Recovery of Entrapped Hydrocarbons

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ABSTRACT

There are several ways in which hydrocarbons that are trapped in underground salt storage cavities may be recovered. Depending entirely on the conditions surrounding the cavity and the entrapped product, the methods which can be used are (1) drilling to a target of the highest elevation in the entrapment, (2) re-perforating, fracturing and/or washing at the Product Recovery Well and (3) de-watering the cavity so that the product is exposed to the bore of the Recovery Well.

A major portion of entrapment associated with the storage of hydrocarbons in salt cavities is the absorption of the trapped air by the product. Thus, the product fills the space of the original pneumatic trap. This paper deals with the recovery of product from a trap of over 700,000 barrels by drilling to a pre-designated target in the trap area.

INTRODUCTION

In 1956 two salt wells which were designed to furnish raw brine for the Watkins Glen Refinery of the International Salt Company were coalesced by hydraulic fracturing. This fracture was initiated in the lower portion of the bottom salt bed of the Salina formation just above the contact with the underlying soft Vernon shale. The target well for the fracture was 500 feet west of the injection well.

After having produced over 1,500,000 tons of salt in brine form, these wells and the cavity which had been formed were converted into a storage jug for liquid petroleum gas. This conversion occurred in 1964 with some 200 foot thickness of salt forming the roof of the cavity. The 200 feet constituted the top portion of an aggregate total thickness of salt beds of slightly over 500 feet. Pressure testing of the cavity and wells was accomplished by use of a dead weight indicator, with a wellhead test pressure of 0.8 times the vertical height to the top of the cavity. This 72 hour test indicated that the cavity and wells were "tight." Because of the sustained period of pumping required to obtain the pre-selected test pressure it was obvious that a sizeable air pad was associated with the cavity. Due to the fact that only fresh water was available for this test, an extended period of time was required for the cavity pressure to stabilize. This stabilization period was necessitated not only by use of fresh water which had to become saturated with salt, but also to allow the 40°F temperature of the water to reach the 72°F ambient temperature of the cavity. Rough approximations showed the volume of the air pad to be approximately 2,500,000 cubic feet. The entrapped air led to the entrapment of 431,622 barrels of propane at a wellhead pressure of 870 psig. (Table I)

ENTRAPMENT EVALUATION

A number of possible recovery methods were considered and abandoned because of their impracticality, circumstances surrounding the entrapment and/or cost. Among the systems of recovery suggested by various individuals were: (1) Exposing the bore of the well at the top of the cavity to atmospheric pressure; (2) Use of a floating snorkle-tube device whose open end would penetrate the propane above the brine-propane interface and (3) Plugging the bore of the injection well just below the top elevation of the cavity, perforating and fracturing to this high point in the cavity. At the time of this recovery effort, September 1970, there existed a serious question as to whether or not a sonar survey conducted in brine could penetrate a brine-propane interface and successfully record the configuration of the surfaces confining the entrapment. As shown in Figure 1, a successful sonar survey was conducted on September 15, 1970 and the area of entrapment outlined. Entering Well #27, the prophane injection well, with the sonar tool, we outlined the trap in

TABLE I

Watkins Glen, N.Y. Gallery #1—Evaluation of cavity volume

Depth	Thickness	Area Sq. Inch	Area Sq. Feet	Volume Cu. Feet	Barrels	Bbl. Cumulative
2050-2055	5	.7	1,750	8,750	1,558.37	
2055-2060	5	2.11	5,275	26,375	4,697.39	
2060-2070	10	6.19	15,475	154,750	27,560.98	
2070-2080	10	9.42	23,550	235,500	41,942.55	Total barrels
2080-2090	10	12.91	32,275	322,750	57,481.78	down to the 2110
2090-2100	10	17.51	43,775	437,750	77,963.28	depth,
2100-2110	10	20.64	51,600	516,000	91,899.60	347,622 bbl.
2110-2118	8 ←			Entrapment	→	431,622
2110-2120	10	23.75	59,375	593,750	105,746.87	453,369
2120-2130	10	25.26	63,150	631,500	112,470.15	565,839
2130-2140	10	27.47	68,675	686,750	122,310.17	688,149
2140-2150	10	33.40	83,500	835,000	148,713.50	836,863
2150-2160	10	36.91	92,275	922,750	164,341.77	1,001,205
2160-2170	10	38.98	97,450	974,500	173,558.45	1,174,763
2170-2180	10	39.19	97,975	979,750	174,493.47	1,349,256
2180-2190	10	38.36	95,900	959,000	170,797.90	1,520,054
2190-2200	10	34.34	85,850	858,500	152,898.50	1,672,953
2200-2210	10	33.83	84,575	845,750	150,628.07	1,823,581
2210-2220	10	18.04	45,100	451,000	80,323.10	1,903,904
2220-2230	10	12.11	30,275	302,750	53,919.77	1,957,824
						+5% = 97,891 = 2,055,715 bbl.

ten foot contours and selected that area above the depth of the 1990 foot elevation as the target area. This target area is shown in black. The bottom of Well #27, in a true vertical depth position, was calculated at 2,043 feet. The brine-propane interface of the trap occurred at this point.

GEOLOGY OF THE AREA

The Salina salt formations of the Upper Silurian are underlain by the slightly dipping Vernon shale (Fig. 2). The first salt sequences resting on this uniform plane are the D Salts. Progressing upward through 800 feet of evaporites, we encounter a composite aggregate thickness of 500 feet of salt.

Tectonically, the Salina has been disturbed by several thrusting actions of the Appalachian uplift. This diastrophism has given rise to a series of low angle thrust, tear and slip faults. In order to correlate beds of salt across these fault zones, all beds were defined by previously established nomenclature from geophysical logs (Fig. 3). Confusion arises from the fact that despite the thousands of feet of horizontal displacement that have occurred within the evaporites, the upper contact of the topmost salt bed and the lower contact of the bottom salt bed can be said to be parallel.

WELL DESIGN

As shown in Figure 4, the Recovery Well – Well #46, was equipped with 16" 65# per linear ft. H40 casing, in a 22" hole. This was set through glacial fill and into bedrock 140 feet. The extra depth to which this surface casing was set was necessitated by glacier created fractures in the upper portions of the rock which gives rise to mud losses.

After cementing the casing back to surface, drilling continued with a 15" bit to a depth of 1,494 feet. Zones of lost circulation are encountered in the Marcellus, Cherry Valley and Oriskany at an elevation of 1,255 feet to 1,445 feet below the surface. These zones normally contain a hydrogen sulphide bearing, ammonia contaminated connate water which will not only foul the artificial brine but also will throw stored hydrocarbons off specifications.

An intermediate string of 13-3/8" H40 48 pound per linear foot casing was set to a depth of 1,494 feet. This casing was centralized and cemented back to the surface, thus sealing off all the aquifers above the salt horizons. The hole was continued from this point with a 12-1/4" bit, penetrating the top of the first salt bed at −1,848 feet sea level (s.l.) and bottoming at −1,888 feet (s.l.). A string of 8-5/8", K55, 32 pounds per linear foot casing with long

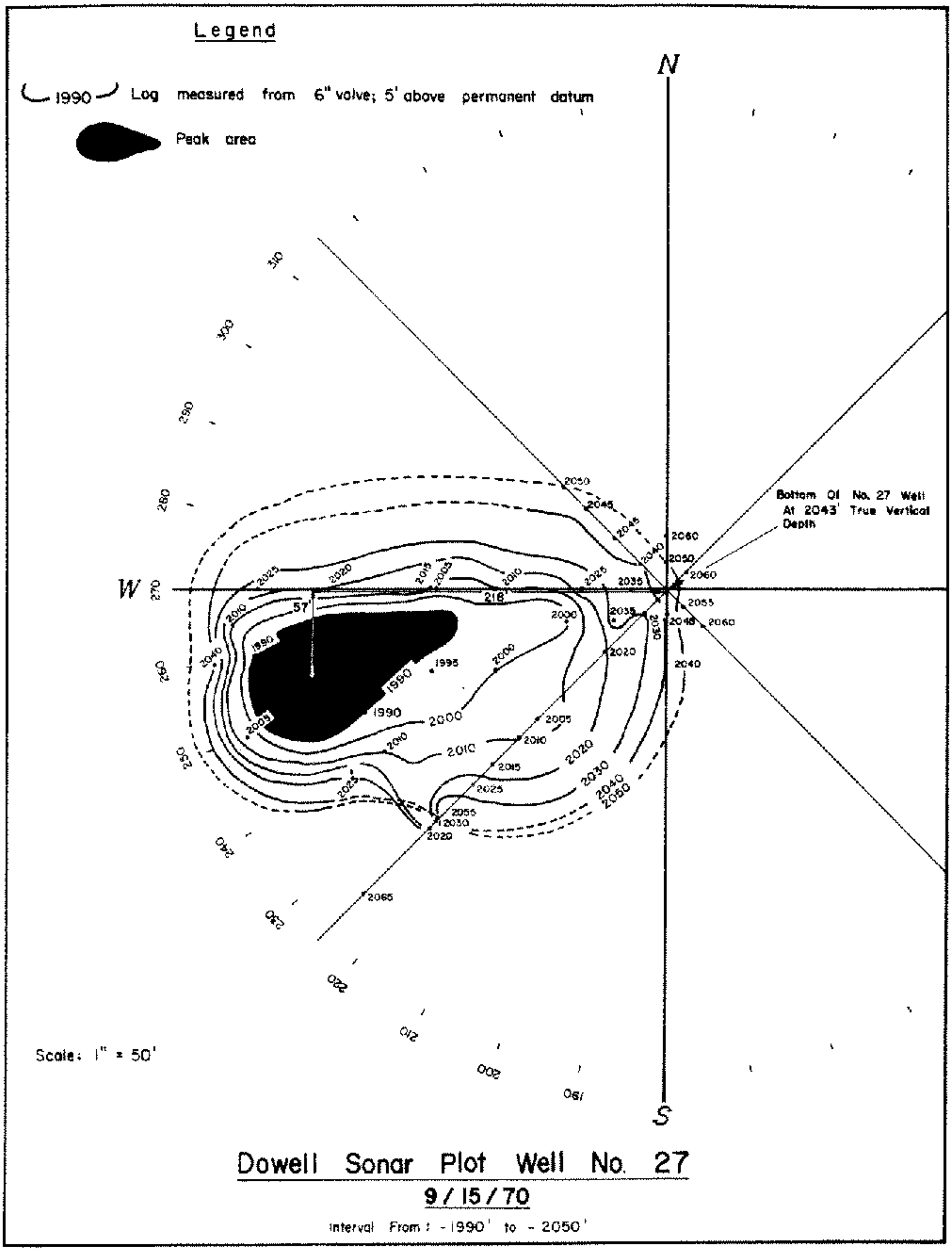

Figure 1. Map of storage area showing the location of the propane injection well #27.

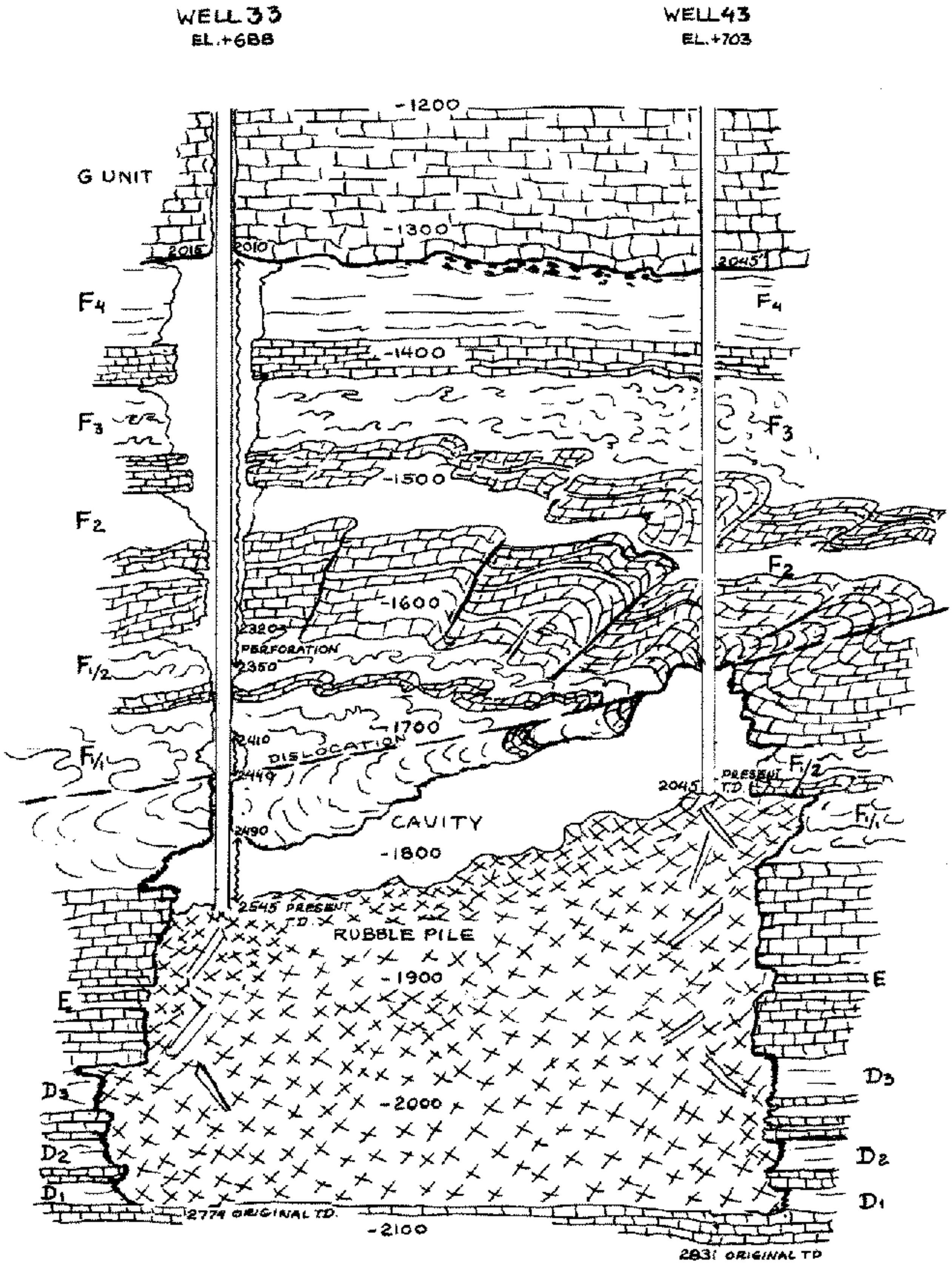

Figure 2. Diagram of the salt storage cavity in the Salina Salt and overlying strata.

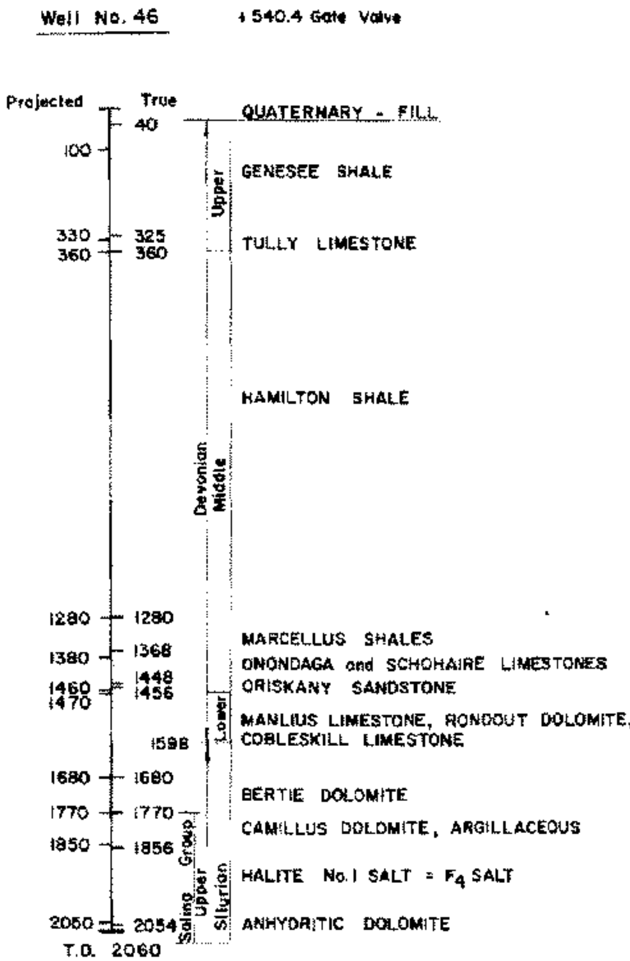

Figure 3. Lithologic log of the stratigraphic sequence as displayed in Well #46.

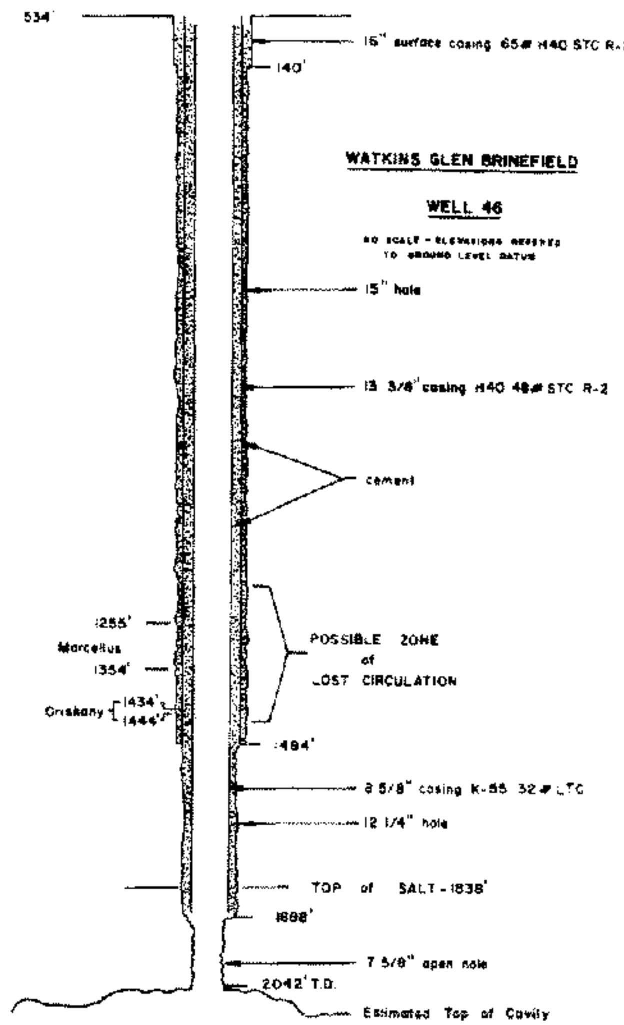

Figure 4. Diagram showing the Recovery Well #46, its casing, and the formations penetrated by the well.

threads and collars was set to the total depth and cemented back to surface. After the cement had set, a 7-5/8" bit was used to drill into the cavity. As the top of the cavity was approached, voids associated with parting planes below the cavity's stress arch were encountered before the piercement of the cavity.

WELL COMPLETION & RECOVERY

Figure 5 illustrates the deviation of the well from the pre-selected target area. Since this deviation was in an up-dip direction and since the solution of salt in situ normally occurs in an up-dip direction, this deviation was considered to be of miniscule importance. The surface location for Well #46 was selected so as to take advantage of the normal deviation experienced in the previously drilled Wells #27 and #28. Due to the incorporation of a bumper sub in the drill string, a device not available during the construction of Wells #27 and #28, the recovery well showed less than normal deviation, thus requiring the setting of two whipstocks for directional control. The first of these whipstocks was set at 1,587 feet and the second at 1,770 feet.

Sperry-Sun supplied the single-shot, vertical-deviation survey instrument whose data was used to develop Figure 5. A slight deviation in the form of a clockwise spiral was noted down to a survey point #5 or 1470'. The whipstock set at 1,587' started a proper hole trajectory as shown in point #6 located at a depth of 1,701 feet. The second whipstock set at 1,770 feet increased the angle of deviation as shown by point #7 located at 1,812 feet. Total deviation from the 10 foot target was 12 feet to the north northeast.

Upon completion of the cementing of the 8-5/8" casing a Hydrill double-ram, blow-out preventers and a rotating head were installed before the follower plug and cement were drilled out. As a safety measure in the penetration of the cavity, the bumper sub and drill collars were omitted

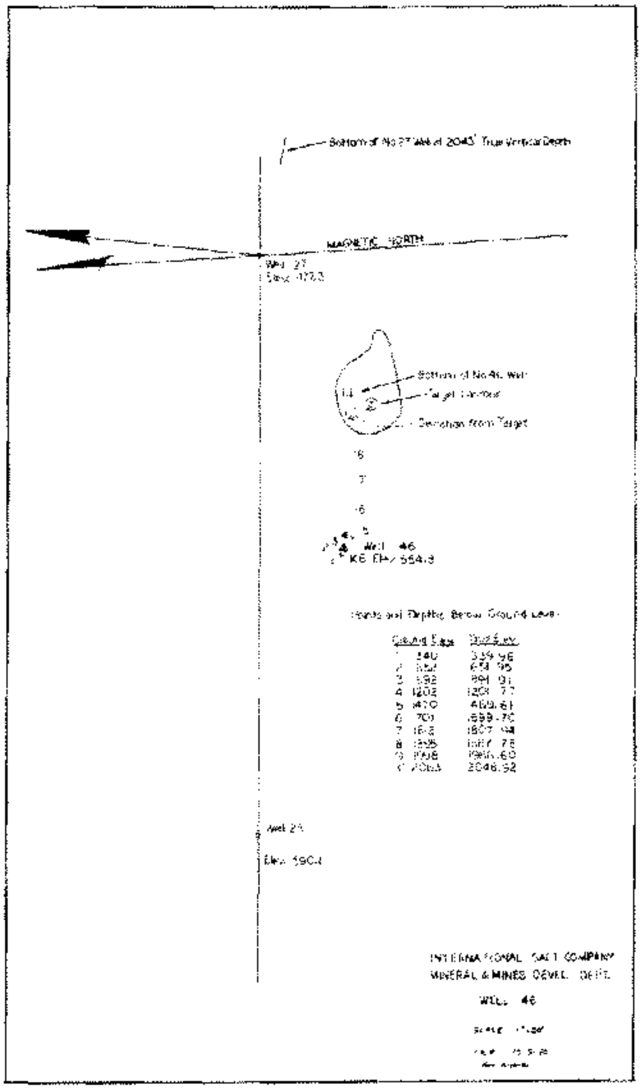

Figure 5. Deviation of the Recovery Well #46 from the pre-selected target.

from the drill string. All equipment and the well were pressure tested before drilling out the cement and after drilling out to a depth of 1,940 feet. Below a depth of 2,025 feet the well began to encounter strata or roof separations. With depth these separations became of great dimension with a corresponding increase in the loss of drilling fluid.

The recyling well, Well #28, had been set in an open flow condition so that drill fluid entering the cavity could displace brine thus maintaining an unobstructed flow of the brine drilling fluid into the cavity. All circulation was lost at a depth of 2,039 feet. The rig pump maintained a flow of 250 gpm at 0 psi. A standby pumping unit began injecting brine into the choke line on the blow-out preventer at 200 gpm and a minor return flow developed. The cavity was intercepted at a depth of 2,048 feet and all return circulation was lost. In order to prove the validity of a cavity interception rather than that of a parting, the drill bit was lowered 4-1/2 feet in the cavity. There was no further return circulation of drilling fluid and no propane was detected at the end of the blooey line with the pipe rams closed.

Consultants for the insurance company insisted on the installation of a Baker stationary-snubber, a platform and another blow-out preventer on top of the Hydrill blow-out preventer which had been installed previously. Withdrawal of the 2-7/8" drill pipe began with the pipe being laid down as it was withdrawn. When all but 5 joints of drill rods had been extracted there was a slight odor of propane from the rods. The rods were filled with brine by connecting up the kelly while still injecting brine into the annulus. Subsequently, the pulling of the rods continued successfully until the bit was landed and the master valve closed. It was unnecessary to use the snubbers.

Immediately a caliper log and gamma ray log were run in the hole. A sonar log was run the following day within the propane entrapment. Figure 6 delineates the parameters of the entrapment area. Well #46, although north of the original projected target, is still south of the high point of the cavity in this survey. The dashed line represents the area of residual entrapment not recoverable through Well #46.

The top of the rubble pile was surveyed resulting in Figure 7. Cross sections of the sonar survey of the cavity in an east west direction are shown in Figure #8. This cross section shows the limit of the original entrapment and the calculated maximum depth of propane-brine interface. This calculated value assumes voids. Subsequent to the survey, the porosity of the rubble pile was found to decrease markedly with increases in depth. As the size of the pile increases with depth and the porosity decreases, the storage volume decreases to a miniscule value near the bottom of the cavity. Figure 9 is another cross section developed as a result of the survey, showing the profile of the cavity and rubble pile in a northeast-southwest direction. Illustrating the northwest-southeast profile of the cavity is Figure 10.

SUMMARY

In summarizing this propane recovery effort with respect to the circumstances surrounding the entrapment, the geology and the recovery effort itself, the following observations can be made:

1. In a cavity capable of holding approximately 2,000,000 barrels of hydrocarbons, an entrapment of over 400,000 barrels is exceedingly inefficient.

2. The entrapment was a direct result of the solubility of the air pad in propane so that the volume of hydrocarbons entrapped was directly related to the volume of air.

3. Cavities in bedded salts in general have larger roof areas per unit of volume of space than dome salts and,

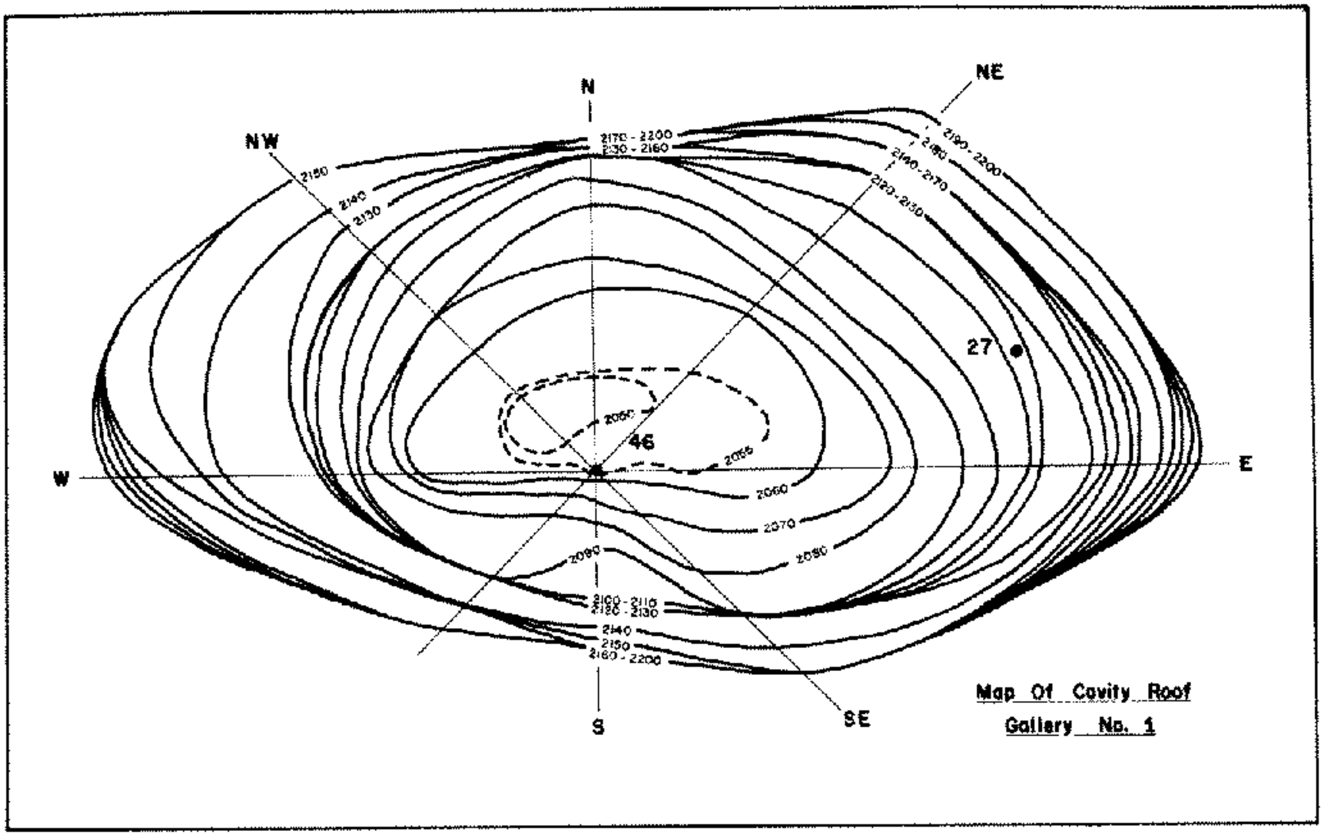

Figure 6. Map of the roof of the cavity in Gallery No. 1.

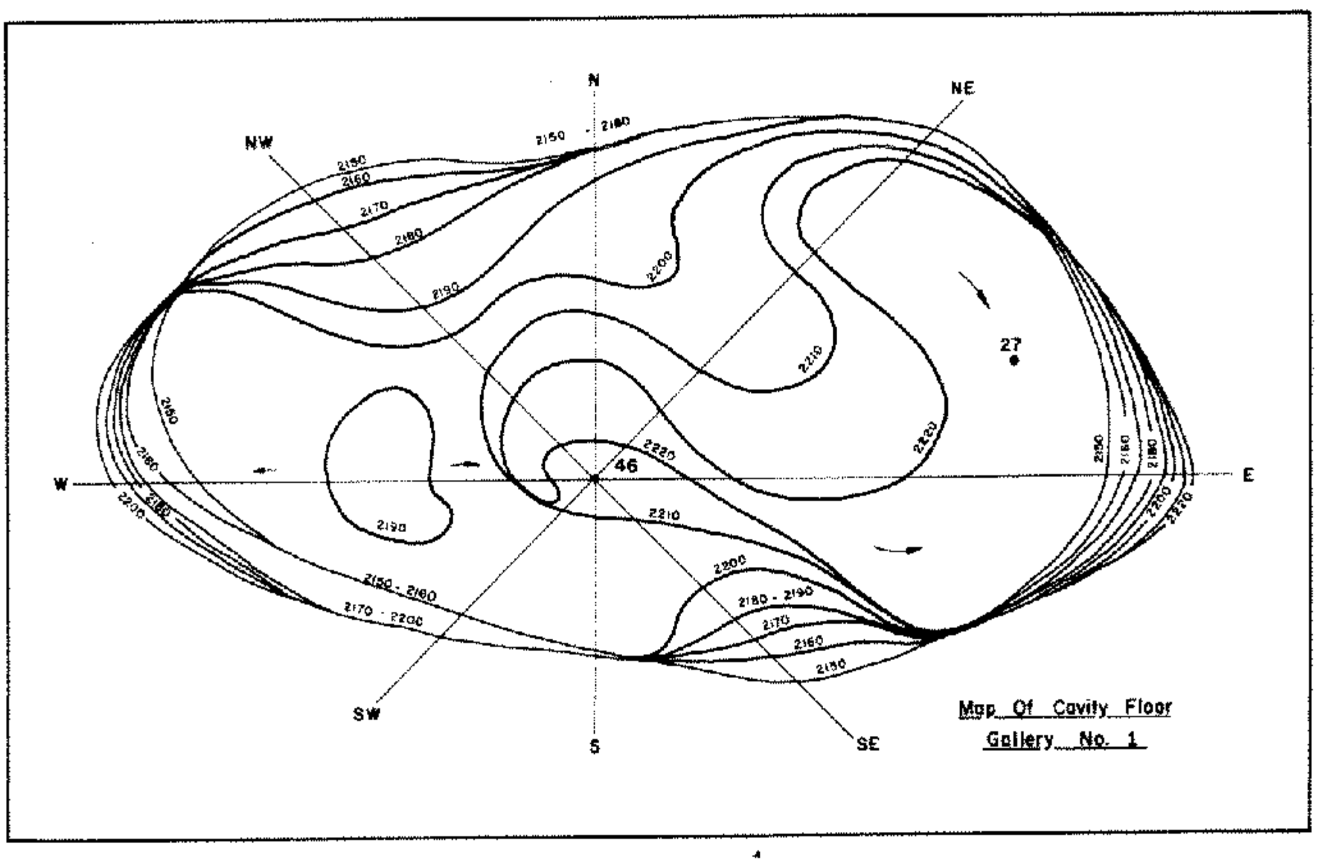

Figure 7. Map of the cavity floor in Gallery No. 1.

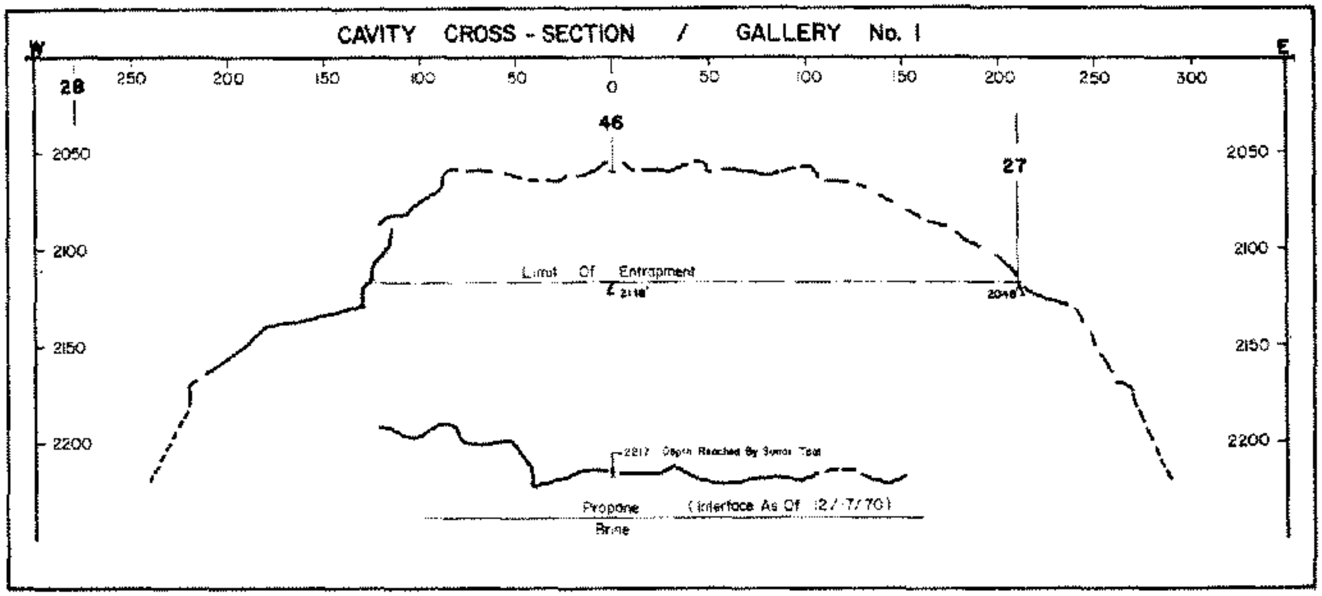

Figure 8. Cross section of the salt storage cavity through Gallery No. 1 (E-W).

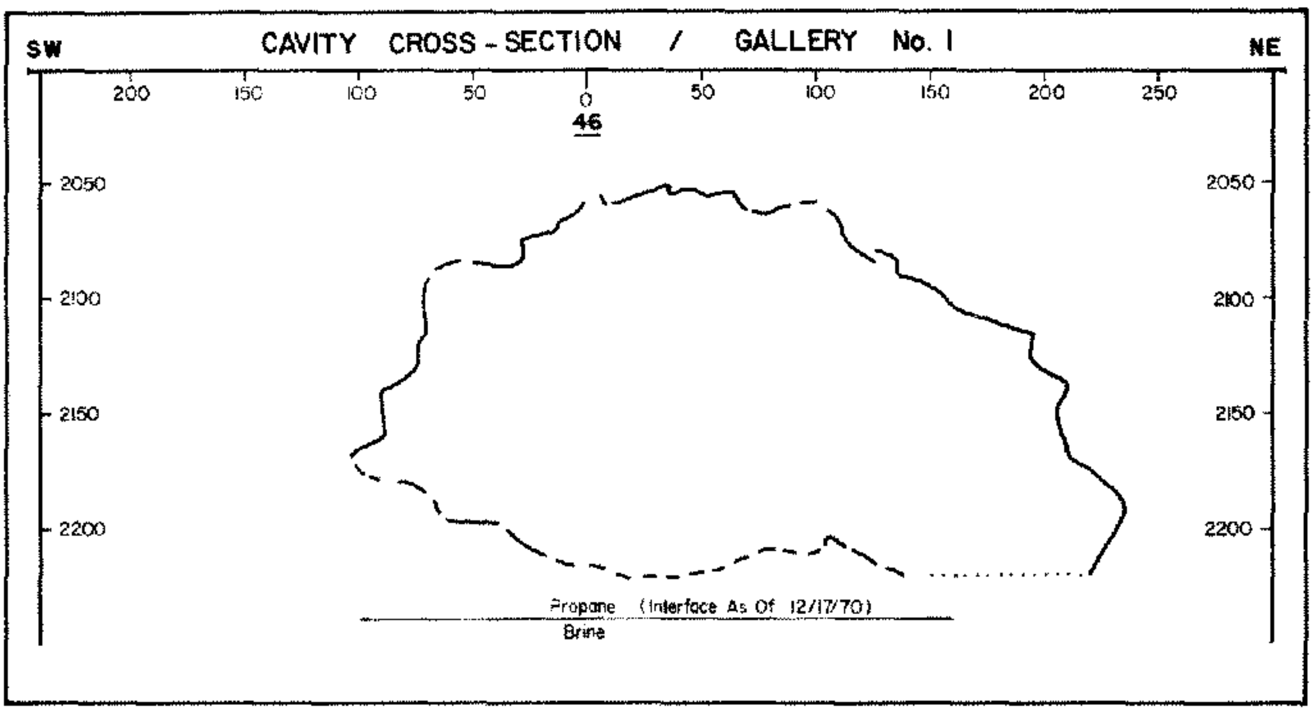

Figure 9. Cross section of the salt storage cavity through Gallery No. 1 (SW-NE).

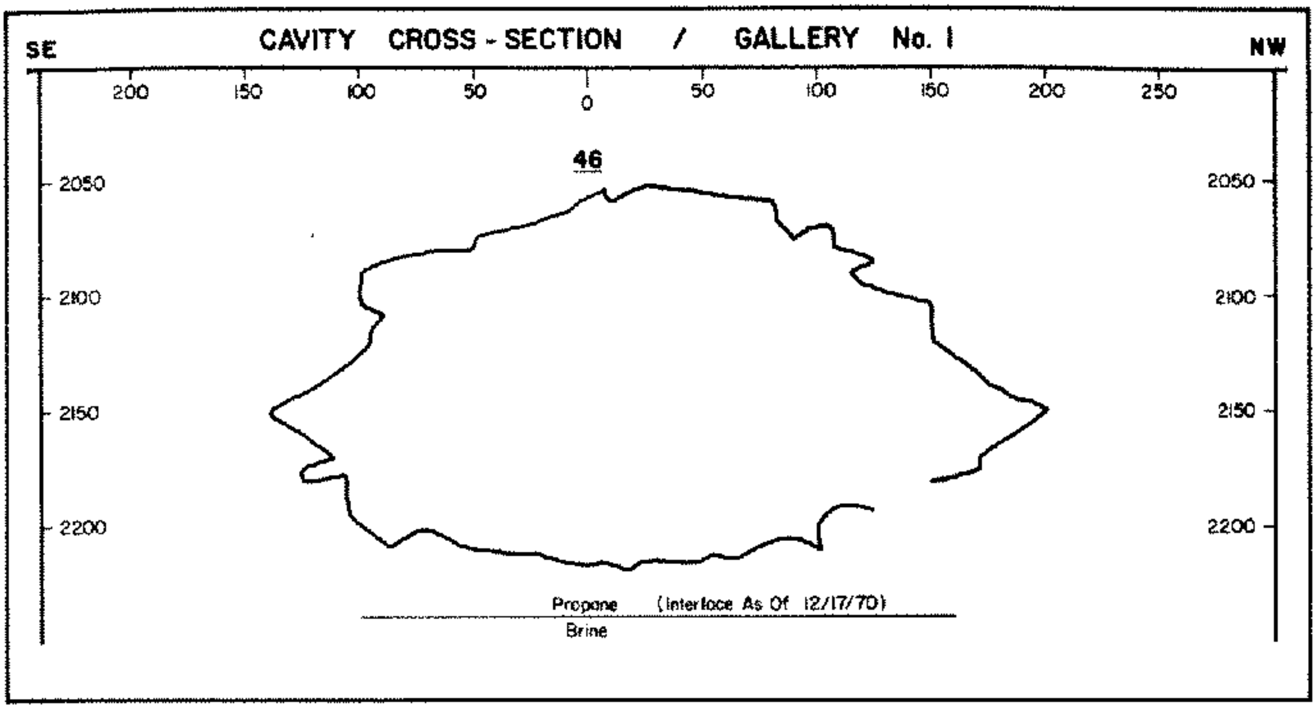

Figure 10. Cross section of the salt storage cavity through Gallery No. 1 (SE-NW).

therefore, a greater potential for a larger entrapment per unit volume of hydrocarbon stored.

4. Since all but approximately 15% of the 431,622 barrels was recovered, the recovery effort was considered successful.

5. The original sonar survey was indicative of the high point in the area of entrapment but the definition was insufficient to provide a precise target for interception by drilling.

6. Separation of laminae or partings may be expected above the cavity roof and below the stress arch. It should be anticipated that these voids may contain propane.

7. Using the proper hydrodynamic techniques, drill rods and bits may be extracted from the recovery well after penetrating the hydrocarbon without the use of such special equipment as stationary snubbers.