Storage of Hydrocarbons in Cavities in Bedded Salt Deposits Formed by Hydraulic Fracturing

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ABSTRACT

In the last two decades a new concept of hydrocarbon storage has been created by the dissolving of cavities in salt and the use of these cavities for hydrocarbon storage. Storage operations in bedded salt are dissimilar to those in dome type deposits. Similarly, the operation of cavities formed by hydraulic fracturing varies from single well jug type operations.

Fractured cavities, although creating more space for the storage of product, are more severely influenced by the geology of the salt deposit. This is true, not only from the standpoint of creating the cavity but also with respect to its operation. Pressure variation created by the input of product and its subsequent recovery, together with the character of the recycling fluid, is of utmost importance.

INTRODUCTION

Until recently, little was actually known about the geology of the bedded salts of the Appalachian Basin. Gradually there are emerging a few basic concepts which tend to explain some of the more complex geological problems that are being encountered in this area today. The existence of this complex geology has been shown during recently accelerated activities in the storage of hydrocarbons, exploration for new salt mines and development of brine fields. The number of new mines in the northeast section of the United States and adjacent to Canada has, in the last ten years, increased from 4 to 9. This increase in the number of salt mines was brought about by the increase in salt consumption in the United States from 16,053,802 tons in 1947 to 34,687,000 tons in 1965.

In 1948, a far reaching experiment was conducted in Keystone County, Kansas by a man named Ballue. In his experiment, Mr. Ballue took advantage of the extremely low permeability of salt to successfully store liquified petroleum gas in an artifically leached salt cavern. It is true that for many years prior to this time, dry salt mines had been used for the storage of various commodities and art treasures but never before had L.P.G. been stored in bedded salt.

This seemingly simple idea has blossomed until now over 17 billion gallons of liquified petroleum gas is stored annually in salt cavities in the United States. The full importance of this storage comes into focus when one realizes that a major portion of this same volume of gas was previously flared or burned at the refinery. If one multiplies this volume of gas by a wholesale price of 10¢ per gallon, you arrive at a rough estimate of the value of Mr. Ballue's idea—$1,700,000,000 per year.

As a waste product, propane, butane and isobutane are hazardous and the economic attendant with their surface storage in large volumes is adverse. Depending upon the type of product and the conditions necessary for its storage and recovery, underground storage can be accomplished for a cost of 1/20th to 1/100th that of surface storage. At the present time, such facilities as International Salt Company's Watkins Glen, New York plant have a static capacity of some 4,000,000 barrels in two cavities created by hydraulic fracturing.

Another visionary, Mr. H.L. Gentry, in 1961 undertook an experiment at St. Clair, Michigan, in which over 300 million cubic feet of natural gas was successfully stored in an abandoned single well brine cavity. Again a major contribution had been made to our standard of living, for now large amounts of natural gas can be stored in anticipation of consumer demand during the peak period of extremely cold weather when fuel demands are at a maximum.

Faulting—Watkins Glen, N.Y.

Watkins Glen, New York is one of two locations in the United States where L.P.G. is being stored in fractured cavities. A recent geological interpretation of the structure of the Watkins Glen area is shown in Figure 1. The four wells forming this cross section are in an eastwest direction. As is illustrated in this figure, both the top and bottom of the salt are horizontal in parallel planes. The underlying Vernon shale has a slight regional dip to the south. All wells in the cross section were cored and logged with gamma neutron tools.

When the original wells were drilled in this area, the number of major salt sequences were unknown. Thus as the first wells were drilled, six salts were delineated. The contact between the bottom salt and the underlying Vernon shale is sharp and smooth, forming a plane along which the entire salt series was thrust toward the north-northwest.

Because of the differential pressures exerted against the front of the evaporite mass and the variations in frictional resistance, movement was not uniform. Tear faults developed in the salt layers and the intervening strata of rock. Isopach maps of area show that major movement has occurred adjacent to Lake Senaca with a noticeable reduction in the amount of thrusting action in a westerly direction.

Gamma neutron logs show repeated rock sections in Wells 27, 28, 30 and 31. In Wells 27 and 28 the B2 salt, in keeping with Landes's nomenclature, has been thrust over itself and a horizontal fragment of the B2 rock, on two separate tectogenetic occurrences. The D1 salt has, in Well 27, almost doubled its normal thickness. This was due to either an overthrust of the D1 salt within itself or concurrent sedimentation during the downdropping of the C2 rock. The F unit of salt has

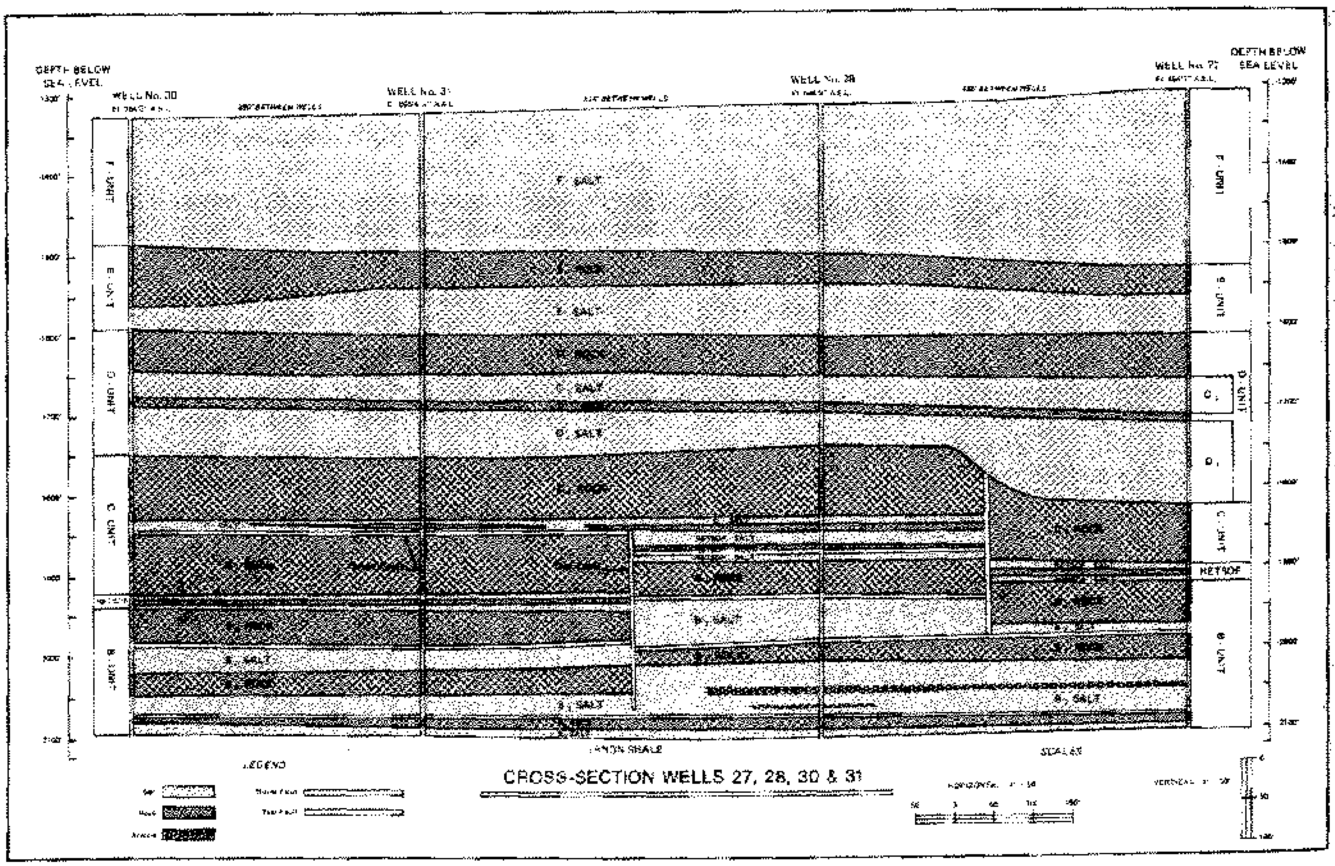


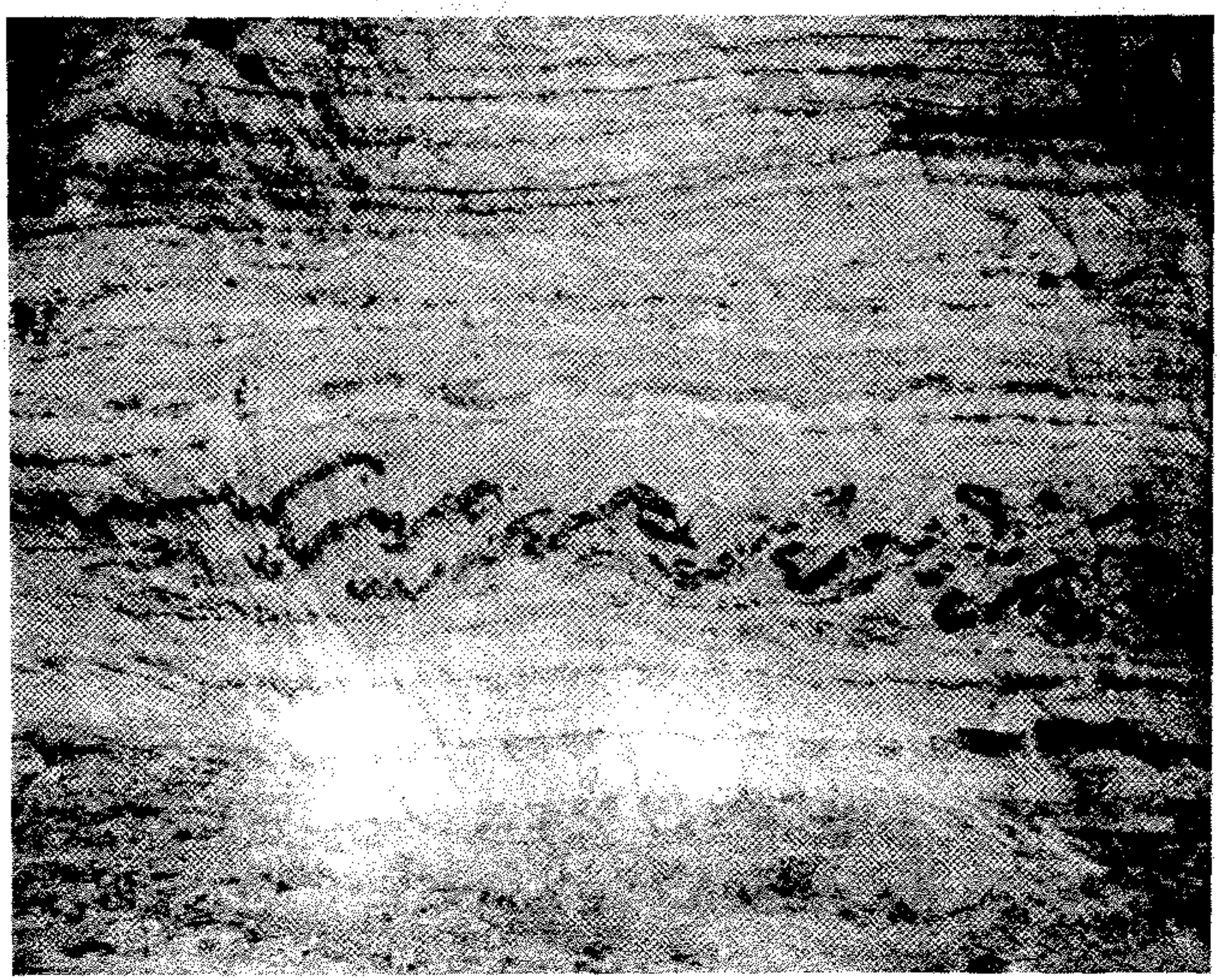
Figure 1.

xperienced a considerable increase in thickness in /ell 27 over the other three wells involved in the ross section. The points of faulting as originally bserved in the gamma neutron logs were conrmed by re-examination of the detail lithological ›gs and cores. At the points on the cross section 'here faulting has been confirmed, fault zones sev:al feet in thickness are present. This generalized ross section does not attempt to take into conderation all the evidences of faulting but only 1ose of primary concern.

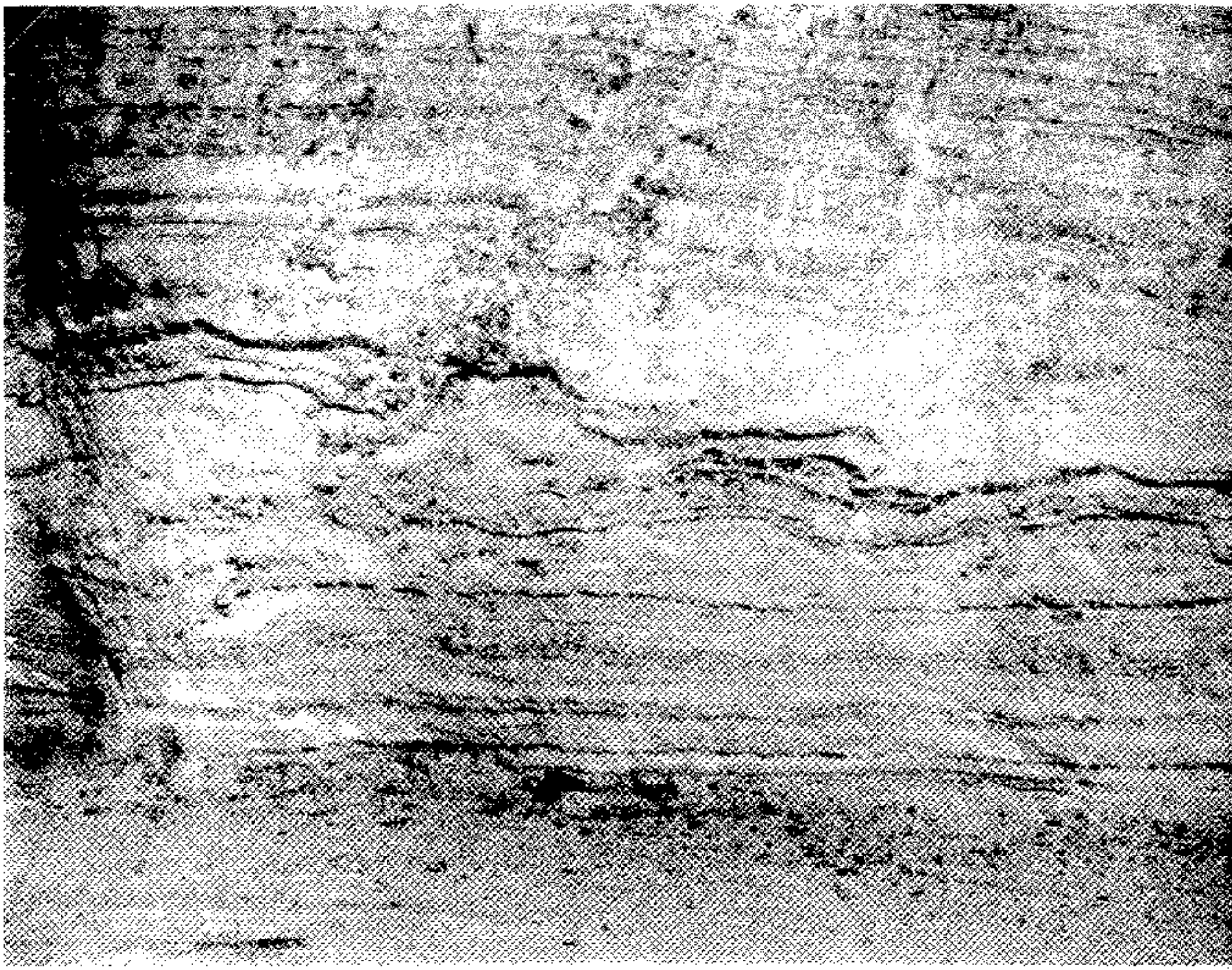
An example of this low angle thrusting section is lustrated by photograph #1 which shows micro 1rust faulting within the bed of salt being mined y International Salt Company at their Cleveland line. Here both the upper and lower laminae of the salt bed are essentially horizontal and parallel to each other. The mid-section of the bed has experienced a thrust action which has folded and then overthrust the dolomitic anhydritic rock stringer upon itself.

In photograph #2 this same rock stringer at another point in the Cleveland Mine can be seen overthrusting itself. Again it is underlain and overlain by horizontal laminae which are generally flat lying.

Recently, the Morton Salt Company in their drilling at Himrod, New York, found good core hole evidence of a tear fault similar to those in the Watkins Glen area. After nearing completion of a core hole which depicted what was considered to be a normal sequence of salt-rock strata, a zone of



Photograph 1. Cleveland Mine. Micro-thrust faulting shown in a mine face.



Photograph 2. Cleveland Mine. Micro-thrust faulting shown in a mine face.

lost circulation was encountered in a salt bed. Plugging the hole back up to a point above the top salt, a whipstock was set and the strata recored. This deflected core hole encountered huge thicknesses of salt which in no way correlated with the original hole but were representative of a tear fault.

L.P.G. and hydrocarbon storage.

In the hydraulic fracturing of salt beds to coalesce two wells, either for the solution mining of salt or the creation of hydrocarbon storage facilities, it has been learned that once fluid circulation has been established between the injection well and the target well, a pressure "prop" of the fracture between the two wells must be maintained until a self-supporting opening has been created. Failure to maintain sufficient pressure to prevent convergence of the overlying and underlying portions of the strata, will result in the "healing" of the fracture. Once this "healing" has occurred, we have never been able to re-establish the fluid connection. It is our opinion that this "healing" is brought about by the same phenomenon observed in salt mine excavations. That is, dilation of the salt in the walls or pillars of the cavity; heaving of the floor, particularly where shale underlies the salt bed and sagging of the roof rock.

As the salt and rock close in on the opening, a crystalline halite begins to grow in the crevice until the void is completely filled. This crystal halite is substantially stronger in tension than the original primary salt, thus resisting refracturing. Thus in refracturing a well at the same point as that at which it was initially fractured, after the collapse of the beds has occurred, the fracturing fluid will take a direction of secondary preference avoiding the target well. Advantage can be taken of this healing effect in refracturing at the point of the original fracture where the fluid in the original fracture has taken an undesired direction. It is this healing effect that allows fractured cavities in faulted salt beds such as those of New York, Ohio and Pennsylvania to be used for the storage of hydrocarbons.

The structural features found in the Salina Group underlying Watkins Glen, New York, are believed to be characteristic of the entire New York portion of the Appalachian Basin.

As related to the creation of cavities and the operation of these cavities for hydrocarbon storage, the significance of this type of structure is:

1. In the coalescence of wells by hydraulic fracturing, fractures which normally have a tendency of developing in an eastwest direction, can progress in these directions only until the fluid intersects one of the northsouth trending tear faults. Establishment of a second fracture from the original target well, designed to intersect the fracturing fluid previously trapped in the tear fault, has only a very modest chance for success.
2. Fracturing new pairs of wells in such an area, where L.P.G. is already being stored, entails the risk of encountering these storage cavities.
3. As illustrated in Gallery No. 2 of Figure 2 of June 1964, the fracture patterns are not predictable unless the detailed geology of the area is available and understood. Here fractures were produced in the lower portion of the B2 salt in both Wells 30 and 31. The connection between the two wells was finally completed in the fault zone in the overthrust block of the B2 salt.
4. Unless saturated brine is used continually in recycling the product, there is distinct possibility of undermining fault blocks. Illustrated

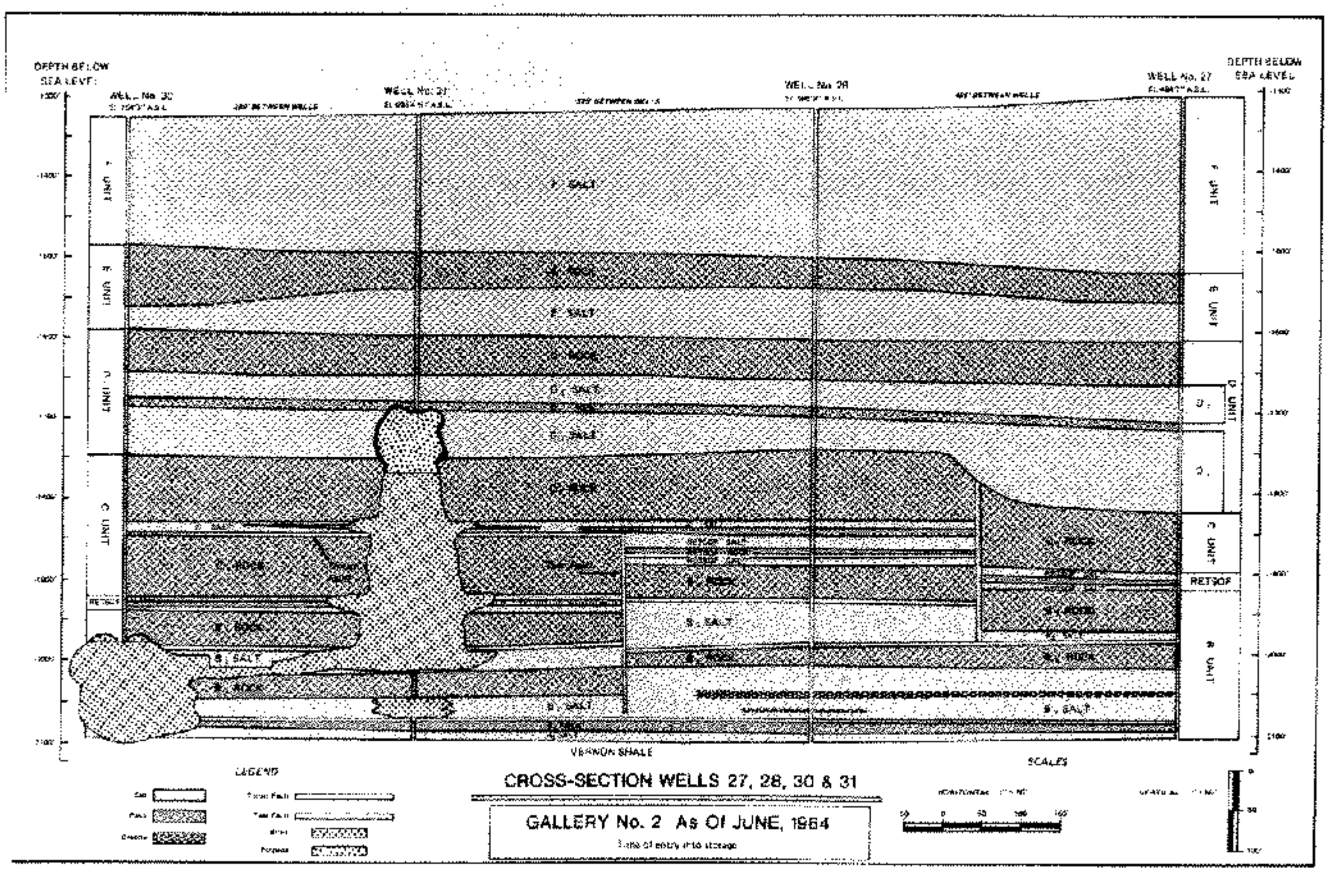


Figure 2.

in Figure 3 is a large block of rock calculated to weigh over 400,000 tons which fell from the roof even with the use of saturated brine. This portion of the cavity was outlined by using sonar surveying equipment. Although saturated brine is used for a recycling fluid, some minor quantities of salt will be dissolved so that the effluent from the brine well will be supersaturated. Steps must be taken to prevent the salting up of the brine well.

5. Where the brine recycled from the cavity is to be used in a salt refining or chlorine-caustic plant, considerable additional dissolved impurities in excess of those normally found, will be encountered. This condition results from the hydrocarbon flooding of the pile of detrital material associated with the injection well. As the residual brine in this pile of rock is flushed out of the pile, it severely contaminates the mass of brine in the open portion of the cavity.

6. Rock falls of small to medium volume (50 tons) may be unnoticed. Larger falls will form a cloudy brine or hydrocarbon if they occur during the storage or recycling operations. Normally, even the worst of these conditions will clear in 24 to 48 hrs. Wide fluctuations in cavity pressures during storing and recycling operations are one of the main factors in roof or ledge rock falls.

7. Entrapment "losses" are largely related to local dips of the rock beds. In areas such as the Appalachian Basin, rock masses unmined at a point removed from the bore of the well may collapse causing large volumes of product to be entrapped at this remote point.

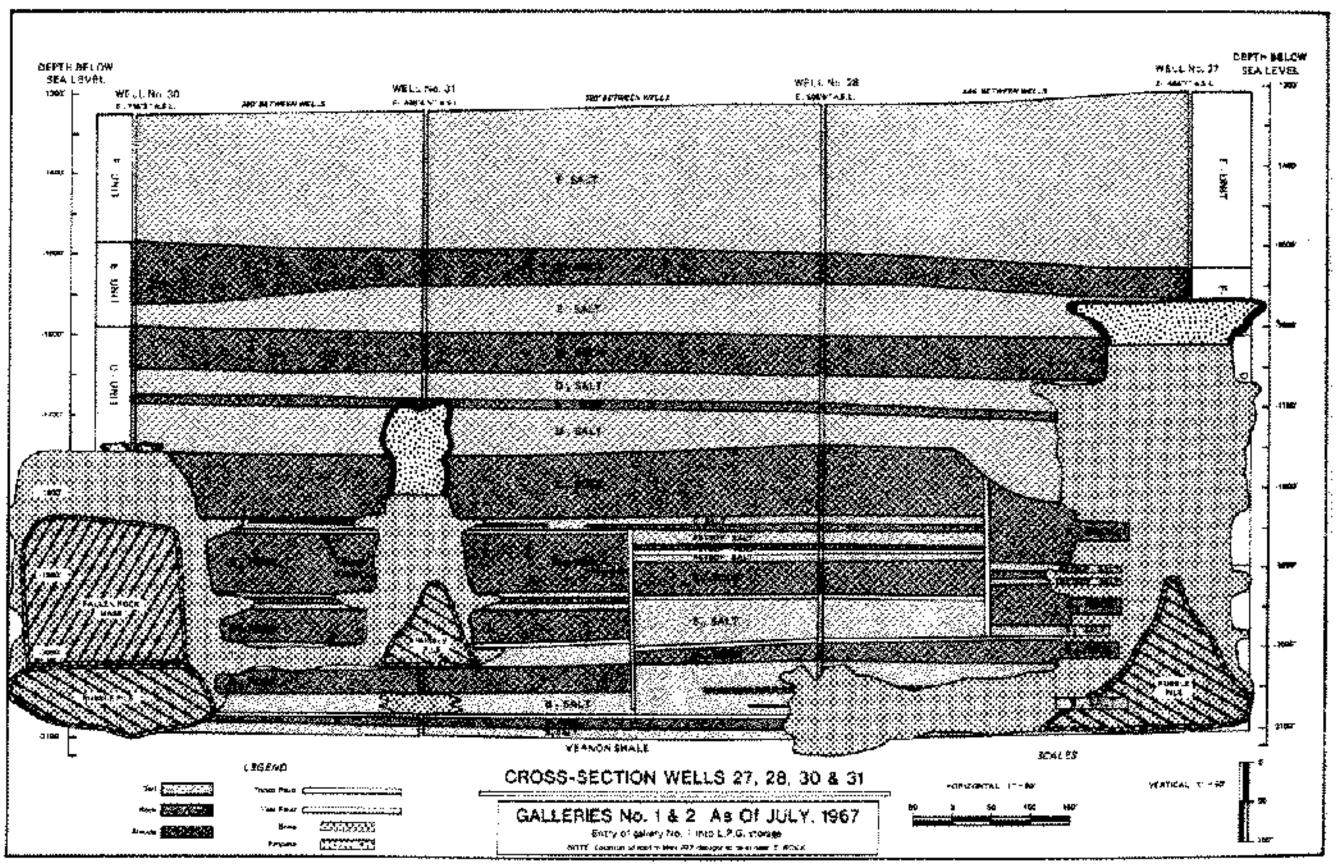


Figure 3.

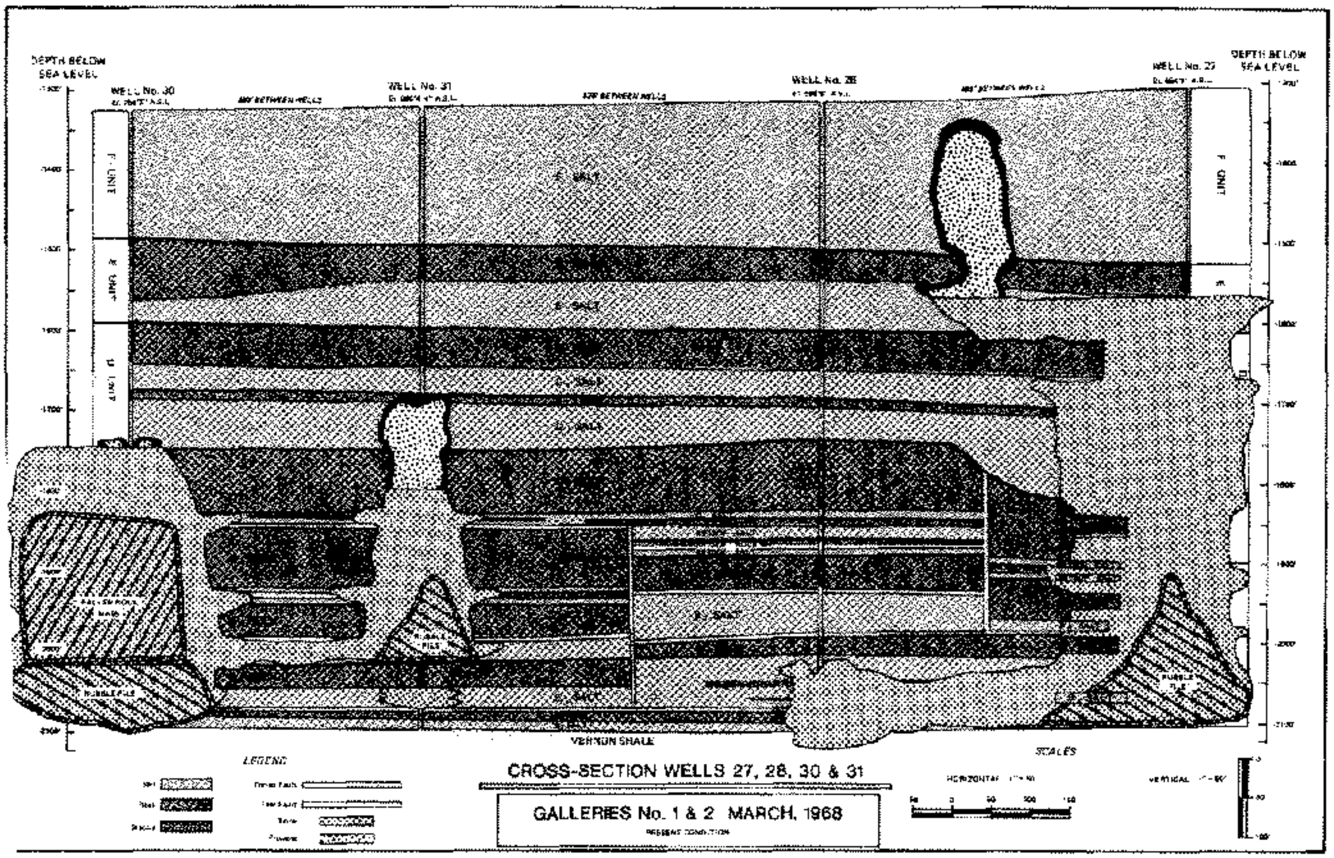

DEPTH BELOW SEA LEVEL
WELL No. 30
WELL No. 31
F UNIT
VERNON SHALE
LEGEND
SCALES
CROSS-SECTION WELLS 27, 28, 30 & 31
GALLERIES No. 1 & 2 MARCH, 1968

Figure 4.