A Case History of Brine Cavity Development with Intermediate Injection

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ABSTRACT

Salt is extracted by solution mining from the Prairie Evaporite Formation for subsequent evaporation and processing by Domtar Chemicals Limited, Sifto Salt Division at Unity, Saskatchewan. The top of the deposit is 3,700 feet below the surface and the thickness at this location is 425 feet with the more soluble impurities predominantly confined to the upper portion of the bed.

Roof control by oil padding has been employed with the two most recent wells to permit selective extraction of the lower high purity salt strata. With a view to influencing the shape of the cavity for maximum yield with minimum roof span, water is injected at or below the midpoint and withdrawal is at the bottom.

The shape is influenced by location of the injection point, a thick dolomite stringer, rubble accumulation and a slight regional dip. A sequence of illustrations indicates the outlines of the cavities as determined by sonar surveys at various stages of development.

Operational data is supplied periodically to the University of Texas for correlation with dissolution studies being conducted for the Solution Mining Research Institute.

INTRODUCTION

Salt is extracted by solution mining from the Prairie Evaporite Formation for subsequent evaporation and processing by Domtar Chemicals Limited, Sifto Salt Division at Unity, Saskatchewan. The plant has been in operation since 1949.

The original two brine wells were operated with top injection and bottom withdrawal until the cavities coalesced and then by injection in one and withdrawal from the other. The dolomite strata at the top of the deposit provided the roof. Failure ultimately occurred due to roof collapse, rubble accumulation and undersaturated brine.

The more soluble impurities, particularly potassium and magnesium chlorides, are found predominately in the upper portion of the deposit. A brine fairly high in these components was produced and necessitated a substantial bleed from the evaporators. This led to a decision to attempt to selectively extract the higher purity salt and control the development of subsequent cavities.

A simplified geological section throughout the deposit is illustrated (Fig. 1). Top of the salt is 3,700 feet below the surface and total thickness is approximately 425 feet with an average purity of about 93%. The major impurities are sylvinite and carnallite mainly present in thin beds near the top of the deposit, a major dolomite stringer, 3 to 4 feet thick at the 3,925 foot level and minor stringers of anhydrite and shale. The beds are essentially flat with a very slight dip.

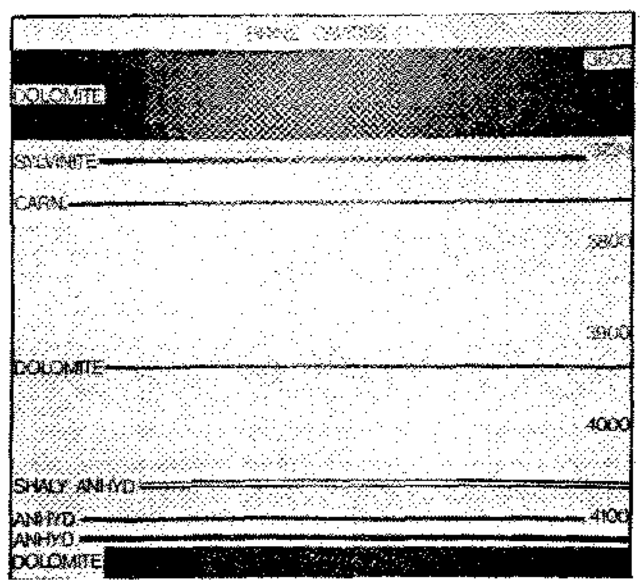

Figure 1. Simplified geological section of the deposit.

CAVITY DEVELOPMENT

Brine well No. 3 was drilled in 1966. The goals established were to confine dissolution to the salt strata below 3,750 feet and obtain maximum extraction. The initial plan was to develop a 4 foot high undercut at the base of the salt to a diameter of about 300 feet using air padding for roof control and then dissolve upwards in 10 to 20 foot lifts.

The piping arrangement used throughout is illustrated in Figure 2. An 8-5/8 inch O.D. casing is cemented into the salt and below the impure upper beds. Two moveable strings are provided. A 6-5/8 inch O.D. liner or tailpipe is hung in the outer casing with a Type D Boll Weevil liner-hanger at a depth of about 3,700 feet and 4-1/2 inch tubing is run from the surface.

For undercutting, the bottom of the liner was set at 4,095 feet and the tubing landed at 4,098 feet. Development began in March 1966, and by mid-September it was estimated that sufficient salt had been extracted to provide the desired undercut and a sonar survey was made (Fig. 3). An undercut was not achieved although large quantities of air were released on removal of the 6-5/8 inch liner. However, dissolution had been restricted to the 3,933 foot level. It was decided to abandon the use of air and replace with oil for roof control.

The injection string was set at 4,030 feet and the tubing at 4,081 feet (Fig. 4). The roof was to be established at approximately 3,900 feet. Initially, no control fluid was added, to allow the roof to migrate upwards to the desired level. Circulation was carried out from September, 1966 to July, 1967, at which time a neutron log indicated the roof to be at 3,886 feet. An oil pad was then introduced.

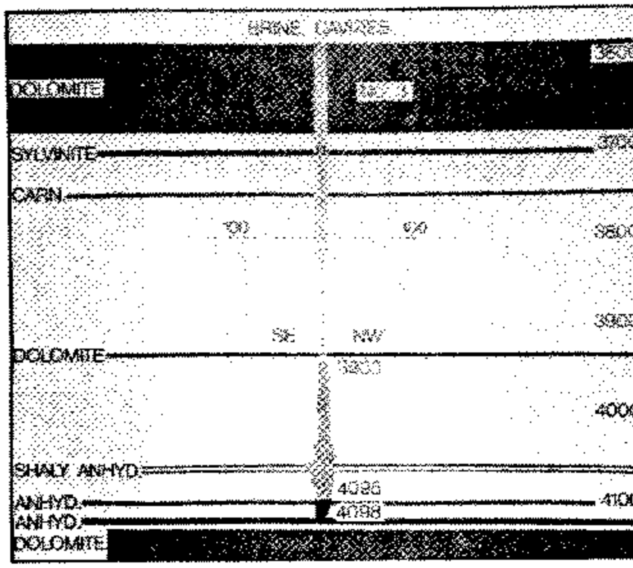

Figure 3. Sonar survey made March 1966, southeast-northwest view.

No significant changes were made in equipment or operation of the well between July 1967 and June 1970. Throughout this period injection through the annulus and withdrawal through the tubing was employed, the roof location was checked by periodic logging and oil was added at regular intervals. Brine saturation remained at 96% and although tubing damage was suspected, circumstances prevented remedial action.

In June 1970, the tubing was pulled for a sonar survey. The tubing had to be cut for withdrawal. A Dowell swing-arm tool was used, with roof surveys made from a point

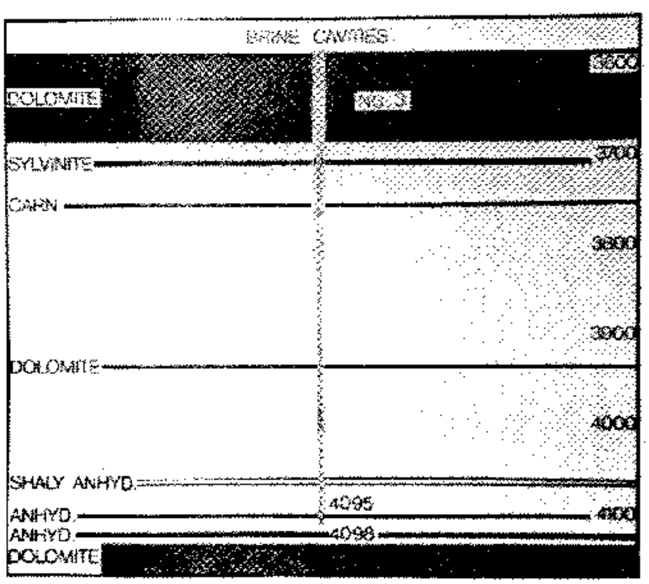

Figure 2. Tubing and tailpipe settings to develop an undercut.

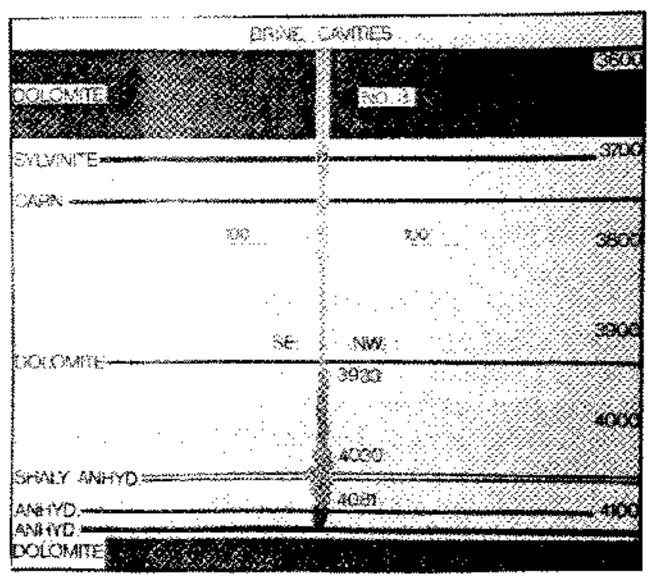

Figure 4. Pipe settings for development of No. 3 well during the period March 1966 to June 1970.

below the bottom of the 6-5/8 inch injection string. The findings were as follows. (Fig. 5.)

The roof was flat at 3,886 feet, the maximum diameter was 235 feet and the total salt extracted from the cavity was estimated at 216,000 tons. The bottom of the cavity had been filled with insoluble material and rubble to 4,040 feet. Dissolving had been retarded above the dolomite stringer at 3,925 feet. However results of the survey showed that dissolution was active over the entire wall area between the roof and the injection point. Dissolution was essentially concentric about the injection string.

Based upon the results of the sonar survey it was decided to cut the injection string at 3,940 feet and terminate the tubing at 3,998 feet, thereby providing essentially mid-point injection with respect to the roof and withdrawal point (Fig. 6). Factors contributing to the decision were:

(a) a greater volume below the tubing was required for accumulation of insolubles and rubble than previously considered, and

(b) it appeared desirable to elevate the injection point to promote dissolution above the dolomite stringer, increase the upper wall area and be assured of saturated brine upon resumption of operation.

Saturated brine was produced on a continuous basis when operation was resumed at a maximum flow rate of 310 U.S. gpm.

In October 1971, a third sonar survey was made of No. 3 well (Fig. 7). The cavity statistics are now as follows:

The roof has moved up slightly to 3,880 feet. The maximum diameter is 290 feet, and the total salt extracted from the well was estimated to be 349,000 tons. The bottom of

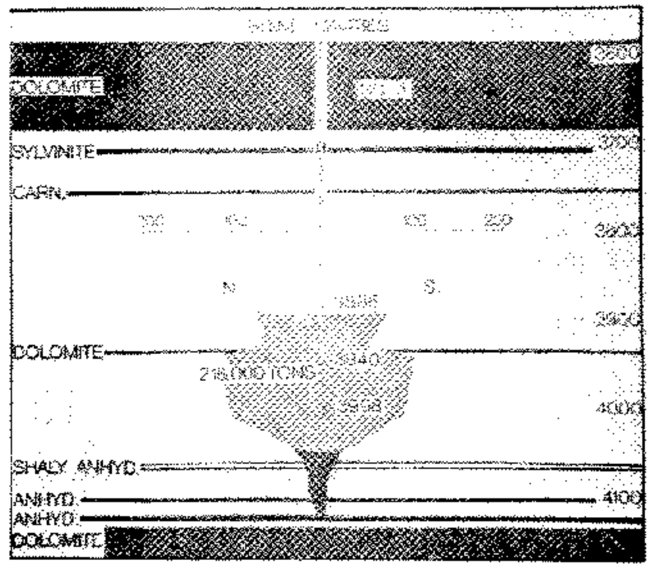

Figure 6. Pipe settings for development of well during the period of June 1970 to October 1971.

the cavity has been filled to 4,020 feet, some 20 feet higher than 18 months earlier.

Distinct irregularities on the bottom of the cavity indicate the presence of rubble, and the dolomite stringer has collapsed to a great extent. Wall dissolution is essentially uniform between the roof and the injection point.

When flow through No. 3 well was stopped for the sonar survey, the saturation of brine at the injection point was found to be 87%; this was accomplished by backflowing up the annulus.

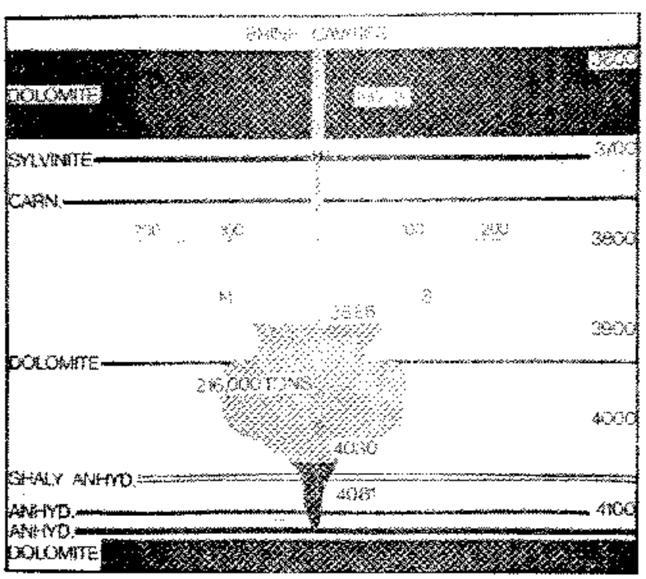

Figure 5. Sonar survey, June 1970; north-south view.

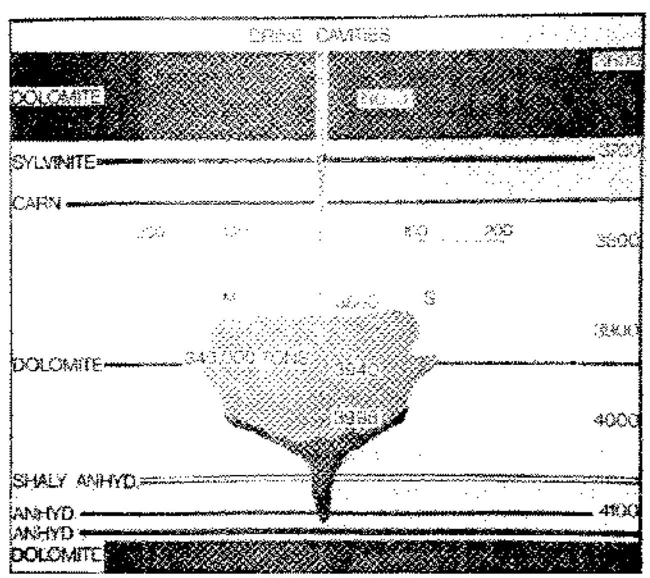

Figure 7. Sonar survey, October 1971, north-south view.

Cavity sizes and shapes from the 1970 and 1971 sonar surveys were compared (Fig. 8). To illustrate changes in volume, the elevation of the injection point was arbitrarily chosen as a basis for calculations. It is, however, recognized that a sharp transition in dissolution rate does not exist at this elevation. During the period between the two surveys, the increase in volume above the injection elevation was calculated to be approximately 2,433,000 cu. ft. whereas the increase in volume below the injection elevation was only 327,000 cu. ft. The increase in volume of insolubles and debris was 431,000 cu. ft.

The calculated wall area above the elevation of the injection point was approximately 55,000 sq. ft. while the active wall area below the injection elevation was 30,000 sq. ft. (Fig. 9). Based upon these areas and the production rate prior to the sonar survey, the average dissolution rate was 0.10 cu. ft. per square foot per day.

Following the survey, it was decided to land the tubing at 4,006 feet, and operation was resumed until March 6th 1973, at which time a fourth survey was made using a Dowell universal swing-arm tool. The survey provided the following statistics (Fig. 10).

The roof has moved up slightly from 3,880 to 3,873 feet, the maximum diameter was now 370 feet, and the bottom of the cavity has been filled to 4,016 feet, up about 4 feet from 18 months earlier. The dolomite stringer at 3,925 feet has collapsed, and distinct irregularities indicate further rubble accumulation. Saturation at the injection point was found to be 90%. The walls have deviated slightly from the vertical sides in 1971.

The cavity shapes determined by the last two sonar surveys were superimposed and compared (Fig. 11). The volume increase during the interval between the surveys was calculated to be 2,230,000 cu. ft. above the injection elevation and 368,000 cu. ft. below this elevation. In addition, the volume of insolubles and debris had increased by 239,000 cu. ft.

The calculated wall area above the elevation of the injection point was approximately 68,000 sq. ft. while the active wall area below this elevation was 37,000 sq. ft. (Fig. 12). Based upon these areas and the production rate prior to the sonar survey, the average dissolution rate was 0.08 cu. ft. per sq. ft. per day. Using the more usually accepted rate of 0.2 cu. ft. per sq. ft. per day, the well

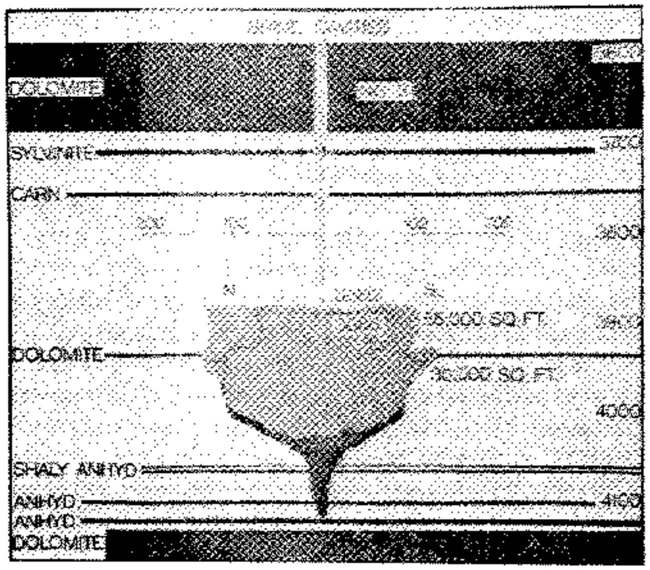

Figure 9. Sonar surveys of June 1970 and October 1971 shown superimposed, surface available for dissolution indicated.

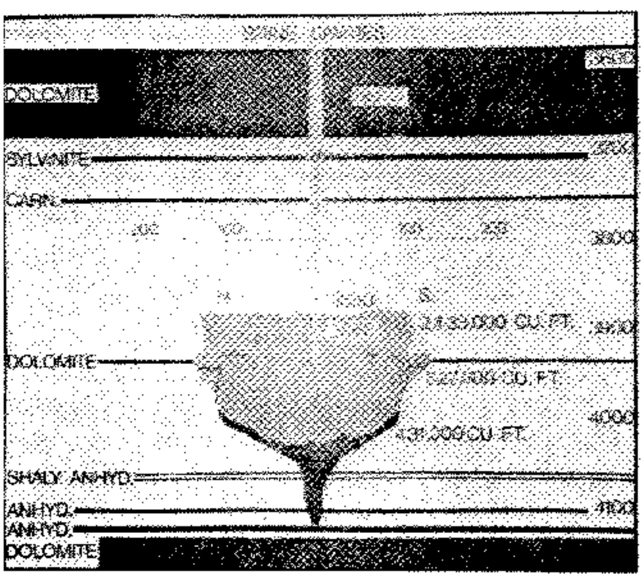

Figure 8. Sonar surveys of June 1970 and October 1971 shown superimposed, north-south view. Volume increases indicated.

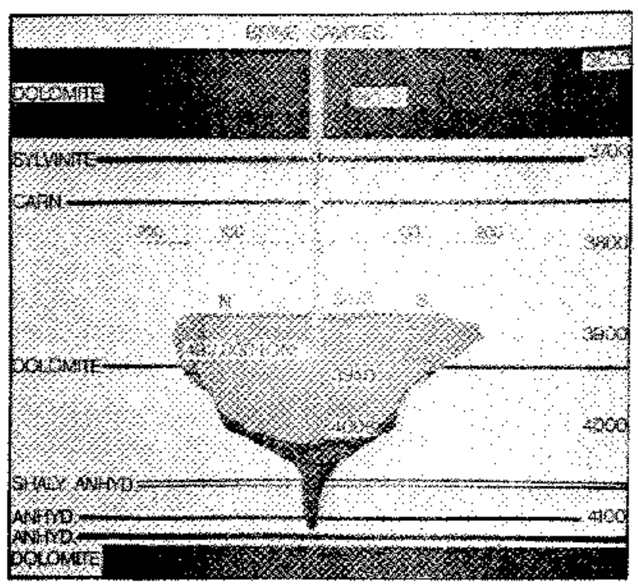

Figure 10. Sonar survey of March 1973, north-south view.

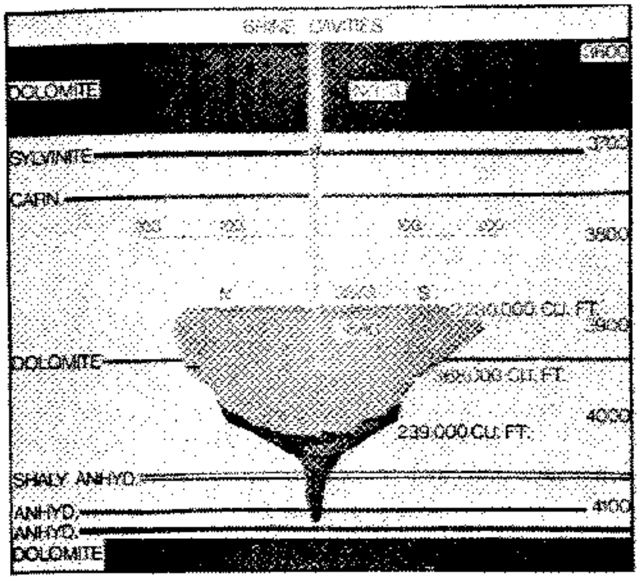

Figure 11. Sonar surveys of October 1971 and March 1973 shown superimposed, north-south view. Increases in volume between the two indicated.

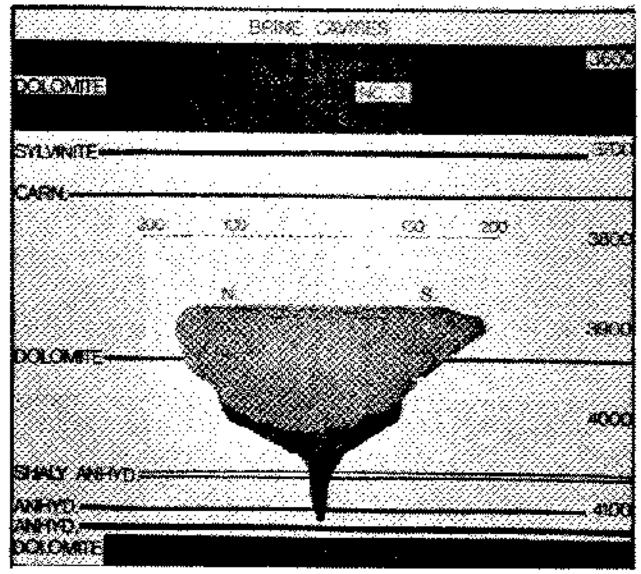

Figure 13. All four sonars of No. 3 well shown superimposed, north-south view note the deviation from vertical walls.

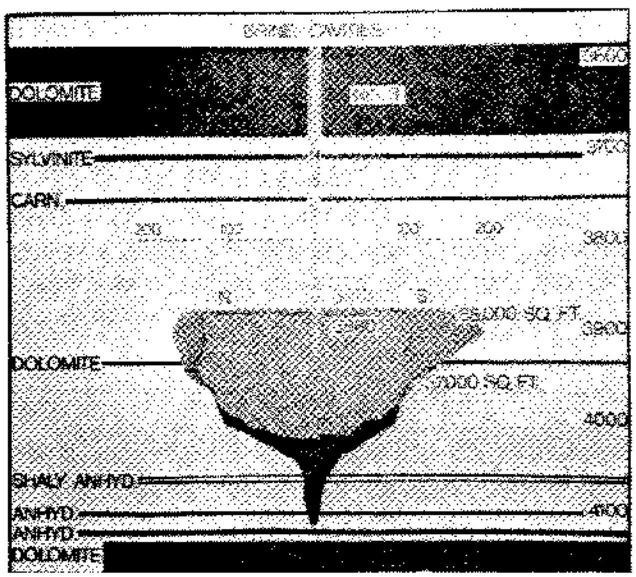

Figure 12. Sonar surveys of October 1971 and March 1973, north-south view surface area available for dissolution shown.

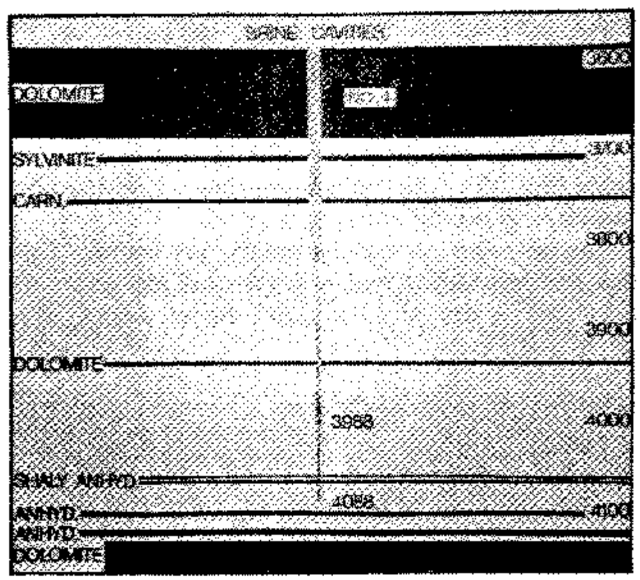

Figure 14. Pipe settings for initial development of No. 4 well.

would have supported a production rate of approximately 1,400 tons per day.

The growth of No. 3 well cavity since 1966 is illustrated in Figure 13. The four sonar logs are shown superimposed.

During 1969 a companion well, No. 4, was drilled 500 feet distant from No. 3. A similar method of control was used for cavity development. Initially the injection point was set at 3,988 feet and the withdrawal point at 4,088 feet (Fig. 14), followed by circulation without a control pad until 88,000 tons had been dissolved. The intention was to establish the roof at approximately 3,825 feet but upward progression was faster than anticipated, reaching 3,797 feet before the location was checked. Oil was added and this became the control elevation.

Sonar surveys were made in October 1970 and May 1972, and are shown superimposed (Fig. 15). Salt removed up to the time of each sonar is also illustrated. Following the first sonar, the injection point was set at 3,960 feet, and the withdrawal point at 3,996 feet. The relatively small separation of 36 feet was with a view to enlarging the base

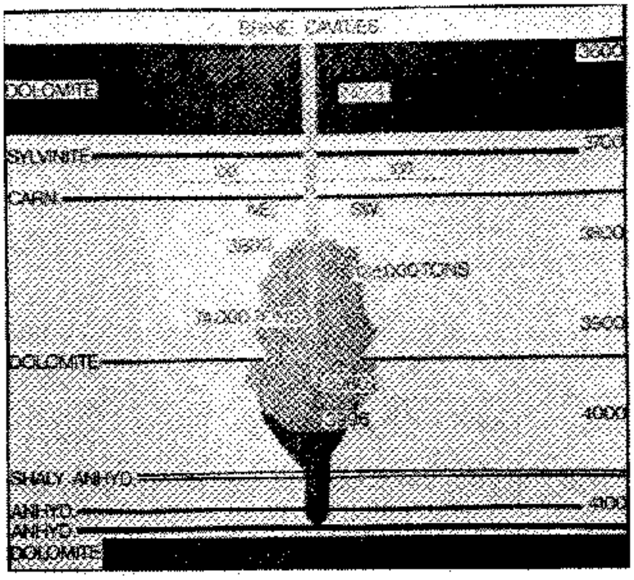

Figure 15. Results of October 1970 and May 1972 sonars shown superimposed, northeast-southwest view. Salt removed up to the time of the surveys shown.

of the cavity and increasing the available extraction.

After the May, 1972 sonar survey, the injection point was set at 3,939 feet and the withdrawal point at 3,995 feet (Fig. 16).

The horizontal relationship of the two cavities is illustrated (Fig. 17), with roof and maximum diameter contour lines shown for each cavity.

Superimposed on this illustration are contour lines from a seismic survey, from which the staff geologists have calculated a very slight regional dip of zero degrees

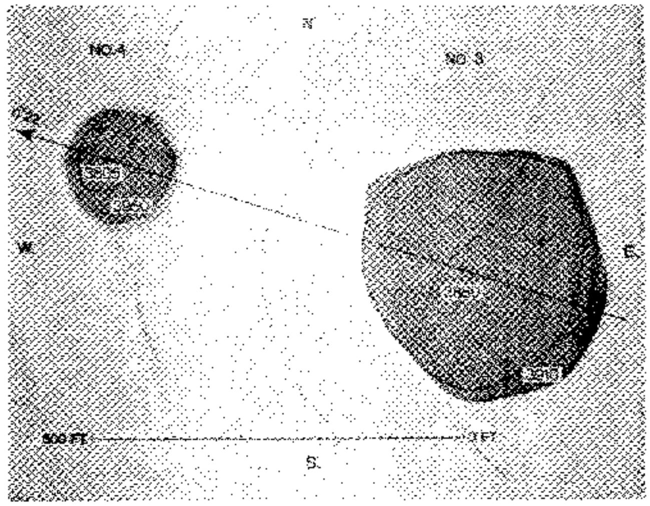

Figure 17. Horizontal relationship of Nos. 3 and 4 cavities. Seismic contour lines and direction of dip shown.

twenty-two minutes to the west-north-west, thereby accounting for the eccentricity of the two cavities.

The vertical relationship of the two cavities is illustrated, (Fig. 18), in the direction east to west. The lighter shade around No. 4 cavity indicates the anticipated boundary based upon the salt extracted since the last sonar survey of May 1972.

FUTURE DEVELOPMENT

Operating procedure will be to develop No. 4 cavity and delay further development of No. 3 with a view to achieving approximate symmetry prior to coalescence.

After the wells have coalesced, injection would then be

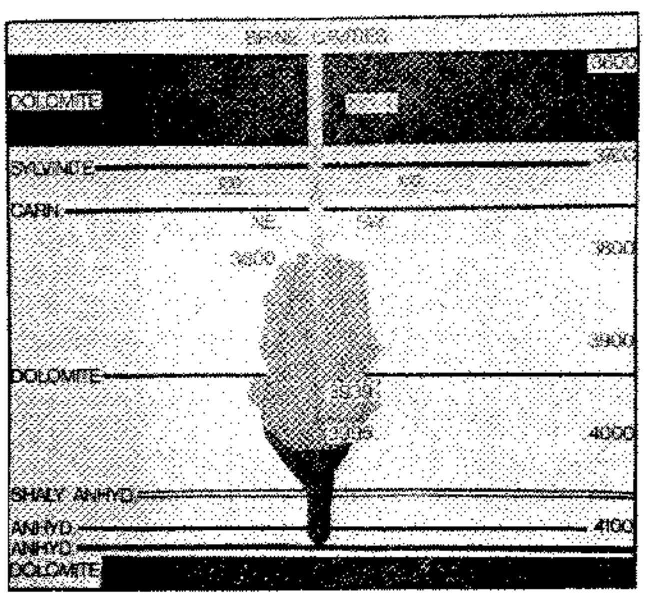

Figure 16. Pipe settings after the May 1972 sonar.

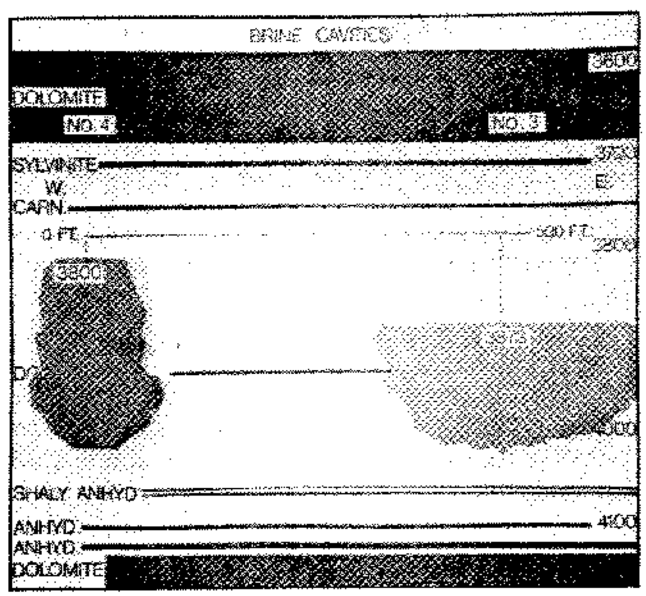

Figure 18. Vertical relationship of the two cavities, east-west view.

from about the midpoint of one cavity and withdrawal near the base of the other. It is felt that regardless of the elevation of intersection, ultimately the oil pad from the roof of lowest elevation will migrate to that of highest elevation, and that finally a common roof will be established somewhere around 3,780 feet, permitting additional extraction from the roof of No. 3 cavity.

Additional extraction will become available from between the boundaries of the individual nearly circular cavities. Although roof failure may prevent the final goal from being reached, it is planned to terminate production from the pair when the roof span reaches 500 feet in one direction and 1,000 feet in the other. Estimated extraction until coalescence is 1.5 million tons and final estimated extraction is 2.5 million tons.

SUMMARY

The influence of intermediate injection with roof control upon the shape of two brine cavities under the prevailing geological conditions has been illustrated.

A substantial loss of available salt at the base of the deposit was experienced due to the accumulation of insolubles in the relatively small diameter initial cavity or washout. On future wells it would appear desirable to create, at the base, a washout or sump of larger diameter. This could be accomplished by introducing an oil pad, say 25 to 50 feet, above the base followed by circulation. After the desired extraction, the oil would be removed and circulation resumed until the roof had reached the final location. Oil would then be re-introduced and operation continued as outlined. The preferred method would be three-quarter point injection, as in No. 4 well, rather than midpoint injection, if short-circuiting were not experienced.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the association with the Solution Mining Research Institute. Field data is supplied for correlation with computer programs of the University of Texas conducted for the S.M.R.I. Predictions on cavity growth are developed and checked against sonar surveys.

The late Dr. Frank Jessen was consulted in the early stages of these brine well experiments.

The original slides were shown with a talk by Mr. A. P. Sander at the December 1971 meeting of the S.M.R.I.