

Sonar Measurements of Brine Cavity Shapes

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ABSTRACT

The size, shape and orientation of subsurface salt cavities, such as those formed during brining operations or used for underground storage, may be determined by means of the Sonar Caliper technique. A special subsurface surveying tool is lowered into the well bore by means of an electrically conductive wireline. This tool emits periodic sound pulses which are reflected from the cavern walls, and return to the tool. The time interval required to receive the echo indicates the distance to the cavern wall. Recordings are made at the surface, with the tool at various depth intervals; from these data, cavern capacities can be calculated, vertical and horizontal profiles determined, and specific operating difficulties evaluated. Three-dimensional models are prepared which permit accurate visualization of the configuration of the subsurface cavity.

INTRODUCTION

Solution mining techniques have been extensively employed for the recovery of soluble underground mineral deposits. More recently, this process has been adapted for the creation of convenient, economical storage capacity for liquid petroleum products, and natural gas. Such storage facilities have been successfully utilized for temporary off-season storage, providing "peak-shaving" resources during periods of maximum demand.

Essentially, such cavities are formed by drilling a conventional bore hole into the mineral deposit, setting casing and tubing, and then pumping fresh water down the well bore. This water dissolves the soluble mineral, and the saturated solution is returned to the surface. As a result, a cavity is formed, the size and shape of which are dependent upon a number of factors, including: (1) Casing and tubing settings; (2) type of injection (conventional or reverse); (3) volume and rate of injection; and (4) chemical and physical characteristics of the formation itself.

This final factor often proves quite unpredictable from the surface so that, although conventional brining procedures may be employed, the resultant cavity may be unorthodox in configuration. This in turn can result in perplexing operational problems, especially when the cause of the difficulty is unsuspected.

SONAR CALIPER SURVEYS

A subsurface logging technique, known as the "Sonar Caliper," has been successfully used for a number of years to provide an accurate evaluation of the size and shape of such underground cavities. (1), (2) As shown in Figure 1, a special tool is lowered into the cavity through the well bore, where it emits directional sound impulses, and measures the elapsed time until the echo, reflected from the cavern wall, is received and recorded. Determinations are made at successive depth intervals, until a complete profile of the cavity has been obtained.

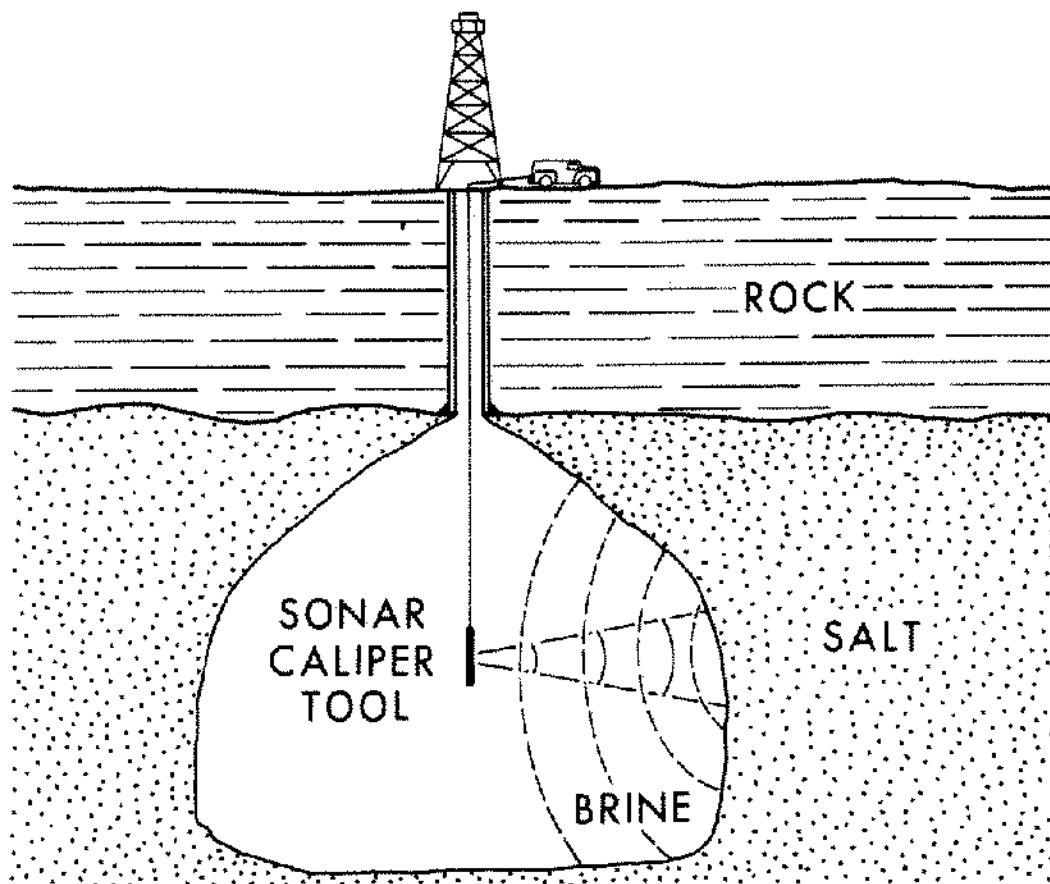


Figure 1. Schematic diagram of Sonar Caliper survey. Intermittent sound pulses are directed toward the cavity wall and the time interval until the reflected echo is received and is recorded at the surface.

An accurate record of the size and shape of an underground cavity, such as that furnished by the Sonar Caliper survey, is of invaluable assistance to the engineer in charge. Some of the ways in which such information may be utilized are as follows:

1. To Determine Roof Structure

The roof of an underground cavity is an important factor in the trouble-free use of the cavity. If it is inadequately supported, the strength of the formation may be exceeded, resulting in caveins, and requiring expensive remedial operations. Such falling rock sometimes produces severe pipe damage, necessitating replacement.

2. To Measure Cavity Size

The capacity of an underground cavity is essential if the cavity is to be used for storage purposes. For solution mining operations, determination of the cavity volume provides a check on the amount of minerals that have been removed.

3. To Determine Cavity Shape

Surveying the vertical profile of the cavity not only provides valuable data on "volume versus depth" relationships, essential in estimating the relative volumes of brine and petroleum product in the storage cavity at various interface depths, but may also reveal unconventional cavity shapes (such as those resulting from insoluble stringers) which might later result in caving or other operational difficulties.

4. To Check Brining Schedules

Knowledge of the size and shape of the underground cavern permits the engineer to evaluate his brining schedules, regulating them so as to obtain maximum salt recovery from the well. If abnormalities in cavity shape are revealed, the cause of the deviation can often be deduced from the profile, enabling the engineer to take appropriate corrective measures.

5. For Exploratory Purposes

In addition to revealing the size and shape of the cavity, its orientation is also indicated. Thus, if the survey shows that the cavity is being hollowed out preferentially in one direction from the original well bore, and that there is danger of communication with a nearby storage cavity, modification of brining techniques may be required to avoid interconnection, and later contamination between adjacent storage cavities. In the case of solution mining, it may be desirable to obtain communication between offset wells, so as to inject fresh water into one well and produce saturated brine from the other.

6. Prior to Remedial Operations

Many times, difficulties are experienced in storing and recovering petroleum products from underground cavities. This may be due to abnormalities in cavity shape, cavings from wall and roof, or damage to casing and tubing. In such a case, remedial operations are greatly facilitated by "pinpointing" the cause of the difficulty, as revealed by a Sonar Caliper survey.

7. As a Guide During Completion

When an underground cavity is being prepared for storage purposes, a vertical profile of the cavity serves as a valuable guide in positioning casing and tubing, so as to provide maximum storage volume without having the end of the operating string too close to insoluble debris at the bottom of the cavity.

8. As Evidence in Lawsuits

Sonar Caliper surveys provide a positive, detailed record of the areal extent of underground cavities, clearly indicating any encroachment on offset properties, or absence thereof.

EQUIPMENT AND TECHNIQUES

The equipment used in conducting a Sonar Caliper survey consists essentially of three assemblies: (1) the subsurface sonar tool; (2) the surface power supply; and (3) the surface recorder. The downhole tool is 50 inches long and 3 5/8 inches in diameter, permitting it to pass through clean 4 inch I. D. pipe. It operates on 115 volts AC, 60 cycles, and is run into the well on a single conductor wire line. When suspended in the well, a transducer in this tool produces an intermittent sound pulse, which is directionally focused in a narrow beam. The sound wave so produced, travels through the fluid in the cavity until it strikes the wall and is reflected back to the surveying tool where it is detected by the receiving transducer. The tool rotates continuously so that the individual sound pulses cover a 360° arc about the tool. Thus, the distance between the tool and the wall of the cavity is measured in all directions.

Figure 2 shows a block diagram of the electrical circuitry of the Sonar Caliper. It may be seen that the reflected sound pulses, as detected by the receiving transducer in the tool are amplified and transmitted to the surface through the electrically conducting wireline. There the signals are displayed on the face of an oscillograph tube which has been previously calibrated so that the observed distances to the cavity walls may be measured upon it. Surface controls can be regulated to provide five different range scales, enabling the instrument to measure a maximum radius of 25, 50, 100, 250, or 500 feet, depending upon the setting. Provisions are also made for transmitting a special "marker" pulse each time the directional sound beam passes magnetic north. This also is displayed upon the oscillograph screen, permitting directional orientation of the recorded horizontal profile.

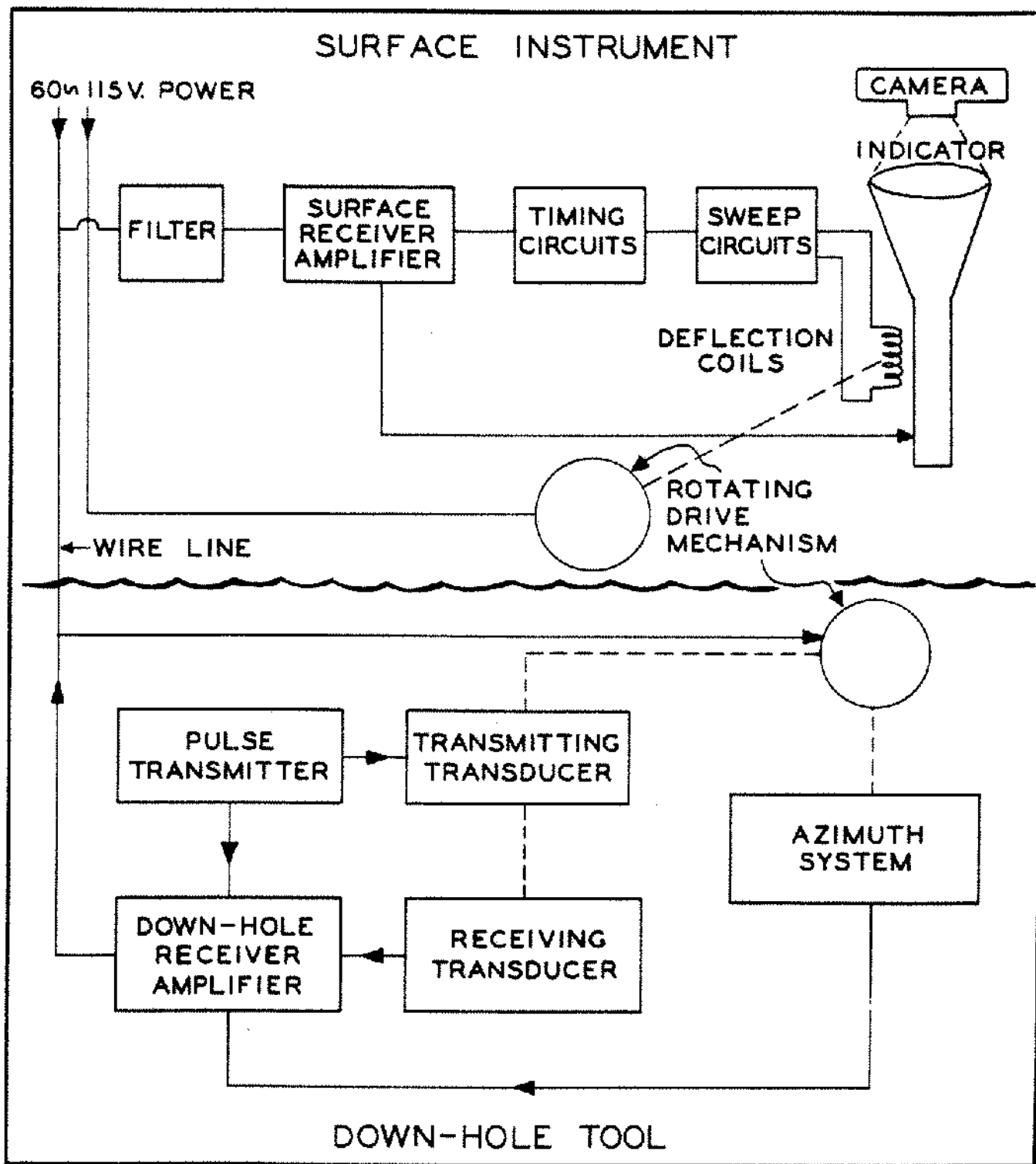


Figure 2. Block diagram showing the electrical circuitry between the down hole caliper tool and the recording instruments at the surface.

The oscillograph, as shown in Figure 3, is fitted with a special Polaroid camera attachment, permitting each trace to be recorded for a later exact measurement. A typical cross section photograph is shown in Figure 4. In this manner, a permanent record of the cavity cross section is obtained, without laborious and time-consuming hand-plotting of observed data. These photographic records also reduce to a minimum the time required to calculate the cross sectional area of the cavity.

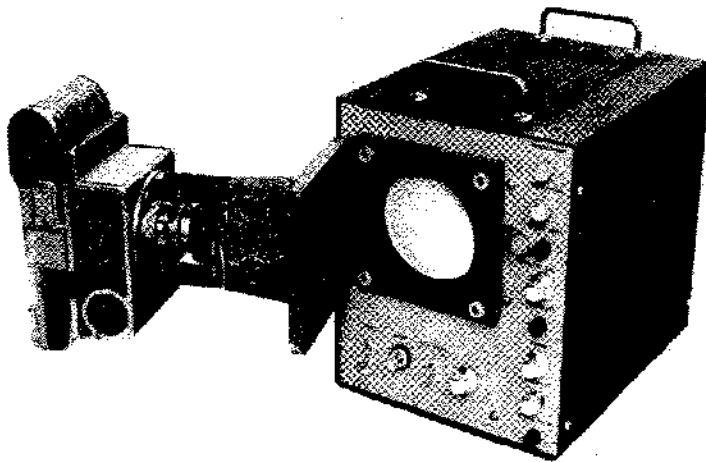


Figure 3. Oscillograph records the distance from the tool to the cavity walls in a 360° sweep, by means of the attached camera.

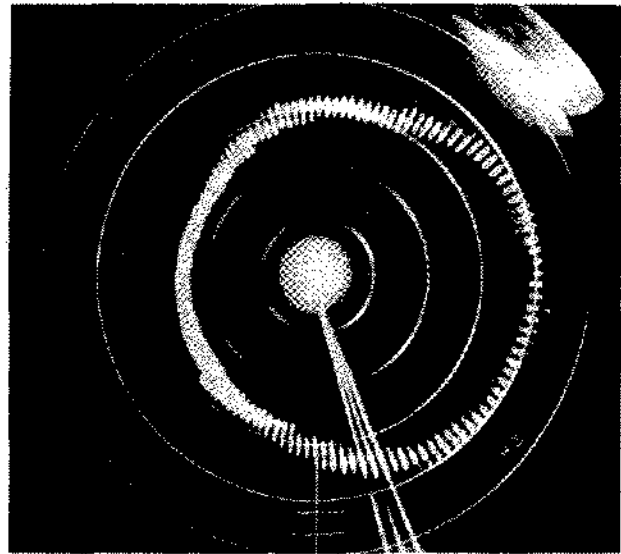


Figure 4. The recorded signals, as shown in this typical photograph, delineate the horizontal cross section of the cavity at a particular depth. Reference rings permit measurement of cavity diameter and the long white lines extending from center indicate magnetic North.

During a survey, consecutive cross sections are recorded, at regular depth intervals varying from five to 20 feet, depending upon the rate of change of the cavity configuration. In this manner, a series of individual horizontal cross sections provides an accurate, three-dimensional image of the subsurface cavity.

Data from these Sonar Caliper surveys are reported in a number of ways. Cross sectional data sheets give the radial distance from the center of the well bore to the cavity wall, in the eight major directions from the center point, for each depth surveyed. Another form of reporting is by means of area and volume calculations, based on the individual depth profiles. Such tables show the cavity's cumulative volume, from the top of the surveyed area to the total depth, in incremental depth units. The third type of data presentation consists of cross sectional profiles, drawn to scale on graph paper and revealing the horizontal profile of the well, oriented with respect to compass directions, at any desired survey depth. The fourth method of presentation, and probably the most informative, is a three-dimensional plastic model, carefully constructed to scale from the cross sectional data obtained during the survey. Such models clearly indicate the size and shape of the underground cavity, and clearly reveal any abnormalities in configuration.

A typical model is shown in Figure 5. The purpose of this particular survey was to observe what effect operating a storage cavity with fresh water, by tubular injection, would have upon the

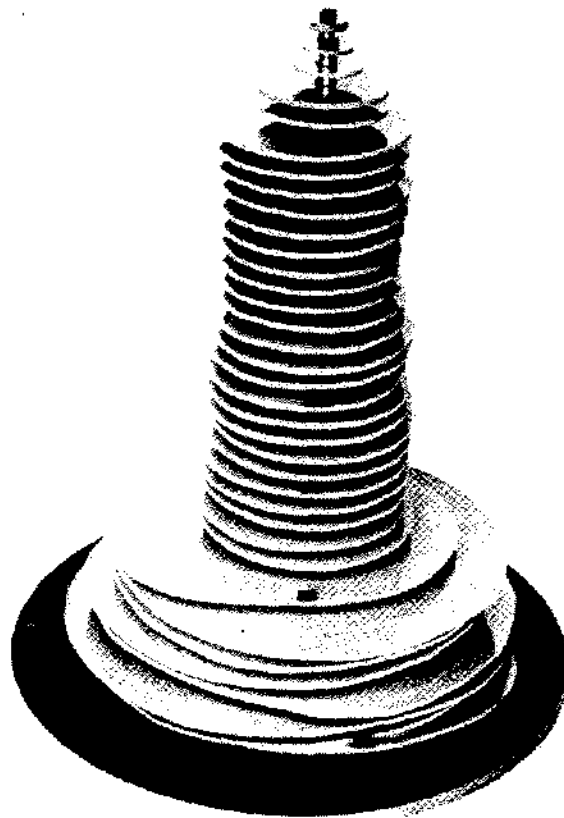


Figure 5. Three-dimensional plastic model of a storage well, the bottom of which was leached out by the injection of fresh water during operation.

shape of the cavity. As was clearly shown by the resultant three-dimensional model, considerable enlargement of the lower portion of the cavity occurred.

CASE HISTORIES

The Sonar Caliper is perhaps most useful in determining the cause of otherwise inexplicable operating difficulties. For example, in one particular well, total depth measurements with a wireline and sinker bar showed no apparent obstruction. Yet, when the operating string was set, it would become plugged after only a short time. A Sonar Caliper survey showed that a considerable pile of soft, insoluble material had built up in the center of the cavity, as shown in Figure 6. The sinker bar penetrated this material easily and, as a result, wireline readings gave a false total depth picture to the operator, who placed his operating string too near the build-up of sand in the bottom of the well. Based on the bottom contour of the cavity as indicated by the Sonar Caliper, the operator was able to place the operating string at the proper height in the cavity, so as to obtain maximum storage volume, yet avoid plugging difficulties from the insolubles in the bottom of the cavity.

In another case, difficulties were being experienced due to shearing of the operating string by shale ledges embedded in the layered salt, as shown in Figure 7. The Sonar Caliper Log accurately recorded the depth and thickness of the individual shale stringers, and the diameter of the cavity in the zones of relatively clean salt. On the basis of this information, the operator

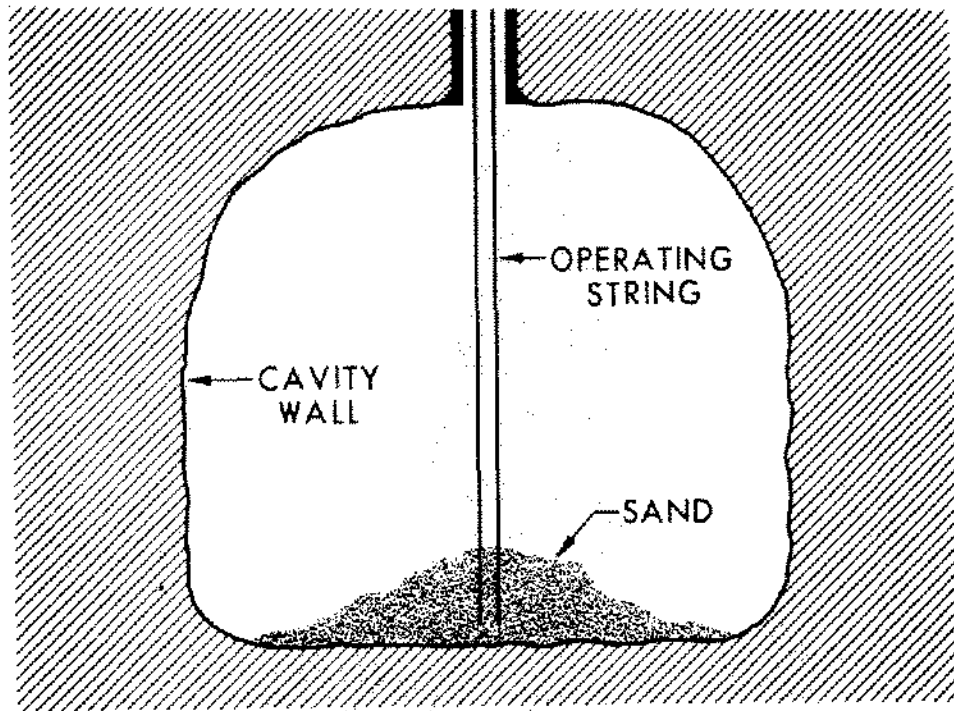


Figure 6. Schematic diagram of storage cavity in which the end of the operating string was blocked by a soft pile of insolubles, as revealed by the Sonar Caliper.

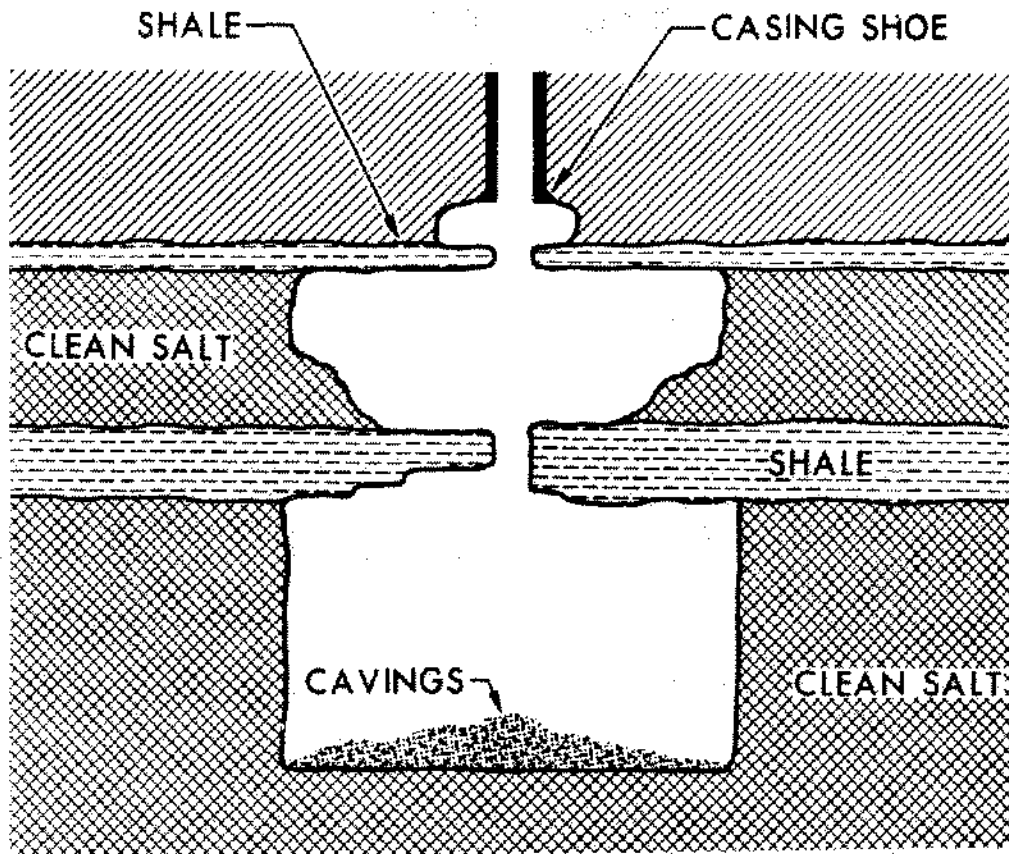


Figure 7. Sonar Caliper survey revealed the depth and thickness of these shale stringers, so that appropriate remedial measures could be taken.

was able to wash the individual cavities selectively, undermining the ledges until they fell. (3) Once the shale sections had been eliminated, no further difficulties were experienced in placing the storage cavity into operation.

Another example may be cited of how the Sonar Caliper can be useful in diagnosing operating difficulties. A storage cavity had been washed out of a salt deposit, using conventional methods. It soon became evident that something was wrong, as full returns of the product put into the storage cavity were not being obtained. A Sonar Caliper survey was run, and it was found that salt had washed out behind the cemented casing string, as shown in Figure 8, so that the cavity was 40 feet in diameter at the casing shoe. A neutron log was then run which revealed a washed-out area behind the pipe, extending 35 feet above the casing shoe. It was now obvious that the cemented casing string could be perforated or cut off at the true top of the cavity, so as to liberate the trapped product.

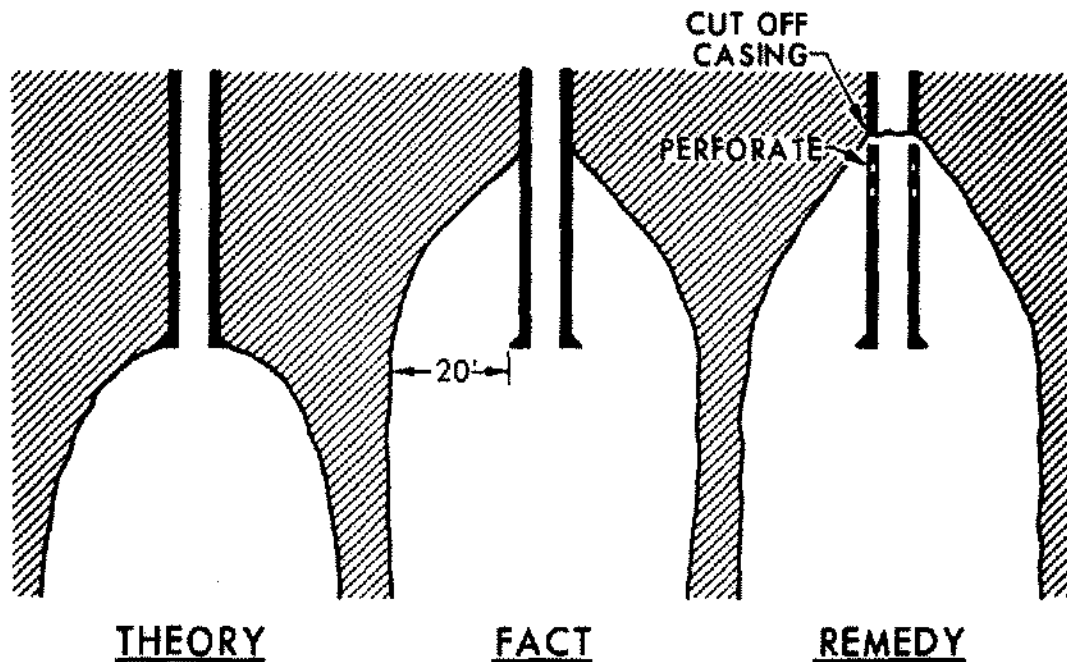


Figure 8. Sonar Caliper survey indicated extensive washout so that stored petroleum products were trapped in the upper cavity.

An additional example may be cited to illustrate the usefulness of the Sonar Caliper in evaluating unknown downhole conditions. A storage cavity had been completed with the operating string passing through a 10 3/4 inch diameter protective casing string. Difficulties were encountered which indicated that the protective string had become plugged. As a result, the protective string could not be pulled nor the interior traversed with wireline tools. The Sonar Caliper tool was then run to survey the situation. As shown in Figure 9, approximately 60 feet above the supposed plug in the 10 3/4 inch casing, the Sonar Caliper tool indicated the presence of a large diameter cavity. It was found that a section of the 10 3/4 inch pipe had been sheared off by formation slippage, and had fallen to the bottom of the cavity. It was also revealed that what had been supposed to be a plug in the casing was actually an insoluble ledge on the cavity wall. After the ledge was removed, the survey was continued to include the rest of the cavity. As a result, a much greater section of salt had been washed out of the top portion of the cavity than had been desired.

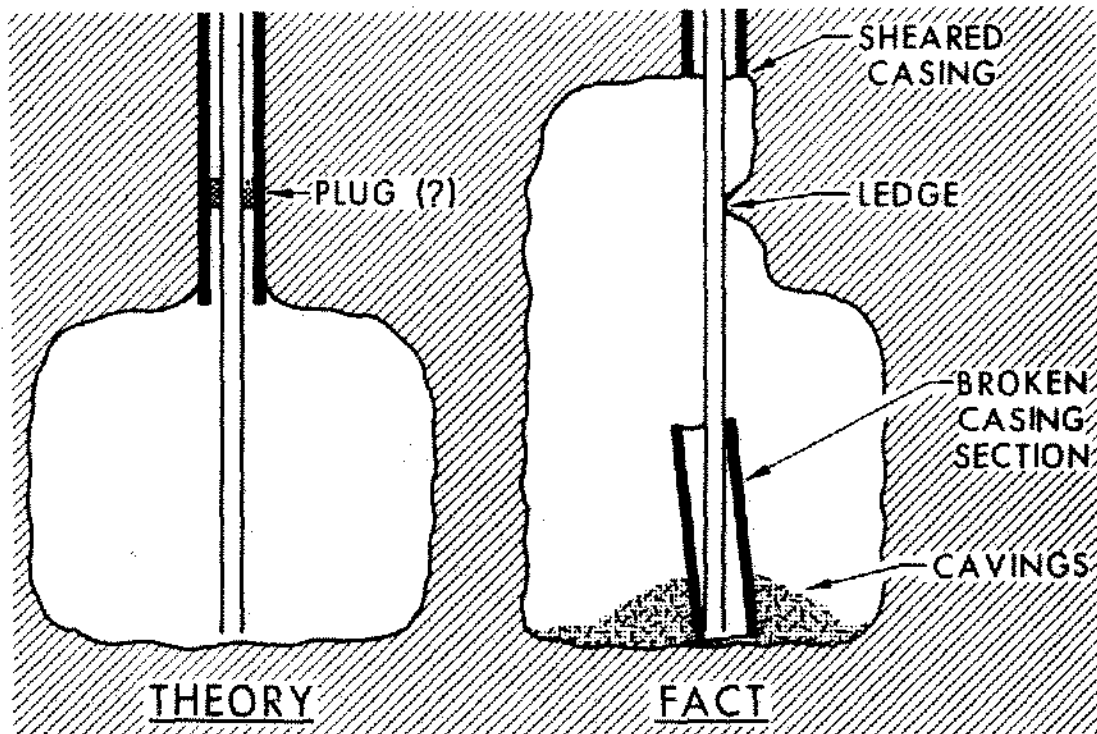


Figure 9. Supposed plug in 10 3/4 inch protective casing string was revealed to be a ledge. The casing had previously sheared off and fallen to the bottom of the casing, permitting enlargement of the upper portion of the cavity.

CONCLUSIONS

Many other examples could be cited, but these are typical of the diverse situations which are encountered and defined by the Sonar Caliper survey. In addition to its basic function of supplying accurate volumetric data on underground cavities, the information it provides on cavity shape and orientation can serve as a valuable aid in planning and conducting remedial operations, should such be required.

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