DEEP WATER WELL AT THE JAYHAWK ORDNANCE WORKS IN CHEROKEE COUNTY, KANSAS

By

G. E. Abernathy

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By G. E. Abernathy[2]

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[1] Published with permission of C. Y. Thomas, General Manager, Military Chemical Works, Inc., Prime Contractors of the Jayhawk Ordnance Works.

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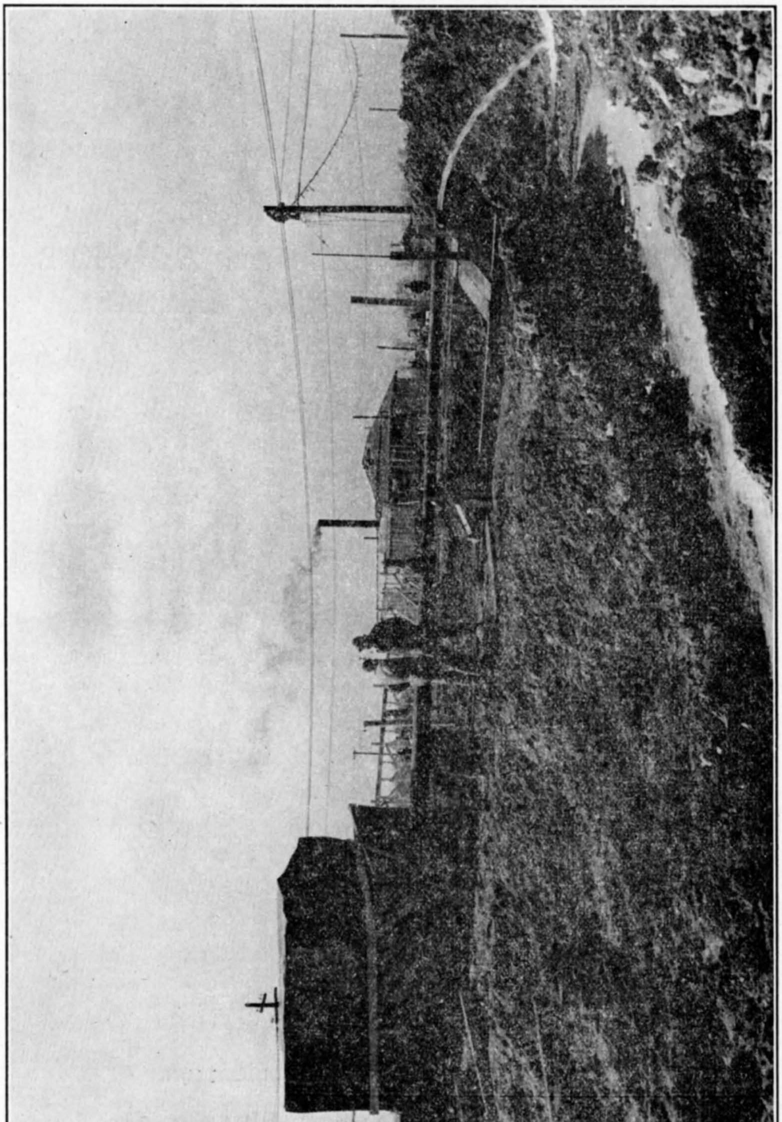

PLATE 1. The Jayhawk Ordnance Works well in Cherokee County, Kansas.

Contents

Illustrations

Tables

ACKNOWLEDGMENTS

Participation of the State Geological Survey in planning and constructing the Jayhawk Ordnance Works deep water well was under the general administration of R. C. Moore, State Geologist, and John C. Frye, Assistant State Geologist.

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DEEP WATER WELL AT THE JAYHAWK ORDNANCE WORKS IN CHEROKEE COUNTY, KANSAS

By G. E. ABERNATHY

ABSTRACT

At the request of officials of the Jayhawk Ordnance Works, a representative of the State Geological Survey of Kansas supervised the drawing of plans and specifications and acted as consulting geologist during drilling operations for a deep water well. The well was begun at the Jayhawk Ordnance Works, in Cherokee county, Kansas, on December 16, 1941, and was completed on January 22, 1942.

The first rocks penetrated in the well are Mississippian in age. The deepest formation penetrated is the Gasconade of early Ordovician age. In southeastern Kansas, Mississippian rocks lie upon Ordovician rocks.

The most important water-producing formation encountered in the well is the Roubidoux of the Ordovicion which was penetrated at 745 feet to 875 feet below the surface. The Roubidoux is a light gray, sandy dolomite. It contains two sandstone beds throughout southeastern Kansas. One sandstone bed is 25 feet thick and occurs at the base of the formation; the other is about 20 feet thick and is separated from the lower bed by about 50 feet of sandy dolomite. In favorable areas the sandstone beds and porous dolomites yield fair supplies of moderately hard water which is low in chloride. Other Ordovician formations, the Jefferson City and the Cotter, yield smaller amounts of water. The Burlington, Keokuk, and Reeds Spring formations of the Mississippian system contain large quantities of water. The water in the Mississippian rocks, however, is extremely hard because of considerable iron and iron and sulphur compounds. The water from the Mississippian rocks was cased off in the well under consideration. Permanent casing was set at 335 feet and was grouted with cement from the bottom of the casing to the surface of the ground.

This Ordnance well is the first deep water well in this district known to have been treated with acid. A pumping test was made before the well was acidized and additional tests were made after use of the acid. The tests indicated that the specific capacity of the well was increased more than four times as a result of acid treatment.

DRILLING OPERATIONS AND STUDIES

PARTICIPATION BY THE GEOLOGICAL SURVEY

The Jayhawk Ordnance Works deep water well, NW cor. SE NE sec. 4, T. 34 S., R. 25 E., Cherokee county, Kansas, (fig. 1) is the first deep water well in the Tri-State area known to have been

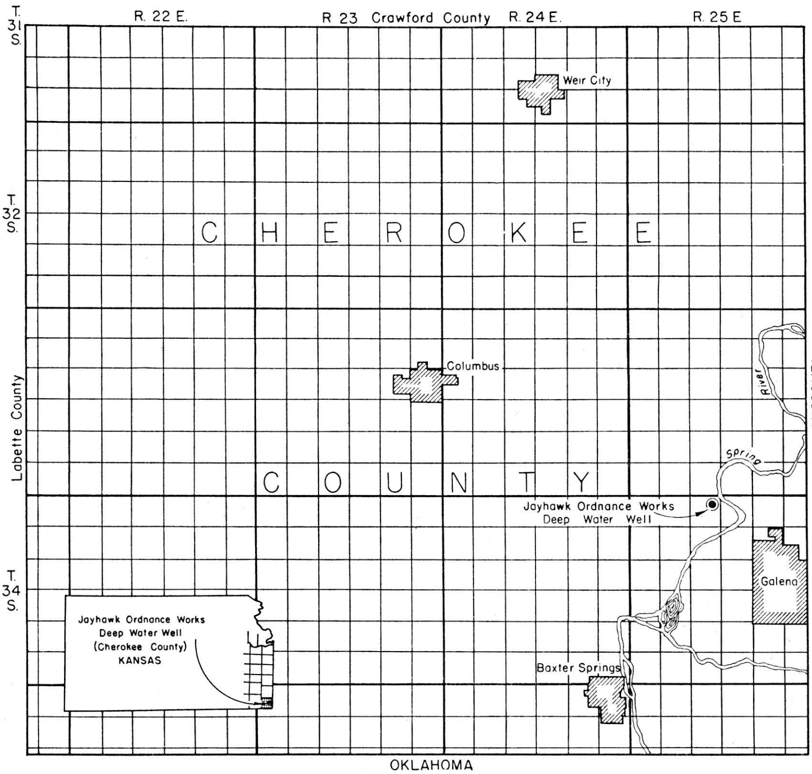


FIG. 1. Index map of Cherokee County, Kansas showing location of the Jayhawk Ordnance Works well.

treated successfully with acid. The well was electrically logged and was test-pumped both before and after acid treatment.

During the 13 months that the well was being planned and drilled, members of the State Geological Survey of Kansas advised in the preparation of specifications and supplied geological advice. They collected drill cuttings and water samples from various water-bearing formations and, finally, prepared this report in order that other war industries located in the Tri-State area, or in areas where similar water supply problems occur, may have a complete record of the drilling method and treatment of a deep water well. Also included in this report is a part of the detailed information gathered in 1941 in a survey of ground-water conditions in south-eastern Kansas, a preliminary outline of which was published in 1941 (Abernathy).

The Geological Survey began to study the problem on February 28, 1941, when C. Y. Thomas, Chief Engineer of the Jayhawk Ordnance Works, requested information relative to a ground-water supply in Crawford and Cherokee counties. On March 3, 1941, the Survey made a preliminary report which was immediately followed with additional investigation.

In conference with War Department officials and Army Engineers, the Survey furnished much advice relative to electric logging, selection of points for temporary and permanent casing, cementing, acid treatment, setting the deep-well pump, and testing the well capacity. This work, begun August 1, 1941, was completed March 12, 1942.

Rocks Penetrated

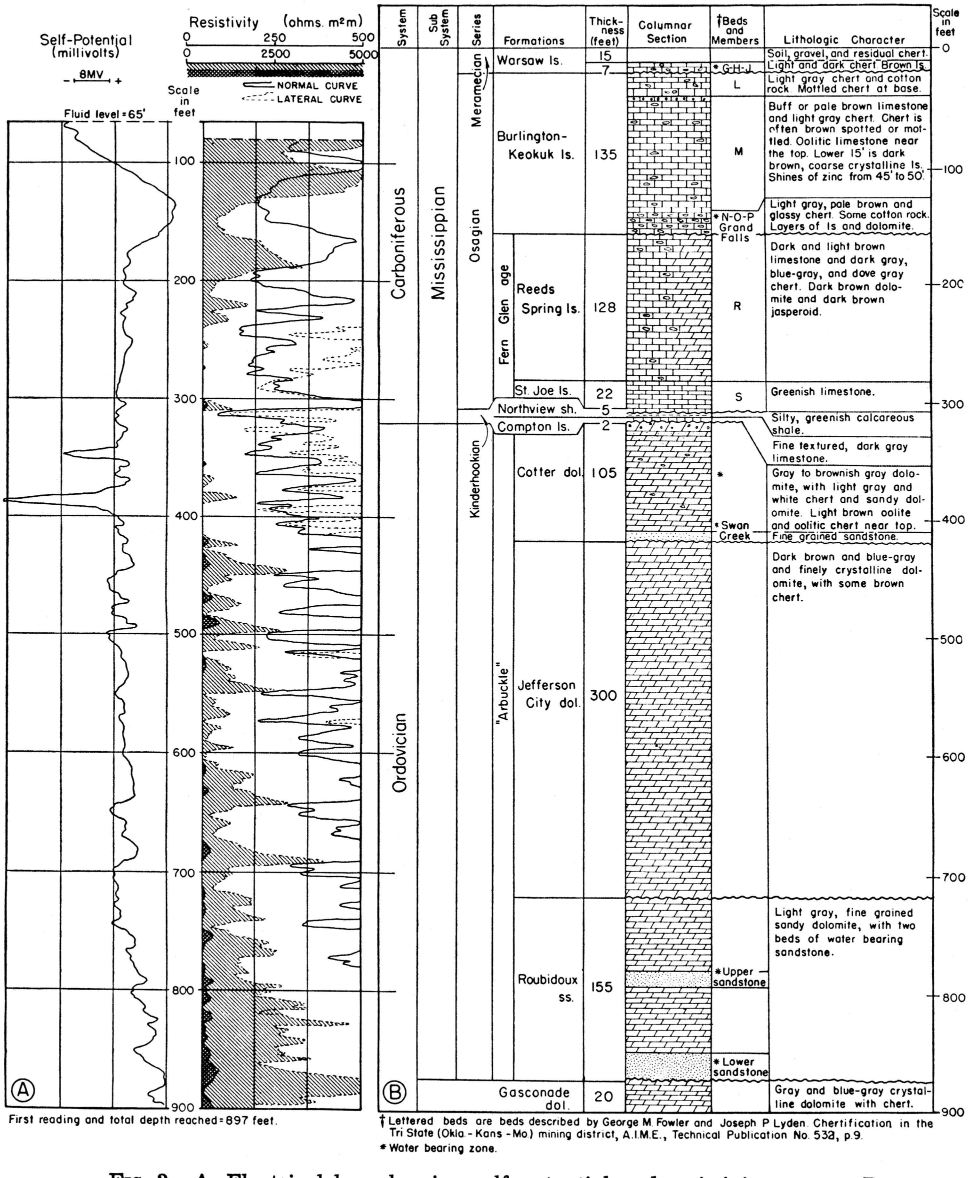
Rocks of Mississippian age crop out on the reservation of the Jayhawk Ordnance Works, which is located a few miles east and south of the outcrop of the disconformity between rocks of the Mississippian and Pennsylvanian subsystems. The discomformable surface between Mississippian limestone and Pennsylvanian sediments is a very irregular one, with a local relief of 100 or more feet.

Mississippian rocks in this part of Kansas lie disconformably on rocks of Ordovician age. The subsurface formations of Mississippian and Ordovician age penetrated by the deep well at the Jayhawk Ordnance Works are shown in figure 2. The rocks of Ordovician age in the well consist mostly of cherty dolomite, some sandy dolomite, and sandstone. The rocks of the Mississippian subsystem consist mostly of cherty limestone, limestone, and a thin bed of shale.

The correlation shown in figure 2 is my own, made with the aid of insoluble residues and cuttings. Wallace Lee, Federal and State Geological Surveys, J. G. Grohskopf, and O. R. Grawe, Missouri Bureau of Geology and Water Resources, and R. P. Keroher, formerly of the State Geological Survey of Kansas, separately studied residues and cuttings and made correlations that do not agree in all respects.

Rocks of Ordovician Age

Gasconade formation.—The oldest rocks penetrated by the deep well at the Jayhawk Ordnance Works belong to the Gasconade formation. Grohskopf-Gott identified 20 feet of Gasconade rocks in



First reading and total depth reached = 897 feet.

† Lettered beds are beds described by George M Fowler and Joseph P Lyden Certification in the Tri State (Okla.-Kans.-Mo.) mining district, A.I.M.E., Technical Publication No. 532, p.9.

* Water bearing zone.

FIG. 2. A. Electrical log, showing self-potential and resistivity curves. B. Columnar section of rocks penetrated by the Jayhawk Ordnance Works deep water well.

a correlation made by an examination of the siliceous residues. Cuttings from Gasconade rocks in this well consist of: (1) fine crystalline, brown and gray dolomite; (2) light gray and light brown granular dolomite; (3) glassy gray chert; (4) white and light gray vitreous chert; (5) clear quartz sand grains; (6) pyrite; and (7) calcite. Some siliceous oölite and light gray chert are found in the siliceous residues of these rocks.

Roubidoux formation.—The Roubidoux formation is commonly described as consisting of alternating beds of dolomite and sandstone. In southeastern Kansas the formation consists of brown-gray dolomite and two sandstone members.

TABLE 1.—*Driller's time-log for deep water well at the Jayhawk Ordnance Works, NW cor. SE NE sec. 4, T. 34 S., R. 25 E., Cherokee county, Kansas (Altitude: top of well, 854.33 feet; bottom of hole, —46.67 feet. Drilling began December 16, 1941; completed January 22, 1942. Static water level in completed well, 65 feet below land surface.)*

Date	*Formation*	*Thickness (feet)*	*Total depth (ft.)*	*Diameter of hole (in.)*
1941				
Dec. 16	Clay	12	12	20
	Gravel	2	14	20
	Flint, blue, gray, and white	4	18	20
	Flint, gray, and limestone	2	20	20
Dec. 19	(Set 20 feet of 18 inch pipe)			.
Dec. 20	Flint, gray, and limestone	15	35	16
	Flint, white, gray, and blue	2	37	16
	Flint, white, gray, and blue	3	40	16
Dec. 21	Flint, blue-gray	5	45	16
Dec. 22	Flint, blue-gray, and zinc "shines"	2½	47½	16
	Limestone, gray, and flint, gray	2½	50	16
Dec. 23	Limestone, gray, and flint, gray	7	57	16
	Limestone, gray	7	64	16
Dec. 24	Limestone, gray, and flint, gray	11	75	16
	Limestone, gray	3	78	16
Dec. 25	Limestone, gray	32½	110½	16
Dec. 26	Limestone, gray	3½	114	16
	Limestone, gray, and flint, gray	12	126	16
	Flint, white and gray	3	129	16
Dec. 27	Flint, gray	11	140	16
	Flint, gray, and limestone, gray	6	146	16
	Flint, light blue and gray, and zinc traces	4	150	16
	Limestone, gray-brown, and pyrite	7	157	16
	Limestone, brown and white	3	160	16
	Flint, white-gray and blue	7	167	16
Dec. 28	Limestone, brown and white	2	169	16
	Flint, white and blue, and limestone, dark	5	174	16
	Flint, blue and gray, and limestone, gray	6	180	16

TABLE 1.—*Driller's time-log for deep water well at the Jayhawk Ordnance Works, NW cor. SE NE sec. 4, T. 34 S., R. 25 E., Cherokee county, Kansas (continued)*

Date	*Formation*	*Thickness (feet)*	*Total depth (ft.)*	*Diameter of hole (in.)*
Dec. 29	Flint, blue and gray, and limestone, gray	9	189	16
	Flint, blue, and limestone, gray	11	200	16
	(Reduced hole from 16″ to 13″ at 200′)			
	Limestone, blue-gray, and flint, gray	5	205	13
	Limestone, gray, and flint, gray	4	209	13
	(Water level, 40′ from top)			
Dec. 30	Limestone, gray, and flint, blue and gray	9	218	13
	Limestone, flint, and shale, dark	3	221	13
	Limestone, gray, and flint, blue	14	235	13
	Limestone, gray, and flint, gray	9	244	13
	Limestone, gray, and flint, gray	6	250	13
Dec. 31	Limestone, gray, and flint, gray	5	255	13
	Limestone, gray	5	260	13
1942				
Jan. 1	Running pipe and welding joints (temporary casing)			
Jan. 2	Running pipe and welding joints (temporary casing)			
Jan. 3	Running pipe and welding joints (temporary casing)			
Jan. 4	Running pipe and welding joints (temporary casing)			
Jan. 5	Limestone, gray	10	270	10
	Limestone, gray, and flint, blue	5	275	10
	Flint, blue-gray and white	5	280	10
	Limestone, gray and green, and flint, gray	5	285	10
	Limestone, gray	6	291	10
Jan. 6	Limestone, gray	14	305	10
	Limestone, green	6	311	10
	Limestone, gray and green	4	315	10
	Limestone, gray, and flint	15	330	10
	Limestone, gray, and flint, gray	5	335	10
	Flint, gray and white, and limestone, gray	6	341	10
Jan. 7	Flint, white and blue, and limestone, gray	31	372	10
	Limestone, gray, and flint, gray	18	390	10
	Limestone, gray, and flint, gray-blue	5	395	10
	(120 gal. in 5 min. 25 ft. draw down)			
	(Pulled temporary casing)			
	(Started reaming hole)			
Jan. 9	(Reamed hole)	56	316	—
Jan. 10	(Reamed hole)	19	335	8¼-13
	(Reamed hole)	21	356	8¼-10
Jan. 11	(Reamed hole)	34	390	8¼-10
	(Reamed hole)	5	395	8¼-10

TABLE 1.—*Driller's time-log for deep water well at the Jayhawk Ordnance Works, NW cor. SE NE sec. 4, T. 34 S., R. 25 E., Cherokee county, Kansas (continued)*

Date	*Formation*	*Thickness (feet)*	*Total depth (ft.)*	*Diameter of hole (in.)*
Jan. 12	Flint, white and blue	3	398	10
	Limestone, gray	3	401	10
	Limestone, gray, and flint, blue	9	410	10
	Limestone, gray, and sandstone	22	422	10
	Limestone, gray, and sandstone, and flint, gray	13	435	10
	Limestone, gray, and flint, gray	5	440	10
	Flint, white and blue, and flint, gray	24	464	10
Jan. 13	Flint, white and blue, and limestone, gray	8	472	10
	Limestone, gray, and flint, white	23	495	10
Jan. 14	Limestone, gray, and flint, white	20	515	10
	Limestone, gray, and flint, gray	31	546	10
Jan. 15	Limestone, gray, and flint, gray	24	570	10
	Flint, blue-gray, and limestone, gray	30	600	10
	Limestone, brown, and flint, white	12	612	10
Jan. 16	Limestone, brown, and flint, white	23	635	10
	Limestone, brown, and flint, white and blue	20	655	10
	Flint, blue-gray, and limestone, brown	10	665	10
	Limestone, gray, and flint, gray	5	670	10
	Limestone, brown, and flint, gray	7	677	10
Jan. 17	Limestone, brown, and flint, gray	21	698	10
	Limestone, brown sandy	12	710	10
	Flint, white-gray, and limestone, gray	10	720	10
	Flint, gray-white-blue	10	730	10
Jan. 18	Flint, gray-white and blue	17	747	10
	Limestone, gray sandy calcite	8	755	10
	Limestone, gray calcite	7	762	10
	Limestone, gray-white-blue	3	765	10
	Limestone, gray-white and blue	10	775	10
Jan. 19	Limestone, gray, and flint, blue and white	7	782	10
	Limestone, gray, flint, gray-white, and sandstone	3	785	10
	Sandstone	7	792	10
	Limestone, sandy	13	805	10
Jan. 20	Limestone, sandy	20	825	10
	Flint, gray-white, and limestone, gray	10	835	10
	Flint, gray-white	5	840	10
	Limestone, sandy	9	849	10
Jan. 21	Sandstone	24	873	10
Jan. 22	Sandstone	3	876	10
	Limestone, very little sandstone	6	882	10
	Limestone, sandy gray	13	895	10
	Limestone, gray, S.L.M.	6	901	10

In the Jayhawk Ordnance Works well, the Roubidoux formation is 155 feet thick. The top of the formation was reached at a depth of 720 feet. The uppermost sandstone member is 15 feet thick and occurs in the middle of the formation. The lower sandstone member is about 25 feet thick and occurs at the base of the formation. Both sandstone members contain subangular to rounded quartz grains, medium to coarse in size. The grains are unfrosted and many show concentric coatings of silica, the results of secondary enlargement. Chert, which is dense and glassy and light gray and light blue, occurs abundantly in the Roubidoux formation. The average content of insoluble residue in the Roubidoux dolomite is 74.82 percent. Some of the chert in the siliceous residues is dead white in color. Dark gray, siliceous oölite is common to the chert found in the siliceous residues. The dolomite in the Roubidoux has fine granular texture and is brown and gray.

Jefferson City formation.—The Jefferson City formation comprises a finely crystalline, cherty dolomite, dark brown and blue-gray in color, 300 feet thick in the Jayhawk Ordnance Works well. The top of the formation was reached at a depth of 420 feet.

Chert occurs abundantly in the Jefferson City formation. It is light in color, translucent, and has a waxy luster. This peculiar chert is characteristic of the Jefferson City. The electric log and the drillers' time log indicate that the formation consists of fairly porous dolomite and streaks or thin bands of impervious chert. The average content of insoluble material in the Jefferson City formation is 84.58 percent.

Cotter formation.—The Cotter formation lies above the Jefferson City formation and is the uppermost Ordovician formation in the well. The Cotter formation consists of tan and light gray, sandy, cherty dolomite and some thin beds of sandstone. The total thickness of the Cotter formation in the wells is 105 feet. The top was reached at 314 feet.

Chert of the Cotter formation is gray and brown. Pyrite and concentrically banded cherts are common. Oölitic chert, brown in color, and brown oölite coated with fine quartz crystals are very characteristic of the Cotter formation. Vugs and cavities lined with quartz crystals are common in the upper members of the formation. The average acid insoluble content of the Cotter dolomite is 85.75 percent.

The base of the formation is marked by 10 feet of sandy dolomite (Swan Creek).

Rocks of Mississippian (Early Carboniferous) Age

Pre-Carboniferous unconformity.—Southeastern Kansas lies on the Chautauqua Arch, and in several counties Mississippian rocks lie on rocks of medial and early Ordovician age. Devonian, Silurian, and late Ordovician deposits were eroded from most of the Chautauqua Arch before burial under Mississippian sediments.

Subsurface Mississippian rocks of Kansas have been studied by Lee (1940); his investigation included studies of cuttings from several wells in the same general area of the Jayhawk Ordnance well.

Compton formation.—Beds assigned to the Compton formation consist of bluish gray, compact, fine-grained limestone. In the Jayhawk Ordnance Works well the formation is 5 feet thick. The upper beds of the formation merge into the soft bluish green shale of the Northview formation.

Northview formation.—The well cuttings of Northview shale from the Jayhawk Ordnance Works well consists of soft, bluish green shale, 5 feet thick. This shale is easily distinguished from the shale of other associated formations by its color and plastic, sticky properties.

St. Joe formation.—The St. Joe formation includes the beds between the overlying Reeds Spring formation and the underlying Northview formation. In the Jayhawk Ordnance Works well, rocks of this formation consist of beds of light bluish gray, fine-grained, and compact limestone, 25 feet thick. The formation contains some chert. It is distinguished from the overlying formations by its smaller content of chert, and from the lower formations by its larger content of limestone and the absence of dolomite.

Reeds Spring formation.—The Reeds Spring formation includes the beds between the overlying Burlington formation and the St. Joe limestone. It consists of dense, hard, fine-grained, bluish limestone, some dolomitic limestone, some dolomite, some siltstone, an abundance of chert, dark brown and dark gray in color and 125 feet thick in the Jayhawk Ordnance Works well.

Burlington-Keokuk formations.—The Burlington-Keokuk formations include all of the beds between the overlying Warsaw and the Reeds Spring formations. The Burlington-Keokuk formations are separated from the Warsaw by an unconformity. The formations consist of gray and tan limestone, dolomite, and an abundance of chert. In the Jayhawk Ordnance Works well the formations are 135 feet thick. The base of the formation is the Grand Falls chert member, 35 feet thick. The chert is speckled—light gray, dove gray, ash gray, and brown. The Grand Falls member consists of 80 percent insoluble material (chert), gray limestone, and some gray dolomitic limestone. In the Tri-State mining district the Grand Falls member is designated as "N, O, P, and Q" beds, or the "sheet-ground."

M bed overlies the N, O, P, and Q beds. It is characterized by light brown oölite in its upper members, light brown limestone, and a low content of chert. In the Jayhawk Ordnance Works well, M bed is 81 feet thick.

L bed, 20 feet thick, overlies the M bed and is the uppermost bed of the Burlington-Keokuk formations. In the Jayhawk Ordnance Works well it consists of light gray limestone and white, leached chert, known as "cotton rock."

Warsaw formation.—The Warsaw formation in the Jayhawk Ordnance Works well consists of light and dark gray chert with some gray limestone. The base of the formation is marked by the J bed (Cowley) (Lee, 1940, p. 81), which consists of dark brown limestone and flint with some glauconite. The thickness of rocks assigned to the Warsaw formation is 88 feet. About 12 feet of detrital material overlies the Warsaw rocks.

Physical and Hydrologic Properties of Formations Penetrated

Water-level Measurements

While the well was being drilled, the depth to water level was measured using a steel line each time a different formation was penetrated, or at intervals within a given formation. The results are given in table 2. After drilling had reached a depth of 260 feet, the temporary casing was set to this depth preventing any effect of the hydrostatic pressure of water in the Reeds Spring limestone on that of water in the lower formations. The well was drilled from 260 feet to the bottom without using casing in this part of the hole; therefore, the water-level measurements made below a depth of 260 feet do not necessarily represent the hydrostatic pressure of water in the particular formation reached by the drill; but they do represent the resultant head of water from all formations pene-

TABLE 2.—*Depths of rock formations penetrated and corresponding static water levels*

Rock formation	*Depth of formation (ft.)*	*Static water level (feet below land surface)*
Warsaw	0—110	dry
Burlington and Keokuk	110—145	dry
Reeds Spring	145—285	40
Cotter	315—320	195
Cotter	320—330	150
Cotter	330—335	65
Cotter	335—410	57
Swan Creek	410—420	57
Jefferson City	420—472	60
Jefferson City	472—495	65
Jefferson City	495—715	60
Roubidoux	715—747	60
Roubidoux	747—850	70
Roubidoux	850—862	63
Roubidoux	862—865	68
Roubidoux	865—876	67
Gasconade	876—901	65

trated below 260 feet. Water-bearing formations having a lower head than the resultant probably were receiving water from the well; those having a higher head probably were contributing water. Moreover, the accuracy of individual water-level measurements doubtless was affected by the quantity and period of bailing, the length of time the well was allowed to rest before the measurements were made, and the possible sealing effect of drill cuttings in the bottom of the hole.

SOLUBILITY OF DRILL CUTTINGS

The drill cuttings were tested for solubility by the Halliburton Oil Well Cementing Company and also by the State Geological Survey of Kansas. The analyses by the Geological Survey, which are very similar to those made by the Halliburton Oil Well Cementing Company, are given in table 3.

A curve showing the percentage of soluble material in each sample is given in figure 3. The analyses indicate that the lower part of the Burlington (Keokuk) limestone has low solubility, and the Grand Falls chert member at the base of the Burlington is nearly insoluble. The upper part of the Reeds Spring limestone also has low solubility. The remainder of the curve shows high

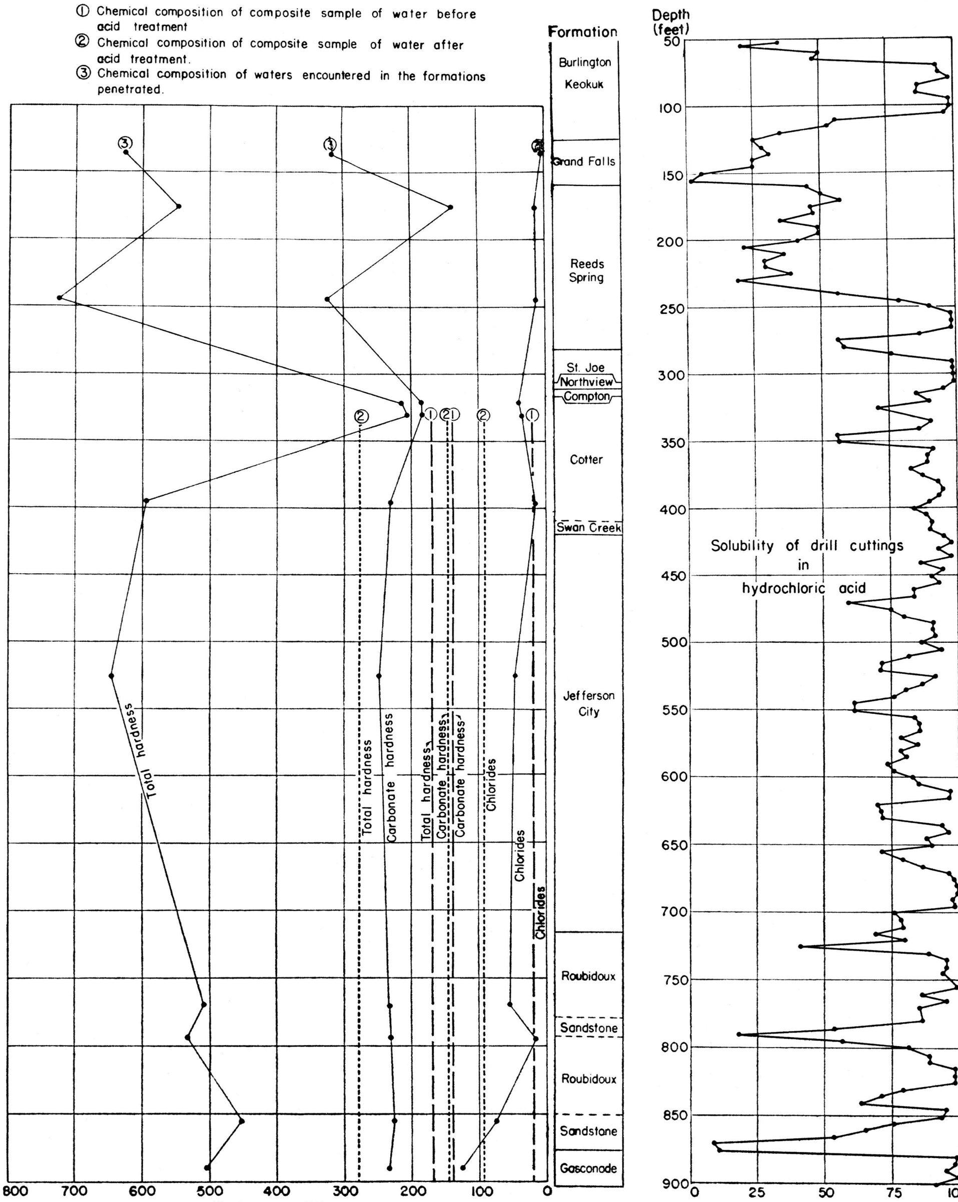


FIG. 3. Solubility of rocks penetrated and the hardness and chloride content of waters contained in the various formations of the Jayhawk Ordnance Works deep water well.

TABLE 3.—*Solubility in (hydrochloric acid) of drill cuttings from Jayhawk Ordnance Works water well. (Kansas Geological Survey No. 3108. Analyses by R. P. Keroher.)*

Depth (feet)	*Solubility (percent)*	*Depth (feet)*	*Solubility (percent)*	*Depth (feet)*	*Solubility (percent)*
50 — 52.5	35	221 —225	39	475 —480	80
52.5 — 55	21	225 —229	19	480 —485	91
55 — 57	87	229 —234	—	485 —490	91
57 — 60	50	234 —239	57	490 —495	92
60 — 64	48	239 —244	79	495 —500	89
64 — 66	47	244 —250	91	500 —505	94
66 — 68	64	250 —255	99	505 —510	82
68 — 70	94	255 —260	99	510 —515	72
70 — 72.5	65	260 —262	98	515 —520	72
72.5 — 75	95	262 —265	99	520 —525	92
75 — 78	99	265 —270	87	525 —530	87
78 — 83	99	270 —275	56	530 —535	81
83 — 87.5	86	275 —280	58	535 —540	77
87.5 — 91	86	280 —285	76	540 —545	62
91 — 95	99	285 —290	99	545 —550	62
95 —100	99	290 —295	99	550 —555	84
100 —104	98	295 —300	99	555 —560	86
104 —108	79	300 —305	99	560 —565	86
108 —110.5	56	305 —310	95	565 —570	78
110.5 —114	53	310 —315	85	570 —575	85
114 —117	33	315 —320	90	575 —580	79
117 —120	35	320 —325	71	580 —585	82
120 —123	68	325 —330	—	585 —590	73
123 —126	25	330 —335	91	590 —595	76
126 —129	29	335 —340	86	595 —600	83
129 —133	32	340 —345	61	600 —605	85
133 —137	31	345 —350	57	605 —610	97
137 —140	25	350 —355	91	610 —615	97
140 —143	26	355 —360	89	615 —620	70
143 —145	25	360 —365	89	620 —625	71
145 —150	6	365 —370	83	625 —630	72
150 —154	2	370 —375	87	630 —635	94
154 —157	1	375 —380	93	635 —640	96
157 —160	45	380 —385	95	640 —645	88
160 —162	57	385 —390	93	645 —650	90
162 —164	37	390 —395	90	650 —655	72
164 —167	54	395 —400	84	655 —660	78
167 —170	57	400 —405	88	660 —665	82
170 —174	41	405 —410	92	665 —670	97
174 —177	42	410 —415	90	670 —675	98
177 —180	45	415 —420	95	675 —680	99
180 —184.5	35	420 —425	98	680 —685	99
184.5 —189	49	425 —430	93	685 —690	98
189 —192	53	430 —435	97	690 —695	98
192 —196	49	435 —440	86	695 —700	76
196 —200	41	440 —445	95	700 —705	78
200 —202	31	445 —450	90	705 —710	79
202 —205	21	450 —455	93	710 —715	69
205 —209	36	455 —460	84	715 —720	80
209 —213	28	460 —465	84	720 —725	41
213 —219	28	465 —470	68	725 —730	88
219 —221	29	470 —475	78	730 —735	95

TABLE 3.—*Solubility in (hydrochloric acid) of drill cuttings from Jayhawk Ordnance Works water well. (Kansas Geological Survey No. 3108. Analyses by R. P. Keroher.)*
(Continued)

Depth (feet)	Solubility (percent)	Depth (feet)	Solubility (percent)	Depth (feet)	Solubility (percent)
735 —740	95	790 —795	57	845 —850	93
740 —745	94	795 —800	81	850 —855	76
745 —750	—	800 —805	89	855 —860	65
750 —755	99	805 —810	89	860 —865	53
755 —760	86	810 —815	98	865 —870	9
760 —765	95	815 —820	98	870 —875	11
765 —770	85	820 —825	98	875 —880	98
770 —780	—	825 —830	79	880 —885	97
780 —782	86	830 —835	71	885 —890	95
782 —785	53	835 —840	63	890 —895	99
785 —790	18	840 —845	95	895 —901	91

solubility of the formations penetrated, with the exception of a zone of dolomitic limestone in the Reeds Spring at a depth of 270 feet, a zone in the Cotter dolomite at 335 feet, a few minor zones in the Jefferson City dolomite, a relatively insoluble zone at a depth of 720 feet at the base of the Jefferson City, and another in the upper sandstone of the Roubidoux at a depth of 790 feet. This upper sandstone of the Roubidoux, though not as soluble as the dolomitic zones of the formation, has an average solubility of about 70 percent, indicating that its porosity could be improved by acid treatment. The lower sandstone of the Roubidoux, at a depth of 870 feet, has a solubility of about 9 percent, indicating that acid treatment would be ineffective on this bed.

POROSITY OF FORMATIONS

In the development of a deep-well water supply, it is helpful to have information on the porosity and degree of saturation of the formations. Information of this type may be obtained from cores cut from the formations or from electric well logs. Some information already was available from several hundred deep water wells in this area, so it was not deemed advisable to take a core of each water-bearing formation; however, an electric log was made of the hole after drilling was completed.

The deep well at the Jayhawk Ordnance Works was electrically logged on January 24, 1942, by the Schlumberger Well Surveying Corporation. A copy of the electrical log is given in figure 2. The self-potential curve indicates the presence of very porous zones at depths of 65 feet to 110 feet, 290 feet to 305 feet, and 375 feet to 400 feet. The normal resistivity curve indicates the base of the Mississippian limestones at 316 feet, the base of the Jefferson City and the top of the Roubidoux at 705 feet. This curve also indicates that both sandstones of the Roubidoux should produce water and that the lower sandstone probably would be more productive than the upper. The curve indicates that between the depths of 415 feet and 705 feet the Jefferson City dolomite is broken or is made up of a number of beds, each having different resistivity. Some of the beds are indicated to be porous and some fairly porous; the porous beds probably contain water.

CONSTRUCTION OF WELL

Drilling and Casing

The well was drilled by the Cascho and Pugh Drilling Company, using a No. 5½ Keystone cable-tool drill. Drilling was begun on December 16, 1941, and completed on January 22, 1942.

A hole 20 inches in diameter was drilled to a depth of 20 feet and lined with 20 feet of temporary 18-inch casing. The hole was drilled to a diameter of 16 inches from a depth of 20 to 200 feet, 13 inches from a depth of 200 to 260 feet, and 8 inches from a depth of 260 to 395 feet.

The 8-inch hole was reamed to a diameter of 13 inches between the depths of 260 and 335 feet, and the permanent 10-inch casing was placed from the surface to a depth of 335 feet, in order to exclude the hard water of the Reeds Spring limestone and the water at the base of the Mississippian formations and at the top of the Cotter dolomite, which contains considerable hydrogen sulphide. The remainder of the 8-inch hole (between depths of 335 and 395 feet) was reamed to a diameter of 10 inches. Drilling was then resumed using a 10-inch bit, and the well was deepened to a total depth of 901 feet.

The driller's time-log, indicating the nature of the formation drilled and the size and depth of the hole drilled each day, is given in table 1.

Cementing the Casing

After drilling had been completed, the 10-inch temporary casing was removed from the hole and a 10½-inch wooden plug was cemented (with five bags of Hi-Early cement) into the hole just below the casing point, at a depth of 335 feet. The plug was driven into place with drilling tools, and the cement was placed by using a dart-valve bailer.

After the cement set for 24 hours, the lengths of permanent casings were welded together and lowered into the hole. The fifteen lengths of 10-inch I.D. casing had a total length of 337 feet and 11 inches; but after deducting approximately 3 feet of casing lost because of poor threads, the total length of permanent casing set in the hole was about 334 feet and 11 inches.

The Halliburton Oil Well Cementing Company then filled with cement the annular space between the casing and the hole. Two hundred eighty bags of Hi-Early cement, 14 bags of Aquajel, and 350 pounds of Flocele were mixed and put into the casing. A bridging plug was placed on top of the cement. The plug was pushed to the bottom, causing the cement to be forced out of the bottom and upward around the casing, filling all the space and openings between the walls of the hole and the casing. Several hundred pounds of the cement was forced out of the top of the hole, indicating that all of the space between the walls of the hole and the casing had been filled.

After setting for 72 hours, the remaining cement was drilled out of the casing and the hole was cleaned out for about 3 feet below the casing bottom. The bailer was run once each hour for a period of 12 hours to test for a water leak at the bottom of the casing. No water came into the hole during this test, and the hole was cleaned out to a depth of 901 feet, its total depth.

PUMPING TESTS AND ACID TREATMENT

All pumping tests were made using a Deming deep well turbine pump, comprising 18 stages of 10-inch bowls, and a direct connected 440 volt, 60 cycle, 100 h. p., U. S. Electric motor. The pump was set below 450 feet of discharge pipe, and 10 feet of suction pipe was added below the pump bowls. Before the first pumping test the static depth to water level was measured with a steel line and found to be 65 feet. During the pumping tests, the level of the water in the hole was recorded by means of an air line extending into the well and attached to an air gauge marked in feet. The discharge of the well was measured by the orifice method, using a 3-inch orifice at the end of a 6-inch horizontal discharge pipe, 20 feet long, and a gauge for measuring the water pressure behind the orifice. The tests were made under the supervision of the writer and Roy A. Cobb, of the Deming Pump Company.

Pumping Test Before Acid Treatment

The first pumping test was made on February 25, 1942. When the pump was first started, the water level dropped to the bottom of the suction pipe after about one minute and 30 seconds of pumping, indicating that the rate of pumping was too great for the well. Back pressure was then put onto the discharge line by partly closing a gate valve until the level of the water in the well remained over the bowls of the pump while the pump was in operation. This discharge pressure was about 180 pounds to the square inch and the pumping water level was about 388 feet. The results given in table 4 indicate that after 19 hours of pumping, the well yielded only 154 gallons a minute with a draw-down of 323 feet, or only about 0.48 gallon a minute per foot of draw-down. The pumping test was continued for a total of 26 hours and 22 minutes, but the rate of discharge was increased slightly after 19 hours of pumping.

Acid Treatment

The quantity of water obtained from the well during the pumping test was so small in comparison with the quantity required and with the yield of other wells in the area that it was decided to acidize the well.

The practice of acidizing was borrowed from the oil industry. For several years almost every oil well producing from limestone formations in Kansas and elsewhere has been treated with hydrochloric acid in order to increase its yield of oil. When put into a well under pressure and applied to a soluble limestone or dolomite, hydrochloric acid dissolves part of the rock allowing it to be removed in liquid form. The result of acidizing is to increase the porosity of the formation by enlarging the existing openings and by removing material that fills pores and fractures. Acid treatment of sandstone tightly cemented with calcium carbonate also increases the porosity by removing part of the cementing material that fills the space between the grains of insoluble quartz

In the acidizing of limestone or dolomite the percentage of soluble material indicates the possible success of the treatment; however, no exact percentage of solubility can be given as a criterion for successful acid treatment, because factors such as the porosity and permeability generally influence the results attainable.

On March 3, 1942, the well was treated with acid by Dowell Incorporated as follows: Treatment was started at 10: 45 a.m. using 250 gallons of 30 percent hydrochloric acid added under pressure. At 11: 00 a.m. the pressure was 15 pounds. At 11: 15 a.m. the pressure gauge read zero. At 11: 40 a.m., 750 gallons of 15 percent acid was added, and at 11: 55 a.m. an additional 1,000 gallons of 15 percent acid was put into the well, after which the pressure gauge still registered zero. At 11: 58 a.m., a water flush was started, and by 1: 00 p.m. 1,000 gallons of water had been added under a pressure of 10 pounds.

The part of the well treated was the entire section of rock from the bottom of the casing (335 feet) to the bottom of the hole (901 feet), or 566 feet. The solubilities of the rock formations penetrated in the Jayhawk Ordnance Works water well are given in table 3, and indicate that the solubility of the rocks in this part of the hole ranged from 9 to 99 percent and averaged about 80 percent. The self-potential and resistivity curves of the electric log (fig. 1) indicate a high porosity and probable high degree of saturation between depths of 340 and 352 feet and between depths of 375 and 395 feet. Most of the Jefferson City and Roubidoux formations (between depths of 400 and 901 feet) are indicated to be fairly porous and probably contain considerable water.

This is the first deep water well in the Tri-State area known to have been treated with acid. As indicated by the pumping tests described in a later section of this paper, the results were very satisfactory, because following the acid treatment, the specific capacity of the well was increased more than four and one-half times.

Pumping Tests After Acid Treatment

The pump was again installed after the well had been treated with hydrochloric acid. On March 7, 1942, another pumping test of the well was made (table 5). During this and subsequent pumping tests a 5-inch orifice was used in measuring discharge. As indicated in the table, after 2 hours and 27 minutes of pumping, the well yielded 678 gallons a minute with a draw-down of 287 feet, or about 2.4 gallons a minute per foot of draw-down.

On March 12, 1942, another short pumping test was made (table 6). At the end of this pumping test (29 minutes) the well was yielding 698 gallons a minute with a draw-down of 246 feet.

This test was followed by a third pumping test (table 7) during which the discharge was held constant at 505 gallons a minute by regulating a gate valve in the discharge pipe. At the end of this test (one hour and 26 minutes) the draw-down was 157 feet, indicating a yield of about 3.2 gallons a minute per foot of draw-down.

A fourth pumping test (table 8) was made during which the discharge was held constant at 300 gallons a minute. The draw-down at the end of this test (30 minutes) was 92 feet.

Quality of Water

The chemical character of the water obtained from different formations in the Jayhawk Ordnance Works deep water well is indicated by the 12 analyses given in table 9. All but the last two samples of water were obtained by means of a bailer from the bottom of the hole, while the well was being drilled. Some of the water samples, therefore, may have been modified by the infiltration of water from overlying formations.

The waters from the Burlington and Keokuk limestones are very similar to the waters of the Reeds Spring limestone. The distinguishing features of water from the upper part of the Cotter are low content of calcium and sulphate and low noncarbonate hardness. The characteristic features of the water from the upper sandstone of the Roubidoux are low chloride content (18 parts per million) and the absence of sodium.

The characteristic features of the composite sample of water obtained before the well was acidized (which represents water from the lower part of the Cotter, all of the Jefferson City and the Roubidoux, and the top of the Gasconade, 335 to 901 feet) is the low content of chloride, sulphate, calcium, and magnesium. It contains by far less total solids, total alkalinity, and hardness than any water sampled during the drilling below the permanent casing point. The better quality of the water in the composite sample taken before the well was acidized and after the pump had been running three hours probably is due to the fact that most of the water came from the upper sandstone of the Roubidoux, whereas

TABLE 4.—*Pumping test of well before acid treatment. (February 24 and 25, 1942. Static water level, 65 feet; temperature of water, 65° F.)*

Time	*Water gauge (inches)*	*Discharge (gal. per minute)*	*Discharge pressure (pounds)*	*Pumping head (feet)*	*Air gauge (ft. water)*	*Depth to water level (feet)*	*Draw-down (feet)*
February 24							
10:00 a.m.	25.	168	100	590	113	360	295
10:05	24.5	165	125	674	87	387	322
10:10	24.	166	160	781	61	413	348
10:15	24.	166	162	792	54	420	355
10:20	24.	166	162	792	54	420	355
10:30	24.	166	162	793	53	421	356
11:00	24.	166	162	793	53	421	356
11:30	24.	166	165	802	51	423	358
12:00 m.	24.	166	165	802	51	423	358
12:30 p.m.	20.5	152	180	832	56	418	353
1:00	20.5	152	180	807	81	393	328
1:30	20.5	152	180	797	91	383	318
1:35	33.	187	......	809	......	460	395
1:45	27.	170	150	800	......	474	409
4:00	21.5	158	180	802	82	392	327
4:30	21.	157	175	794	82	394	329
5:00	20.	150	190	820	91	383	318
5:30	20.5	153	185	808	91	383	318
6:00	20.5	153	185	803	96	378	313
6:30	21.5	156	172	793	76	398	333
7:00	21.5	156	175	770	76	368	305
7:30	20.	150	180	798	90	384	319
8:00	20.5	153	180	798	90	384	319
8:30	20.5	153	180	798	90	384	319
9:00	20.5	153	180	798	90	384	319
9:30	20.5	153	183	804	90	384	319
10:00	20.	150	185	808	91	383	318
10:30	21.	157	180	799	89	385	320
11:00	21.	157	180	799	89	385	320
11:30	20.5	153	180	799	89	385	320
12:00	20.75	154	180	802	86	388	323
February 25							
12:30 a.m.	20.75	154	180	802	86	388	323
1:00	20.75	154	180	802	86	388	323
1:30	20.75	154	180	802	86	388	323
2:00	20.75	154	180	802	86	388	323
2:30	20.75	154	180	802	86	388	323
3:00	20.75	154	180	802	86	388	323
3:30	20.75	154	180	802	86	388	323
4:00	20.75	154	180	802	86	388	323
4:30	20.75	154	180	802	86	388	323
5:00	20.75	154	180	802	86	388	323
5:30	20.5	153	176	800	88	396	331
6:00	20.5	153	178	805	88	396	331
6:30	20.5	153	180	802	86	388	323
7:00	20.5	153	180	802	86	388	323
7:30	20.5	153	180	802	86	388	323
8:00	20.5	153	180	802	86	388	323
8:30	21.	156	180	806	82	392	327
9:00	20.5	153	175	790	86	388	323
9:30	20.5	153	175	790	86	388	323

TABLE 4.—*Pumping test of well before acid treatment. (February 24 and 25, 1942. Static water level, 65 feet; temperature of water, 65″F.) (Continued)*

Time	*Water gauge (inches)*	*Discharge (gal. per minute)*	*Discharge pressure (pounds)*	*Pumping head (feet)*	*Air gauge (ft. water)*	*Depth to water level (feet)*	*Draw-down (feet)*
10:00	22.5	156	160	786	65	368	303
10:15	24.5	165	150	779	51	434	369
10:30	24.5	165	150	779	......	434	369
11:00	24.5	165	150	779	......	434	369
11:15	24.	161	150	779	......	434	369
11:30	24.5	165	150	......	......	......	......
11:45	24.	161	150	......	......	......	......
12:00 m.	24.5	165	150	......	......	......	......
12:05 p.m.	26.	170	135	......	......	......	......
12:10	25.5	169	135	......	......	......	......
12:15	26.	170	120	......	......	......	......
12:17	25-27	Variable	90-110	......	......	......	......
12:20	25-27	Variable	90-110	......	......	......	......
12:22		Pump stopped					

TABLE 5.—*First pumping test of well after acid treatment, (March 7, 1942 Static water level, 65 feet.)*

Time (p. m.)	*Water gauge (inches)*	*Discharge (gals. per minute)*	*Air gauge (ft. of water)*	*Depth to water level (feet)*	*Draw-down (feet)*
1:38	25	610	350?	102?	37?
1:40	....	......	240	212	147
1:41	34	712	180	272	207
1:42	....	......	155	297	232
1:43	33	702	145	307	242
1:44	....	......	140	312	247
1:45	32	697	135	317	252
1:46	32	697	132	320	255
1:47	32	697	130	322	257
1:48	32	697	130	322	257
1:49	32	697	127	325	260
1:50	32	697	127	325	260
1:51	32	697	127	325	260
1:52	....	......	126	326	261
1:53	32	697	125	327	262
1:54	....	......	125	327	262
1:55	....	......	125	327	262
1:56	31.75	688	125	327	262
1:57	31.75	......	123	329	264
1:58	....	......	122	328	263
1:59	....	......	122	328	263
2:00	....	......	122	328	263
2:01	....	......	121	327	262
2:02	....	......	121	331	266
2:03	31.5	685.5	121	331	266
2:04	....	......	120	332	267
2:05	....	......	120	332	267
2:06	....	......	120	332	267
2:07	31.5	685.5	119	333	268
2:08	....	......	119	333	268
2:09	....	......	119	333	268

TABLE 5.—*First pumping test of well after acid treatment. (March 7, 1942. Static water level, 65 feet.) (Continued)*

Time (p. m.)	*Water gauge (inches)*	*Discharge (gals. per minute)*	*Air gauge (ft. of water)*	*Depth to water level (feet)*	*Draw-down (feet)*
2:10	......	......	118	334	269
2:11	....	......	117	335	270
2:12	....	......	117	335	270
2:13	....	......	115	337	272
2:14	....	......	115	337	272
2:15	31.25	683	115	337	272
2:16	....	......	118	334	269
2:17	....	......	118	334	269
2:18	....	......	120	332	267
2:19	....	......	120	332	267
2:20	31	680	119	333	268
2:25	....	......	119	333	268
2:30	31	680	118	334	269
2:35	....	......	118	334	269
2:40	31	680	116	336	271
2:45	30.75	678	115	337	272
2:50	....	......	115	337	272
2:55	30.75	678	110	342	277
3:00	30.75	678	110	342	277
3:05	30.75	678	110	342	277
3:10	30.75	678	105	347	282
3:15	30.75	678	105	347	282
3:20	30.75	678	105	347	282
3:25	30.75	678	105	347	282
3:30	30.75	678	105	347	282
3:35	30.75	678	100	352	287
3:40	30.75	678	100	352	287
3:45	30.75	678	100	352	287
3:50	30.75	678	100	352	287
3:55	30.75	678	100	352	287
4:00	30.75	678	100	352	287
4:05	30.75	678	100	352	287
4:06		Pump stopped			
5:49			350	102	37

TABLE 6.—*Second pumping test of well after acid treatment, (March 12, 1942. Pumping head, 475 feet; static water level, 65 feet.)*

Time (a. m.)	*Water gauge (inches)*	*Discharge (gals. per minute)*	*Air gauge (ft. of water)*	*Depth to water level (feet)*	*Draw-down (feet)*
11:13			452?	65?	—
11:14	36	736	250	202	137
11:15	35	725	190	262	197
11:16	34	714	165	287	222
11:17	34	714	160	292	227
11:18	34	714	155	297	232
11:19	33.5	708	155	297	232
11:20	33.5	708	150	302	237
11:21	33.5	708	150	302	237
11:22	33.5	708	150	302	237
11:23	33.5	708	150	302	237
11:24	33.5	708	145	307	242

TABLE 6.—*Second pumping test of well after acid treatment. (March 12, 1942. Pumping head, 475 feet; static water level, 65 feet.) (Continued)*

Time (a. m.)	Water gauge (inches)	Discharge (gals. per minute)	Air gauge (ft. of water)	Depth to water level (feet)	Draw-down (feet)
11:25	33.5	708	145	307	242
11:26	33	703	145	307	242
11:27	33	703	145	307	242
11:28	33	703	145	307	242
11:29	33	703	145	307	242
11:30	33	703	145	307	242
11:31	33	703	145	307	242
11:32	33	703	142	310	245
11:33	33	703	142	310	245
11:34	33	703	142	310	245
11:35	33	703	142	310	245
11:36	33	703	142	310	245
11:37	32.5	698	142	310	245
11:38	32.5	698	141	311	246
11:39	32.5	698	141	311	246
11:40	32.5	698	141	311	246
11:41	32.5	698	141	311	246
11:42	32.5	698	141	311	246
Pump stopped					
11:43	....	......	166	286	221
11:44	....	......	221	231	166
11:45	....	......	316	136	71

TABLE 7.—*Third pumping test of well after acid treatment. (March 12, 1942. Discharge held constant at 505 gallons per minute; static water level, 65 feet.)*

Time (p.m.)	Water gauge (inches)	Discharge (gals. per minute)	Discharge pressure (pounds)	Pumping head (feet)	Air gauge (feet of water)	Depth to water level (feet)	Draw-down (feet)
1:34	6	......	......	......	......	......	......
1:35	17	505	185	845	230	222	157
1:40	17	505	190	855	240	212	147
1:45	17	505	190	855	240	212	147
1:50	17	505	190	855	240	212	147
1:55	17	505	190	855	240	212	147
2:00	17	505	190	855	237	215	150
2:05	17	505	190	855	235	217	152
2:10	17	505	190	855	235	217	152
2:15	17	505	190	855	235	217	152
2:20	17	505	190	855	235	217	152
2:25	17	505	190	855	235	217	152
2:30	17	505	190	855	235	217	152
2:35	17	505	190	855	235	217	152
2:40	17	505	187	849	230	222	157
2:45	17	505	185	845	230	222	157
2:50	17	505	187	849	230	222	157
2:55	17	505	187	849	230	222	157
3:00	17	505	187	849	230	222	157

TABLE 8.—*Fourth pumping test of well after acid treatment. (March 12, 1942. Discharge held constant at 300 gallons per minute; static water level, 65 feet.)*

Time (p.m.)	Water gauge (inches)	Discharge (gals. per minute)	Discharge pressure (pounds)	Pumping head (feet)	Air gauge (feet of water)	Depth to water level (feet)	Draw-down (feet)
3:05	6	300	280	1035	290	162	97
3:10	6	300	280	1035	295	157	92
3:15	6	300	285	1045	295	157	92
3:20	6	300	285	1045	295	157	92
3:25	6	300	285	1045	295	157	92
3:30	6	300	285	1045	295	157	92
3:35	6	300	285	1045	295	157	92

the samples of water taken while the hole was being drilled probably represent mixtures of waters from different formations.

The water from the Gasconade formation contains more chloride than the water from the Roubidoux. The chloride content of the water sampled after the well was acidized is considerably higher than the composite sample before the well was acidized. This may have resulted from a greater degree of acid reaction on the Gasconade dolomite than on the sandy dolomite of the Roubidoux formation, so that the Gasconade yielded a proportionately larger quantity of water after acidization. Use of hydrochloric acid in the well also may have increased the chloride content if the resulting chloride had not been removed entirely by pumping by the time the sample was collected.

The fluoride content of the sample of water from the Jayhawk Ordnance Works well ranges from 0.1 to 0.6 part per million. The lowest content is in the water from the Roubidoux formation, while the highest content is in the water from the Cotter dolomite which was cased out of the well. The final composite sample, however, also contained 0.6 part per million of fluroide.

CONCLUSIONS

The Mississippian rocks contain abundant supplies of water; however, at least in some areas in southeastern Kansas, the water is objectionable for domestic purposes because of its high mineral content. In these areas the water from the Mississippian should be excluded from the well. In areas where the Mississippian

TABLE 9.—*Chemical analyses of water from the Jayhawk Ordnance Works deep water well. (Analyses by Kansas State Board of Health. Quantities are expressed in parts per million; reacting values are given in italics.)*

Laboratory No.	Geological formation	Depth (feet)	Date of collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (No_3)	Total solids	Insoluble residue	Total alkalinity as Co_3	Hardness as Co_3 Total	Hardness as Co_3 Carbonate	Hardness as Co_3 Non-carbonate
42235†	Burlington-Keokuk	125	12-26 1941	1.7	0.13	328. *11.88*	6.8 *.56*	17. *.74*	384. *6.30*	324. *6.74*	4.0 *.11*	0.2 *.01*	1.1 *.02*	951.	81.	315.	622.	315.	307.
42299†	Reeds Spring	175	12-28 1941	0.94	0.0	184. *9.18*	21. *1.73*	26. *1.15*	168. *2.76*	430. *8.94*	12. *.34*	0.2 *.01*	0.75 *.01*	860.	22.	138.	546.	138.	408.
42234†	Do.	244	12-30 1941	2.7	0.2	226. *11.28*	40. *3.29*	27. *1.19*	395. *6.48*	426. *8.86*	14. *.39*	0.3 *.02*	0.93 *.01*	1164.	117.	324.	728.	324.	404.
4293†	Cotter	320	1 - 6 1942	0.44		24. *1.20*	37. *3.04*	31. *1.35*	215. *3.53*	35. *.73*	40. *1.13*	0.4 *.02*	1.1 *.02*	306.	7.6	184.	212.	184.	28.
4291†	Do.	330	1 - 6 1942	0.44		26. *1.30*	35. *2.88*	21. *.93*	202. *3.31*	26. *.54*	36. *1.02*	0.6 *.03*	0.93 *.01*	310.	14.	176.	209.	176.	33.
4292	Do.	395	1 - 7 1942	3.0		182. *9.08*	34. *2.79*	16. *.70*	282. *4.62*	359. *7.47*	16. *.45*	0.3 *.02*	0.75 *.01*	1035.	65.	231.	594.	231.	363.
42236	Jefferson City	525	1 -14 1942	0.68	0.11	140. *6.99*	72. *5.92*	41. *1.79*	304. *4.99*	401. *8.34*	48. *1.35*	0.3 *.02*	0.0 *.00*	989.	18.	249.	646.	249.	397.
42300	Roubidoux	770	1 -18 1942	0.42		97. *4.84*	65. *5.34*	23. *1.02*	285. *4.67*	243. *5.05*	52. *1.47*	0.1 *.01*	0.0 *.00*	769.	13.	234.	509.	234.	275.
42301	Roubidoux, upper dolomite	790	1 -19 1942	1.3	0.0	134. *6.69*	48. *3.94*	0.0 *.00*	281. *4.61*	235. *4.89*	18. *.51*	0.2 *.01*	0.0 *.00*	788.	69.	230.	532.	230.	302.
42328	Roubidoux, upper sandstone	855	1 -21 1942	0.76	0.05	75. *3.74*	65. *5.34*	55. *2.40*	242. *3.97*	240. *4.99*	72. *2.03*	0.1 *.01*	0.62 *.01*	754.	18.	222.	454.	222.	232.
42329	Gasconade	890	1 -22 1942	0.34	0.05	68. *3.39*	81. *6.66*	66. *2.88*	259. *4.25*	225. *4.68*	127. *3.58*	0.1 *.01*	0.31 *.01*	815.	11.	232.	502.	232.	270.
42877	Composite sample from pump*	901	2 -25 1942	0.38		38. *1.90*	18. *1.48*	15. *.66*	170. *2.79*	31. *.64*	20. *.56*	0.5 *.03*	1.2 *.02*	227.	9.2	140.	169.	140.	29.
42985	Composite sample from pump**	901	3 - 6 1942	1.2	0.08	62. *3.09*	30. *2.47*	7.4 *.32*	172. *2.82*	20. *.42*	92. *2.59*	0.6 *.03*	1.4 *.02*	378.	8.	141.	278.	141.	137.

† Waters excluded from composite samples No. 42877 and No. 42985 by permanent casing.
* Before well was acidized (after pumping 3 hours). ** After well was acidized.

waters are not objectionable, the acid water from the overlying Cherokee shale should be excluded from the well.

Undesirable water may be excluded from a well by setting casing to the desired depth below the water to be excluded and by grouting with cement between the casing and the walls of the hole, from the bottom of the casing to the surface of the ground. The objectionable water to be excluded may be sufficiently acidic to corrode, forming holes in uncemented iron casing within a few years time.

The capacity of many wells can be greatly increased by shooting sandstone members or by treating soluble limestones, dolomites, or sandstones tightly cemented with calcium carbonate, with acid. The capacity of the water well at the Jayhawk Ordnance Works was increased more than four times by acid treatment.

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APPENDIX

Specifications for Deep Water Well

The Geological Survey assisted in preparing the following specifications for drilling the deep water well at the Jayhawk Ordnance Works.

November 17, 1941

Specifications for deep water well for Jayhawk Ordnance Works.

SPECIFICATION NO. 87B1

A. Scope

1. The work covered by these specifications includes the drilling, casing, and developing of a deep water well in rock. The contractor shall furnish all labor, materials, equipment, tools, supplies, power, water drayage, freight, and miscellaneous items necessary for the proper execution and completion of the work as herein specified.

B. Definitions

1. The following organizations are referred to, in this specification, by title; and such titles, where used, shall refer to the company or companies listed below:

Title	Company
Contractor	Sub-contractor to the constructor
Constructor	F. H. McGraw & Company and Freeto Construction Company
Prime Contractor	The Military Chemical Works, Inc.
Architect-Engineer	Chemical Construction Corporation

C. Location of work

1. The well will be located near the site of the permanent Administration Area of the Jayhawk Ordnance Works, at Boston Mills, in Lowell Township, Cherokee County, Kansas. The site is further described as occupying the NE quarter of section 4, T. 34 S., R. 25 E. The exact location for drilling of the well will be designated by the Constructor after consultation with and the approval of the Architect-Engineer and the Prime Contractor.

D. Start and Completion

1. The work hereinafter described shall be started within ten days after awarding the contract and shall be completed within the number of working days mutually agreed upon by the Constructor and Contractor. The Contractor shall furnish a bond suitable to the Constructor to guarantee performance within these limitations.

2. The Contractor shall permit and provide every facility for the Constructor or his representatives to inspect the drilling equipment he proposes to use before work commences. This equipment shall be satisfactory to the Constructor.

3. Work under this specification shall not be suspended without permission of the Constructor.

E. Geologic Conditions

1. The elevation of the ground at the site is about 850 feet above sea level, and it is contemplated that the well will extend into the Roubidoux sandstone, terminating at the base of this formation. The point at which the well shall be completed will be determined by the Constructor. It is desired to obtain a flow of at least 500 G.P.M.; and, if this quantity of water is obtained in the Roubidoux sandstone, the well will be stopped at this stratum. In making his proposal, the Contractor shall state his proposal price for work below the Roubidoux sandstone as well as for work above or in the formation.

2. So far as is known, the following geologic formations will be encountered at the approximate depth indicated.

0-50	ft.	Keokuk limestone and flint
50-100	ft.	Burlington limestone and flint
100-120	ft.	Grand Falls chert
120-180	ft.	Reeds Spring limestone and chert
180-265	ft.	St. Joseph limestone
265-725	ft.	Cotter and Jefferson City dolomite
725-840	ft.	Roubidoux sandstone
840-1045	ft.	Gasconade dolomite
1045-1110	ft.	Van Buren dolomite
1110-1130	ft.	Gunter sandstone
1130-1155	ft.	Procter dolomite

F. Field Measurements

1. All measurements for depth shall be taken from the existing surface of the ground at the well site and to the bottom of the bore hole. All measurements shall be made in the presence of a representative of the Constructor. When the size of the hole is to be reduced or any change of classification made, the drilling shall not proceed until all necessary measurements have been made.

G. Samples and Records

1. At least one week before starting to drill the well, the Contractor shall send a written request to the office of Dr. G. E. Abernathy, representative of the State Geologist, having his office at the Kansas State Teachers College at Pittsburg, Kansas, who will furnnsh sample sacks, drill record books, and instructions regarding the collecting and handling of drill cuttings. The contractor shall save a sample of each cutting at each time the well is bailed, or at intervals of about 5 feet, and place them in sacks, properly labelling same with the figures showing the depth from which the samples were obtained. These cuttings shall be taken from the bailer and not from the slush pit. The sacks containing the cuttings, properly marked as to depth, shall be delivered to the Constructor each day, where they will be picked up by the State Geologist's representative. These cuttings will be examined by the State Geologist's representative, who will compile a log of the well and submit a copy of the completed log to the Prime Contractor for their records. If the well is drilled by rotary drilling, the samples shall be taken and carefully preserved, marked with elevation in accordance with instructions from the State Geological Survey of Kansas or its representative, and turned over to the State Geological Survey of Kansas, Pittsburg, Kansas.

2. At the time they are encountered, the driller shall duly and consistently note, in the drill record book, the location and depths of any openings; the material, mud, water, etc. therein; the presence of any soft or broken ground encountered; together with information as to the size and depth of casing, method of sealing same, and result of the test to determine whether or not a satisfactory seal has been obtained. The driller shall also note in the drill book the depth at which water is encountered and the static water level upon completion of the well. The drillers record book shall be available at the well for inspection at any time by the Constructing Quartermaster, State Geologist, Constructor, Prime Contractor, or the authorized representative of any of these.

H. Method of Procedure

The general method of procedure shall be as follows:

1. A hole shall be drilled, either by rotary drilling or churn drilling, to accommodate a 10 inch I.D. casing from surface of ground to casing point, which point will be determined by the Constructor, upon advice of the State Geologist's representative.

2. It is probable that water will be encountered at the top of the Keokuk limestone which may require temporary casing off.

3. A considerable flow of water will probably be encountered at the Reeds Spring formation, which may retard drilling. The Constructor shall be consulted as to the necessity of installing a temporary casing to this point. If this water should prove to be suitable for use, and if the well is completed to the Roubidoux formation, provision should be made for cutting the casing at the proper level to permit use of the Reeds Spring water. A complete series of samples of water encountered at each point in the drilling shall be collected and analyzed together with an estimate of the flow developed.

4. The Cotter dolomite is the next known water bearing formation. If a useful volume of suitable water is found at this level, provision should be made for its use either above or in conjunction with the Reeds Spring water, as directed by the Constructor.

5. Any temporary casing shall be furnished without extra cost. From this point, a 10 inch hole shall be continued to such point as shall be determined by the Constructor upon advice of the State Geologist's representative. After the hole has been drilled to its proper depth, and after all the necessary cleaning and shooting has been done, a bridge or plug shall be set below the casing point, and the 10 inch casing pipe shall be set and grouted by an approved pressure grouting method for its entire length. The cement used shall be Hi-Early strength cement, and the grouting shall be done in the presence of an authorized representative of the Constructor.

6. The size of the hole to be drilled for temporary casing above the 10 inch hole shall be determined by the Contractor, with due regard to the cementing required.

7. After the pipe has been cemented, drilling operations shall be suspended for a period of not less than 48 hours, following which the plug shall be partly drilled below the casing point to facilitate determination of the tightness at the casing point. The seal shall then be tested by bailing the water from the hole. Operations shall then cease for a period of 4 hours, after which the hole is to be again bailed to determine if any water is entering at the point of casing. The static water level inside of the casing is to be noted by the driller at this point. The seal shall be tested in accordance with the requirements of the State Geologist; and the tightness of the seal shall be demonstrated to the representatives of the State Geologist, State Board of Health, the Constructor, and the Prime Contractor. After this has been done, the remainder of the plug shall be drilled out and thoroughly cleaned at the bottom of the hole. The static water level shall again be recorded after the plug has been removed. Thereafter, the driller shall tightly seal and cap the top of the well in such a manner that the cap may be removed for the installation of the pump. The well casing shall extend to a point at least 6 inches above the elevation of the pump house floor, which shall be at least 18 inches above the normal ground line at the site.

8. Prior to cementing the pipe as hereinbefore specified, the contractor shall run the entire string to the shoulder or point at which the hole was reduced. This shall be done without driving, binding, or the use of force in any manner whatsoever. The pipe shall then be raised off the bottom of the hole and, while suspended by means of casing elevators, shall be turned freely in the hole to demonstrate that the hole is vertical and properly aligned.

9. The contractor shall insure that the 10 inch hole to final depth shall be started concentric with the upper part of the hole in order that a shoulder of uniform width is provided for the support of the casing.

10. The proper casing point shall be determined by the Constructor and all grouting shall be done in the presence of his representative.

11. Casing is to be removed from the well during drilling or shooting operations.

I. Provision, In Case Caving Shale Is Encountered

1. If caving shale is encountered below the casing point, the method of procedure shall be altered to permit the installation of a wrought iron liner and the continuation of drilling. However, it is not considered likely that a liner will be required. The contractor shall state in his proposal the unit price per foot for furnishing and installing the liner, as hereinafter specified. The point of setting and the amount of liner required will be determined by the Constructor on advice of the State Geologist's representative. If at any time during the drilling operation it becomes apparent to the Contractor that caving shale is encountered or, for any other reason, that a liner will be required, the Contractor shall immediately notify the Constructor.

2. The liner, if required, shall be of genuine wrought iron, with 9 inch outside diameter, as hereinafter specified. If this liner is necessary, the hole below the liner will be reduced to 8⅝ inches in diameter, and will continue to such a point as determined by the Constructor upon advice of the State Geologist's representative. The Contractor shall state in his proposal the price per foot which he bids for drilling a 8⅝ inch hole, both above and in the Roubidoux Sandstone strata.

J. Testing the Well

1. When the depth of the well reaches a point which, in the opinion of the State Geologist's representative, requires a test for capacity, and upon instructions by the Constructor, the Contractor shall install casing and a pump for testing purposes and run a 24 hour test. This pump shall have a capacity of not less than 1000 G.P.M., and the Contractor shall install suitable gauges and apparatus for determining the flow (number of gallons per minute), drawdown, etc. Before the 24 hour test is started, the static level shall be determined.

2. In order that the State Geologist may determine the rate of recharge of the well to its original static water level after pumping for the 24 hour period has ceased, it is desirable that the drawdown head and the return to static level be recorded at given intervals to the nearest hundredth of a foot. If the Contractor's equipment does not permit such accurate drawndown measurement, he should communicate with the State Geologist at Lawrence, Kansas or the State Geologist's representative at Pittsburg, Kansas and request permission for the use of their apparatus for this purpose. The Contractor should apply for this permission at least 10 days in advance of any contemplated testing operation.

3. If the results of the tests for capacity and quality of water are satisfactory to the Constructor, Prime Contractor, and the State Board of Health, no further drilling will be done and the permanent seal shall be installed. If the results of the test are not satisfactory, the well will be shot, or drilling will be resumed. As many of these tests shall be made as are required by the Constructor upon advice of the State Geologist's representative. The Contractor shall state in his proposal the price bid for making the test as specified, using a pump furnished by himself.

K. *Shooting the Well*

1. If, in order to increase the flow of the well, the State Geologist's representative deems it advisable to shoot the well, the contractor shall do the shooting, or sub-contract the shooting to an experienced and responsible sub-contractor fully equipped and qualified to do this work. The sand strata shall then be shot with not more than 1000 pounds of 100 percent blasting gelatine, the charges to be spaced throughout the depth of the formation, as recommended by the State Geologist's representative. The charges are to be sand tamped in order to obtain the best results possible and prevent damage to the liner.

2. If it is necessary to shoot the well, the contractor shall remove from the hole all rock, sand, or other material loosened by the explosion or as a result of the shooting; and he shall take every precaution to insure against the loosened material falling into the hole.

3. Shooting shall be done only after agreed upon mutually by the Constructor, Prime Contractor, and the State Geologist.

L. *Drilling Below the Roubidoux Strata*

1. If for any reason it is determined by the Constructor, the Prime Contractor, and the State Geologist that it is desirable to continue the well below the Roubidoux sandstone, the Contractor shall do this work in accordance with the bid prices, which shall be stated in his proposal.

M. *Procedure, If Necessary to Extend Well Below Roubidoux Sandstone*

1. If necessary to proceed below the Roubidoux sandstone formation the following procedure shall be adopted: After passing through this formation, the Contractor shall take one gallon of water from the bottom of the well each morning, by means of the bailer, and place this water in suitable container for delivery to the State Geologist's representative. The Contractor shall indicate on the container the depth from which the water was obtained and the date of the sample. The water will be delivered to the State Geologist's representative by the Constructor and will be analyzed by the State Board of Health; or, if too much time is lost in this procedure, the Constructor will have the water sample analyzed locally. If the water is found unsatisfactory, the drilling operations will be stopped.

N. *Casing—Sizes, Weight, Etc.*

1. All casing and liners shall be new, genuine wrought iron well casing of the following sizes, and equal to Byers genuine wrought iron well casing: The 10 inch casing shall have an outside diameter of 10.75 inches and a wall thickness of .36 inch, weighing 41 pounds per foot with couplings (plus or minus 5 percent). This casing shall be standard oil well casing with standard couplings and threaded eight threads per inch. The casing shall be straight and free from imperfections with couplings of heavy wrought iron. The liner, if required, shall be of genuine wrought iron with outside diameter of 9 inches and a wall thickness of .34 inch, weighing 34 pounds per foot (plus or minus 5 percent). Connections shall be welded to reduce maximum external diameter.

O. *Sterilization of the Well*

1. Before making the final pumping test, the well shall be thoroughly disinfected by introducing calcium hypochlorite or bleaching powder at the bottom of the hole by means of the bailer. Five pounds of disinfectant (HTH) shall be used in order to assure

satisfactory results. This shall be made into a smooth paste with a small amount of water, crushing out all lumps. It shall then be dissolved in about 5 gallons of water and introduced into the well as above specified.

P. Approval of State Board of Health

1. These specifications shall be carried out and the well completed in a manner satisfactory to the State Board of Health of Kansas.

2. The Contractor shall at all times protect the work from tampering and shall close the top of the hole in a manner satisfactory to the Constructor, so that the hole will be closed at all times when no representative of the contractor is present at the well site.

Q. Clean Up Process

1. Upon completion of the work, the Contractor shall clean up the site and remove all machinery, equipment, and material to the satisfaction of the Constructing Quartermaster, U.S.A. The slush pond shall be drained and filled with top soil.

R. Tools Lost In the Well

1. The Contractor shall assume all responsibility for his equipment and tools; and, should he lose a drill, bailer, or other piece of equipment in the well, he shall promptly recover same at his own expense.

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