and improve the control of the process. Some of the new instrumentation was not installed at the time of the site proof injection.

The rectangular mixing tub (surge tank) was replaced by a new stainless steel tub with a circular cross section that could be more easily cleaned and decontaminated. The Densometer pump and connections were removed.

The inside surfaces of one of the four solids storage bins were painted to provide a smoother surface to improve solids flow characteristics.

The air distributors in the solids storage bins were renovated to provide better flow characteristics along the walls of the bins.

The ventilation system for the five waste storage tanks was modified by the addition of an exhaust fan and a second HEPA filter in series with the present filters. Ventilation was provided for the building housing the waste pumps. The existing ventilation capacity of the system serving the mixing, wellhead, and pump cells was increased and the off-gas ventilation from the mixing tub was improved and its capacity increased.

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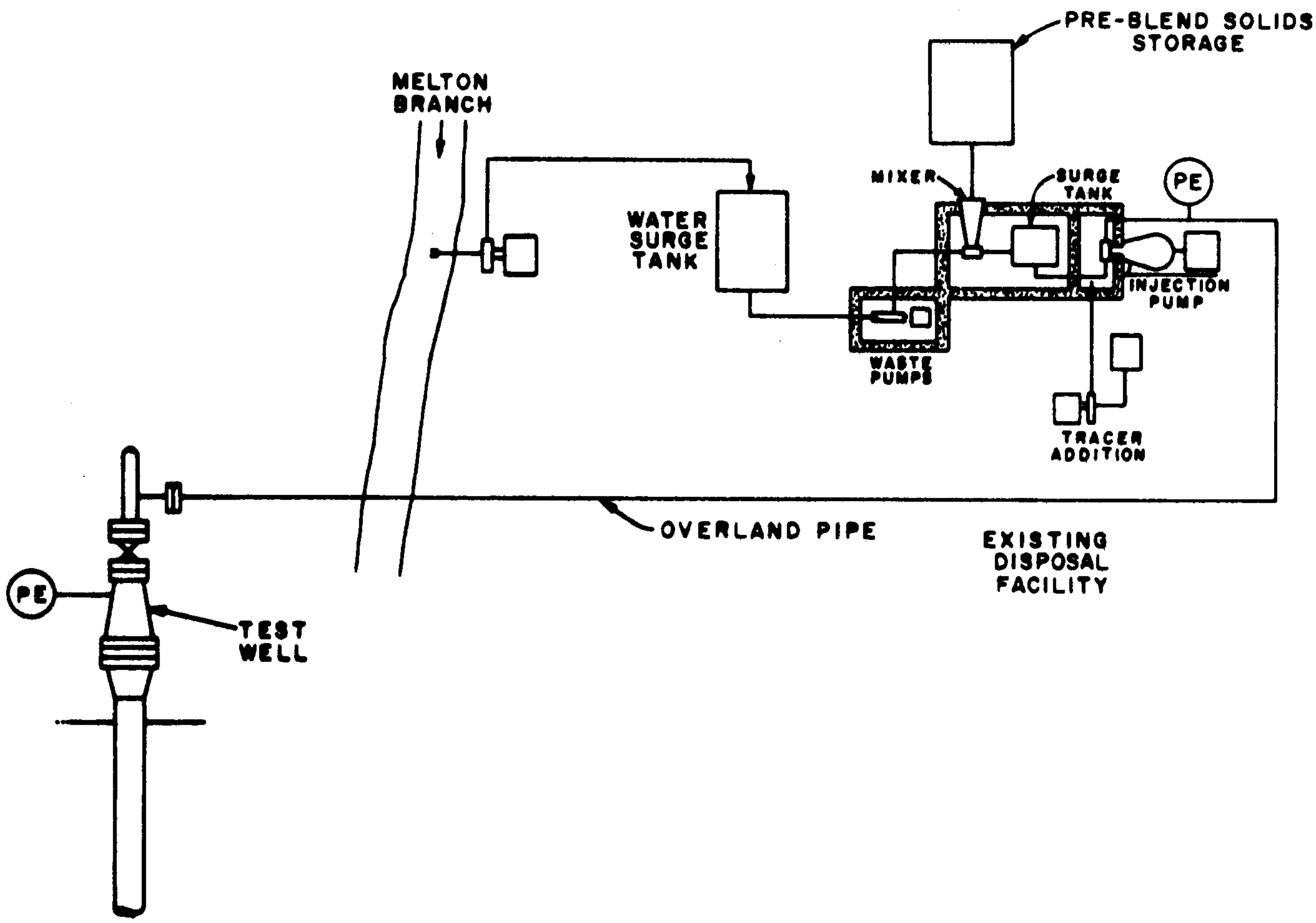

Fig. 9. Flow Diagram of Equipment Arrangement for Injection

A new valve control was installed on the solids flow valve so that automatic operation of this valve could be attempted.

The injection cell hatch was strengthened to contain any missiles that might be formed as the result of a high pressure piping failure.

Injection well pressure sensing instrumentation which will automatically terminate an injection if the wellhead pressure exceeds 5500 psig was installed.

4.2.2 Injection Wellhead Installation. The wellhead for the new injection well consisted of an O.C.T. C-22 casing head threaded on the 9-5/8 in. surface casing, an O.C.T. T-16-00 tubing head bolted to the casing head and providing a seal for the 5-1/2 in. casing, an O.C.T. BO-2 tubing head adapter bolted to the tubing head and providing a support for the 2-7/8 in. tubing string, and a shutoff valve and plug container borrowed from the existing wellhead. A sketch of the wellhead assembly is shown in Fig. 10.

The tubing string in the well was external upset K-55, 6.5 lbs/ft, nominal 2-1/2 tubing. A jet seating nipple was installed on the bottom of the tubing string. This was followed by a 4 ft and a 6 ft pup joint, with a centralizer at each end of the 6 ft joint. The rest of the tubing string was made up with approximately 30 ft lengths of tubing; no other centralizers were used.

The stand-by injection pump was connected to one of the wing valves on the tubing head. The other wing valve was connected to a pressure gage.

4.2.3 Overland Line. The overland line between the existing disposal facility and the new injection well consisted of 26 lengths of external upset K-55, 2-1/2 in. nominal tubing. This line orginated at the valve rack in the existing facility, was brought through a hole in the cell wall, crossed under the nearby road, went over Melton Branch, crossed under a second road, and terminated at the plug container on the new wellhead. At intervals Chicksan swivel joints were installed to provide needed flexibility to the line. These joints were a 2 in. nominal size and the tubing was a 2-1/2 in. nominal size; each swivel joint, therefore, required a reducing fitting at each end. At the wellhead end of the line a by-pass loop was installed to permit the withdrawal of grout samples for use in viscosity and phase separation measurements. The line was tied down by chains

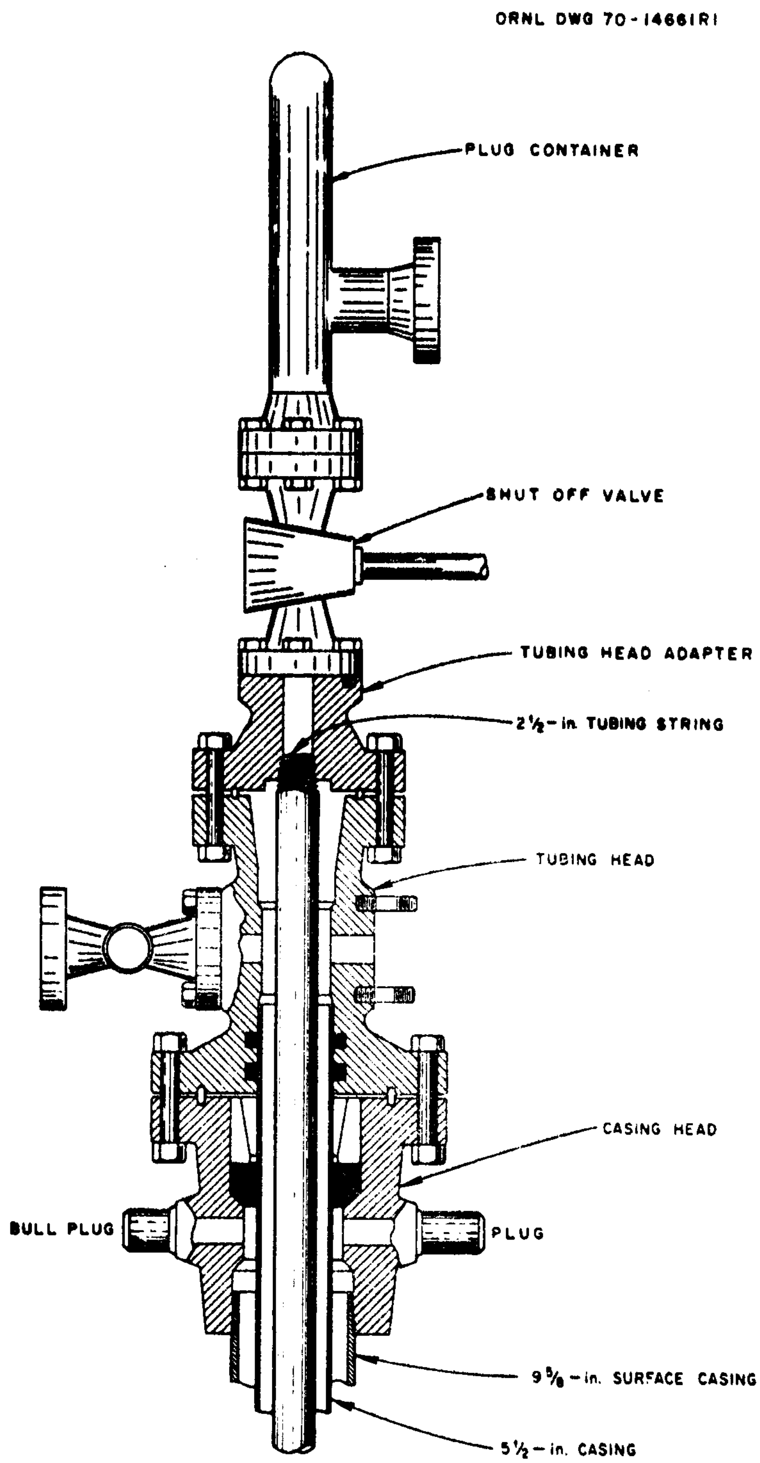

Fig. 10. Wellhead Assembly

to concrete anchors at intervals to minimize the jumping caused by pulsations of the piston type injection pump and to prevent whipping of the line if it should fail while at high pressure.

4.2.4 Water Supply. The water tank at the existing disposal site was too small to provide the water needed for the injection and the rate of supply of potable water to the site was much lower than the probable injection rate of 200 gpm. Water from Melton Branch of White Oak Creek was therefore used for the injection. A centrifugal pump pumped an excess of water from Melton Branch to a surge tank near the disposal facility. From the surge tank the water needed for the injection was fed to the suction of the Moyno waste pumps; the excess water flowed through an overflow line back to Melton Branch.

4.2.5 Tracer. The detection of the injected grout near the observation wells required the presence in the grout of some radionuclides. It was anticipated that some contamination would be dislodged from the equipment of the injection facility and injected with the grout, but an additional more positive addition was deemed necessary. Because much of the equipment used in the site proof injection would be reused shortly, it was thought desirable to use a tracer with a relatively short half-life that would decay to innocuous levels fairly quickly and ^{198}Au (2.7 days) was chosen. A total of 20 Ci was mixed with 20 gal of water in a shielded drum. During the injection this solution was pumped by a positive displacement pump into the suction manifold of the high pressure injection pump. Two tracer injection pumps were provided - one for standby service in case of failure of the primary pump. The pumps were set for an injection rate of about 180 ml/min.

4.2.6 Sampler. It has long been known that many of the properties of the cement grouts used in waste injections are affected by the amount of shear to which these grouts are subjected. The amount of shear imparted by the injection facility has been only approximately known and a determination of this value has long been needed. The site proof test offered a unique opportunity to determine the effect of shear on various grout properties and plans were made to obtain a series of samples for tests. One set of samples was taken from the surge tank (where the amount of shear to which the grout had been subjected would be a minimum) and the second set was taken from a sampler near the injection well (where the amount of shear would approximate that at the bottom of the injection well in a normal waste injection). The high pressure sampler used to obtain the second set of samples consisted of a by-pass loop so valved that the grout being pumped to the injection well could be pumped first through the by-pass loop to flush it and then through the main line. The by-pass loop could then be valved off and depressurized and the sample of grout trapped in the loop could be removed.

4.2.7 Solids Blending. The solids blend used in the previous injections has contained Grundite - an illitic clay used to retain cesium in the grout. The supplier of this clay has stopped production and no alternate source has yet been found. Since no waste was to be injected during the site proof injection and since laboratory tests indicated that the omission of Grundite had no appreciable affect on the physical properties of the grout, the site proof test injection was made with a solids blend that did not contain Grundite.

The solids were blended on five days - June 10-14. The solids blended on each of the first four days were stored in different bulk storage bins; the solids blended on the fifth day were left in the blending tanks until a bin was emptied during the injection. The weights and proportions of solids blended each day are shown in Table 8.

Samples were taken of the solids blended on each of the first four days. These samples were tested in the laboratory to determine significant physical properties. The results are summarized in Table 9. They indicate that a solids-to-water mix ratio of about 8.5 lbs/gal would be optimum for the first two batches blended, but that about 8 lbs/gal would be optimum for the third blend. There was not sufficient time to determine the properties of the June 13 and 14 blends before the injection.

Samples were taken of the individual ingredients used in the solids blending step. These samples were blended in the laboratory and this blend was compared with a field mixed blend made from the same ingredients. Each blend was mixed with water at a mixer speed of 3200 rpm and a mix ratio of 7 lbs/gal. The laboratory blend had a phase separation of 1.4% and a viscosity at 300 rpm of 60 cp; the field mixed blend had a phase separation of 4.8% and a viscosity of 21 cp. A similar difference between lab and field mixed solids has been observed earlier.

Table 8. Weights of Solids Blended

Blending Date	June 10	June 11	June 12	June 13	June 14
Bin #	4	3	1	2	Blending Tanks
Cement, lbs	46,852	46,870	47,020	47,000	47,512
Fly Ash, lbs	36,485	34,490	45,870	46,630	41,030
Attapulgite, lbs	17,940	18,496	18,124	18,327	18,000
Retarder, lbs	54	54	54	54	54
Total Solids, lbs	101,331	99,910	111,068	112,011	106,596

Table 9. Grout Properties

	lb/gal	Density	Phase Separation	Viscosity at 300 rpm (cp)
Blended June 10	6	11.15	21.0%	10.5
	7	11.51	12.9%	15.8
	8	11.85	5.8%	39.6
	8.5	12.0	5.0%	
	9	12.2	3.6%	41.8
Blended June 11	6	11.23	18.6%	11.2
	7	11.6	10.2%	17.9
	8	12.0	5.0%	28.1
	9	12.3	3.0%	44.9
Blended June 12	6	11.15	23.0%	12.8
	7	11.55	4.3%	21.5
	8	11.85	2.7%	36.2
	9	12.16	1.3%	60.5
Blended June 13	6	11.11	15.0%	12.8
	7	11.45	4.8%	21.0
	8	11.75	3.5%	36.0
	9	12.07	2.2%	57.3

4.2.8 Slotting. The well was slotted at a depth of 1090 ft (measured along the casing string from the top of the 9-5/8 surface casing) on June 12. A slurry of sand and water was pumped down the tubing string and out a jet at the bottom of the string to erode the casing at the chosen depth. The initial slotting pressure was 3500 psi; this dropped to 3000 psi within a few minutes and was maintained at this value for 55 minutes. A total of forty sacks of sand was used.

The formation fractured at 2650 psi and accepted water at a rate of four barrels per minute (168 gal/min) at 2200 psi.

4.3 Injection

The injection was started at 1100 on June 14 and immediately ran into difficulties. The flow of solids to the mixer could not be controlled and the mixer cone was quickly jammed with solids. The injection was promptly shut down so that the excess solids could be cleared and the cause of the difficulty determined. It was found that the controls to the solids master valve had been installed backwards so that the valve was opening instead of closing and vice versa. The controls were reversed and the mixer cone and mass meter were cleared of solids. During this time (about two hours) about 15,000 gal of water was used to carry away the solids that were lodged in the mixer cone. This very thin slurry was injected in the test well.

The injection was resumed at 1305 and ran well. A total of 65,700 gal of water was mixed with the stored solids and injected. The injected grout volume was 97,643 gal. The injection rate averaged 247 gal/min at an average pressure at the facility of 2900 psi. The overall solids to liquid ratio was 8.05 lbs/gal; this ratio was varied somewhat during the injection to compensate for the different properties of different batches of blended solids.

There was a brief shutdown of the injection at 1430 to clean the window of the surge tank. The injection was restarted without difficulty.

At 1808 the injection rate was slowed to about 220 gpm to determine the effect of the slower rate on various injection parameters. This lower rate was quite difficult to maintain; the pressure on the jet mixer was lower and this lower pressure resulted in an irregular flow of solids through the mixer. After 35 minutes of reduced flow the injection rate was increased to about 260 gpm.

The injection was stopped at 1940 when the supply of solids was exhausted. The wiper plug was pumped down the well, the slot in the well was pumped free of grout with 420 gal of water, and the well was valved shut. The facility was washed.

The slurry flow rate and the water flow rate during the injection are shown in Fig. 11. The pressure at the injection pump and at the well annulus are shown in Fig. 12.

No attempt was made to run the solids control valve on "automatic." After the initial difficulty with this valve it functioned very well on "manual" and no one wanted to risk a repetition of the startup incident until after the valve operation had been thoroughly checked.

4.4 Data Analysis

The flow of solids to the mixer is indicated by the mass meter readings. These readings averaged about 20% low throughout the injection. This was made evident by the fact that as each bin of solids was emptied, the total weight of solids that had been removed from the bin (as indicated by the mass meter totalizer readings) was about 20% less than the total weight of solids that had been stored in the bin. The bins were checked after the injection and found to be essentially empty; the error, therefore, must have been in the mass meter. This error was most likely caused by the plug of dry solids that inundated the mass meter during the abortive start of the injection. The error was relatively constant between bins and a constant 20% error has been assumed in the analysis of the data. Corrected values for the solids flow rate during the injection are shown in Fig. 13. The mix ratio (obtained by dividing the solids flow rate by the water flow rate) is shown in Fig. 14. The mix ratio of the injected grout was about 7.5 lbs/gal for the solids in Bin 1 and 2, about 8.5 lbs/gal for the solids in Bin 3 and Bin 4, and about 7.3 lbs/gal for the solids in the blending tanks. These mix ratios were very close to those planned prior to the start of the injection. The mix ratio got above 9 lbs/gal at one time during the injection. It was at this time that both injection pressures reached a maximum. The viscosity of this particular mix at 9 lb/gal was apparently quite high.

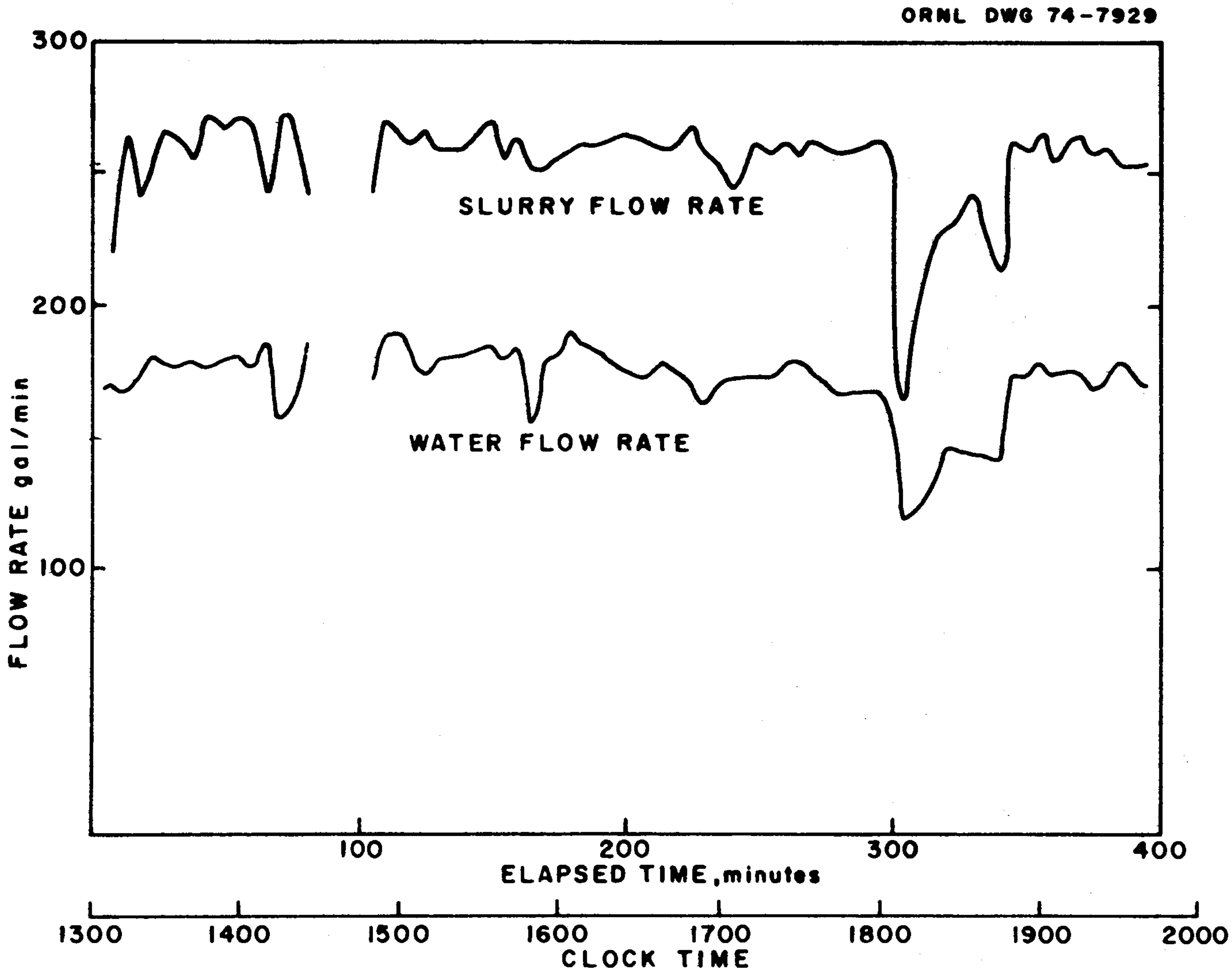

Fig. 11. Flow Rates During Injection

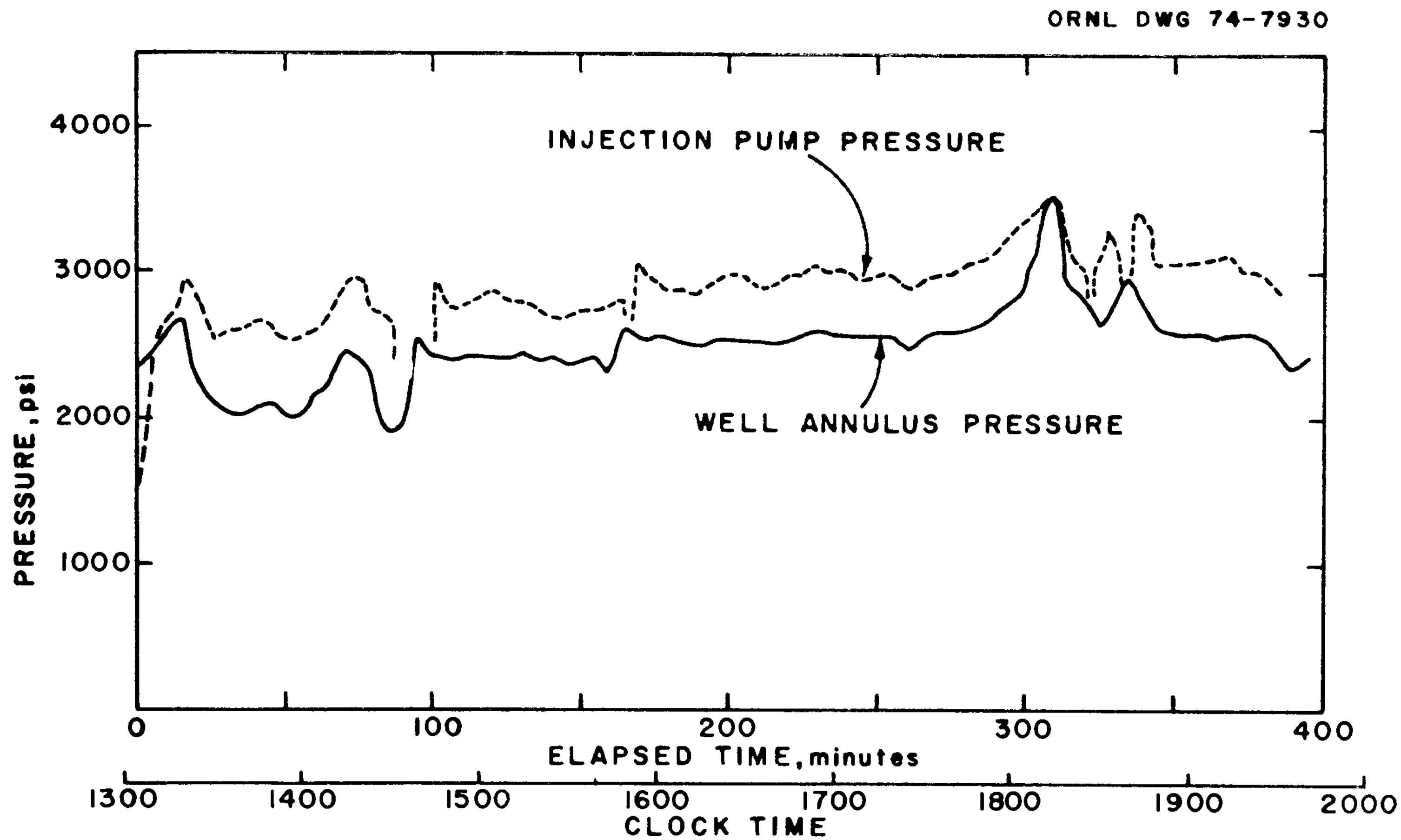

Fig. 12. Pressure at Injection Pump and Well Annulus During Injection

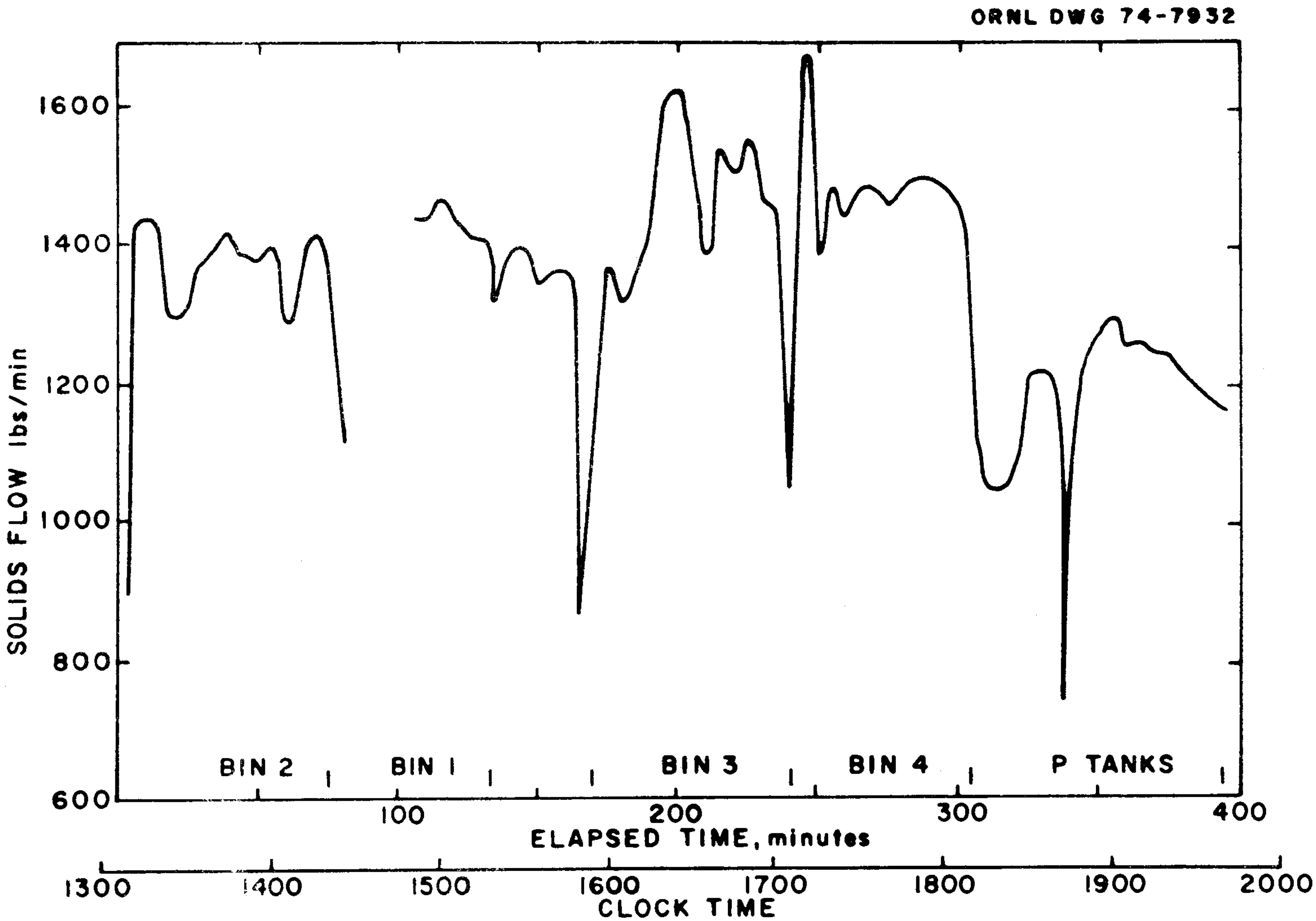

Fig. 13. Solids Flow Rate During Injection

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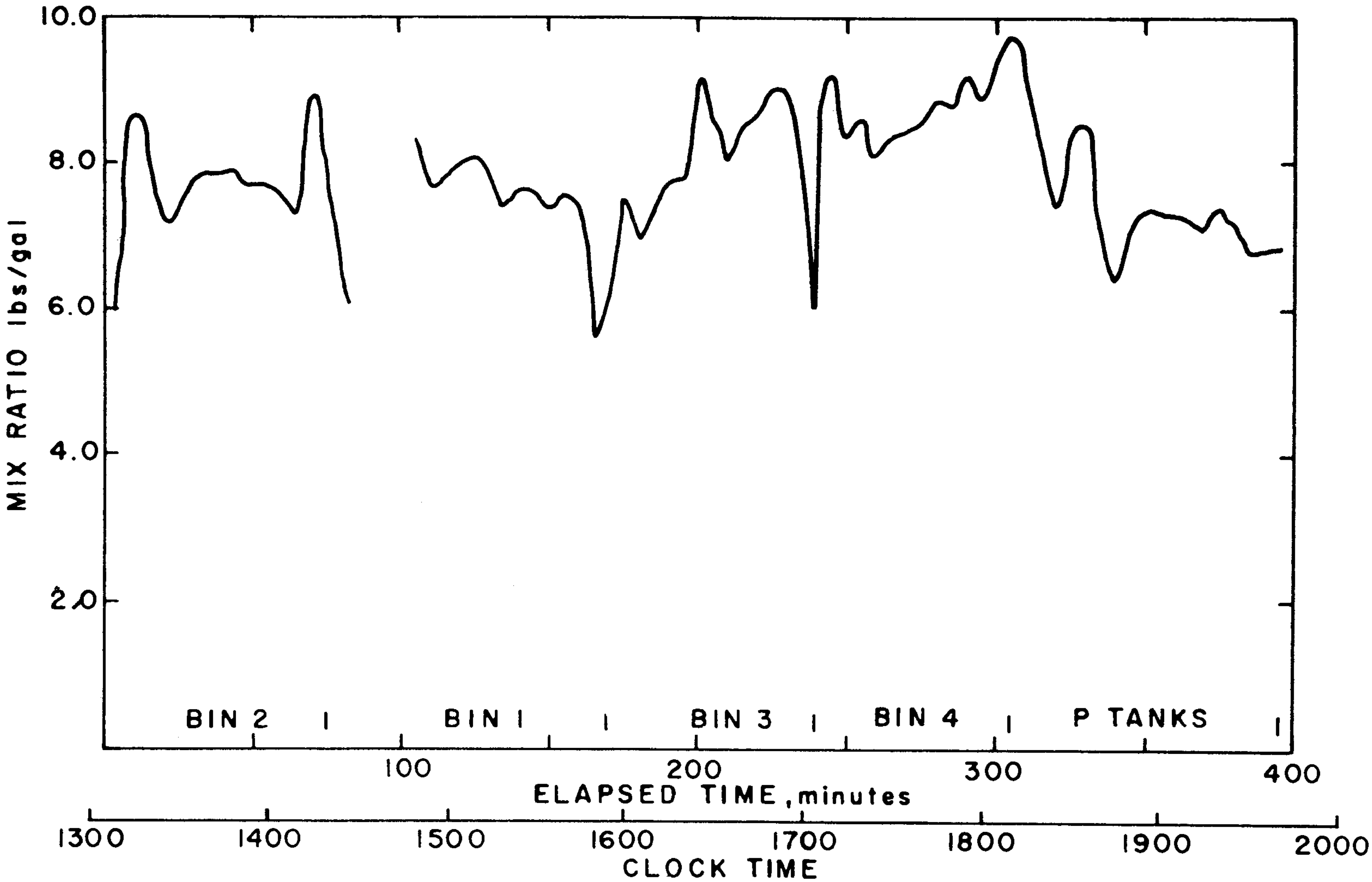

Fig. 14. Mix Ratio During Injection

An attempt to determine relative grout viscosity from amperage readings of the mixing tub agitator was not successful. The readings varied by no more than 5% throughout the injection.

Prior to the site proof injection the solids storage bins had been cleaned, one of the bins had been painted, and new air pads had been installed on the bins. The flow of solids was much improved in this injection, but it is not obvious which change in the system (if any) contributed most to the improvement. The clean bins probably helped more than anything. The new air pads were used when two of the bins were being emptied and were not used when a different two bins were being emptied; no particular difference was noted. Solids flow from Bin 2 (the painted bin) was quite smooth the first time the bin was emptied and less smooth the second time (after the solids stored in the blending tanks had been emptied into it); the effect of painting the bin is not apparent. Smoother solids flow was observed when Bin 1 and Bin 2 (the first time) was being emptied. These bins contained the solids blends with a relatively high fly ash content; the fly ash content of the solids stored in the other bins was about 15% less.

There were six samples of grout taken during the site proof injection, three at the mixing tub and three at the wellhead. Phase separation, density, and viscosity measurements were made on four of the samples to determine the effect of shear on these properties. The phase separation of the grout at the wellhead was lower by a factor of 3 to 5, and the viscosity was higher by a factor of about 1.5. This effect of shear on grout properties was produced by pumping the grout from the mixing tub through about 800 ft of 2.4 in. ID overland pipe to the wellhead. This length of pipe is roughly equivalent to the length of the tubing string used in a regular injection. The shear effect measured in this injection is therefore probably typical of that that occurs in all injections.

The shut-in pressure in the injection well has decreased steadily since the end of the injection. Figure 15 is a plot of observed pressures for a two month interval. This pressure decay pattern is typical of both water and grout injections.

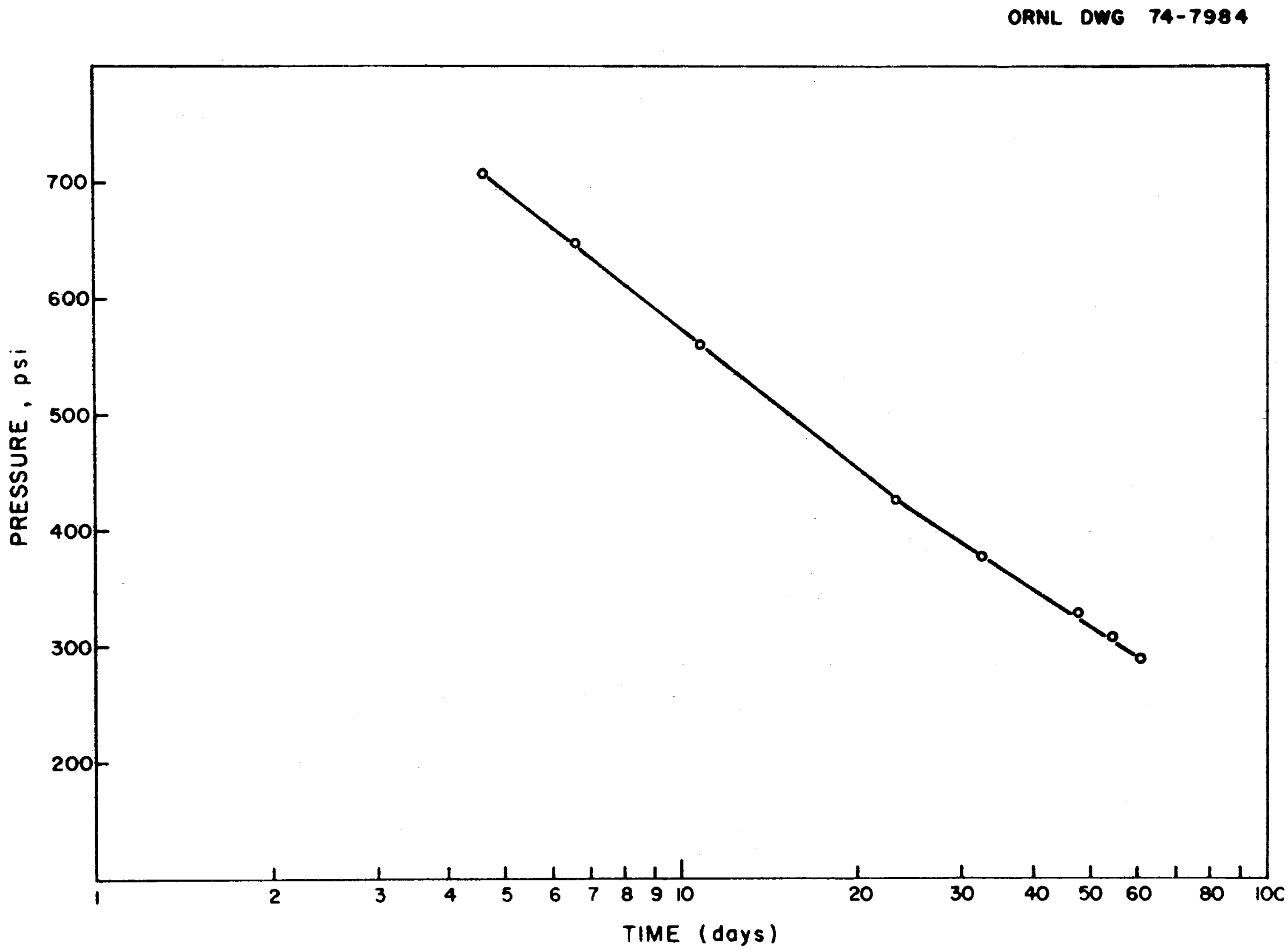

Fig. 15. Pressure in Injection Well after Injection

4.5 Determination of Grout Sheet Orientation

After the completion of the test injection the four observation wells were logged promptly with a gamma sensitive probe; the north and west observation wells the day after the injection, and the two other wells two days later.

A small but well defined gamma peak was found in the north observation well at an elevation of -251 ft msl, 22 ft above the elevation of the slot in the injection well. The north well is up dip stratigraphically from the injection well and the fracture had closely followed the bedding. By chance this new peak came in directly on top of an earlier very low peak resulting from a fracture originated at the present operating disposal well. The new peak was at least ten times as high as the old peak and is undoubtedly due to the test injection of June 14. This new peak, while distinctly larger than the old, is much smaller than the peaks found in the west and south observation wells after the test injection, so that the new fracture at the north well must be very thin and is probably close to the northern limit of the test injection of June 14.

Six thick fractures were found in the west observation well. The principal fracture is at an elevation of -271 ft msl, 2 ft above the elevation of the slot in the injection well. The Rome-Pumpkin Valley contact also rises about 2 ft between these two wells, so it may be concluded that the principal fracture follows the bedding, and that the bedding is little, if any, distorted in this area. The five slightly smaller fractures were found at elevations of -278 ft, -279 ft, -281 ft, -282 ft, and -284 ft. These clearly had broken downward slightly with respect to the bedding. The probable cause was the several stops and starts during the injection, for once stopped, a new injection tends to break out along a new path. It is possible that the multiple fracturing represents minor folding in the shale but even if this is the case, the folding is not of sufficient apparent size to affect the use of the site for waste disposal.

A single thick fracture was found in the south observation well at an elevation of -321 ft, msl, 48 ft below the elevation of the slot in the injection well. This direction is down dip, and the Rome-Pumpkin Valley contact falls about the same amount between these two wells, so that the fracture follows the bedding and the local structure very closely. It is a little surprising that the fracture should have extended with greater thickness down dip to the south than it did up dip to the north, but the dip is gentle and apparently is less of a factor in determining the direction taken by a fracture than minor variations in the strength of the shale.

The east observation well was drilled only to the top of the Rome and over 30 ft of depth was lost when the casing was cemented. As a result the elevation of the bottom of the completed well is at -290 ft msl, only some 17 ft below the slot in the injection well. The east well is down dip from the injection well, and the Rome-Pumpkin Valley contact is some 35 ft lower in the east well than it is in the injection well, so the fracture probably passed 18 ft or so below the lowest point that can be logged in the east well, if, as is probable, it moved out in this direction. In any case no evidence of the fracture was found in the east well.

5.0 CONCLUSIONS

The results of the test injection of June 14 were entirely favorable. The injection pressures were, if anything, slightly less than had been anticipated. The fracture moved out parallel to the bedding and to the structure of the area in advancing to the three observation wells in which it was detected, so that there can hardly be any important folding in the Pumpkin Valley shale, at least at the depth of the test. The multiple fractures observed in the west well are of no real significance as the same have been noted in apparently undeformed shale at the present operating site. In our opinion the investigations and tests completed show clearly that the proposed new site is well suited to waste disposal by hydraulic fracturing, as had been anticipated from earlier extensive experience in this general area.

Overall, despite the difficulty with the solids control valve, the operation of the injection facility went quite well. The flow of solids was much smoother in this injection than in previous injections and the control of the mix ratio was somewhat improved. The main difficulty encountered was with lack of vision in the mix tub.

ACKNOWLEDGEMENT

The preparations for the site proof injection and the injection itself involved the work of many people, both outside contractors and ORNL forces. The engineers and operators of the Halliburton Company, W. H. Longaker of the Plant and Equipment Division, and L. C. Lasher of the Operations Division were greatly involved in all aspects of the injection and were particularly responsible for the success of the entire operation.

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APPENDIX

DESCRIPTION OF CORES; SITE OF SECOND FRACTURING PLANT (SITE 4), SOUTH WELL; DATUM IS LAND SURFACE

694-709	Gray shale, typical, with thin limestone beds up to 2 inches thick. Dips vary gently from 5° to 25°; average about 20°. No evidence of sharp folding.
709-724.8	Gray shale, typical, with thin limestone beds. Dips very gentle, 0° - 5°. No sharp folding.
724.8-740.5	Gray shale, dark gray. Very little limestone. Dips very gentle, 0° - 5°. No sharp folding.
740.5-755.7	Gray shale, typical with thin limestone beds. Dips 0° - 5° except for small drag folds at 746, 750, and 754 feet.
755.7-771.6	Gray shale, typical with thin limestone beds. Beds locally have dips of 0° - 5°, but in places dip up to 60°. There is, in general, much folding and distortion. One sharp fold from 755.7 to 761. Second fold from 764 to 771.6. Much of this section would fracture irregularly because of folding.
771.6-787.3	Gray shale, typical, with limestone beds. Beds are regular and even down to 786.5 with dips of 15° - 25°. 786.5-787.3 crumpled.
787.3-803.0	Red or reddish shale, but not typical red color. Bedding is regular with dips of 20°, except for crumpling and faulting 802-803.
803-818.8	Red or reddish shale, not typical red, with limestone bed from 810-811.5. Beds are regular with dips of 20° - 30°. No folding or distortion.
818.8-834.3	818.8-826 - Typical gray shale with some limestone. Dips 20°; no folding or distortion. Note: Gamma-ray log places contact of gray and red shale clearly at 820. 826-834.3 - red or reddish shale. Dips 0°. No folding or distortion.
834.3-849.5	All typical red shale with sandy layers. Dips 0° - 5°. No folding or distortion. Very even thin bedding.
849.5-869.5	All red shale with a few sandy beds. Dips very constant at 20°. No folding or distortion.
869.5-884.9	All red shale. No sandy or glauconitic layers. Beds have regular dip of 20°. No folding or distortion.

884.9-900	Dark red shale. No sandy layers. Beds show regular dip of 20° to 30° except for distortions 884.9-889 and 889-900.
900-915.9	Dark red to dark reddish gray shale; no sandy beds. From 900-908, no distortion; dips 20° - 30°. 908-913 - Rock much broken in core with some irregular distortion. 913-915.9 - Bedding regular, dips 10° - 15°.
915.9-932.0	All red shale; much sandy or glauconitic beds. Bedding irregular; dips 10° - 20°.
932.0-948.5	All red shale, bedding well developed. Dips 10° - 20°. No deformation.
948.5-961.4	All red shale; bedding well developed. Dips 10° - 20°. No deformation.
961.4-976.6	All red shale; locally some light colored sandy beds 1 inch to 2 inches thick. All well bedded except 974-976.6 which is massive due to turbidity currents. Dips regular at 10°; no distortion.
976.6-993.5	All red shale. Some shows no bedding (turbidity currents) but in rest of bedding is well developed. Dips 10°; no deformation.
993.5-948.5	All well bedded red shale. Dips 10° - 20°; no deformation.
948.5-961.4	All red shale. Bedding well developed. Dips 10° - 20°; no deformation.
961.4-976.6	All red shale; locally some light colored sandy beds 1 inch to 2 inches thick. All well bedded except 974-976.6 which is massive (turbidity currents). Dips 10°; no deformation.
976.6-993.5	All red shale, massive (turbidity currents) 976-982. In rest bedding is well developed. Dips 10° - 20°; no deformation.
993.5-1007.0	Largely gray shale with one or two 4 inch beds of red. Shale locally massive but most is well bedded. Dip 0°; rock not deformed.
1007-1022	Dark gray shale with faint local tinges of red. All is well bedded. Dip 0°; no deformation.
1022-1037	Generally gray shale with many light colored sandy layers. Reddish tinge 1034-1037. Bedding well developed. Dips 0° except for small fold 1036-1037.

1037-1052	Largely gray shale with locally pinkish tinge. Some sandy layers. Bedding generally well developed, locally poor. Dip 0°; no deformation.
1052-1066.8	All red shale. Massive (bedding destroyed) 1052-1054. Well bedded 1054-1058. Massive 1058-1066.8. Dip 20°; no deformation.
1066.8-1081.9	Gray shale with reddish tinge. Dips generally 45° - 60°. Folds at 1067 and 1074. Beds much deformed 1066-1076. Beds regular 1076-1081.9. Dips 10°.
1081.9-1104.5	Mostly red shale from 1081.9-1090. Red shale with sandy beds 1090-1104.5. Dips 10° - 20°; no deformation.
1104.5-1120.5	All red or reddish shale. A few light colored sandy beds. Generally well bedded but locally massive. Dips 10° - 15°; not deformed.
1120.5-1134.5	All red shale. Many sandy layers 1120.5-1122. Well bedded 1122-1127. Massive 1127-1134.5.
1134.5-1149.9	All red shale with a few light colored sandy layers. All well bedded. Dips 0° - 10°, except 30° 1146-1148.
1149.9-1172.1	Red shale with some sandy layers 1149.9-1170. Contact between red shale and Rome sandstone at 1170. Hard white to light gray sandstone 1170-1172.1. Dips 0° - 10°; no deformation in shale or sandstone.

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