Exploration by Horizontal Drilling at Avery Island, Louisiana

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ABSTRACT

Because salt impurities in salt domes of the Gulf Coast region lie in vertical or near vertical flowage planes, it was decided to test the quality and internal structure of the Avery Island Dome by horizontal drilling from the mine floor. The authors describe the method of approach, equipment, drilling and testing of a 1,200 foot and a 2,000 foot horizontal hole. The device used to control the vertical deviation of the hole eliminated the necessity of whipstocks or extra strings of casing to prevent downward deflection of the second core hole.

ACKNOWLEDGEMENT

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INTRODUCTION

At least one major internal fault within the salt mass of the Avery Island dome separates the present mine workings from the main mass or domal core of salt. At the shallow depth of the present mine workings, which is 500 feet, this fault forms a water barrier with the presence of both connate and meteoric water (See Plate 1). In order to determine whether future mine development would be at a second lower level or designed to penetrate the fault barrier, it was decided that it was necessary to drill two horizontal holes from the present mine floor. This would allow us to determine the extent and complexity of the faulted zone, together with the geological and salt characteristics of that portion of the dome where future mining activities might be conducted.

LOCATION AND HISTORY

Avery Island is approximately 10 miles southwest of New Iberia in Iberia Parish, Louisiana, and inland approximately 25 miles due north from the Gulf of Mexico. The Island, a topographic high, forms a hill which is surrounded by sea level marshes. The highest point reaches an elevation of 152 feet above mean gulf level.

Salt has been produced from the Island since 1791 when salt springs were discovered by pioneer settlers. During the Civil War, open pit mining methods were used to exploit the then recent discovery of rock salt. Union forces destroyed the workings in 1862. After the Civil War, various attempts were made to mine the deposit with a shaft being sunk to the salt in 1869. Seepage, mechanical and transportation problems hindered expansion. In 1886 a railroad was built

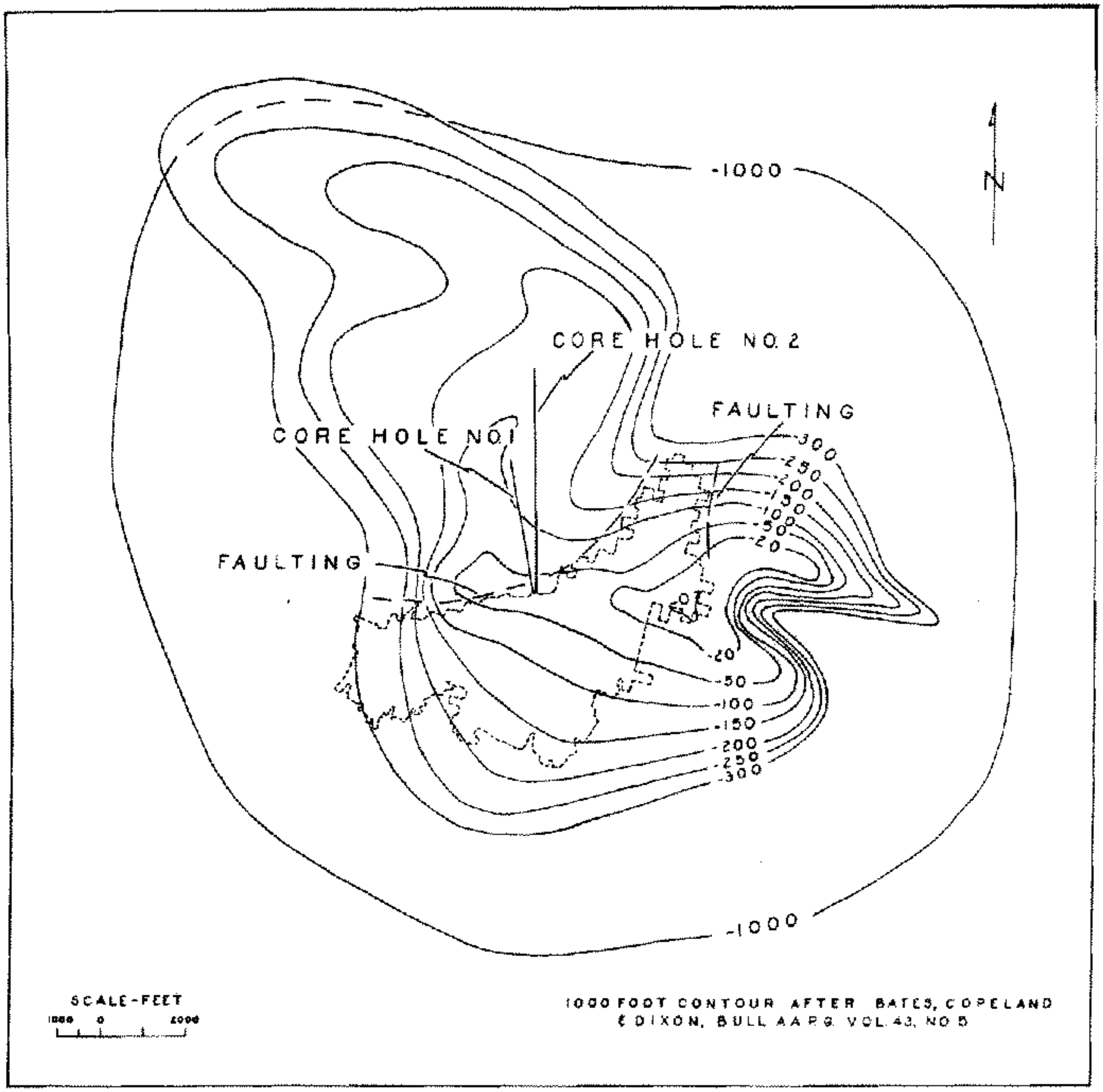

PLATE NO. 1 - MAP RELATING MINE AREA TO THE TOP OF SALT, FAULTING, AND HORIZONTAL CORE HOLES AVERY ISLAND, LA.

into the Island. A second shaft was sunk 13 years later to a depth of 510 feet. This is the present hoist and was sunk when the International Salt Company assumed operations. Over the period of years, 9 to 10 million tons of salt have been produced from the mine by room and pillar mining where the ceilings are approximately 100 feet high. The mine workings are about 500 feet below the surface and cover a triangular shaped area of approximately 2400' x 5100' x 3600' width and feet in length.

In 1942 oil was discovered along the flanks of the dome and since then this area has become an important source of oil. The presently exploited oil sands range in depth from 4500 feet to 15, 600 feet, occurring on the northeast side and along approximately one-third of the western side of the dome (1).

GEOLOGY

Three salt dome basins occur in the State of Louisiana (see Figure 1). These are the North Louisiana Salt Dome Basin, the Mississippi Salt Dome Basin and the Gulf Coast Salt Dome Basin.

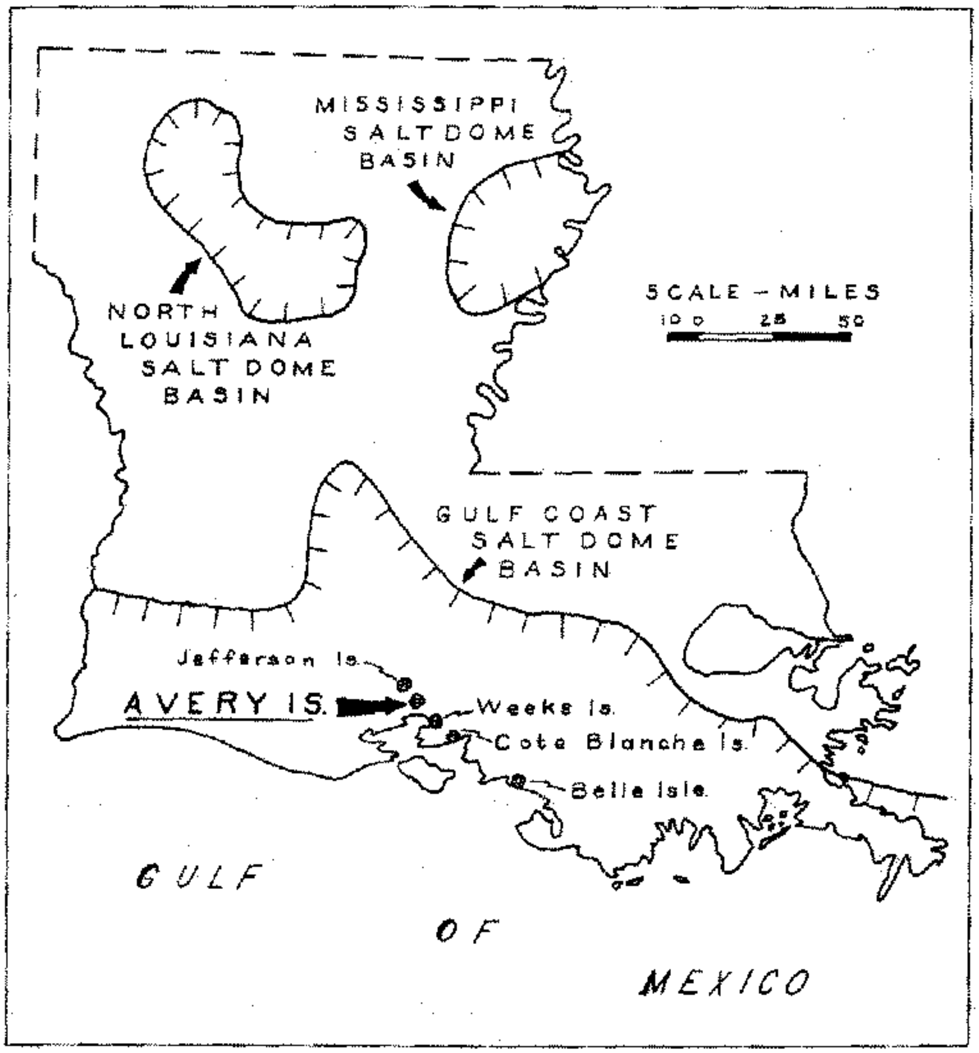

FIGURE I. - MAP OF LOUISIANA SHOWING LOCATION OF "FIVE ISLANDS" AND SALT DOME BASINS

The latter is the largest and extends from Texas to Southeastern Louisiana. This basin contains the majority of presently known Louisiana salt domes, or 103 out of 131. It is also the location of Avery Island, one of the famous "Five Islands" -- Jefferson Island, Avery Island, Weeks Island, Cote Blanche Island and Belle Isle, which are named consecutively from northwest to southeast. These domes are characterized by their orderly arrangement, forming practically a straight line, and the shallow depths of a few hundred feet at which the top of salt is encountered. These domes lay along the southwest flank of the Iberia trough, and their intrusion was in all probability responsible for the formation of the trough.

The salt domes are composed of the Louann Salt which has been assigned a Late Triassic -- Early Jurassic age on the basis of recent palynologic studies (3). The Louann is a bedded salt in the extreme northern part of Louisiana and southern Arkansas, and is encountered at depths downwards of 5300 feet below sea level (4). In the salt dome basins, it is diapiric and, in some cases, comes within a few feet of the surface.

The salt forming the dome at Avery Island is believed to come from a depth of 5 to 7 miles and extends upward to within 16 feet of the surface (5). In outline, the dome is oval and measures approximately 7500 feet along a north-south axis and 8100 feet along an east-west axis at 1000 feet below sea level. It has an overhang on the east side and is tilted slightly toward the north-east. Diapiric shale is encountered surrounding the dome where it has been drilled and occurs at depths below approximately 9500 feet on the south-west flank, 11,000 feet on the north-west flank, 10,000 feet on the north-east flank below the overhang which extends down to 8000 feet. There is no caprock over the dome, but a hard impervious layer does exist a few feet above the salt which separates a brine zone in contact with the salt from the fresh water above (7). Known radial faulting occurs along the northern and western flanks encompassing about one-half of the circumference of the dome. The sediments encompassing the dome are of a Miocene to Recent age as identified from the oil well drilling down to a depth of 16,456 feet and dip away from the salt massif which forms a local "high." The Miocene section is characterized by sands and shales with the top at 7000 feet below sea level. Above this are undifferentiated Plio-Pleistocene-Recent materials consisting of soft, thick sands and gravels with intercalated clay beds (8). The surface materials consist of brownish-yellow, loamy soil with some exposures of gravel, and on the southern part of the Island, outcrops of sand and gravel and on the northern part, green clays (9).

The salt diaper itself, as exposed in the mine, consists mainly of dense, fine to medium crystalline white salt with vertical to near vertical bands of very fine to finely crystalline gray salt which form a series of plunging anticlines and synclines throughout the mine. On the basis of petrographic studies of the insoluble residues of the salt, they were found to contain anhydrite, dolomite, sandstone, calcite, pyrite, limonite, hauerite, sulphur, hematite and kaolenite, given in order of abundance with anhydrite composing 80% or more of the residue. Minor sandstone bands and inclusions of a local nature occur along with thin bands of calcareous clay. Occasional small patches of oil stained salt are encountered, but these are very rare in occurrence. Overall the salt is very pure running 99% NaCl or better.

EXPLORATION -- PREVIOUS METHODS

Because of the vertical banding within the dome, it was decided that exploration holes should be of a horizontal nature to properly evaluate the quality of future reserves of salt beyond the fault zone. One horizontal hole in the dome would be worth an innumerable number of vertical holes, as the latter may travel between bands or within bands of low grade salt, thus giving a false picture of the deposit.

Previous to this time, control of drill holes was maintained by the use of open hole wedges or whipstocks run on the end of casing. These wedges are very costly to set, as they involve a large amount of rig time in setting and may never be retrieved from the hole. Further difficulties may be encountered if the wedge or whipstock contains sufficient deflection to cause twist offs and fishing job. In a slim hole, if the tools cannot be retrieved, twist offs would result in the loss of the hole. The setting of a casing whipstock must be accompanied by a reduction of hole size and consequently, a reduction in core size, which leads to samples and assays of a less reliable nature. This makes their use undesirable.

EXPLORATION -- METHOD USED

It was decided that due to the lack of knowledge of the sag characteristics of drill rods and tools in a horizontally cored hole within a semi-homogeneous mass of salt and the unknown influence on the hole's deviation of near vertical flowage lines within the mass, that a preliminary test run with no vertical control should be accomplished.

The drill rig was made especially for the job and utilized on electric powered drive with a hydraulic feed. The rig was designed so that the "quill" or drill unit had a 21 foot travel, thus reducing the number of times the drill had to be stopped to "chuck up." The front end of the machine was seated on a metal "A" frame which was bolted to a cement pad. The attachment of the "A" frame to the machine contained a pivot bar so that the front end could be directed upward or downward. The rear end of the drill was placed on jacks which could be raised or lowered to obtain the desired inclination of the drill hole. A rod rack capable of handling sixty foot lengths of drill rod was constructed behind the drill so that each trip utilized 60 foot stands of rods. In coming out of the hole, a electric wench and cable was used to retrieve the drill rods. This materially reduced the time required in pulling the rods as compared with their extraction using the hydraulic system of the rig.

The drill fluid was a saturated brine without mud or additives. Being a fully saturated brine, it made a perfect drilling fluid and a full size core was obtained from all core pulled.

This first hole was cored with a 57 foot barrel without attempt to control its deviation to a total depth of 1212 feet. The hole was started with an upward inclination of 1° and had 21' of 4" "surface" pipe cemented in the salt face.

Due to the rapid rate of penetration and the ease with which the rods were installed and pulled, the first deviational survey was conducted when the hole was at a depth of 872 feet, at this point a deviation of 13 1/2 degrees below horizontal was recorded. No attempt was made to correct this deviation.

At the completion of the hole, it was surveyed with a Sperry-Sun Magnetic Multishot Deviation survey instrument, run on the end of the drill rods. Multishot readings were taken every 21 feet, as this was the distance through which the quill traveled. The time required to loosen the chuck, run it back and re-tighten it, was ample for the compass in the instrument to come to rest and obtain an accurate recording. A maximum vertical deviation from horizontal of 19° 45' was recorded at the hole's total depth of 1212 feet and change of 3° in the horizontal direction of the hole (see Figure 10). At the completion of 100 feet of drilling, a downward inclination of 1/2 degree below horizontal was noted, and at a depth of 300 feet a total of 3 1/2 degrees deflection was noted. Beyond this the rate of inclination varied between 1 1/2 to 2 degrees per 100 feet of drilling.

The management of the B.B.R. Drilling Company and International Salt Company felt that due to the "clean" characteristics of the first hole, which included the lack of any "squeezing" of the hole or the encountering of "tight" materials, a core bit could be used which would cut a hole almost the same diameter as the core barrel. The barrel was equipped with a stabilizer shell slightly smaller than the outside diameter of the diamond bit and somewhat larger than the core barrel (Figure 2). This shell was located on the barrel at a calculated distance behind the core bit so that the rear end of the barrel, which was constructed of a heavy walled tubing, would act as a lever on the fulcrum shell. By adjusting the location of the shell, the angle of inclination of the hole was controlled with a high degree of accuracy. Rigidity in the core barrel was maintained by placing subs slightly under 3 feet in length at varying points behind the frontal section of core barrel which was slightly under 37 feet in length. The remaining sections of the core barrel varied in length from 11 feet to 17 feet, which allowed barrels to be made up measuring from 37 feet to 86 feet in length with the longer assemblies resulting in excellent rates of penetration.

The second hole was located thirty feet east of the first core hole. This hole had forty-two feet of 4" conductor pipe set and cemented in the salt face. The hole was started with an inclination of two degrees above the horizontal. The horizontal angle between the two holes was 9°. The reason for this 30 foot spacing was our desire to correlate vertical flowage lines and faults found in the two holes. The horizontal angle was designed to prove reserves at depth without losing the continuity of the geology developed in the first hole.

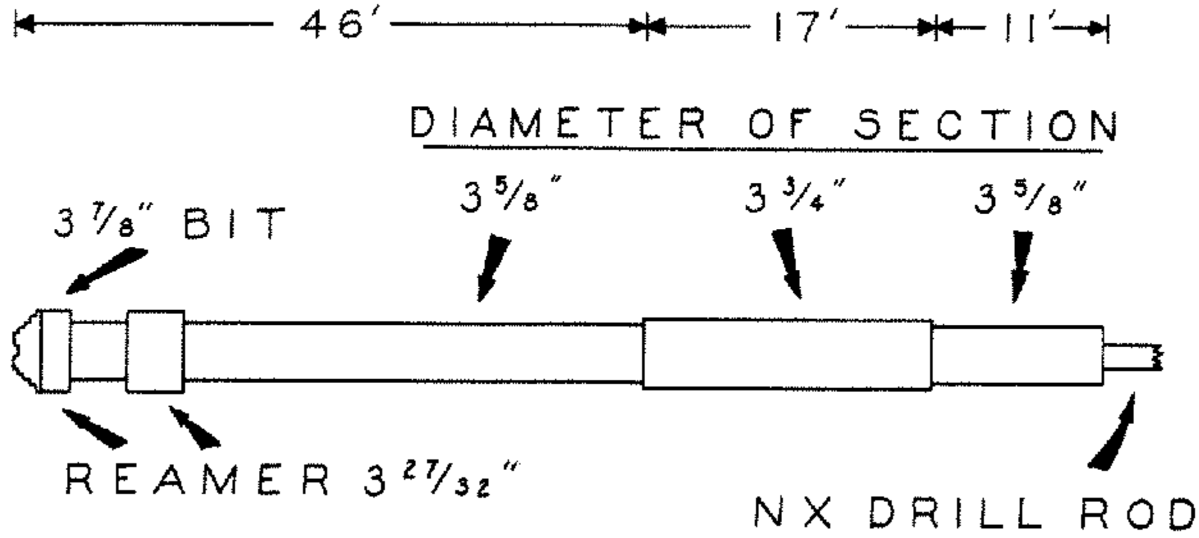

FIGURE 2 - TYPICAL ASSEMBLY OF CORE BARREL FOR CONTROLLED DRILLING

As the hole progressed, results dictated various changes that had to be accomplished. After 176 feet of drilling in Core Hole no. 2 with a 57' barrel, (see Figure 3) and a large diameter

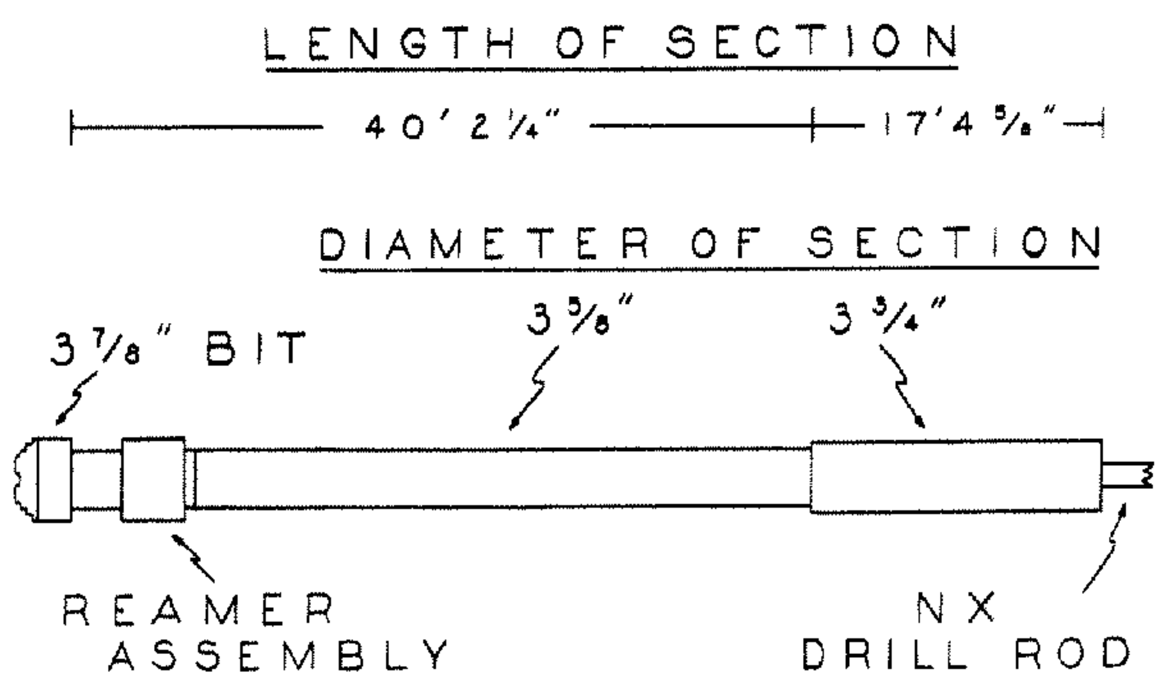

FIGURE 3 - CORE BARREL ASSEMBLY 42' TO 176'

series step type bit, the hole had reached an upward inclination of 5° above horizontal. It was decided that additional upward inclination might prove difficult to correct, so attempts to reduce the rate of climb were started. A 37 foot barrel (Figure 4) was run with a regular bit and stabilizer shell and the hole again surveyed at a depth of 214' with a resultant reading of 5 1/2°. Thus, a decrease in the rate of ascension from 2.56° per 100 feet to 1.39° per 100 feet was obtained. The 57 foot barrel (Figure 5) alternately equipped with conventional and large diameter series

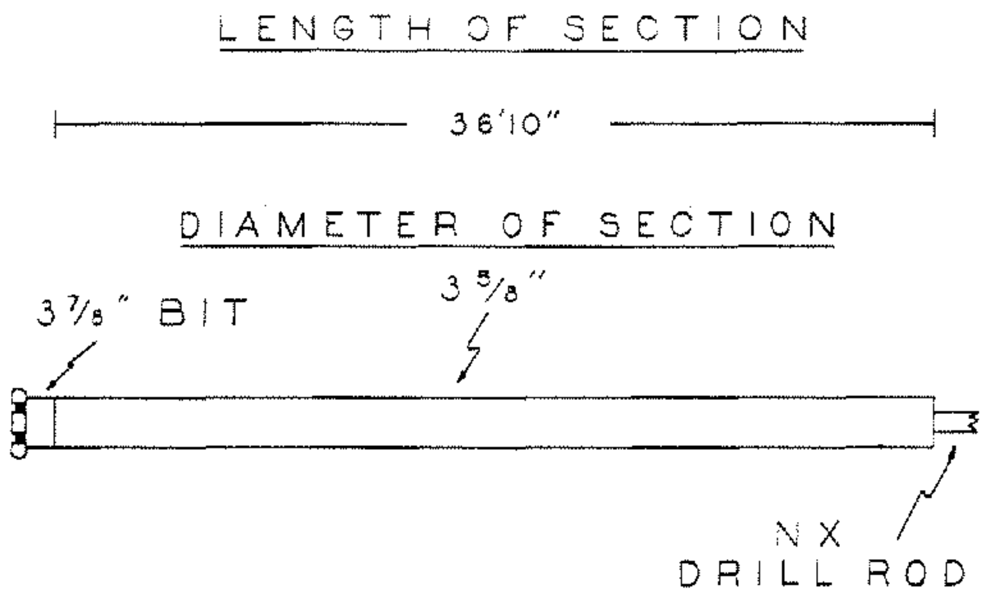

FIGURE 4 - CORE BARREL ASSEMBLY 176' TO 214'

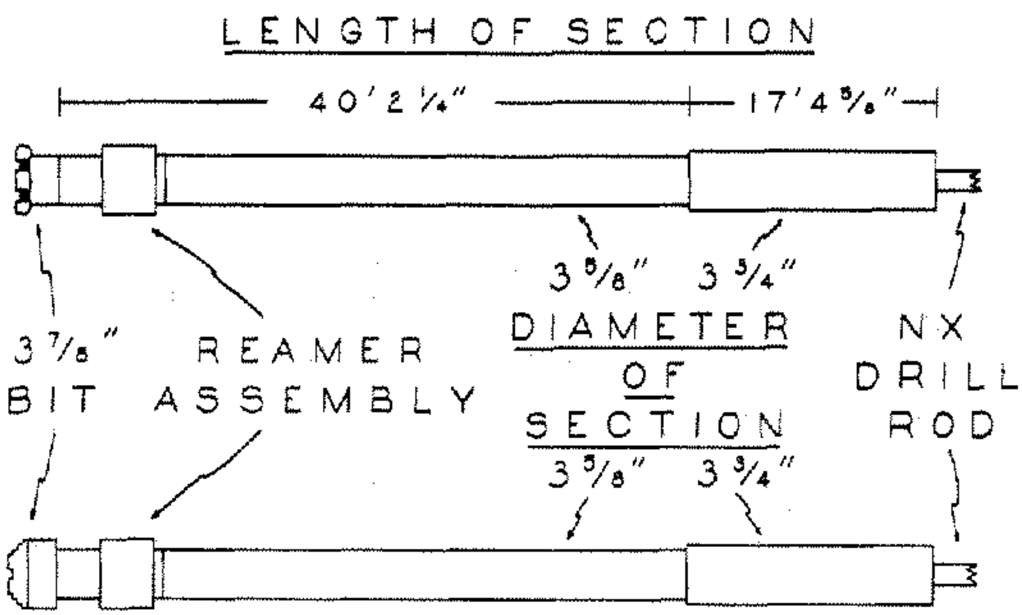

FIGURE 5 - CORE BARREL ASSEMBLY 214' TO 672'

bits, was then run and the angle of inclination was decreased until the angle of the hole was brought to within 1° of the horizontal. This took place through a distance of 400 feet. When a depth of 672 feet was reached, a 74 foot core barrel was made up and run (Figure 6). This was done in order to reduce the time per foot of core cut, which was becoming lengthy. The hole remained within a degree of horizontal and at 1054 feet, it was decided to incline the hole downward. This downward dip was believed necessary due to the fact that the top of salt in the area of the dome which we were approaching was approximately 200 feet lower than in the section underlain by the mine.

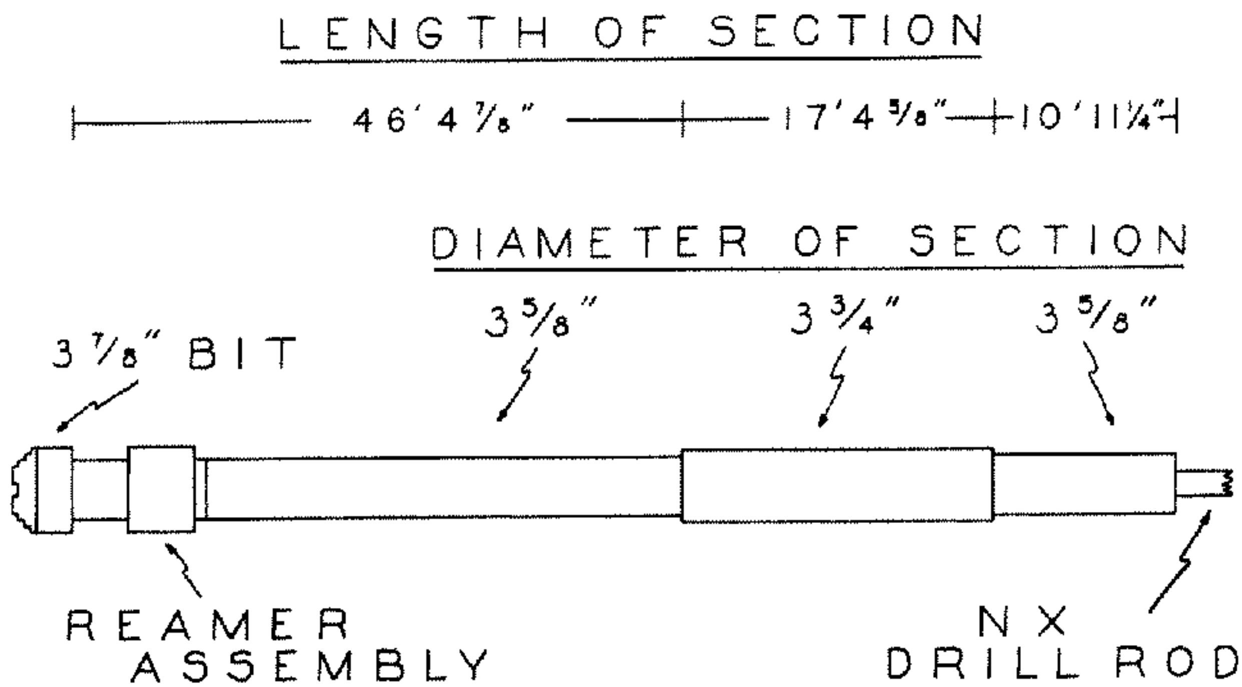

FIGURE 6 - CORE BARREL ASSEMBLY 672' TO 1054'

The hole at this point was 30.46 feet above its collar elevation. The drop was to be developed gradually, as a sharp change in the hole's inclination might result in a twist-off. The use of the 74 foot barrel was continued and a conventional core bit with a 3 5/8" shell was employed (Figure 7). The inclination rate of the hole was 0.51° per 100 feet as measured at 1200 feet, with an inclination of 1/2° below horizontal in this section as compared to 1/4° above horizontal at 1054 feet. At this depth, an 86 foot barrel was made up and run, (Figure 8) with a resultant gain in downward inclination to 1.45° per 100 foot for the first 86 feet of drilling. During the next run, the barrel blocked and only 20 feet of drilling was accomplished, bringing the depth of the hole to a total 1306 feet. The next run resulted in a twist-off, which occurred at the commencement of the drilling. It is believed by the authors that this twist-off was a result of a combination of the sharp changes in the rate of inclination between 1200 feet (0.51°/100') and 1286 feet (1.45°/100'), and drilling with a blocked barrel at 1286 feet to 1306 feet, which weakened the drill string. The tools were successfully fished with a tap and only one shift was lost. The use of an 86 feet barrel was continued down to 1443 feet when a bend in a section of inner tube was discovered and the length of core barrel reduced to 50 feet.(Figure 9). The rate of inclination as measured at 1424 feet was 1.09° per 100 feet (3 1/4° below horizontal). This rate was cut down almost by

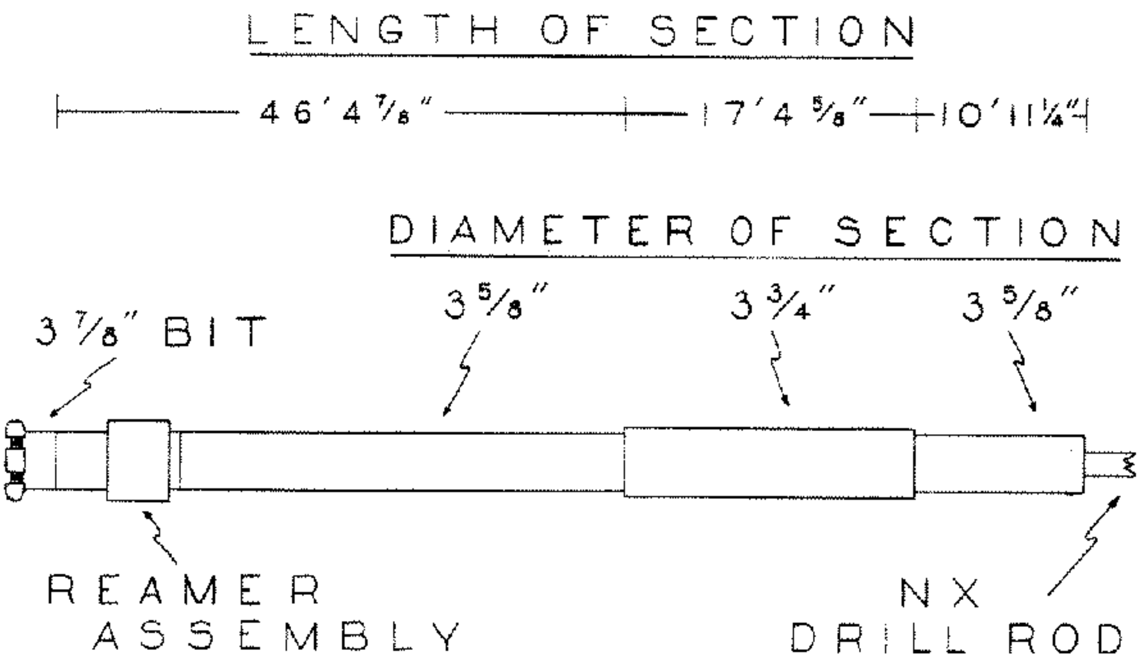

FIGURE 7 - CORE BARREL ASSEMBLY 1054' TO 1200'

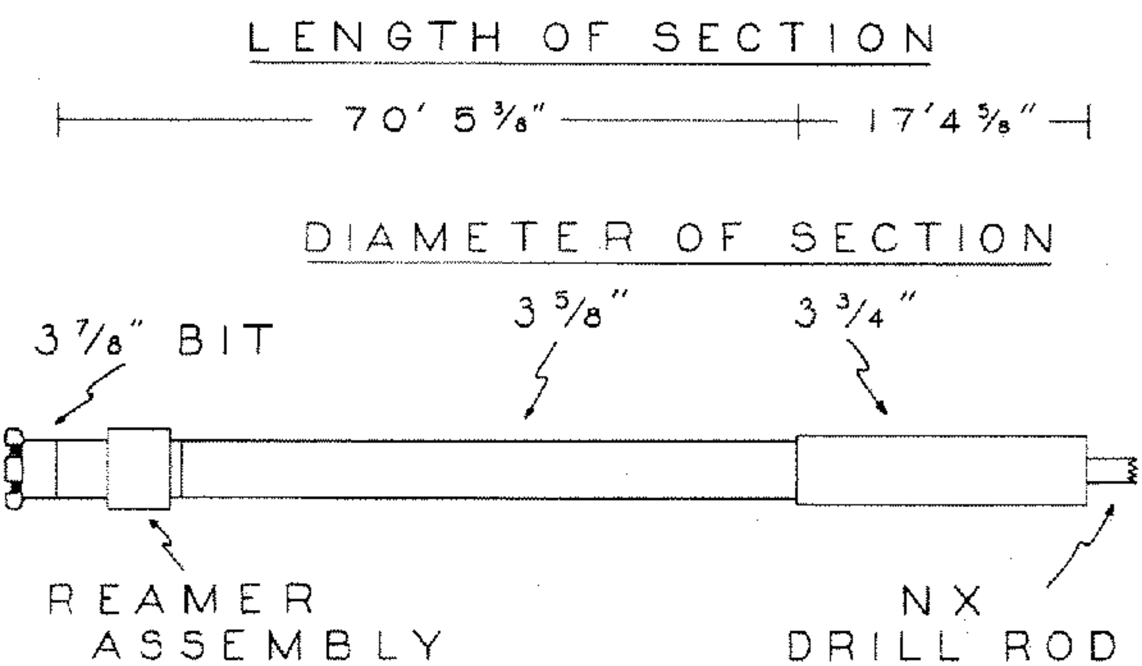

FIGURE 8 - CORE BARREL ASSEMBLY 1200' TO 1443' - 1885' TO 2023'

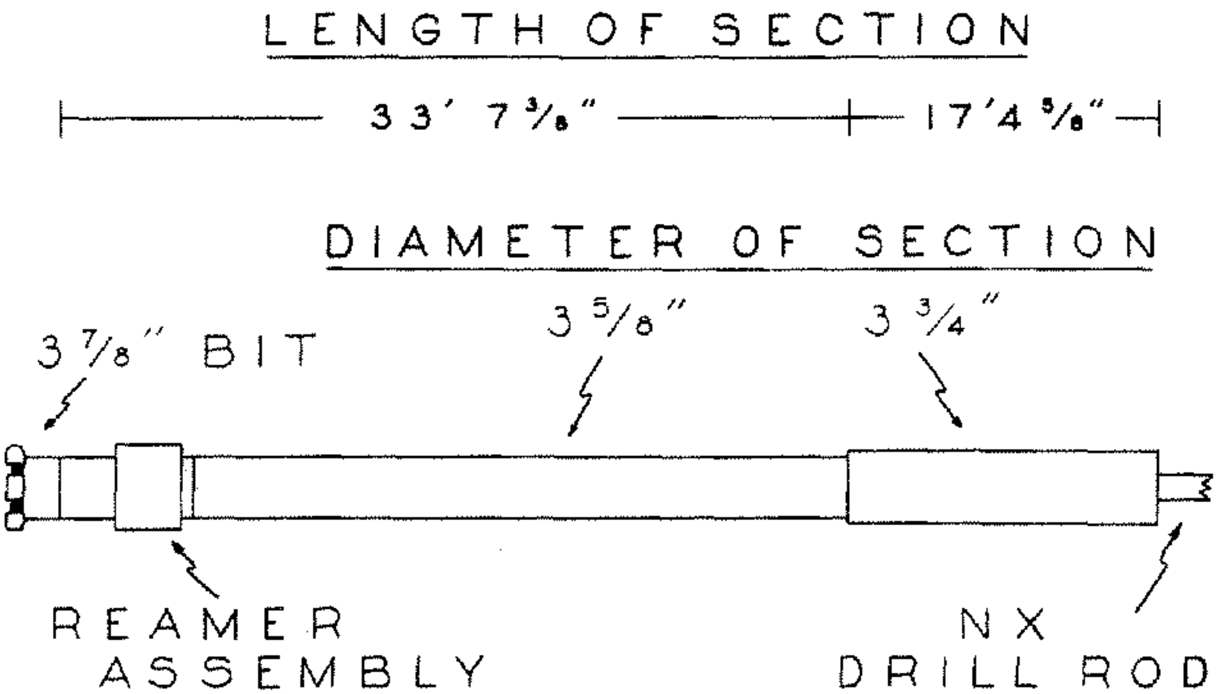

FIGURE 9 - CORE BARREL ASSEMBLY 1443' TO 1885'

one-half in the next one hundred feet, 0.66° per 100 feet, and averaged 0.42°/100 feet down to 1900 feet where an 86 foot barrel was employed to complete the hole. This did not increase the rate of inclination as was experienced at a depth of 1200 feet, but assumed the drop as established by the 50 foot barrel. As measured at 1900 feet, the rate of drop was 0.25° per 100 feet between 1800 and 1900 feet (see Figure 10).

A change of the rate of inclination did occur between 1700 feet and 1800 feet when the rate went from 0.38° per 100 feet to 0.75° per 100 feet. No explanation can be given for this change at present, as there was no significant change in the character of the salt in this section, and there was no change in the core barrel makeup. The final deviation at the total depth of 2,023 feet was 5 1/2° below horizontal and hole was 30.42' below the collar elevation. Core recovery was in excess of 99%.

SURVEYS

All deviation measurements, with the exception of that run at the completion of Hole No. 1, which was accomplished with a Sperry-Sun Multishot instrument, were made with a Sperry-Sun Single Shot Magnetic Directional Surveying instrument. To save rig time on surveying Hole No. 2, the instrument was run in the hole on 2/8" and 1/2" water pipe by hand with a maximum depth of 700 feet being reached this way. For the deeper shots, the pipe was adopted to fit the drill rods and run in by the hydraulic feed of the drilling machine.

A mechanically wound clock was used until the depth became such, as to make further shots impractical from a time consumption standpoint. Sperry-Sun then provided a hydraulic type activated mechanism for the instrument which was actuated by a fluid pressure of 70 to 100 psi. This enabled the instrument to be placed at the recording point without the limitations of time, and then pressurized by the pump on the rig. Deviation measurements were taken in this manner, starting at 1200 feet and carried on to the completion of the hole at 2023 feet.

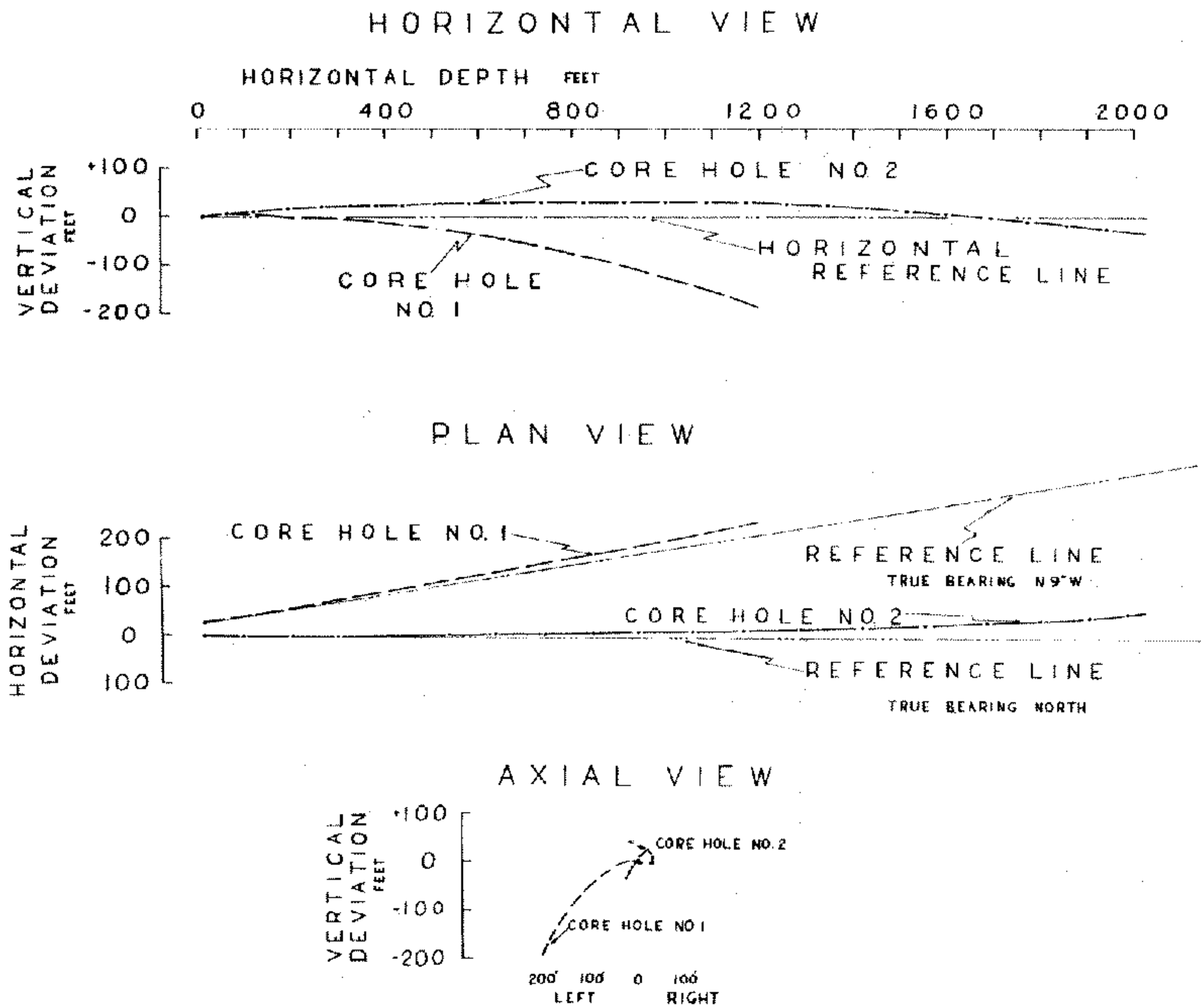

FIGURE 10 - DIAGRAM COMPARING DEVIATION OF CORE HOLES

TEMPERATURE MEASUREMENTS

Temperature measurements were made simultaneously with deviation measurements by placing a maximum recording thermometer in the nose of the Sperry-Sun instrument. When the pressure activated mechanism was installed on the Sperry-Sun deviational survey instrument, a new protective casing was provided which would have placed the compass mechanism too close to the thermometer, so measurements with the maximum recording thermometer were discontinued.

At the completion of the hole, a survey was made of the entire hole using a Halliburton, clock activated, Armerada R-T-7 temperature recording instrument, equipped with a 24 hour clock. Although this instrument had never been run in a horizontal hole before, it was felt that it should function properly. This was run on the end of the drill rods and left at each recording point for 25 minutes, the minimum recommended time.

CONCLUSIONS

It has been demonstrated that a horizontal hole can be drilled with a high degree of vertical control without the employment of open hole wedges or whipstocks. This can be accomplished with an average progress of 39.67 feet per shift. This figure includes rigging up, surveying and cementing. The employment of long core barrels aids materially in establishing this rate of progress. The length of the core barrel appears to have little effect on hole direction when it is properly centralized, weighted and equipped with the correct core bit. The authors feel that this marks a definite advance in the coring and exploration of salt in that it allows an economical method of probing a salt deposit in a lateral direction, thus eliminating the expense of drilling hundreds of feet of overburden to obtain a sample of a mining thickness of only a few feet. We also believe that such horizontal holes can be drilled and controlled in any type of competent rock.

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