International Salt Brine Field at Watkins Glen, New York

by
Charles H. Jacoby
International Salt Company
Watkins Glen, New York

ABSTRACT

This paper deals with the connecting of two wells by hydraulic fracturing. Details of well construction; method of fracturing the two wells; the problems encountered in fracturing; operational results and theories associated with the operation of these wells will be discussed. The wells are in the Watkins Glen, New York area and are operating at what might be termed as a moderate depth of 2,600 feet. This was the first well to well fracturing accomplished by the International Salt Company. The construction on these wells started early in 1957 and was based on previous experience in fracturing from new wells to an existing brine cavity.

INTRODUCTION

Our approach to coalescence of wells by splitting the beds hydraulically was necessitated by several unsuccessful attempts to create Trump type wells in the Watkins Glen area. New wells to replace old standard type wells were necessary from a production standpoint as well as from the aspect of brine quality.

Late in 1955, core drilling was begun at the site of the first well which we intended to fracture. In our past practice of casing injected wells, it had never been considered necessary to core the formations nor make any geological studies.

Subsequently, this core hole was completed as a brine well and fractured. Since this was our first attempt at fracturing, we selected the Old Cavity as a target. Although the fracturing or splitting operation was a success from the standpoint of actually establishing a connection from the new well to the old brine cavity, an extensive pumping period was required. The new well to old cavity well distance was 200 feet so that the operation could not be considered an economical success. We did derive sufficient information on geology and the coalescence of wells from this project so that subsequent operations were successful from both the operational and financial aspect.

LOCATION AND GEOLOGY

The Watkins Glen brine field, located in Schuyler County, is in the south central part of New York State, along the west shore of Lake Seneca (See Figure 1). It is approximately four miles north of the Village of Watkins Glen. Physiographically, the region consists of the Allegheny Plateau which has been peneplaned, uplifted and glaciated. Due to glaciation, the area is marked by deep valleys which are now occupied by the Finger Lakes and hanging tributary valleys.

The sediments encountered by the wells drilled at Watkins Glen, range in age from Upper Devonian, West River-Geneseo shales, to the Upper Sulurian, Salina Group, Syracuse salt and

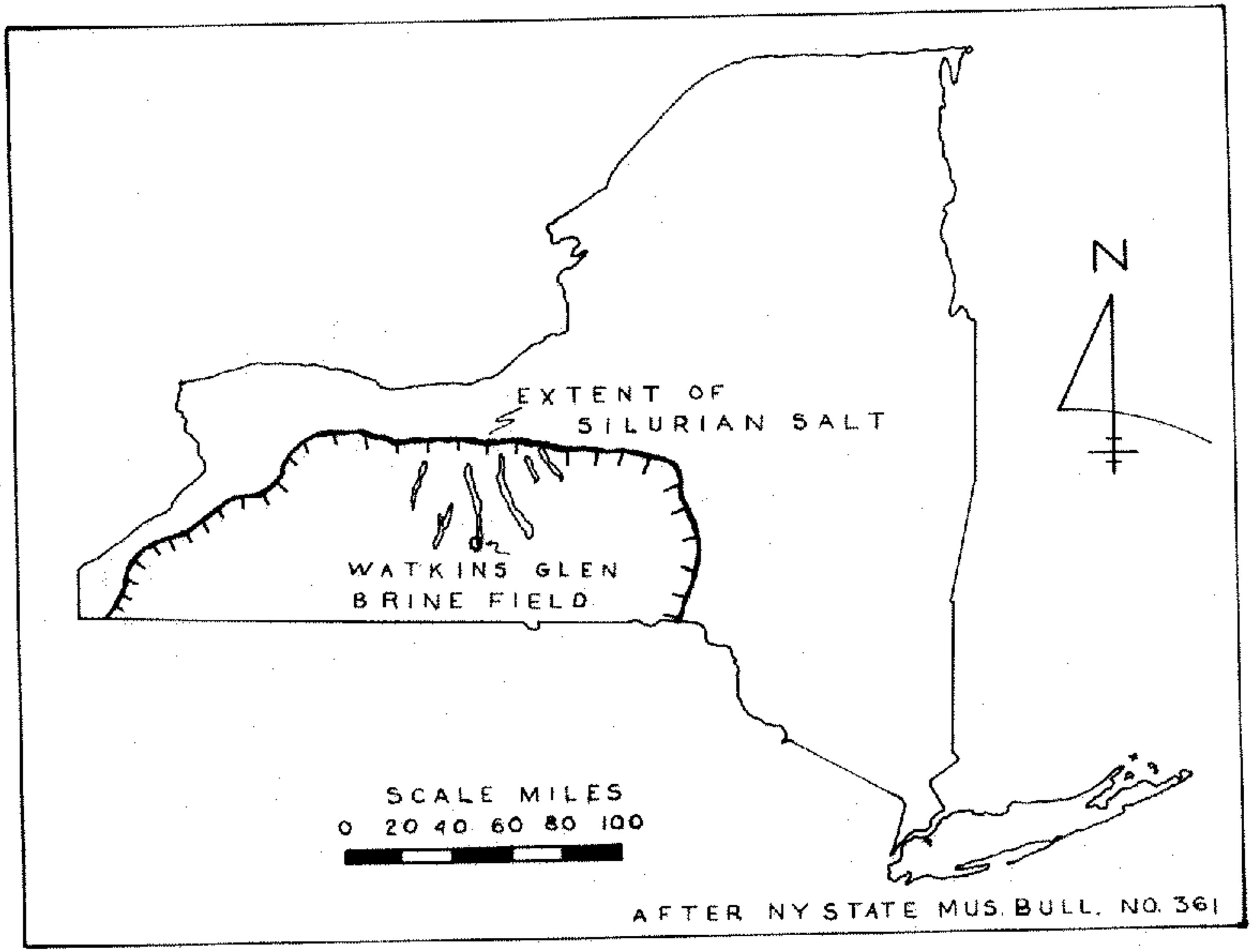


FIGURE I - MAP OF NEW YORK SHOWING RELATION WATKINS GLEN BRINE FIELD AND SILURIAN SALT underlying Vernon shale (Figure 2). These sediments are composed of shales, sandstones, limestones and dolomites with the shales of the Middle Devonian, Hamilton Group, being 800 feet in thickness and separated from the Upper Devonian shales by about thirty feet of Middle Devonian Tully limestone. The Hamilton Group is underlain by the Middle-Lower Devonian, Onondago limestone which overlies the Lower Devonian Oriskany sandstone. The Oriskany in this area is rather sporadic in occurrence and has not been identified in all the wells.

Below the Oriskany, sediments of the Upper Silurian, Bertie and Salina Groups, are encountered and consist of limestones, dolomites, shales, anhydrite and salt evaporites. The salt being brined is part of the Syracuse salt formation which is a member of the Salina Group of the Cayugan Series of the Upper Silurian system. It consists of six distinct beds with the possibility of a thin salt stringer some 40 feet below the Sixth salt (Figure 3). The salt beds are intensely folded into a series of local east-west anticlines and synclines with only a few tens of feet from crest to crest. It is the opinion of the author that the salt and incompetent shales of this section flowed plastically and absorbed the shock of the regional tectonic forces during the Appalachian Revolution. The forces involved in the uplift of the area during the Mesozoic Era, gave rise not only to the intense folding but also faulting of the salt section. This is apparent when the structure of the salt is compared to that of the overlying sediments. The overlying sediments are characterized by broad, gentle east-west synclines and anticlines with axes which, in general, parallel those of the sharp folds of the underlying evaporites. These features are well exhibited in the mine of Cayuga Rock Salt Company, 20 miles to the east, in which faulting is noted together with recumbent folding within the salt bed. On the basis of the cores from the Watkins Glen brine field, some beds appear to pinch out completely, while others double in thickness over a distance of 300 to 400 feet as depicted in cross sections developed along a north-south line. The east-west cross sections show a thickening of the salts adjacent to Lake Seneca (Figure 4).

BED SPLITTING

Although the term hydraulic fracturing is common terminology for the application of hydraulic pressure on rock beds, we prefer the term "hydraulic splitting." In relatively flat lying evaporite beds, it has been our experience that the overburden above the point of the application of pressure, is actually lifted. We visualize that a "water wedge" is driven hydraulically into the salt bed. This wedge immediately becomes a saturated brine and from that point forward, can accomplish nothing but a splitting and lifting action.

It has been our experience, based on our method of well completion, that depending upon the specific gravity of the fluid in the well at the time pressure is applied, the initial pressure required at the well head to split the bed of salt is 1.05 times the vertical distance to the point at which the pressure is applied. Pressure requirements in excess of this figure generally indicate some basic well trouble. One of the most common of these is the settling out of finely divided particles of mud and cement from the fluid in the casing. This settling occurs during the interval between well completion and the application of pressure for splitting and may be a sizable volume if the fluid is contaminated and the period of time extended.

The direction of the flow of the splitting fluid is a direct function of the geology of the area where the splitting operation is taking place. Faults, folds, joints and post deposition solution within the salt beds are some of the governing factors.

After splitting and pumping, we have found it necessary to maintain pressure on the cavity in order to avoid a collapse of the cavity. It is our opinion that this pressure prop must be maintained until a self supporting connection has been established. It has been determined that once a cavity has collapsed, no amount of pressure or volume of fluid can re-establish this crevice. In certain cases where bed jumping has occurred, this phenomenon has been used effectively to close the undesired opening and redirect the flow of fluid. This has been accomplished by "bleeding off" a sizable volume and allowing the split to cure, or by closing in the undesired connection and continuing to pump until the desired connection has been obtained and a self supporting cavity established.

The redistribution of stresses around an active cavity is a continuous process from the moment the split is accomplished. As the natural stress pattern within the overlying rocks is

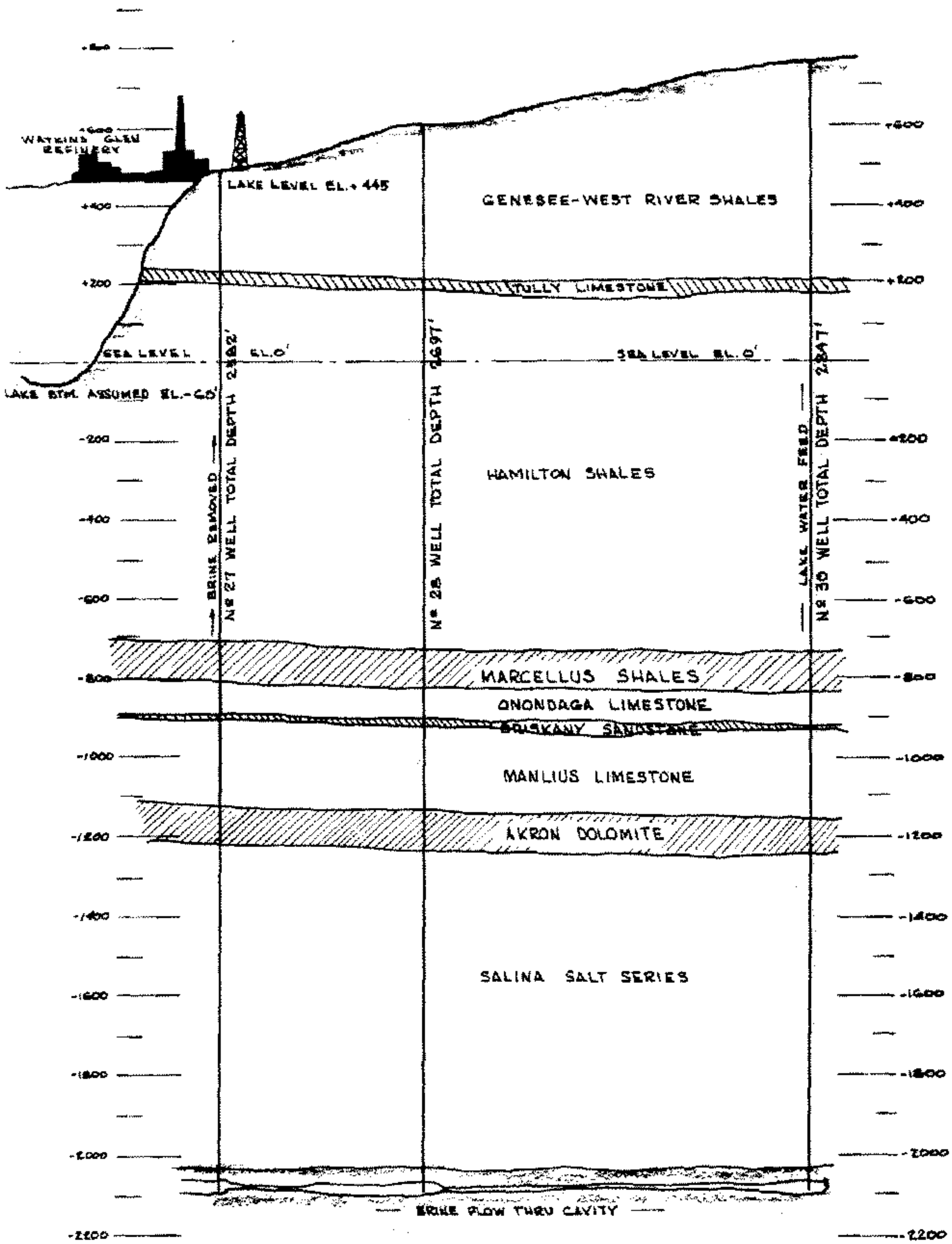
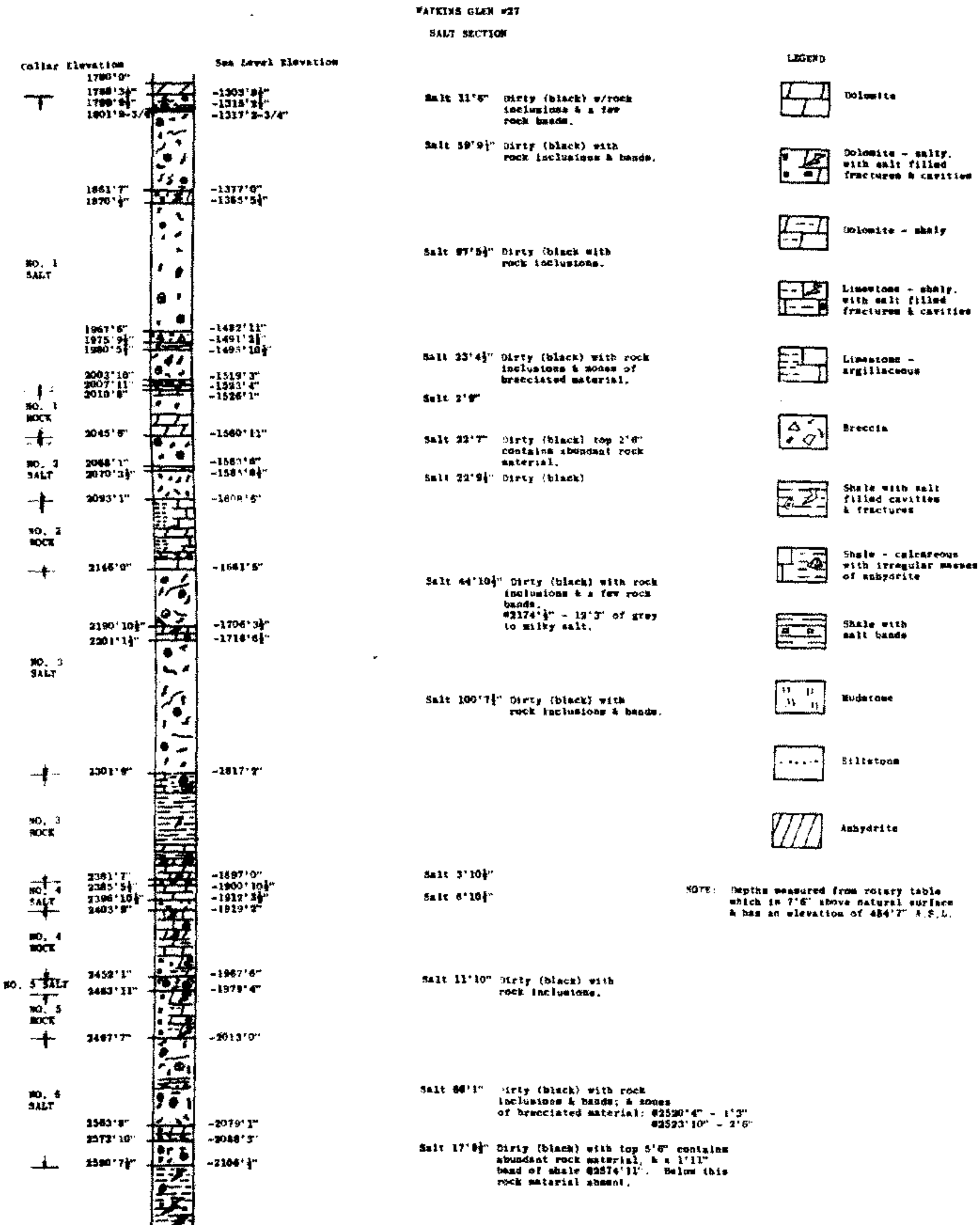


FIGURE 2 PROFILE OF WATKINS GLEN BRINE WELLS Nos 27, 28, & 30

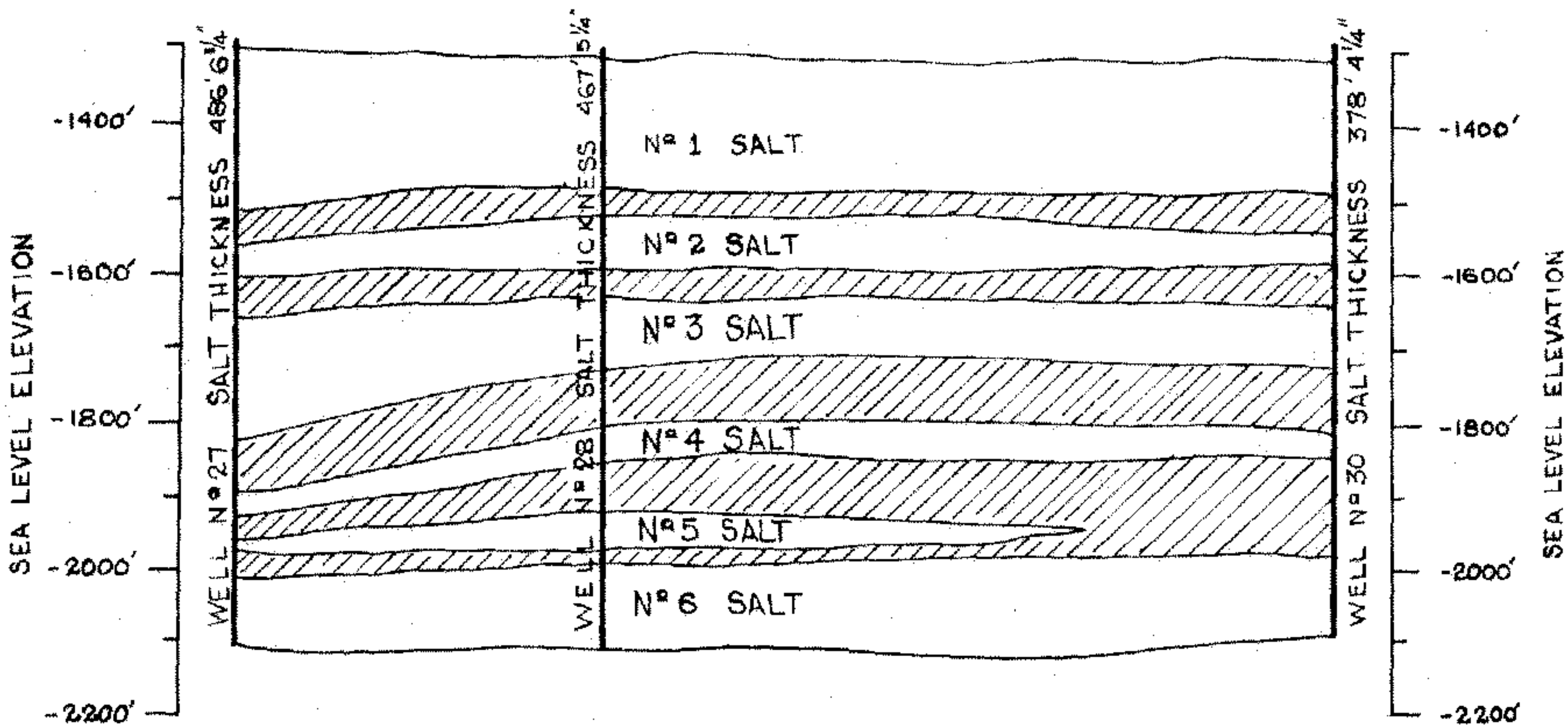


WATKINS GLEN #27
SALT SECTION
Collar Elevation
Sea Level Elevation
1780'0"
1801'9-3/4"
-1317'2-3/4"
1861'7"
-1377'0"
NO. 1 SALT
1967'6"
-1482'11"
2003'10"
-1519'3"
2010'8"
-1526'1"
NO. 1 ROCK
2045'8"
NO. 2 SALT
2093'1"
NO. 2 ROCK
2146'0"
-1661'5"
2190'10½"
-1706'3½"
NO. 3 SALT
NO. 3 ROCK
2381'7"
-1897'0"
NO. 4 SALT
NO. 4 ROCK
2452'1"
-1967'6"
NO. 5 SALT
2463'11"
-1979'4"
NO. 5 ROCK
2497'7"
-2013'0"
NO. 6 SALT
3638'0"
T.D.
Salt 31'6" Dirty (black) w/rock inclusions & a few rock bands.
Salt 59'9½" Dirty (black) with rock inclusions & bands.
Salt 97'5½" Dirty (black with rock inclusions.
Salt 23'4½" Dirty (black) with rock inclusions & zones of brecciated material.
Salt 2'9"
Salt 22'7" Dirty (black) top 2'6" contains abundant rock material.
Salt 22'9½" Dirty (black)
Salt 44'10½" Dirty (black) with rock inclusions & a few rock bands. #2174'½" - 12'3" of grey to milky salt.
Salt 100'7½" Dirty (black) with rock inclusions & bands.
Salt 3'10½"
Salt 6'10½"
Salt 11'10" Dirty (black) with rock inclusions.
Salt 66'1" Dirty (black) with rock inclusions & bands; & zones of brecciated material: #2520'4" - 1'3" #2523'10" - 2'6"
Salt 17'8½" Dirty (black) with top 5'6" contains abundant rock material, & a 1'11" band of shale #2574'11". Below this rock material absent.
LEGEND
Dolomite
Dolomite - salty, with salt filled fractures & cavities
Dolomite - shaly
Limestone - shaly, with salt filled fractures & cavities
Limestone - argillaceous
Breccia
Shale with salt filled cavities & fractures
Shale - calcareous with irregular masses of anhydrite
Shale with salt bands
Mudstone
Siltstone
Anhydrite
NOTE: Depths measured from rotary table which is 7'6" above natural surface & has an elevation of 484'7" A.S.L.

FIGURE 3

FIGURE 4

GEOLOGIC CROSS SECTION OF SALT MEMBERS NOS. 1 THRU 6 OF THE SALINA GROUP, AS ENCOUNTERED IN WELLS NOS. 27, 28 & 30 OF THE WATKINS GLEN NORTH FIELD WATKINS GLEN, NEW YORK



EXPLANATION

Thickness of salt refers to brineable deposits.

Depths refer to sea level datum.

Scale: Vertical & Horizontal 1" = 200'

changed, small crevices and fractures are developed. In dry mining operations, these disturbances are known to sometimes extend from the boundary of the opening upward and outward at a 45° angle.

In the construction of new galleries, we use the rough rule of a minimum spacing from one gallery axis to the other of a distance equal to the depth from the surface to the bottom of cavity plus 25%. This will vary with the geology of the area, the age of the cavity and the amount of salt extracted from the cavity.

WELL CONSTRUCTION

It is our opinion that well construction is one of the most important phases of connecting two wells by splitting or fracturing of the salt beds. Our practice has been to set 20 to 120 feet of surface casing, depending upon local surface conditions. It has been found that bed rock adjacent to the lake is characterized by zones of lost circulation, while well locations up the hill and removed from the lake exhibit no lost circulation near the surface or at a corresponding stratigraphic depth to those on the lake shore. This is believed due to bedrock disturbance by the glacier which moved down Lake Seneca.

After cementing the 13 3/8" surface casing, a 12 1/4" hole is drilled to a point just above the 1st Salt bed. From this point to total depth, which is normally five feet into the shale underlying the 6th Salt, the well is cored with a diamond bit and 50 foot double tubed core barrel. This coring is done in order to secure proper geological control and for a better understanding of the area, necessitated primarily because of the sharp distortion of the salt beds of this region.

A point within the lower portion of the 6th Salt is selected as a splitting point and the core hole plugged back to this point with some type of expanding cement such as cal-seal. The core hole is then reamed to 12 1/4" from the point above the 1st Salt to an elevation just above that selected as the point where the fracture or split is to be initiated or, as in the case of Well #28, (Figure 5) to a point just below the bed contact if you have reason to doubt the quality of the cement job obtained in the core hole. We believe that shales which are laminated and have a high horizontal permeability, must be protected from the splitting fluid in order to prevent fluid from preferentially seeking this path of least resistance. Fluid might travel a goodly distance in these shale layers and accomplish none of the desired dissolving action. Thus, we would add the extra step of recementing the lower portion of the hole to just below the splitting zone.

In general, our casing strings are composed of 8 5/8" steel pipe which allows an adequate space for a good cement jacket. This cement jacket is particularly important in the Watkins Glen area where the Oriskany sandstone is present. The Oriskany in this area carries large amounts of hydrogen sulphide and ammonia. 8" X 12" centralizers are spaced along the casing in keeping with the vertical deviation of the hole so that the cement jacket will be uniform. In spacing centralizers through the salt, we attempt to locate them, insofar as possible, in rock layers or lenses.

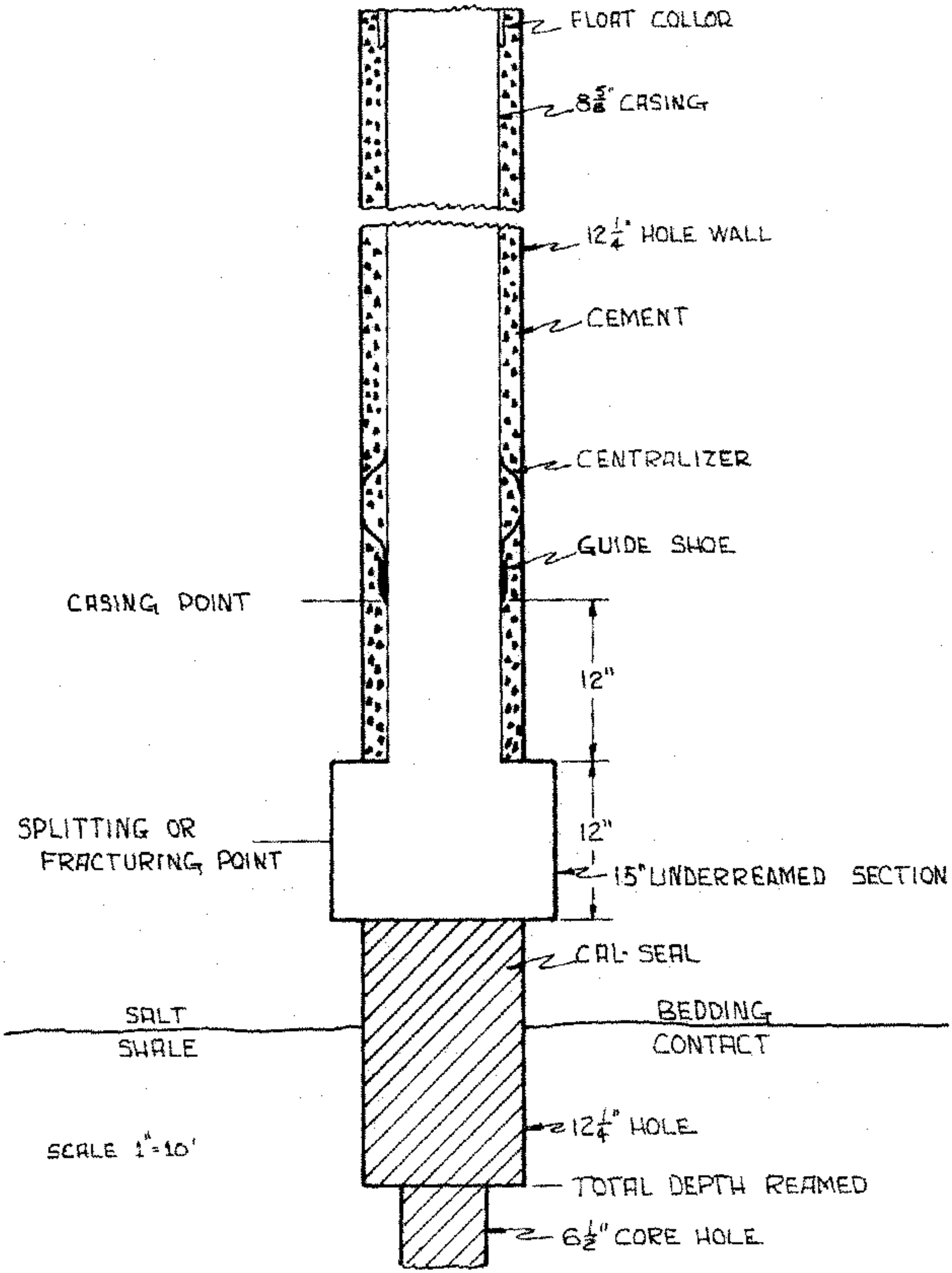
Zones of lost circulation are occasionally encountered in the Oriskany sandstone. If, during drilling, these zones are encountered, a two stage cementing tool and cement baskets are incorporated in the casing string. All drilling is done with saturated brine from our brine field. This is done in part to prevent the sluffing of some of the members of the shale beds overlying the Salina when they are drilled with fresh water, and also because of the availability of the brine.

Our cementing procedure, in general, calls for the use of a straight water based portland, 15 pounds per gallon, cement slurry which is injected into the casing. This cement is immediately followed by a saturated brine based cement of the same weight, which in turn is immediately followed by a brine based cement to which 2% calcium chloride has been added. The quantity of this calcium chloride-brine slurry usually approximates 50 sacks.

These cements are forced down the casing by pumping a wiper plug behind the slurry with the drilling fluid; circulated the cement slurrys out the cementing shoe and up the annulus to the surface. The volume of each type of cement injected depends upon the size of the annulus and the thickness of strata penetrated. The water based cement is placed adjacent to the sedimentary beds overlying the evaporites and the brine based cements are adjacent to the evaporites. Tests

FIGURE 5

WELL # 28 COMPLETION DESIGN



have proven that brine based cements will bond better with evaporites than water based cements. As an aid in determining the required volume of each of these slurries, a caliper log is run after the core hole has been reamed.

Samples of the cements are taken as the cements are injected into the casing. After the wiper plug has landed at the bottom of the casing string and the samples of the brine-calcium chloride based cement have set, a 7 1/2" rock bit on a string of drill pipe is run in the casing. The plug, shoe, cement and one to two feet of rock salt below the reamed depth, are drilled out with fresh water. A wall scraper is then run into the casing and the one to two feet of open hole, exposed during the drilling out of the plug, is underreamed with a hydraulic wall scraper to a diameter of 15". It is our opinion that in certain salt beds multiple splits can occur. Therefore, the smaller the vertical cross section of salt exposed, the less chance there is of multiple horizon being split.

More recently, we have used the 7 1/2" rock bit a foot or two below the reamed depth, thus drilling out the cal-seal and exposing the portion of the hole in which we desire to split. This eliminates the necessity of underreaming. Results from this modification have been successful probably due to the fact that the fresh water used to drill out the shoe and cement, actually leach a sufficiently large kerf to initiate the splitting and lifting action. It is our opinion that the work in the hole, during the drilling out of the plug and the underreaming, has a tendency to puddle the cement in the annulus. Work in the hole while the cement is still plastic, eliminates the necessity of working in the hole after the cement has set which, we believe, injures the bond between the casing and cement. This procedure also eliminates the drill rig cost for waiting on cement as the drill rig is free to move immediately after underreaming or the plug-cement drill-out.

GALLERY #1

Our first attempt to coalesce two new wells into a gallery, was based on the success experienced in our previous establishment of undercuts from new wells to an existing brine cavity. These first well-cavity connections clearly demonstrated the necessity for understanding the geology of the area in which the operation was to be accomplished.

The geology and results of these previous operations led to our location of Well #27 and Well #28 (Gallery #1) in an east-west line with the intention of forming a two well gallery (Figure 6). It is our belief that galleries should be limited to two wells, so that during repair periods as few wells as possible are taken out of service. The spacing of Wells #27 and #28 was limited to 500 feet.

Previous brining operations had been confined to the top 60 to 90 feet of the salt section, which begins at about 1, 317 feet below sea level. Wells #27 and #28 were taken down into the 6th Salt, or an approximate elevation of 2, 100 feet below sea level. Both wells were cored.

Due to the difference of 112 feet in the surface elevations from Well #27 to Well #28, we decided to make Well #27 the target well and Well #28 the injection well. Well #28 was completed in a manner similar to that outlined previously. Well #27 was constructed so that the casing was seated at 2, 013 feet below sea level in the top of the 6th Salt. This was done in order to form a larger target as a guard against "bed jumping" of the splitting fluid. It was also our opinion, that should we fail to get a connection between the two wells, a packer could be set in the open hole in a rock zone occurring between 2, 079 and 2, 088 feet below sea level in Well #27, and this well split toward the large fluid target which had been developed around Well #28.

After the initial split of the salt in Well #28 has been accomplished at a pressure of 2, 835 p. s. i., an immediate breakdown in this pressure to 1, 960 p. s. i. was experienced. This immediate 30% reduction in pressure is one which generally occurs in the Watkins Glen area. During the next 24 hours, the injection pressure continued to drop to 1, 470 p. s. i., or

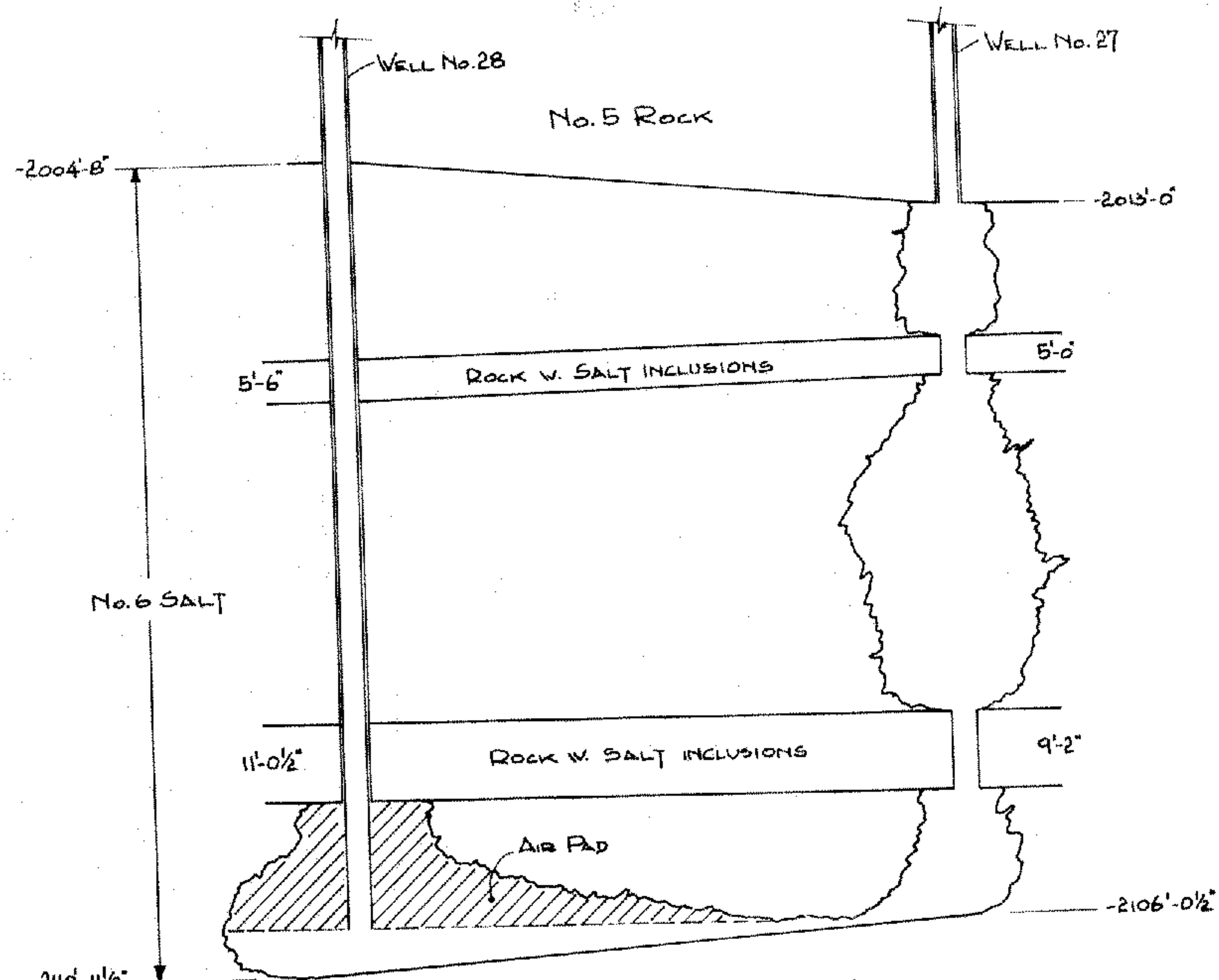


FIGURE 6 WATKINS GLEN GALLERY No. 1

approximately another 18% with an average rate of water injection of 320 gallons per minute. Pressure-volume relationship continued as follows:

Date	Well Head Pressure	Gallons Pumped (Cumulative)
6/10	2,835	0
6/11	1,470	459×10^3
6/12	1,460	926×10^3
6/13	1,480	$1,280 \times 10^3$
6/14	1,140	$1,772 \times 10^3$ (1)
6/15	1,520	$2,161 \times 10^3$
6/16	1,520	$2,613 \times 10^3$
6/17	1,520	$3,065 \times 10^3$ (2)
6/18	1,480	$3,497 \times 10^3$
6/19	1,450	$3,929 \times 10^3$
6/20	1,435	$4,361 \times 10^3$
6/30	1,385	$8,681 \times 10^3$
7/10	1,320	$13,000 \times 10^3$
7/20	1,220	$17,320 \times 10^3$
8/1	850	$22,072 \times 10^3$
8/6	220	$24,230 \times 10^3$
8/8	160	$25,020 \times 10^3$

(1) Pump engine trouble developed at this point. When shut-in for a period of 2 hours and 15 minutes, the well head pressure went up to 1520 on renewal of pumping.

(2) At this point, stroke counter trouble was experienced and only estimates are available after this point.

At this point, plant pumps were able to take over and produce the gallery.

GALLERY OPERATION

Almost immediately after the wash down of Gallery #1, the volume of saturated fluid, which it could produce, began to decrease. By pressure-volume testing of the gallery, it was determined that a pneumatic pad was building up behind the casing of Well #28. As this pad spread laterally, the quantity of saturated brine which the cavity was capable of producing, continued to diminish.

We were unable to determine whether this was air that had been entrained in the injection water and liberated in the cavity as salt was dissolved, or if it were gas which was included in the formation.

Having on hand an adequate supply of saturated brine from other wells; believing that any one of several approaches would easily solve the problem of a greater volume of saturated brine and desiring to extend the undercut over the greatest possible area, we continued to operate Gallery #1 at a very low rate of production. Due to a desire to show production from the gallery, circulation in the cavity was reversed by injecting into Well #27 and producing Well #28. The production of saturated brine was immediately quadrupled with the production of brine being limited by our injection pump capacity and pressure (Figure 7).

During this period, a series of brine samples were taken and analyzed for the soluble impurities contained in the brine. Where several were taken during any given month, they were averaged to produce the following table: (See Figures 8, 9, 10, and Table I showing Brine Impurities Concentration).

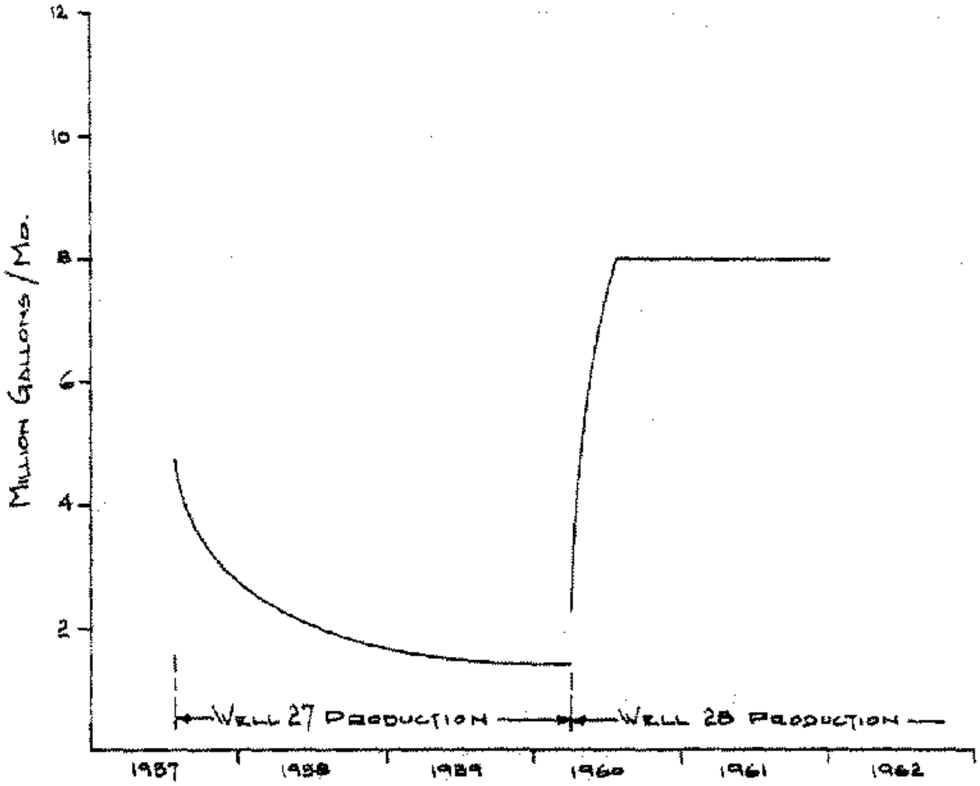


FIGURE 7 GALLERY No. 1
BRINE PRODUCTION

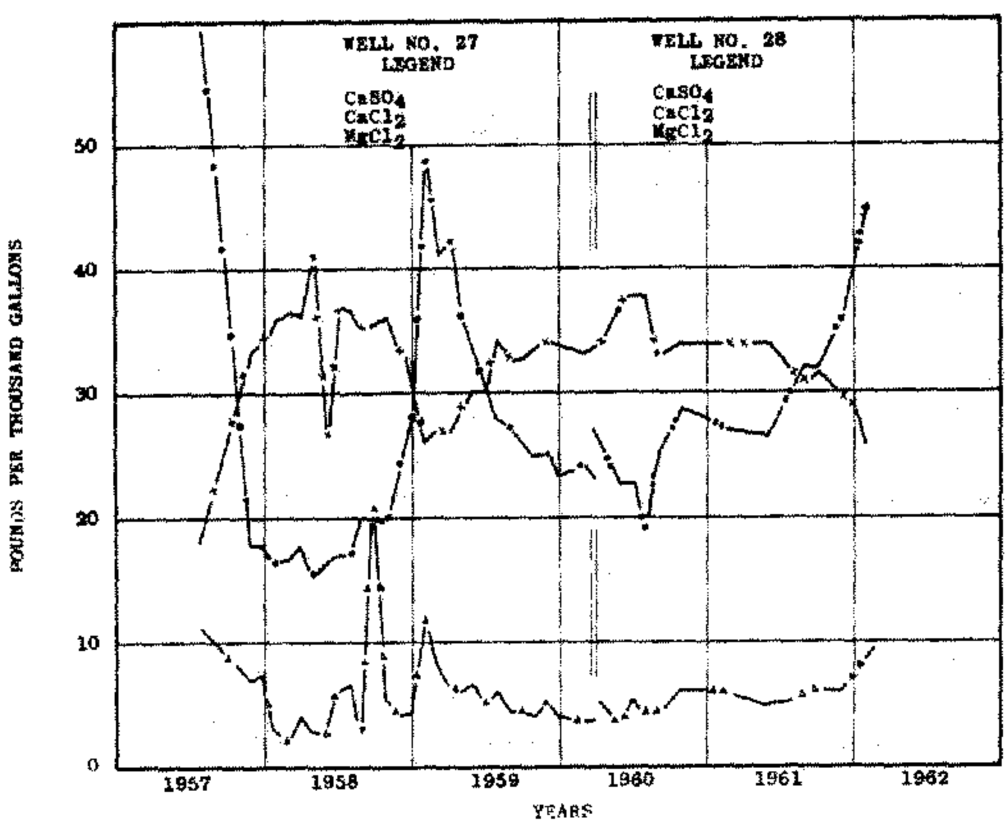


FIGURE 8 CHEMICAL COMPOSITION OF BRINE FROM GALLERY NO. 1 WATKINS GLEN

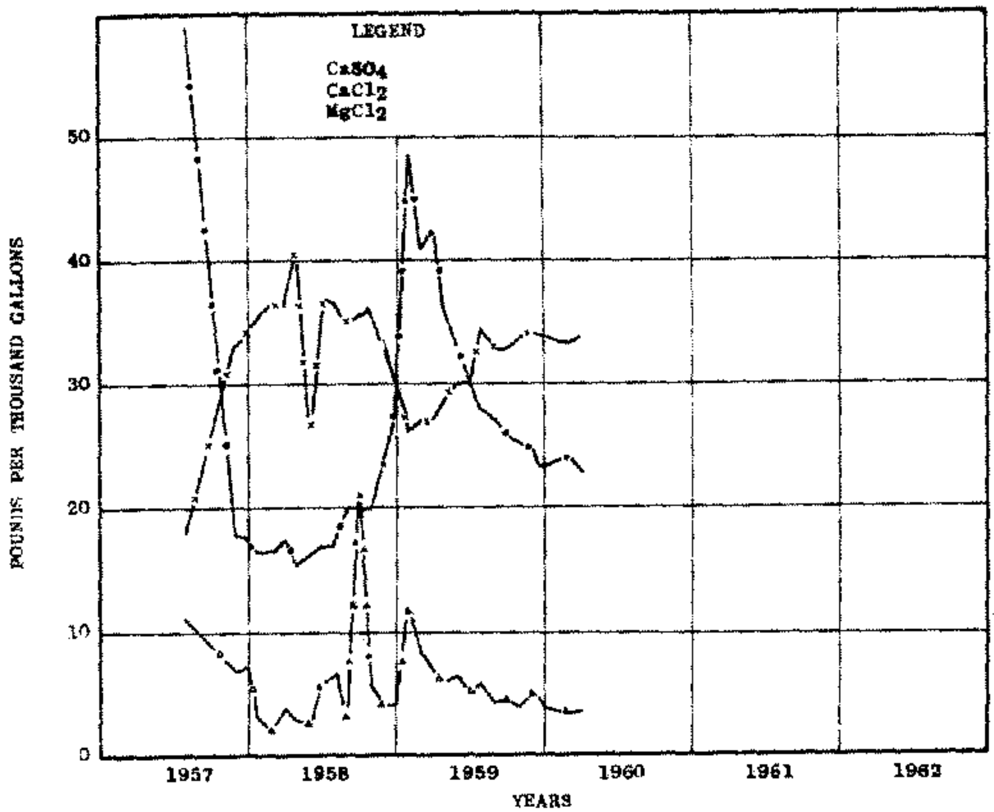


FIGURE 9 CHEMICAL COMPOSITION OF BRINE IN WELL NO. 27

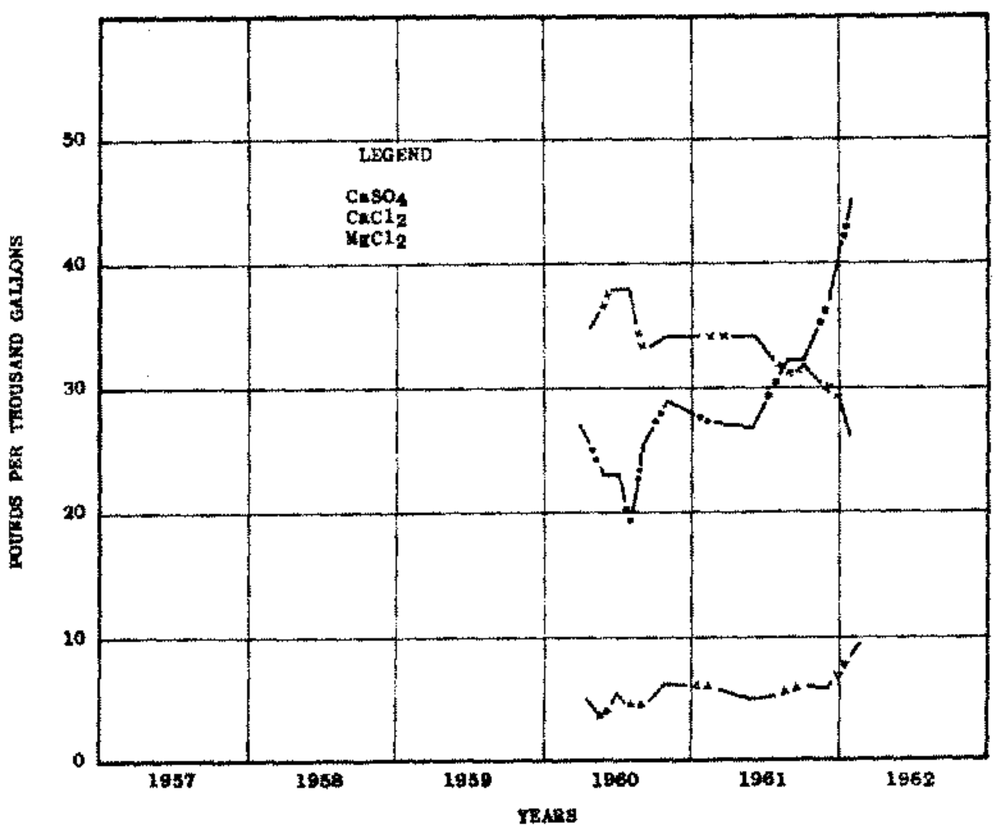


FIGURE 10 CHEMICAL COMPOSITION OF BRINE IN WELL NO. 28 WATKINS GLEN

TABLE 1

BRINE IMPURITIES CONCENTRATION

Gallery No. 1

Well #27	Lbs/M Gal. $CaSO_4$	Lbs/M Gal. $CaCl_2$	Lbs/M Gal. $MgCl_2$
8/57	18.6	59.8	11.4
12/57	33.7	18.0	7.3
1/58	34.5	18.0	7.8
2/58	36.2	16.7	3.2
3/58	36.8	17.0	2.1
4/58	36.5	18.0	4.1
5/58	41.5	15.8	3.0
6/58	26.8	16.8	2.9
7/58	37.5	17.4	6.3
8/58	37.0	17.5	6.9
9/58	35.4	20.4	2.9
10/58	36.0	20.0	21.4
11/58	36.5	20.1	5.7
12/58	33.8	24.9	4.3
1/59	30.9	28.5	4.5
2/59	26.7	49.3	12.2
3/59	27.5	41.2	8.7
4/59	27.2	42.8	6.8
5/59	29.2	36.6	6.4
6/59	31.4	33.7	6.7
7/59	31.4	30.4	5.2
8/59	34.9	28.2	6.1
9/59	33.2	27.7	4.4
10/59	33.3	26.2	4.7
11/59	34.0	25.2	4.1
12/59	34.7	25.6	5.3
1/60	34.3	23.5	4.3
3/60	33.8	24.4	3.8
4/60	34.1	23.2	3.8
Gallery Flow Reversed - Water Injected Well #27 - Brine taken from Well #28			
Well #28			
4/60	34.0	27.4	4.0
5/60	35.3	24.8	4.6
6/60	37.7	23.0	3.6
7/60	38.2	22.9	5.4
8/60	38.0	19.6	4.3
9/60	33.4	25.4	4.3
11/60	34.3	29.3	6.4
2/61	34.3	27.9	6.1
6/61	34.4	26.9	5.3
9/61	31.2	32.3	5.7
10/61	32.1	32.1	6.3
12/61	30.2	36.1	6.1
1/62	29.6	40.5	7.5
2/62	26.0	45.2	9.1

The chart of brine produced from Well #27 during the initial stages of production (Figure 9) shows an abnormally high $CaCl_2$ content with a low $CaSO_4$. It is possible that the splitting solutions have a tendency to follow the more soluble and weaker zones containing higher percentages of calcium chloride. It has been established through core analysis, that there is a wide variation in percentages of calcium chloride in bedded salts.

We believe this layering of high calcium chloride zones is responsible for the peak which occurred in February 1959. These high calcium chloride peaks suppress the calcium sulphate. After this zone, which was encountered during the early part of 1959, had been washed out, our brine composition returned toward the low calcium chloride concentration experienced in 1958. During this entire period, brine was being produced from the top of the cavity.

In April 1960, we reversed circulation producing from Well #28, off the bottom of the cavity. During that year, the calcium chloride content was fairly uniform and somewhat higher than that produced during 1958 off the top of the cavity. We do not believe that this can be said to be a result of stratification of soluble impurities within the cavity, which was one of the factors we had hoped to determine. As is shown in our chart of the chemical composition of the brine produced from Well #28 (Figure 10), our calcium chloride is once again on the rise.

It is our practice to operate our galleries at a low production rate. We feel that such an operating procedure allows a slow redistribution of stresses around the cavity and prevents large stress differentials. We have experienced cavity floor "heave." This was experienced in several wells, one of which was Well #28, Gallery #1. Here the end of the casing became plugged with green shale from the layers underlying the 6th Salt. The quick and easy solution to this was the perforation of the casing near the bottom.