



# Deep Diamond Core Drilling Practice in A Thick Salt Formation Containing Clay/Anhydrite Interlayers

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## INFORMATION

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### Abstract

In mineral exploration, diamond core drilling is the most expensive but provides the most accurate data. To discover metallic minerals, industrial raw materials, and coalfields, and to determine their reserves and operability, diamond core drilling is necessary. Today, all operating mines have been put into operation as a result of diamond core drilling and evaluation of these studies. Diamond core drilling is expensive and time-consuming compared to other exploration methods. However, the importance of diamond core drilling in both scientific and economic studies is increasing day by day, as samples obtained from mineral deposits and drilled rock units are representative of their characteristics. In diamond core drilling, the main goal should be to achieve the best possible drilling rate and the highest core recovery. The high rate of penetration and core recovery depends mainly on the properties of the drilled geological formations. Drilling through thick salt formations is among the most challenging operations in the drilling sector. In these formations, the drilling team faces very different, high-risk working conditions. Also, as the depth increases in diamond core drilling, drilling operations become more difficult, and drilling time and cost increase. In this study, 1501 m-deep diamond core drilling in a thick salt formation with a clay/anhydrite interlayer (sticky and dissolvable) was investigated. Specifically, the casing design and cementing operations, penetration problems, the solutions applied to overcome these difficulties, and the properties of the drilling mud used were examined.

### Keywords

Sticky clay, Anhydrite, salt drilling, Diamond core drilling, Rate of penetration problems, Drilling mud control

## 1. Introduction

The diamond core drilling is widely used in the construction industry. Core drilling is used in dams, highways, railways, airports, and harbor surveys and construction, as well as for obtaining engineering parameters that are critical to building design. Although diamond core drilling has a wide range of applications in the construction sector, its main application area is mineral exploration and exploitation. To discover metallic minerals, industrial raw materials, and coalfields, and to determine their reserves and operability, diamond core drilling is necessary. Today, all operating mines have been put into operation as a result of diamond core drilling and

evaluation of these studies. Diamond core drilling is expensive and time-consuming compared to other exploration methods. However, the importance of diamond core drilling in both scientific and economic studies is increasing day by day, as samples obtained from mineral deposits and drilled rock units are representative of their characteristics (Ozdemir, 2018).

In mineral exploration, diamond core drilling is the most expensive but provides the most accurate data. Diamond core drilling for coal exploration is generally vertical, whereas drilling for metallic minerals and industrial raw



materials is usually angled. In diamond core drilling studies, different types of equipment are required for use inside and outside the borehole to obtain a cylindrical formation sample, called the core. In recent years, conventional equipment has been used for diamond core drilling, whereas today, wireline equipment is widely used. In diamond core drilling, water, bentonite mud, or chemical additive fluids are used as circulating fluids. As the depth increases in diamond core drilling, drilling operations become more difficult, and drilling time and cost increase. It is necessary to determine the most suitable conditions for efficiency and economical core drilling. In core drilling, the main goal should be to obtain the best possible drilling rate and the highest core recovery. The high rate of penetration and core recovery depends on qualified personnel, available equipment, and the

formation properties to be drilled (Cumming, 1980; Heinz, 1985; Ozdemir, 2018).

In the literature, there are some studies in thick salt formations, with mostly oil & gas and salt production rotary drilling practices (Sheffield et al., 1983; Holt and Johnson, 1986; Ersoy and Yonsel, 2001; Whitfill et al., 2002; Dusseault et al., 2004; Israel et al., 2008a; Israel et al., 2008b; Liguó et al., 2008; Chatar et al., 2010; Omojuwa et al., 2011; Håpnes, 2014; Vedøy, 2015; Amer et al., 2016; Lin et al., 2019).

In this study, a deep diamond core drilling practice for salt exploration was conducted within the borders of Ocakbaşı Village in Delice District (Kırıkkale, Central Anatolia, Türkiye) (Fig. 1).

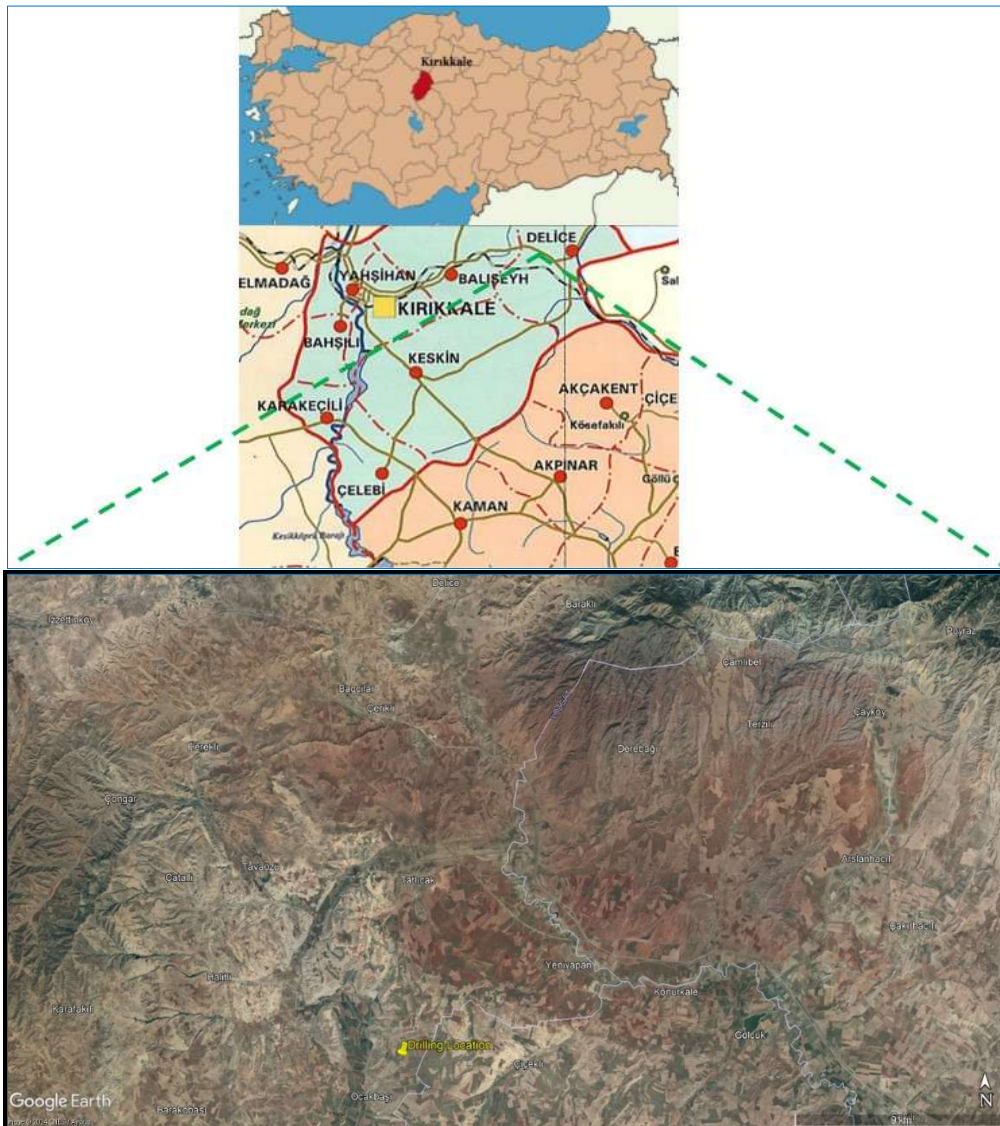


Fig. 1. Location map of the borehole

Underground salt deposits are primarily found in Türkiye, in Central, Southern, and Eastern Anatolia (Fig. 1). As a result of a significant regression event in Central Anatolia and compression in northern and southern Anatolia, mountain basins formed there. Evaporitic units, such as salt and

gypsum, were deposited in salt-marsh environments and under arid climatic conditions in these mountain basins (Unucok et al., 1981; Uygun, 1982). The Sekili evaporite member of the Incik formation, which is widely distributed in and around the study area, consists of these salt and

evaporitic units (Gülen, 2011). The thickness of the unit has been reported to be around 3100 m in the Çankırı-Çorum Basin and around İncik (Birgili et al., 1975). The thickness of the unit in and around the study area has been estimated as 1100-1500 m (Donmez et al., 2005).

In the study, 1501 m of diamond core drilling was conducted in a thick salt formation with a clay/anhydrite interlayer. The casing design and cementing operations, penetration problems, the solutions applied to overcome these difficulties, and the properties of the drilling mud used were investigated.

## 2. Literature Review

The structure of thick salt formations is not homogeneous. Salt formations may consist of pure halite (sodium chloride), anhydrite (calcium sulfate), silvite, potash, and trace amounts of other minerals. They may also be interbedded with units such as clay-claystones and marl, etc., or may contain these units in bands (Håpnes, 2014). Typically, the main problems encountered when drilling thick salt formations are the following (Fig. 2):

1. Clay balling of the bit and drill string due to mobile shales/clays/claystones in the salt,
2. Wellbore enlargement/disruption due to mobile shales/clays/claystones along and/or above or below the salt formation,
3. Wellbore enlargement results from salt dissolution,
4. Well wall weakened by leaching water, gas, and other minerals out of the salt,
5. Salt-creep ledges impinge on the drill string,
6. Accumulated cuttings jam the drill string,
7. Well deviation results from wellbore enlargement and
8. Excessive drilling mud consumption.

Properties such as hardness, fractures, cracks, etc., are not frequently encountered in salts. In such formations, the properties of the drilling mud used are more important. Clays and claystones are encountered in salt zones. If these clay zones-claystones are not drilled with the appropriate rate of penetration and mud type, they adhere to the drill bit and drill string, forming a clay mass around the drill bit and drill string that prevents both rotation and penetration of the drill string.

This phenomenon, called balling, is encountered in salt drilling, albeit to a limited extent. In addition, these clayey levels/anhydrides dissolve and mix into the drilling mud, increasing mud density/viscosity and pump pressure and causing pump failures. Therefore, pressure losses in the pump should be accurately calculated when drilling such formations.

During drilling, small-scale collapses may occur. These zones may need to be cased or cemented. Since the working environment is salty, the mud should be saturated with salt before it is pumped into the borehole. This prevents the salt formation from dissolving in the mud and causing core loss. Since the drilled units are homogeneous and the unit does not contain a large amount of discontinuities (cracks, fractures, etc.), significant borehole deviations due to formation are not observed (Ozdemir, 2018).

When drilling in basins with thick salt formations, the first problems often appear in the formations above the salt structures. This is because the density of salt does not increase with burial depth. Because the density of the salt formations is lower than that of the surrounding formations, the salt formations will begin to collapse (breccia zones will form around the salt) and push the overlying rocks (the breccia zone, which may lie beneath or adjacent to the salt formation, usually consists of a series of highly mobile shale fragments embedded in loose sand). The combined effect of compressive forces and salt tectonics can create complex stress patterns in the formations surrounding salt structures, leading to significant drilling hazards when drilling salt formations.

The creep property of salt can also cause some problems. Salt creeping into the wellbore can interfere with drilling and casing operations. This can lead to a jammed drill string, wellbore stability issues, and increased lateral vibration during drilling. Salt creeps into the wellbore during drilling is a positive function of time. Therefore, minimizing drilling time as much as possible will reduce problems associated with salt creep. In other words, drilling operations in salt formations should be carried out rapidly (high rate of penetration) (Chatar et al., 2010; Ozdemir, 2012; Håpnes, 2014; Ozdemir, 2018).

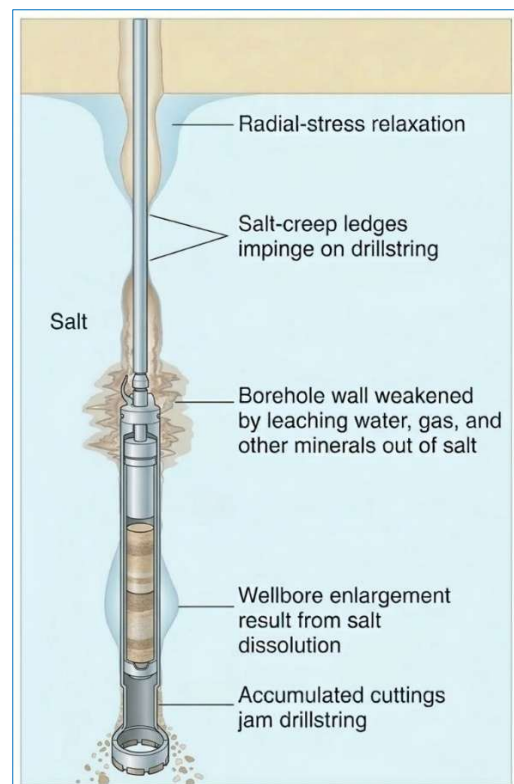


Fig. 2. Problems that can be encountered in diamond core drilling of salt formations (compiled from Farmer et al. (1996), Håpnes (2014) and Mohammed et al. (2019))

Salt drilling is among the most challenging operations in the drilling sector. In thick salt formations, the drilling team faces a very different and risky working environment in any drilling application. Salt is a creep and/or deformable geologic unit.

This is one of the problematic properties of salt. When sediments accumulate on top of the salt and begin to compress, a critical depth is reached at which the density of the cover layer equals that of the salt. At this point, salt creep begins (Fossum and Fredrich, 2002).

Temperature and stress differences are the main drivers for salt creep. Drilling thick salt formations differs from drilling other formations due to these characteristics (Chatar et al., 2010; Håpnes, 2014). These differences include (1) well stability problems (Infante and Chenevert, 1989; Willson and Fredrich, 2005; Carcione et al., 2006; Håpnes, 2014; Perez et al., 2008), (2) salty drilling mud (Leyendecker and Murray, 1975; Grant et al., 1989; Barker et al., 1994; Muecke, 1994; Whitfill et al., 2002; Willson, 2016), (3) cementing requirement (Yearwood et., 1988), (4) specialty casing design (Jr. Cheatham and McEver, 1964; Hackney, 1985; El-Sayed and Khalaf, 1992; Willson et al., 2003; Wang and Samuel, 2016; Taheri and Ali Pak, 2020), and (5) special deviation control (Håpnes, 2014).

### 3. Borehole Design and Drilling Operation

The borehole, drilled to a depth of 1501 m, was drilled using a whole-hydraulic crawler-type drilling rig (Fig. 3). Initially, the borehole was drilled with a full-cored HQ-diameter drill string. Upon observing that the alluvium ended at 175 meters, penetration was terminated. The drill string was pulled from the borehole, and the borehole was enlarged by connecting a 6 ¼" diameter insert-tooth tricone bit to the end of the drill string. Then the PW casing was set to 175 meters. The casing was grouted with cement grout at a density of 1.75 g/cm<sup>3</sup> up to the borehole head (Fig. 4).



Fig. 3. A view of the drill machine and drilling operation

Up to 600 meters of full cored drilling with a PQ diameter drill string was drilled, and the PQ diameter drill string was left in the borehole as casing. Then, the borehole was drilled to 800 meters as a full-core hole using the HQ-diameter drill string. At this depth, it was observed that the working torque of the drill string increased abruptly from time to time. Despite working with salt-saturated mud, 3 PQ rods were split off during pullout of the PQ-diameter drill string from the borehole and remained in the borehole. While the drill string was being pulled from the borehole, it was observed that the rods were primarily split at the connections. The 3

PQ rods that remained in the borehole were removed by fishing.

To solve the problem, 600 meters of HW left-hand-thread casing was lowered into the borehole. 2/3 of the casing weight was suspended from the borehole head. A 6-meter core barrel was attached to the HQ-diameter drill string, and the borehole began to penetrate. Penetration reached 1100 meters, and the drill string was pulled from the borehole to reduce the borehole diameter.

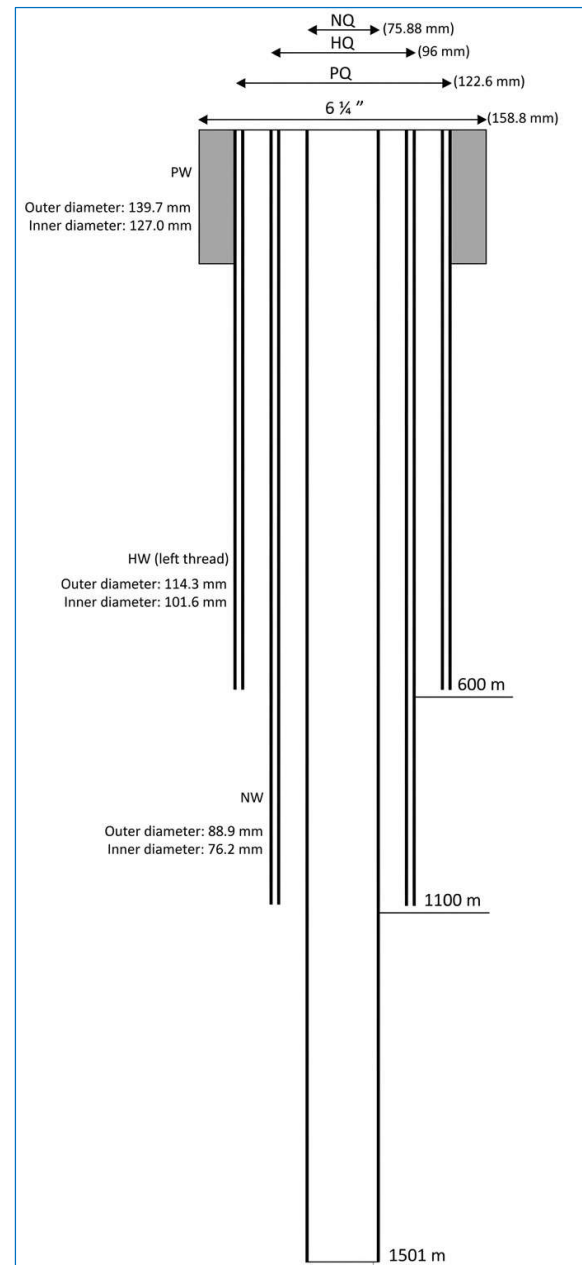


Fig. 4. Borehole design

To avoid repeating the same mistake, the NW casing was set to 1100 meters. When setting the casings, the manufacturer's torque values were taken into account. 2/3 of the weight of the casings was suspended from the borehole head. A 6-meter core barrel was attached to the drill string, and the NQ drill string was lowered into the borehole. The borehole was

terminated at a depth of 1501 meters in full core, without any problems. While drilling with the 6-meter core barrel, the tripping times for coring were halved. In addition, borehole measurements taken at the end of the borehole showed that the borehole deviated from the vertical by a maximum of 0.95 degrees.

This acceptable deviation indicates that a suitable drilling technique was used to drill the borehole. The effect of drilling with a 6-meter core barrel is significant in this low deviation. In this borehole, the salt formation was entered at 175 meters, and although interlayer clay bands were drilled, the salt formation was observed to continue until 1350 meters.



Fig. 5. Views of clays sticking on drill rods and decomposed clays

#### 4. Problems and Solutions

##### 4.1. Balling of sticky clays on the drill string

During the drilling of thick salt formations containing clay layers (such as in the study area), sticky clay can ball on the drill string and cause penetration problems (Fig. 5). It was observed that the clays, which had a muddy consistency, enveloped the drill string and held the drill string even during rotation, causing the drill string to stop completely. When the drill string was pulled from the borehole, the clay on the rods could hardly be cleaned, even with a trowel. To solve the problem, samples of the clay cleaned from the rods, drilling mud, drilling water, and chemicals were analyzed in laboratories.

As a result of the investigation, a new mud program was prepared. The entire drill string was cleaned and lubricated of the clay that had adhered to it, and drilling was resumed

under the new mud program. It is known that in saline formations, when only bentonite-amended mud is used, bentonite is affected by salt, and the expected efficiency cannot be obtained. For this reason, the geological units in the study area (a salt formation with clay interlayers) were drilled without any problems with 4% PAC-R + CMC<sub>heavy</sub> mud with a viscosity of 37-40 cp (centipoise) and 5 kg/ton lubricant (Penetrol Xtra). It was observed that the clay no longer balled and stuck to the rods.

##### 4.2. Anhydride Flocculation in Mud Pits

Especially if anhydrite is present in the clayey levels within the salt layers (due to anhydrite-calcium contamination in the mud), bentonite should never be used in the mud when drilling these units. Continue drilling with salt-saturated PAC-R + CMC<sub>heavy</sub>-based mud with a minimum density of 1.12 g/cm<sup>3</sup>. In this study, it was determined that the salt

degraded the bentonite, preventing the formation of the desired mud cake during filter press tests. Although there are no problems with coring or rate of penetration, the plastic viscosity of the mud increases due to the presence of anhydrite and clay interlayers encountered during drilling.

This even makes it difficult for the mud to flow from the borehole head to the mud pits. Moreover, when the mud is stationary, it completely flocculates in the mud pits and becomes too thick to be sucked by the mud pump and pumped into the borehole (Fig. 6).



Fig. 6. Views of the flocculation in the mud pit and discharging the flocculated mud from the pits

To facilitate the flow of mud from the borehole head to the sediment pit and from the sediment pit to the mud pit, chromium-free lignosulfonate diluted in a barrel was poured into the sediment setting channel drop by drop from a tap,

thereby reducing the plastic viscosity. The mud was continuously mixed with a mixer installed in the mud pits, especially near the sludge pump suction, thereby preventing stagnation and increasing plastic viscosity (Fig. 7).



Fig. 7. Ensuring movement of mud continuously mixed through a mixer placed in the mud pits

## 5. Conclusion

Deep diamond core drilling in thick salt formations is a specialized drilling application that requires technical expertise and experience. Drilling of thick salt formations is quite different from drilling other geological formations. The main problems typically associated with drilling salt formations are clay balling on the bit and drill string due to reactive shale/clay interlayers in salt formation, wellbore enlargement when drilling through the salt formation and/or

through shales/clays above or below the salt formation, excessive torque caused by salt creep and pressures on the drill string from the formation, tendency to deviate and excessive mud losses. In such formations, the properties of the drilling mud used become more important. Since the working environment is saline, the mud must be saturated with salt before it is pumped into the borehole (it is recommended that the mud density not be less than  $1.12 \text{ g/cm}^3$ ). This prevents the dissolution of salt formation from

being drilled and, therefore, of the core loss. When drilling salt formations, salt creeps into the borehole can interfere with drilling and casing operations. This can lead to drill string jamming, wellbore stability problems, and severe drill string vibration during drilling. Reducing drilling time as much as possible (high rate of penetration with controlled deviation) will mitigate salt creep-related problems. The geological units in the study area (salt formation with clay interlayers) were drilled with PAC-R+CMC<sub>heavy</sub> and lubricant-added mud without any problems. The clays in the salt formation were prevented from balling and sticking to the rods. In particular, salt-saturated PAC-R+CMC<sub>heavy</sub> based mud was used as anhydride in the clayey levels within the salt layers, thereby increasing the plastic viscosity of the mud. In addition, diluted chromium-free lignosulfonate was added to the mud, and the sludge was continuously mixed with a mixer placed in the mud pits to prevent mud stagnation and an increase in plastic viscosity. At the end of the penetration, to facilitate the driller's ability to follow the break-off of the core in the bottomhole, the inner diameter of the core lifter used must be narrowed by hand-bending before it is placed into the core lifter case. This ensures that the core enters the core lifter case slightly tighter and more securely and breaks in a way that the driller can feel.

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