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The Assessment of Salt Production Drilling

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ABSTRACT: In this study, the salt production boreholes drilled by die Institute of Mineral Research and Exploration (MTA) for the Mersin Soda Industry in the Adana-Karakuyu-Arabali region were evaluated. The technical characteristics of die drilling equipment and cone (rock) bits used in the boreholes are explained. Caliche, claystone with siltstone, salt and anhydrite interbedding formations of the Pliocene-Messinian Age were drilled. Bentonite and natural water were used as the drilling mud. The density and viscosity properties of the drilling mud were measured continuously. The revolutions per minute (RPM) and weight on bit (WOB) were kept constant or widiin particular interval limits during drilling. This was due to the fact that the geological and mechanical characteristics of the drilled formations did not vary significantly. Although the salt reserve was not determined exactly, the underground salt thickness map suggests that there may be a huge reserve of salt. The salt was saturated with water and was pumped to the Mersin Soda Industry.

1 INTRODUCTION

The development and progress of a country depend on the correct assessment and scientific working of resources of raw materials both underground and at the surface. Drilling is an integral part of the extraction of underground resources.

Solution mining, as a descriptor of mining process, has been increasingly used in the literature over the past fifty years (e.g. Jessen, 1973; Boughten, 1973; Shock and Conley, 1974; Curfinan, 1974; Lefond, 1983; Folle, 1985; Saygili and Okutan, 1996; Haynes, 1997). A more accurate description of the general process could be "bore hole mining". The operation we are considering that of remaining a mineral value by drilling into ore body, circulating an extractive fluid and removing the mineral value. It is interesting note that the Frash process of mining sulfur is an outstanding example *of bore hole* mining This process dates back to the early 1900's. Certainly the many years of successful production of sulfur by the Frash process is a demonstration that bore hole mining has its place as a variable system.

The solution mining of salt offers an alternative to underground mechanical mining. Several operators are currently practicing a form of solution mining whereby a previously mined region is flooded, creating an underground sump, and tne brine is pumped to the surface for processing. The process involves drilling two or multiple wells into the salt bed and establishing a low pressure connection by directional drilling. Water is then injected into one well and the brine is collected from one or multiple production wells.

A little attention has been given salt production by solution mining method with the bore holes in Turkey. However, the Turkish trona deposit was discovered by the Mineral Research and Exploration Institute (MTA) in 1979 during coal exploration. The trona deposits are located approximately 15 km northwest of Beypazari in Central Anatolia, Turkey. Taking into account the whole features of the deposit, the Turkish trona deposit is the second largest natural sodium carbonate formation in the world. However, the production has not been made yet from the trona deposits.

Solution mining with the bore holes for salt production has only been applied for the study area in Turkey. The salt production from the area has been carried out by Mersin Soda Company since 1996. The study area is located in the Adana-Karakuyu-Arabali region. In the study area, caliche, claystone with siltstone, sandstone, and anhydrite interbedding formations are deposited. These formations are from the Pliocene-Messinian Age. The rocks contain salt of significant quality and quantity. The boreholes for salt production were drilled by the Institute of Mineral Research and Exploration for the Mersin Soda Industry.

In the study area, approximately ten boreholes and a total of 6000 m of drilling are completed each year. A total of 33 boreholes for salt production were evaluated, as illustrated in Figure 1. The salt formations were found at a depth of approximately 400-600 m. Fresh water is pumped through the pipe to the salt zone at the bottom of the hole. The salt zone is dissolved and the sail solution is taken out through the annular to the surface.

The purposes of the study include description of the drilling rig, examination of the bit operating parameters and the assessment and report of the salt production.

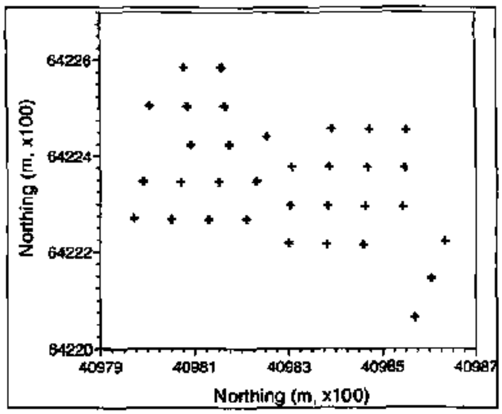


Figure 1. The borehole locations in the study area

2 THE DRILLING RIG

The drilling rig consists of a power pack, drilling assembly, mud pump and draw-works. Two diesel engines are used with the CF 2000 model drilling machine. These engines are reliable, readily available, durable and generally easy to service and maintain. The drilling rig is mounted on a lorry. These mobile units can produce very high outputs under suitable conditions, providing easy transport and using less time. Transmission of the developed power to various parts of the rig is achieved mechanically. In mechanical transmission, the power developed by each engine is gathered in a single arrangement, referred to by the term compound. The compound delivers the engine power to draw-works and a rotary table through roller chains and sprockets. In mechanical transmission, rig pumps are powered by the use of large bolts.

The drilling assembly contains a rotating table, kelly bar, drill pipe, drill collar, stabiliser and bit. The main function of the rotary table is to transfer rotary motion through to the kelly to the drill pipe, and eventually to the drill bit. The main function of the kelly is to transfer motion to the drill pipe, and transfer mud down to the drill pipes and to the bit. The swivel is installed above the kelly and its main function is to prevent the rotary motion of the kelly from being transferred to the drilling line. The drill pipe serves as a medium for the transmission of rotary motion to the bit and also acts as a passage for the mud. The drill pipes used in the drilling operations are 8.9 cm {VA") In diameter and 14.1 kg/m (9.5 lb/ft) in weight. Drill collars are used primarily to put weight on the bit during drilling operations. The drill collars are 10.2 cm (4") in diameter and 74.4 kg/m (50 lb/ft) in weight. A total of six drill collars are used to provide weight on bit and to keep drill pipe in tension in the drilling line. The main functions of a stabiliser are to prevent buckling / bending of drill collars and to control drill-string direction. The drill bit constitutes the heart of the drill string and Is used to cut the rock for the purpose of making boles. Therefore, the proper selection and use of the bit have to be determined. The drill bit cuts the rock under the combined action of weight on the bit and rotary speed. Milling teeth of three-cone-type bits of different diameters are used in salt drilling. A simplified section of the drilling string is shown in Figure 2.

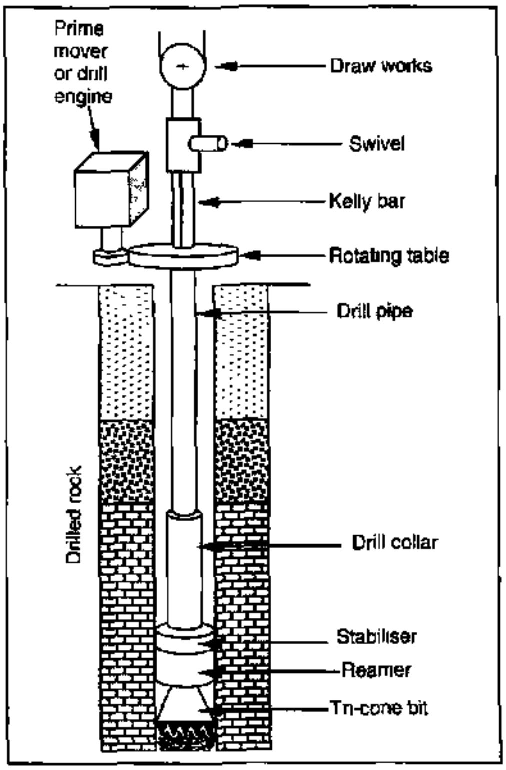


Figure 2. A simplified section of the drill suing.

A Gardner-Denver (FY-FXX) duplex mud pump is used to circulate huge quantities of drilling mud (161-372 gpm) down many hundreds of meters of the drill pipe, through small nozzles at the drill bit and, finally, up to the hole so that it reaches the surface again. Therefore, the pump must produce pressure in order to overcome the fnctional forces and move the drilling mud. The duplex pumps have double-acting pistons which create pressure on both the forward and backward strokes. The technical characteristics of the mud pump used in drilling are presented in Table 1.

The draw-works constitute the heart of the rig, enabling equipment to be run in and out of the hole. It also enables the driller, through the cat heads, to make or break the drill pipe, drill collars and other connections. General and detailed information about the drilling rig may be found in the literature (Rabia, 1985, Adams, 1985).

Tabie I The technical characteristics of ihe mud pump used in the rig

Piston diameter (inch)	Pressure (psi)	Stroke (spm)		Flow rate (jipm)		Max power (HP)
		Normal	Max	Normal	Max	
7 Vi	182			372	42Ü	
7	209			323	365	
614	242	62	70	277	313	53
6	284			235	266	
S'A	338			196	222	
5	409			161	182	

3 GEOLOGY OF THE AREA

The area is formed within the Adana Basın. The dominant hthology is caliche and clay formations with interbedded siltstone, sandstone, anhydrite and salt formations which are from the Upper Pliocene Messinian Age. The Upper Pliocene units of the Adana Basin contain geological records of a catastrophic event known as the "Messinian Salinity Crisis". These events, controlled by tectonics, affected all the sedimentary basins around the Mediterranean. The "Messinian Salinity Crisis" occurred as a result of the designation of the Mediterranean approximately 6 million years ago (Ogunc et al., 2000, Benson et al., 1991).

The following were cut during drilling in a characteristic well, caliche, claystone and clay with interbedded siltstone up to 300 m in depth; claystone, siltstone, sandstone and anhydrite alterations at a depth of 301-400 m; salt at 400-470 m; clay at 471-500 m; and salt at a depth of 501-590 m. A total thickness of approximately 130-150 m salt was drilled. All the drilling wells were stopped at a depth of 600 m from the surface. The characteristic geology of a drilling well is shown in Figure 3.

Geo-mechanical tests of the drilled formations have not been made due to absence of the core samples of the drilled formations. From time to time, core dnlling has been carried out. However, core recovery of the drilled formations is poor (core recovery < % 30) due to ^Konsolidation and softness of the drilled formations. Therefore, enough core samples were not obtained to perform many mechanical tests of the drilled rocks. Only average uniaxial compressive strength of claystone is determined to be 1.3 MPa.

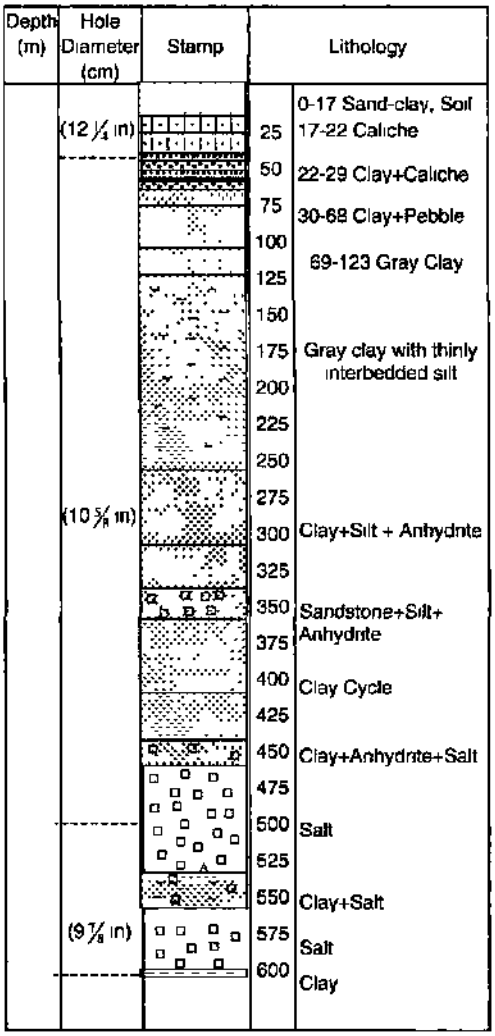


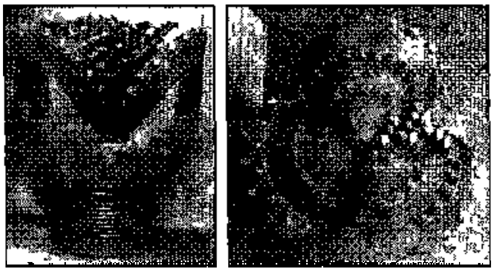
Figure 3. Characteristic geology of (he drilling well.

4 OPERATING PARAMETERS OF THE DRILLING BIT

A milled-tooth type of three-cone bit is used in the drilling, as illustrated in Figure 4. The bit consists of three equal-sized cones and three identical legs. Each cone is mounted on bearings which run on a pin that forms an integral part of the bit leg. Each leg is provided with an opening (for fluid circulation), the size of which can be reduced by fitting nozzles of different sizes.

Four different bit diameters were employed as shown in Figure 5. First, 50 m of the hole was drilled with a 31.2-cm (12.25")-diameter bit. The hole diameter was decreased when the depth was increased and, the 27-cm (10.625")-diameter bit was used to run for the longest part of penetration

The operating parameters of the bit can be identified as the rate of penetration (ROP), weight on bit (WOB), torque, and specific energy (SE). ROP is expressed in units of distance per unit time. It is one of the primary factors affecting the drilling cost. The main factors affecting ROP have been identified as the bit type or selection, WOB, RPM, torque, SE, bit hydraulics, formation or rock properties and fluid properties.



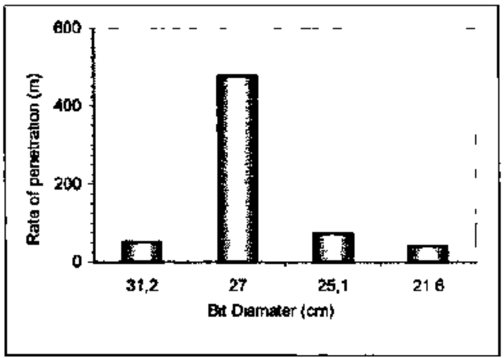


Figure 5 The bit diameters used in ihe drilling.

The daily rate of penetration is presented in Figure 6. ROP is high in the first part of the hole. When the depth of the hole increases, ROP decreases. As the hole depth increases, bit changes, drill string equipment to be run in and out of the hole and well problems take a long time, which causes a decrease In ROP. The cumulative ROP is shown in Figure 7.

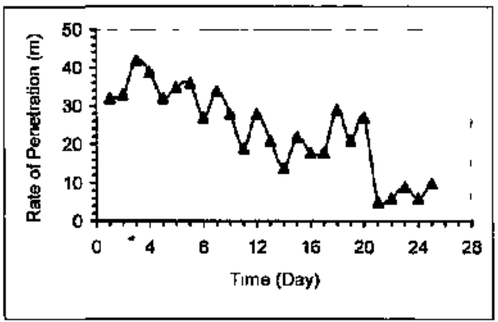


Figure 6 Daily rate of penetration.

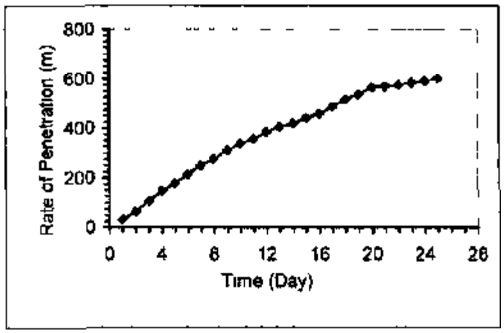


Figure 7 Cumulative rate of penetration

WOB, RPM, torque and SE were not measured continuously during drilling. This was due to the lack of measuring equipment in the rig and the shallow hole depth. WOB and RPM are independent parameters which can be directly controlled by the rig operator. These parameters were kept constant during drilling because the drilled formation does not undergo disturbances from tectonic activities, and the geological and mechanical properties of the rocks do not show significant differences. There is good homogenity and uniformity of the rock properties through the hole. The drilling assembly (the drill string) is approximately 7-8 tonnes in weight. 500-1500 kg of weight was applied on the bit. The other weight of the drill string was held by the hook of the draw-works.

The performance of the bit is significantly influenced by the RPM. An increase in RPM leads to reduction in the WOB required to attain a given ROP. However, the increased bit rotary speed results in greater wear on the bit and may also cause chattering, microchipping and thermal cracking of the cutters of the bit. 120-180 rpm is applied to the bit according to the rock type drilled and the hole depth. This speed is continuously maintained and sufficient flush is provided in order to ensure the removal of rock cuttings from the hole.

SE can be defined as the energy required to remove a unit volume of rock (Teale, 1965). Thus, the drilling SE is a very significant measure of drilling efficiency, and it is directly compatible with cost per meter. The drilling SE can also be used as an indicator of bit condition.

Torque can be described as the turning force applied to the drill rod which leads to the bit rotating against the resistance due to cutting forces and friction. Torque control is performed for safety in drilling. Approximately the avergae torque value was 200 Nm during the drilling.

5 DRILLING MUD

Drilling mud is used to perform the following functions:

- Cool the drill bit and lubricate its teeth.
- Lubricate and cool the drill string.
- Control formation pressure.
- Carry cuttings out of the hole.
- Stabilise the well bore to prevent it from caving.
- Help in the evaluation and interpretation of the well log.

In the study of salt production drilling, different mud types and properties were used at different lines of the well. In the first 100 meters, there is mainly natural soil and gravel, which have a high level of porosity. This can result in water-base mud leakage or fluid loss at the wall of the hole. At this depth, mud cake was formed on the wall using a mixture of water and bentonite. This cake helps to stabilise the wall of the hole, somewhat similar to the effect of adding a layer of plaster to interior house walls. The mud density, mud viscosity and annular mud velocity were frequently measured during drilling. The mud density was 1.1. gr/cm^3 and the level of viscosity of the Marsh Funnel was 40 sn for depths up to the first 100 meters.

From the depth of 100 meters to the salt zone in the well, water was used as mud (approximately 350 m in depth). At this line, claystone was the dominant formation. Thus, the clay cuttings of the bit were mixed naturally and circulated through the well. When the salt stratum was reached, the mud was saturated with salt. This process prevents the salt layers from being dissolved. At this stage, the mud weight was increased up to about 1.35 gr/cm^3 and the Marsh Funnel value was about 32-33 sn for viscosity.

The flow rate of the mud did not change often because there was no significant difference in formation properties through the well. A flow rate of about 197 gpm was selected according to the technical specifications of the mud pumps. This flow rate was optimal for the removal of cuttings produced by the bit from the well to the surface. This requires a particular annular mud velocity. The mud velocity can be calculated by the following equations:

$$V = \frac{24.5 * Q}{D^2 - d^2} \qquad (1)$$

where,

V : Annular velocity (fpm).
Q : Flow rate (gpm).
D : Well diameter (inch).
d : Drill pipe diameter (inch).

$$V = \frac{24.5 * 197}{(10\tfrac{5}{8})^2 - (3\tfrac{1}{2})^2} = 14.63 \text{ m/dk (48 fpm).}$$

This is calculated for the bit diameter of 27 cm (105/8 inch), which was used in most of the drilling. This velocity is enough to carry the drilling detritus.

Deviation control was established for each 100 m in depth of the well. The deviation was measured by Eastman model magnetic Single Shot Instrument which records simultaneously, the hole inclination and magnetic north direction of an uncased hole at a single measured depth (or station). The instrument consists of an angle-indicating unit, a camera section, a timing device and battery pack In the drilling, significant deviation has not been recorded. Measured hole deviation was less than 2°.

6 SALT PRODUCTION

In the study area, two salt strata were determined. The first stratum was reached at a depth of 400-470 m in the well. The thickness of the strata is about 50-60 m. The second strata was found at a depth of approximately 500-590 m. The thickness of the stratum is 90 m. The total salt thickness is 120-150 m in the drilling wells.

Pumps are the hoisting mechanisms. The pump is located on the surface, force-feeding the injection fluid into the cavity at a pressure sufficient to raise the resultant brine to surface.

Top or annular and bottom injection was employed in the study area (Figure 8). However, top injection was the most common type of brining operation used in the area. This approach involves installing a conductor or surface pipe through the unconsolidated surface overburden into the underlying bed rock by forcing a cement slurry down the inside of the casing. A follower plug, powered by mechanicat or hydraulic means, forces the cement to rise İn the annulus formed by the conductor pipe and the open hole. After the cement has been permitted to set, drilling of the hole is continued into the top of the uppermost salt bed and the mean string of casing set and cemented to surface in a manner similar to that used insetting the conductor pipe. The bit size is reduced so that it will be accommodated by the bore of main string Drilling of the hole is continued at this reduced diameter from the bottom of main string of casing to the bottom of the layered salt. The bore of hole then is equipped with a free hanging string of tubing extending from the surface to a point near the bottom of the well. Sometimes operators create a sump at the bottom of the well for the insoluble residues by initially operating the well in reverse (injecting water through the tubing).

The principal advantage of this top annular system is a simple uncomplicated well. Disadvantages are:

- The collection of insoluble around the bottom of the production well;
- The early exposure of large unsupported spans of roof rock which collapse, resulting in the beddmg and shearing of the production tubing;
- Dissolution of the upper portion of the bed by a blanket of insolubles;
- Low percentage of extraction;
- Generally low production rates (less than 3500-4000 liters per minute);

Bottom injection system involves the operation of a well similar in construction to a "top-injection" well, where the water İs continually injected into the tubing. In general, the bottom injection method produces a saturated brine at a lower rate of flow (750-2000 liter per minute)

The advantages claimed for this system are:

- A more uniform cavity shape;
- Less maintenance, due to greater "sump area" for insoluble and detrial material,
- Less blocking or plugging of the tubing with insoluble larger percentage of extraction.

Sometimes operators create a sump at the bottom of the well for the insoluble residues by initially operating the well in reverse (injecting water through the tubing).

A systematic (regular) method is applied to the determination of the drilling hole locations. The distance between the holes vanes from 30 m to 40 m (Figure 1). In this method of salt production, caves occur in the form of reserve cones underground. The range (effect area) of the two holes was united after a certain time. Then, inside pipes in casing are taken out of the holes, and fresh water is pumped to one hole, while the salt solution is taken from the other hole. Because, a cavity operating as single well has relatively low capacity for salt solution. The solution output increases considerably if two cavities are connected and the water is forced down one well and brine is removed from the other well. The salt production has been made in diameter of 30 m of the well. Approximately, pillar diameter was about 20 m between two holes. This distance is left to prevent formation subsidance. Thickness of salt bed is of prime importance because it determines the yield of a well and consequently the economics of the process. Furthermore, as rock salt provides a stronger roof structure, larger cavities can be developed which prolongs the life the rock salt wells.

Host minerals of the salt, such as clay, anhydrite, quartz and feldspar sink to the base of the caves. The inside pipes are shortened from time to time to prevent stoppage of the host minerals. Water comes to the upper end of the cone, whereas the salt solution goes down. The concentration increases continuously on the side wall of the cone.

Contour mapping and three-dimensional graphs, created using the Surfer 7.00 computer package, are very useful for the spatial continuity analysis of large quantities of data (Golden Software, 1999). A three-dimensional graph and contour map of the thickness of the first salt stratum underground are presented in Figures 9 and 10, respectively. Similarly, Figures 11 and 12 show the second salt stratum. Consequently, these figures exhibit that the salt stratum underground is more or less regularly distributed. This allows easy production and low production costs.

In the study area, the quantity of the salt reserve was not determined. However, the distribution of the salt thickness suggests that there may be huge salt potential (Figures 9-11). 500 million tons salt reserve has been estimated İn the area. It should be mentioned that the reserve for the salt formations may be esbmated using contour map of the salt thickness (Figures 10 and 12). This is out of the scope of this study. Produced salt solution has been pumped to Mersin Soda Industry by the pipe line of 46 km in length.

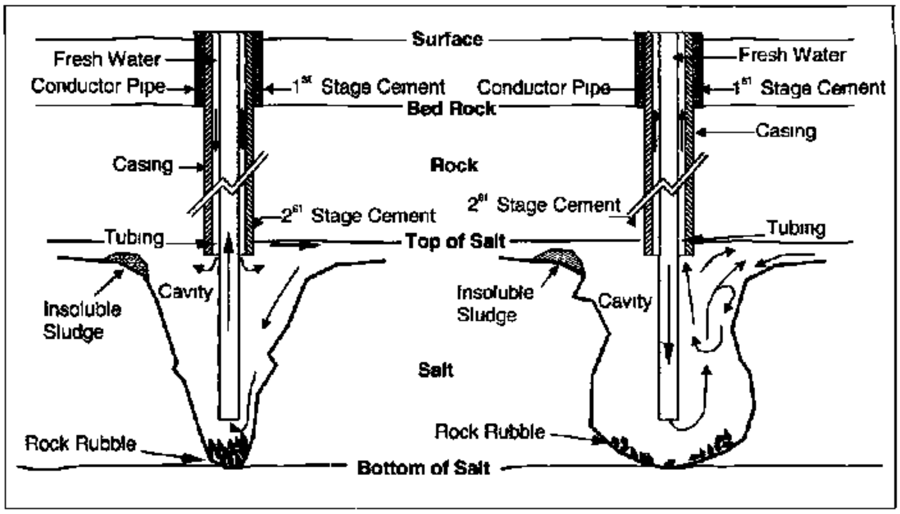


Figure 8 Top and bottom injection for salt production methods with bore hole systems

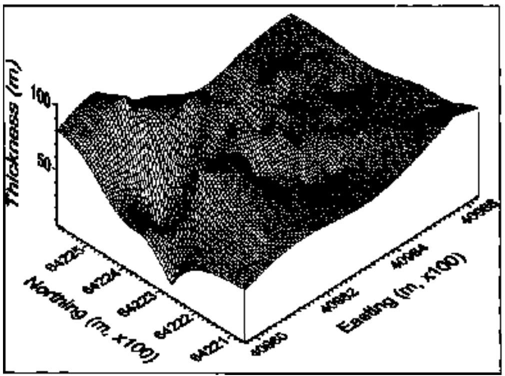


Figure 9 Three-dimensional graph of the thickness distribution for the first salt strata

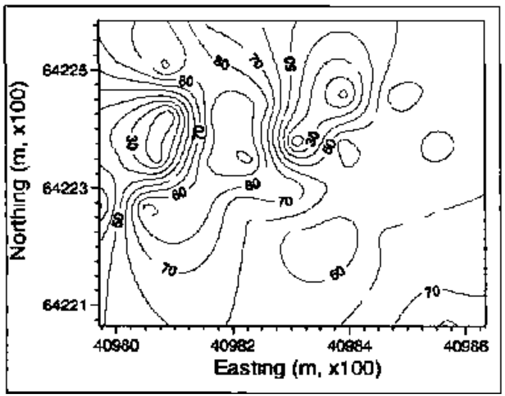


Figure 10 Three-dimensional graph of the thickness distribution for the first salt strata

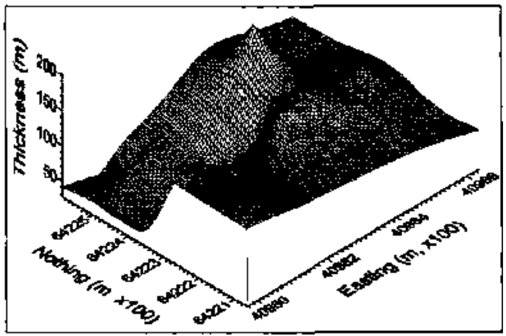


Figure 11 Three-dimensional graph of the thickness distribution for the second salt strata

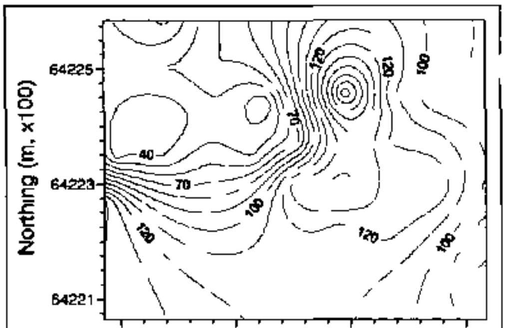


Figure 12 Three-dimensional graph of the thickness distribution for the second salt strata

7 CONCLUSIONS

The main conclusions of the study may be summarised as follows.

1. A total of 33 boreholes for salt production with solution mining method were examined.

2. Caliche, claystone with siltstone, sandstone and anhydrite interbedding formations were drilled through the well.

3. The salt zone was reached at a depth of 450-600 m in the well.

4. A characteristic milled-tooth type of the cone bit was used due to soft and unconsolidated formations were drilled.

5. The bh operation parameters such as WOB and RPM were kept constant or within particular interval during drilling. Approximately the average value of WOB was 1000 kg and the average value of rotational speed was 150 rpm.

6. Drilled formations did not show significant differences In terms of geological and mechanical characteristics of the drilled rocks. Therefore, the operating parameters of the bit were not changed frequently during the drilling.

7. ROP was decreased, when the hole depth increased.

8. Bentonite and water were used as drilling mud up to the salt zone. However, saturated water with salt was applied as mud in the salt zone. The density of the saturated water with salt was about 1,38 gr/cm^3.

9. The measured hole deviation was less than 2°.

10. The salt strata was dissolved by pumping of water and produced through annulus to the surface.

11. Contour maps and three-dimensional graphs of the salt thickness suggest that the salt underground is distributed more or less regularly.

12. One of the main problems during drilling is that clay cuttings stick to the bit and this obstructs the rotation of its cones due to swelling.

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