EFFECTS OF THE FORMATION TO THE ORIENTATION OF THE DIRECTIONAL WELLS IN THE ADIYAMAN REGION

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ABSTRACT

EFFECTS OF THE FORMATION TO THE ORIENTATION OF THE DIRECTIONAL WELLS IN THE ADIYAMAN REGION

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Directional drilling is controlling the inclination and azimuth of a wellbore to reach a predetermined underground target and is a method used widely nowadays. There are various methods for directional drilling operations such as; Mud Motor & Measurement While Drilling System (MWD) or Rotary Steerable System to reach the targets. Within the scope of this study, Mud Motor and MWD were used to change orientation of the hole. While drilling with mud motor, directional drillers (DD) make sliding drilling which means that DD drill with a mud motor rotating the bit downhole without rotating the drill string from the surface with using Tool-face which is taken from MWD system. Controlling hole orientation is important to drill smooth wells, to follow the plan with low tortuosity, to hit the target and to finish the well early. Several studies have been performed to investigate the parameters that affects the hole orientations. The factors affecting the orientation of the hole are weight on bit (WOB), bottom hole assembly (BHA), hole size, rotary speed (RPM), flow rate (GPM), stabilizers position on the drill string, drilling bit and stabilizers gauge. In addition to all of these parameters, orientation of the wells is also affected from the formation properties.

This study detailed the effects of the formations to the orientation of the directional wells in the Adıyaman Region with the help of the field data. Even if the same parameters (WOB: 10-11 tones, flow rate: 450 gpm, RPM:40) are applied and the same equipments (8-3/8” of outer diameter sleeve stabilizer, 7-3/4” of outer diameter integral blade stabilizer, equal length of drill collars, roller cone drilling bit) are used in seven different wells to drill 8.5” (0.216 m) hole in diameter, theoretical expectations with respect to the orientation may not be obtained due to the formation effects. To see this effect, North/South and East/West deviations were calculated according to the wellhead location with the real and the calculated survey data. Real survey data were taken from the wells for every 30 m interval with the help of the MWD system. Moreover, data used for theoretical deviation calculation were obtained with using the output dog-leg of the Mud Motor. The differences between real and calculated results show the effect of the formation to the orientation and this gives us a chance to see if there is a trend or not between the wells when respective results are compared.

As a result of this study, it was observed that there is a trend in the effect of the formation on the orientation in the Adıyaman Region. The direction and the deviation of the wells change for different wells although the formation has the same lithology. Moreover, the results show that when a well is drilled in a certain wellhead location in this region, the direction does not change from top to the bottom of the section.

Keywords: Directional Drilling, Formation Affect to Deviation, Adıyaman Region

ÖZ

ADIYAMAN BÖLGESİNDE YÖNLÜ KUYULARDA FORMASYONUN YÖNELİME ETKİSİ

Ünlü, Ahmet
Yüksek Lisans, Petrol ve Doğal Gaz Mühendisliği
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Yönlü sondaj belirlenmiş bir hedefe ulaşmak için kuyunun yönünün ve açısının ayarlanması için günümüzde yaygın olarak kullanılan bir metottur. Yönlü sondaj operasyonlarında hedefe ulaşmak için sondaj motoru (mud motor) & sondaj sırasında ölçüm sistemi (measurement while drilling system) ya da rotasyon sırasında yönlendirilebilen (rotary steerable) sistemler gibi çeşitli metotlar kullanılmaktadır. Bu tez kapsamında, sondaj motoru & sondaj sırasında ölçüm sistemi kuyu yönünü değiştirmek için kullanılmaktadır. Yönlü sondaj mühendisleri mud motor ile yönlü sondaj yaparken kaydırarak sondaj yaparlar; bu da sondaj masasından rotasyon vermeden sondaj sırasında ölçüm sisteminden gelen matkabın yönünü kullanarak sadece mud motor ile yer altında matkaba rotasyon verilmesiyle yapılan sondaj anlamına gelmektedir. Düzgün bir kuyu kazmak, eğriliği az olacak şekilde kuyu planını takip etmek, hedefi vurmak ve kuyuları erken bitirmek için kuyunun yönünü kontrol etmek önemlidir. Kuyu yönünü etkileyen parametreleri incelemek için birçok çalışma yapılmıştır. Bu faktörler matkaba verilen ağırlık, sondaj dizisi dizaynı, kuyu çapı, rotasyon hızı, debi, dizide bulunan dengeleyicinin pozisyonu, matkap ve dengeleyicinin çapıdır. Bu parametrelere ilave olarak, kuyunun yönelimi formasyon özelliklerinden de etkilenmektedir.

Bu çalışmada saha dataları kullanılarak formasyonun Adıyaman bölgesindeki yönlü kuyuların yönelimine etkisi detaylandırılmıştır. 7 farklı kuyuda 8.5” (0.216 m) çapında sondaj yapılırken aynı parametreler (matkaba verilen ağırlık: 10-11 ton, akış hızı: 450 gpm, dakikadaki rotasyon devri: 40) uygulansa ve aynı ekipmanlar (8-3/8” çapında manşonlu dengeleyici, 7-3/4” çapında integral bıçaklı dengeleyici, eşit uzunlukta sondaj dizisi ekipmanı, konili sondaj matkabı) kullanılsa da yönlendirme için düşünülen teorik sonuçlara formasyonun farklılığından dolayı ulaşılacağı garantilenemez. Bu etkiyi görmek için, Kuzey/Güney, Doğu/Batı yönelimleri gerçek ölçüm değerlerine ve hesaplanan değerlere göre kuyu başı referans alınarak hesaplanmıştır. Gerçek ölçüm değerleri 30 metre aralıklarla sondaj sırasında ölçüm sistemi yardımıyla alınmıştır. Sapmanın teorik olarak hesaplanması için kullanılan değerler sondaj motorunun keskin dönüş açı verileri kullanılarak elde edilmiştir. Gerçek ve hesaplanmış değerler arasındaki fark formasyonun yönelime etkisidir ve birbiri ile kıyaslayarak kuyular arası bir benzeşme olup olmadığını görmemize olanak verir.

Bu çalışmanın sonucu olarak, Adıyaman bölgesinde formasyonun yönelim üzerinde bir etkisi olduğu saptanmıştır. Formasyonun aynı litolojiye sahip olmasına rağmen, kuyuların yön ve yönelimi kuyudan kuyuya değişmektedir. Buna ilave olarak, Adıyaman bölgesinde belirli bir noktada yapılan sondajda delme aralığın başından sonuna kadar yönün değişmediği gözlenmiştir.

Anahtar Kelimeler: Yönlü Sondaj, Yönelime Formasyon Etkisi, Adıyaman Bölgesi

to my beloved decedent mother

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I would first like to thank my thesis advisor Prof. Dr. Tanju Mehmetoğlu. My professor had always faith in my capability. He encouraged me to work hard and believe me that I will do the right things when I encountered problems.

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ABBREVIATIONS

A1	Azimuth at the Upper Survey Station
A2	Azimuth at the lower Survey Station
Azi	Azimuth, °
BHA	Bottom Hole Assembly
BR	Build Rate Angle, °/30 m
DLS	Dog Leg Severity, °/30 m
EW	East West Deviation, m
GPM	Gallons per Minute
GTF	Gravity Tool Face, °
I1	Inclination at the Upper Survey Station
I2	Inclination at the Lower Survey Station
IADC	International Association of Drilling Contractors
ID	Inner Diameter, inc
Inc	Inclination, °
KOP	Kick off Point
Lsliding	Length of Sliding Section, m
LWD	Logging While Drilling
MD	Measured Depth, m
MWD	Measurement While Drilling

NS	North South Deviation,m
OD	Outer Diameter, inc
PDC	Polycrystalline Diamond Compact
R	Radius of Curvature, ft
RF	Ratio Factor
RPM	Revolution per Minute
RSS	Rotary Steerable System
TVD	True Vertical Depth, m
WOB	Weight on Bit, ton
NE	Northeast
NW	Northwest
SE	Southeast
SW	Southwest
NNW	North-northwest
WNW	West-northwest
WSW	West-southwest
SSW	South-southwest
SSE	South-southeast
ESE	East-southeast
ENE	East-northeast
NNE	North-northeast

LIST OF SYMBOLS

SYMBOLS

γ	Formation dip
Gx, Gy	Accelerometer components which are not parallel to the tool axis
h	Anisotropy index
β	Dog-Leg Angle, °
ΔEast	East / West tendency, m
ΔMD	Measured depth between two survey station m
ΔNorth	North / South tendency, m
ΔTVD	Vertical length between two survey location, m
Φ	Instantaneous change of angle, °
α	Bend Angle, °
σ	Standard Deviation

CHAPTER 1

INTRODUCTION

The increasing demand for energy leads to the extraction of hydrocarbons from smaller reservoirs for increasing production. To reach small reservoirs and to increase production with increasing contact length between production tube and reservoir is not an easy task. Directional drilling represents itself as an efficient way to increase the contact length for this kind of purpose. Moreover, surface construction of drilling can be minimized while drilling to the different reservoirs. In addition, one can drill from one location to separate reservoirs. Even though the cost of directional drilling is higher, it reduces the spending for the surface construction.

From past to present, directional drilling is carried out using different techniques. These are intelligent and complex technologies like mud motor with measurement while drilling (MWD) system, real-time multi survey measurement, usage of steerable assemblies, logging while drilling (LWD) and older techniques like whipstocks, rotary assemblies and jetting *(Halliburton, 1997)*.

According to the Turkish Petroleum Corporation 2013 annual report *(TPAO, 2013)*, 25 % of the total oil production of Turkey is from the Adıyaman Region. Therefore, drillings in the Adıyaman Region have increased significantly lately. The number of directional drilling in the Adıyaman Region has also increased to get more oil, to drill smooth wells, to follow the plan with low tortuosity, to reach the target and to finish the well in a short time.

There are many studies about the factors which affect the hole orientation while drilling. These factors are weight on the bit, bottom hole assembly, hole size, formation, rotary speed, flow rate, stabilizers position on the drill string, drilling bit and stabilizers gauge.

According to Lubinski and Woods *(Lubinski & Woods, 1953)*, when drilling operation is in uniform formation, the inclination and dog-leg do not change however, it is hard to find uniform formations while drilling. When they compare the parameters affecting the hole deviation, they found out that formation is the main parameter affecting the hole orientation. According to Boualleg, Sellami, Menand Simon it is mentioned that side forces that change the direction of the bit, can be generated while passing from hard to soft or soft to hard formations. They have a study in which the changes in the inclination have been detailed in isotropic and anisotropic formations. They observed that the inclination changes equally in the isotropic formations while it does not change at a certain rate in the anisotropic formation. Moreover, according to their study, the dip angle is more sensitive to the weight on the bit *(Boualleg, Sellami, Menand, & Simon, 2006)*. As seen in these studies, drilling a directional well faces various challenges. Formation properties are also accepted as the main challenge by the directional drillers because it is not controlled by the drillers.

The effect of the formation to the orientation of the directional wells has been investigated for the Adıyaman Region in this thesis due to its importance in directional drilling as mentioned above. The Adıyaman Region was particularly choosen since it has important oil reserves in Turkey.

To see the effect of the formation, the North/South and the East/West orientations have been calculated for two different inclination, azimuth values according to the distances from wellhead location. One comes from measurement while the drilling system which is accepted as the real values and the other comes from calculations done with the length of the sliding that affects the output dog-leg of mud motor and tool-face of the bit. The differences between the real and the calculated results give us the effect of the formation to the orientation; thus the respective results coming from this difference permits us to see if there is a tendency or not between the wells.

In the Literature Review part, definition, history, application and types of directional drilling, survey calculation methods, studies done before about factors that affect the orientation of directional well borehole have been investigated and formation has been researched deeply for the Adıyaman Region. In Statement of the Problem part, the aim and necessity of this thesis have been detailed. In Materials and Methods, how to make directional drilling and which equipment should be used have been explained. Data obtained from the Adıyaman field was viewed in detail and plotted to see the effect of formation on the orientation of wellbore in the directional wells in the Result and Discussion of this thesis. At the end of this thesis, Conclusions are located.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Directional Drilling

The definition of directional drilling is following a path created from the starting coordinate to the target whose location is a given lateral distance, direction and deviation from the vertical. It is mostly applied in petroleum, natural gas and geothermal fields nowadays. The importance of directional drilling increases day by day.

2.2 History of Directional Drilling

The first directional well has been observed in Seminole, Oklahoma field. At that date, many wells have been drilled in that region and all were very close to each other. It was noticed that they have encountered the producing formation at different measured depths. As a consequence, it was thought that these wells were not vertical. In 1920's tools used to measure inclination and azimuth were developed. When wells were measured in Seminole, 46° of inclination was seen from vertical (*Directional Drilling- Chapter 12, 2007*). In 1930's first directional well was drilled consciously in Huntington Beach, California (*Directional Drilling- Chapter 12, 1996*). The first downhole motor to give direction was designed in 1958. The first tool to measure drift, direction and tool-face was designed in 1969, IADC Drilling Manuel (*Rig, 2015*). At present time, RSS (rotary steerable system) is mostly used to drill directionally with continuous rotation. It eliminates sliding while giving direction *(Oilfield Glossary, 2019).*

2.3 Application of Directional Drilling

Directional drilling is applied in drilling fields for different applications. All applications are detailed below.

2.3.1 Multiple Wells from an Artificial Structure

This technique is applied mostly in offshore drilling as seen in Figure 2.1. Drilling a single well from an individual platform is uneconomical and time-consuming. Therefore, using a single structure to drill multiple wells is possible thanks to the directional drilling.

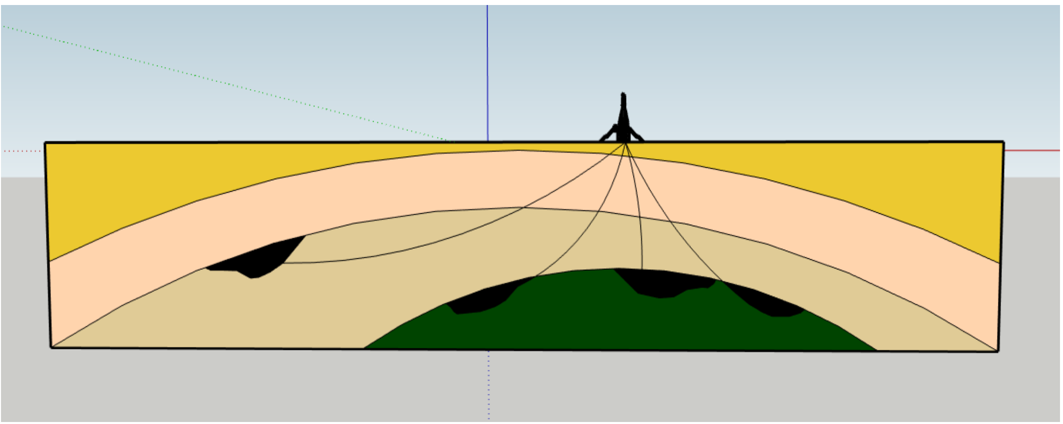


Figure 2.1. Multiple Wells from an Artificial Structure (Baker & Hughes INTEQ Inc, 1995)

2.3.2 Relief Well Drilling

When the reservoir pressure is higher than the hydrostatic pressure created by the drilling fluid weight, sometimes blow out (the uncontrollable release of oil and/or gas from the drilling wells) can occur. After all methods and systems have failed to prevent and to stop blowout, relief well can be drilled to stop it, as seen in Figure

2.2. The plan to drill relief well is made to hit the uncontrolled well. Heavy drilling fluid is pumped into well to overcome the pressure to bring the well under control.

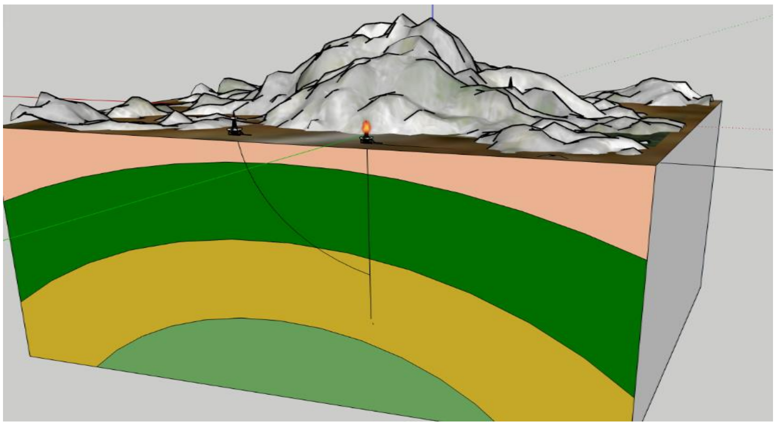


Figure 2.2. Relief Well Drilling (Baker & Hughes INTEQ Inc., 1995)

2.3.3 Straight Hole Drilling

When drilling companies want to drill a straight hole, they need to take help from directional drilling equipment and personnel. The deviation of hole is affected by many reasons are detailed in this thesis. Straight hole seen in Figure 2.3 is drilled to avoid crossing lease lines and to stay within the place determined in the contract *(Baker & Hughes INTEQ Inc., 1995).*

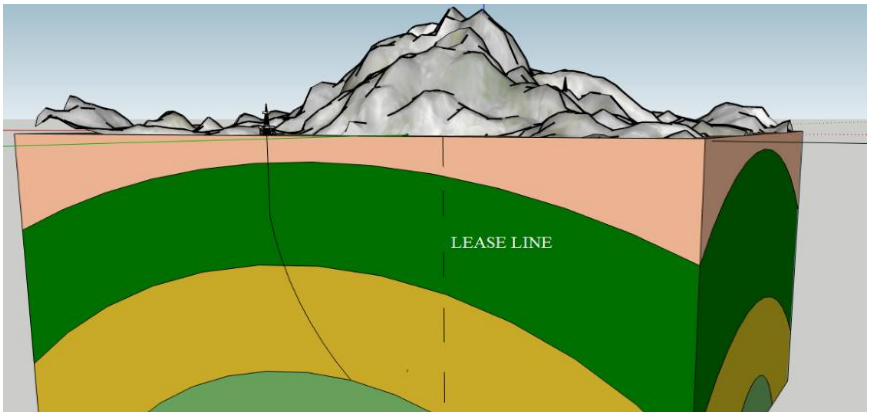


Figure 2.3. Straight Hole Drilling (Directional Drilling- Chapter 12, 2007)

2.3.4 Drilling at Inaccessible Location

When the surface location is not suitable to drill directly, directional drilling is used to reach target which is located under severe topographic features such as towns, rivers, mountains, etc. as shown in Figure 2.4 *(Devereux, 1998).*

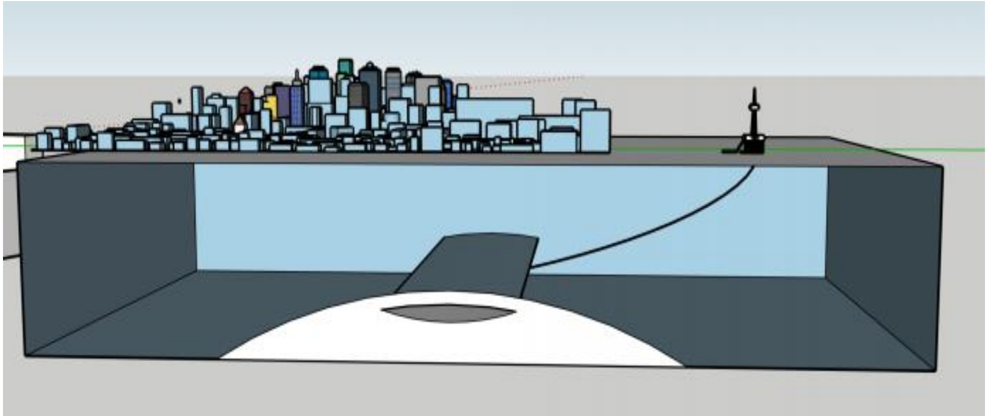


Figure 2.4. Drilling at Inaccessible Location

2.3.5 Drilling a Multiple Well from a Single Wellbore

This application is generally used for exploration wells. After the first well is closed, the second well is drilled to explore different regions. Figure 2.5 shows this application.

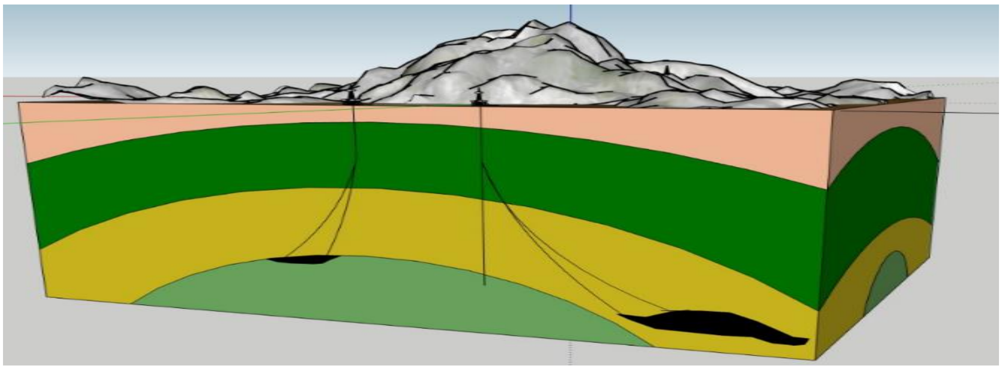


Figure 2.5. Drilling a Multiple Well from a Single Wellbore (Smith, 1996)

2.3.6 Side Track Drilling

Sidetrack operation is one of the directional drilling applications. When the well has an obstruction such as fish, we need to drill a new well to reach predetermined target using digged wellbore above fish. The following Figure 2.6 shows the sidetrack drilling.

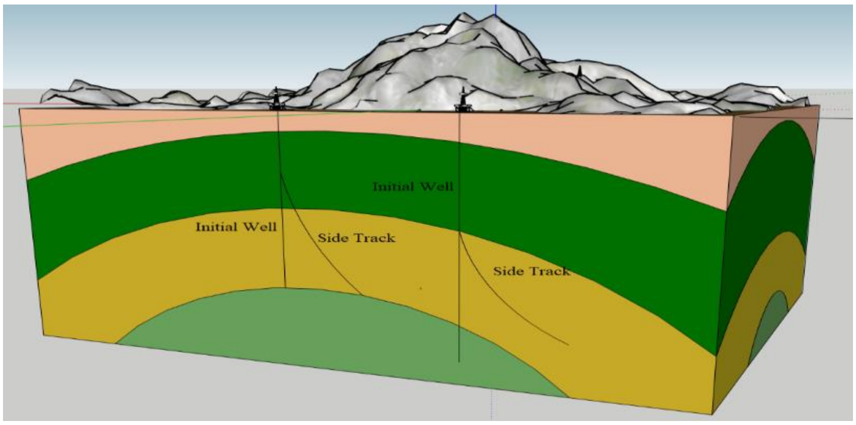


Figure 2.6. Side Track Drilling (Baker & Hughes INTEQ Inc., 1995)

2.3.7 Fault Drilling

Faults have very sharp inclined formations, therefore drilling faults vertically is risky and hard. Directional drilling is used to eliminate risks created by faults. Figure 2.7 shows how the fault is drilled.

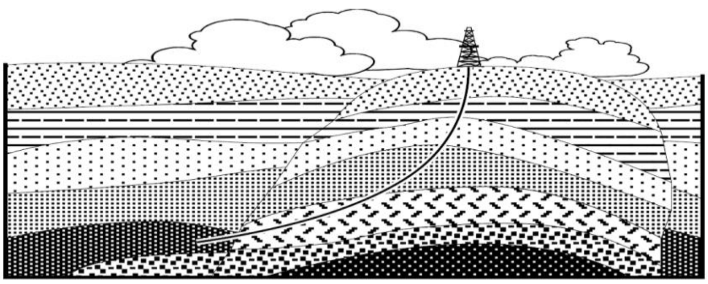


Figure 2.7. Fault Drilling (Baker & Hughes INTEQ Inc., 1995)

2.3.8 Salt Dome Drilling

Drilling salt dome creates drilling problems such as breaking off drill string, caving off formation, etc. Directional drilling is used to overcome this kind of problems. Instead of salt formation, the well is drilled at one side of the dome to reach reservoirs captured under salt dome.

2.3.9 Horizontal Drilling

When inclination of the well is higher than 80°, it is called horizontal well. The purpose of the horizontal well is to penetrate reservoir longer to increase production and to avoid encountering water-oil contact in a short time. Figure 2.8 describes the horizontal drilling.

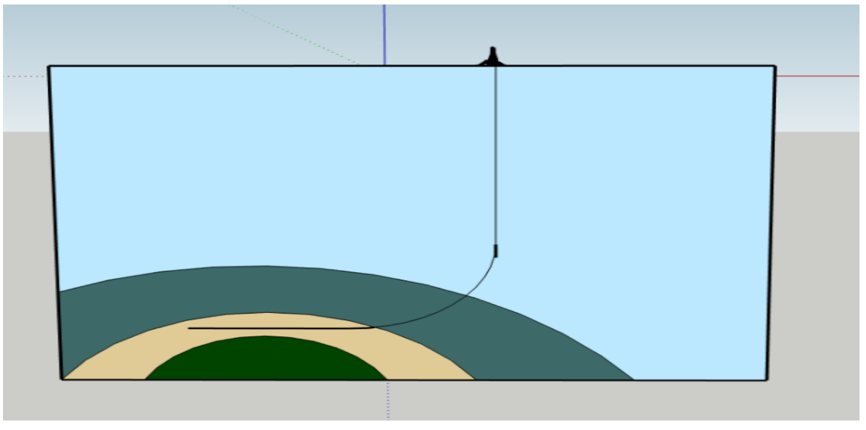


Figure 2.8. Horizontal Drilling (Directional Drilling- Chapter 12, 2007)

2.4 Types of Directional Drilling Design

Directional drilling plans involve three-dimensional design techniques. Although many complex plans can be created on the table, it is generally hard to drill these paths in the field. Therefore, three types of well plans are used commonly *(Baker & Hughes INTEQ Inc., 1995)*. Figure 2.9, Figure 2.10 and Figure 2.11 show the types of the directional drilling designs.

2.4.1 Build and Hold Design

The meaning of build is to increase the inclination of the wellbore. The meaning of hold is to keep the inclination and azimuth of the wellbore. In this type of pattern, a directional driller increases the inclination in the desired direction, then keep the inclination and azimuth to hit the target. This pattern is generally applied for moderate and deep wells with moderate and large horizontal displacement.

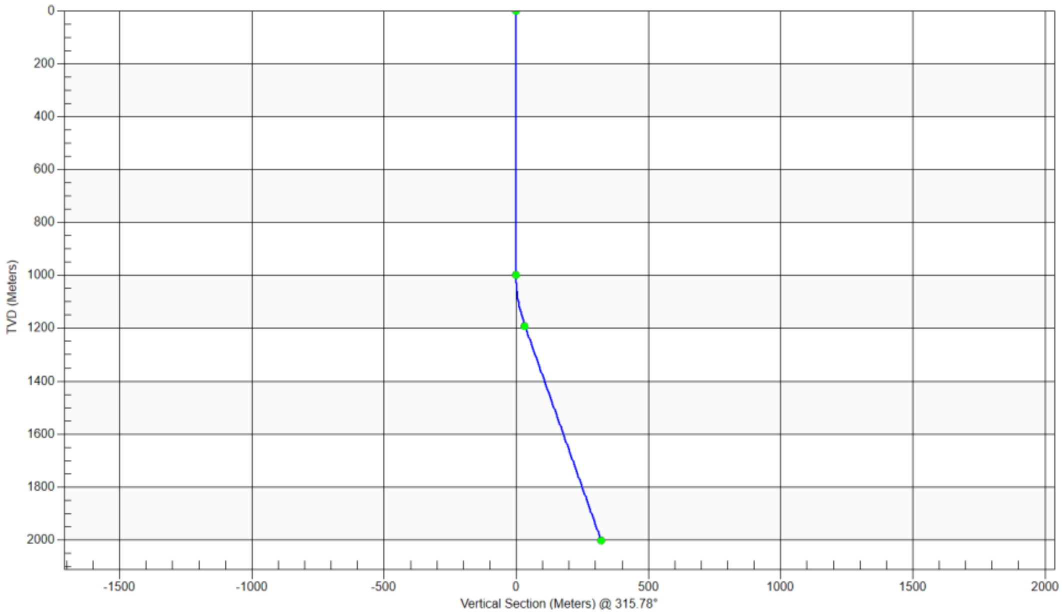


Figure 2.9. Build and Hold Pattern of Well

2.4.2 S Type Design

S type well includes build, hold and dropping section. The meaning of build and hold has been previously explained. The meaning of drop is decreasing the inclination in the desired direction. This pattern is applied for deep holes with small horizontal displacement and also to drill multiple pay zones. This design has some problems like high torque and drag and creates more risk of key-seating.

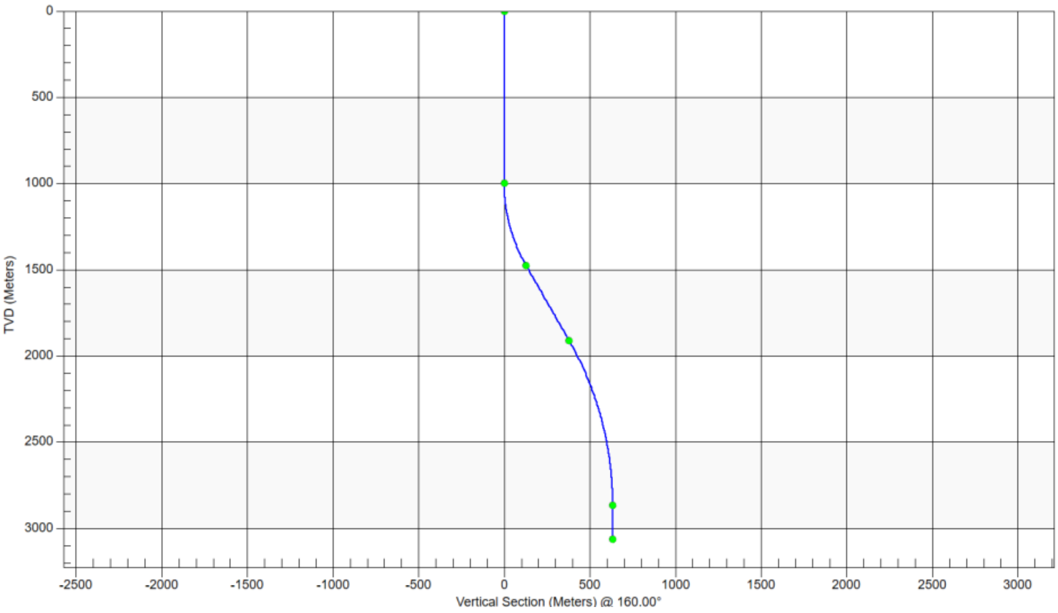


Figure 2.10. S Type Design

2.4.3 Deep Kickoff and Build Design

Before increasing inclination in the desired direction, the well is drilled vertically to a certain depth. After that, inclination is increased to reach the target. This design is generally used for salt dome drilling *(Baker & Hughes INTEQ Inc., 1995).*

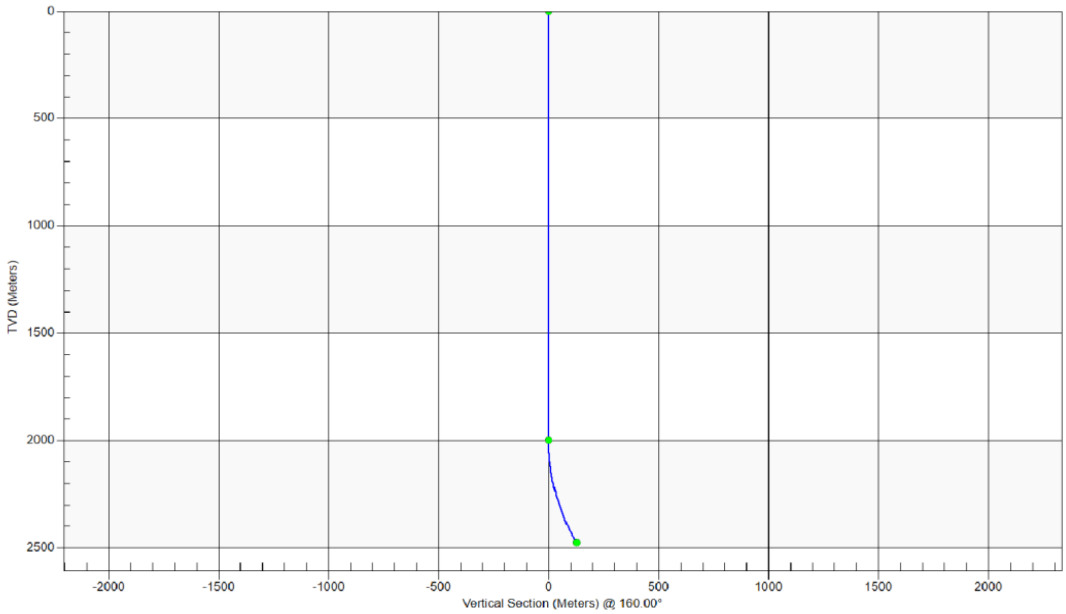


Figure 2.11. Deep Kick-off and Build Design

2.5 Terminology Used in Directional Drilling

There are different terminologies used in the directional drilling to understand the direction, trajectory and design of the wellbore. The terminologies mainly used are listed below(Cooper, 2006).

- Inclination: The angle between vertical line below the surface location of the drilling rig and the tangent line at a position in a wellbore. Inclination is expressed in degrees. In the field, there are some methods to measure inclination such as measurement while drilling accelerometers and gyroscopes.
- Azimuth: The angle between the vertical projection of well on a horizontal plane and the true north or magnetic north. Azimuth is measured clockwise from the north as seen in Figure 2.12.

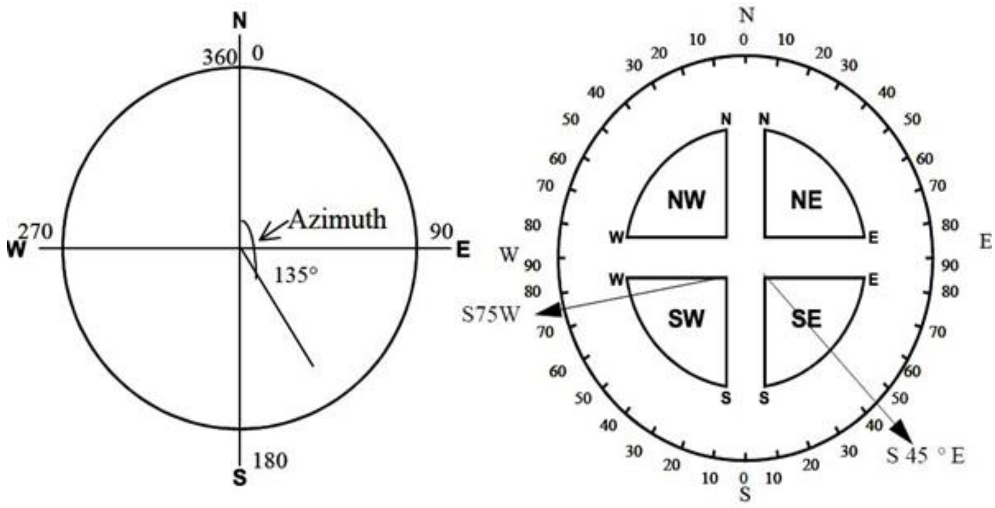


Figure 2.12. Azimuth Direction (Cooper, 2006)

- Grid North: It is the direction of the north along the grid lines of a map projection
- Magnetic North: It is the direction of the north along the north magnetic pole
- True North: It is the direction between gird north and magnetic north.
- Magnetic Declination: The angle between magnetic north and true north.
- Grid Convergence: The inclination between grid north and true north.
- Build Angle (BR): It is the change of inclination increase with depth; it is expressed in ° / 30 m or ° / 100 ft.
- Dogleg Severity (DLS): It is the change of inclination and azimuth of a borehole; it is expressed in ° / 30 m or ° / 100 ft.
- Hold (Tangent): The meaning of hold is keeping inclination and azimuth of the wellbore.
- Horizontal Displacement: It is a distance between two points which are projected on a horizontal plane.
- True Vertical Depth (TVD): It is the vertical depth of a borehole.
- Measured Depth (MD): It is the actual length from a surface location to the end of the wellbore.

- Kickoff Point (KOP): The first depth on the wellbore where inclination is increased purposely.
- Course Length: It is the difference between measured depths of two stations on the wellbore.
- Departure: It is a horizontal displacement of one station from another station in an east or west direction.
- Survey: It is the result of inclination and azimuth at a determined measured depth.
- Revolution Per Minute (RPM): It is the number of turning of drill string in a minute while drilling.
- Weight on Bit (WOB): It is applied weight to the bit while drilling operations.
- Flow Rate: It is the flow pumped into the wellbore to clean hole and to keep hole under stable position.

2.6 Survey Calculation Methods

There are several survey calculation methods to obtain TVD, north/south tendency and east/west tendency. Four of them are commonly used in directional operations. These are average angle, tangential, radius of curvature, and minimum curvature methods *(Farah, 2013).* Terms listed below are used for the calculations.

ΔMD: Measured depth between two survey location (m)
I1: Inclination at the upper survey (°)
I2: Inclination at lower survey (°)
A1: Azimuth at the upper survey (°)
A2: Azimuth at the lower survey (°)
RF: Ratio factor
ΔNorth: North / South tendency (m)
ΔEast: East / West tendency (m)

ΔTVD: Vertical length between two survey location (m)

2.6.1 Average Angle Method

Average angle method has very basic trigonometric calculations; therefore it is not a totally reliable method *(Škrjanc & Vulić, 2016*). Equations 2.1, 2.2 and 2.3 are used to calculate north deviation, east deviation and true vertical depth, respectively.

$$\Delta \mathrm{North} = \Delta \mathrm{MD} \times \sin(\frac{\mathrm{I1+I2}}{2}) \times \cos(\frac{\mathrm{A1+A2}}{2}) \tag{2.1}$$

$$\Delta \mathrm{East} = \Delta \mathrm{MD} \times \sin(\frac{\mathrm{I1+I2}}{2}) \times \sin(\frac{\mathrm{A1+A2}}{2}) \tag{2.2}$$

$$\Delta \mathrm{TVD} = \Delta \mathrm{MD} \times \cos(\frac{\mathrm{A1+A2}}{2}) \tag{2.3}$$

2.6.2 Tangential Method

This method uses only inclination and azimuth values at lower survey. The wellbore is assumed straight line. Therefore, this method is the least reliable method *(Škrjanc & Vulić, 2016)*. Equations 2.4, 2.5 and 2.6 are used to calculate north deviation, east deviation and true vertical depth, respectively.

$$\Delta \mathrm{North} = \Delta \mathrm{MD} \times \sin(\mathrm{I2}) \times \cos(\mathrm{A2}) \tag{2.4}$$

$$\Delta \mathrm{East} = \Delta \mathrm{MD} \times \sin(\mathrm{I2}) \times \sin(\mathrm{A2}) \tag{2.5}$$

$$\Delta \mathrm{TVD} = \Delta \mathrm{MD} \times \cos(\mathrm{I2}) \tag{2.6}$$

2.6.3 Radius of Curvature Method

This method uses the inclination and azimuth values from the lower and upper survey stations. Two survey stations are located on the cylinder and the axis of it is vertical and this method has a radius equal to the radius of curvature in the horizontal plane. In this method, TVD is not affected by changes in azimuth. This method is more reliable than the tangential and average angle methods *(Škrjanc & Vulić, 2016)*. Equations 2.7, 2.8 and 2.9 are used to calculate north deviation, east deviation and true vertical depth, respectively.

$$\Delta \text{North} = \frac{\Delta \text{MD} \times [(\cos(\text{I1}) \times \cos(\text{I2})) + (\sin(\text{A2}) \times \sin(\text{A1}))]}{(\text{I2} - \text{I1}) \times (\text{A2} - \text{A1})} \quad (2.7)$$

$$\Delta \text{East} = \frac{\Delta \text{MD} \times [(\cos(\text{I1}) \times \cos(\text{I2})) + (\cos(\text{A2}) \times \cos(\text{A1}))]}{(\text{I2} - \text{I1}) \times (\text{A2} - \text{A1})} \quad (2.8)$$

$$\Delta \text{TVD} = \frac{\Delta \text{MD} \times (\text{Sin}(\text{I2}) - \text{Sin}(\text{I1}))}{\text{I2} - \text{I1}} \quad (2.9)$$

2.6.4 Minimum Curvature Method

Minimum curvature method creates a circular arc between the lower and upper survey stations instead of a straight line. To calculate the length of arc, RF is used as a dog-leg scale factor. This method is the most reliable method to make calculations in the directional drilling *(Škrjanc & Vulić, 2016)*. Equations 2.10, 2.11, 2.12, 2.13 and 2.14 are used to calculate north deviation, east deviation and true vertical depth, respectively.

$$\Delta\text{North} = \frac{\Delta\text{MD}}{2} \times [\sin(\text{I1}) \times \cos(\text{A1}) + \sin(\text{I2}) \times \cos(\text{A2})] \times \text{RF} \qquad (2.10)$$

$$\Delta\text{East} = \frac{\Delta\text{MD}}{2} \times [\sin(\text{I1}) \times \sin(\text{A1}) + \sin(\text{I2}) \times \sin(\text{A2})] \times \text{RF} \qquad (2.11)$$

$$\Delta\text{TVD} = \frac{\Delta\text{MD}}{2} \times ((\cos(\text{I1}) + \cos(\text{I2})) \times \text{RF} \qquad (2.12)$$

$$\cos(\theta) = \cos(\text{I2} - \text{I1}) - \sin(\text{I1}) \times \sin(\text{I2}) \times (1 - \cos(\text{A2} - \text{A1})) \qquad (2.13)$$

$$\text{RF} = \frac{2}{\theta} + \tan(\frac{\theta}{2}) \qquad (2.14)$$

2.7 Parameters Effecting Orientation of Wellbore

In this chapter, the studies done previously about the factors affecting the orientation of directional well boreholes have been investigated and the formation of the Adıyaman region has been given as mentioned in the Introduction part.

Dogleg severity is the change of inclination and azimuth within the specific measured depth as mentioned in terminology. Therefore, parameters affecting dog-leg also affect the orientation in directional well. Gharip and Kirkhope investigated the effects of weight on bit , stabilizers clearance, borehole enlargement, type of bottom hole assembly (BHA) and weight on bit (WOB) effect in their study *(Gharib & Kirkhope, 2017)*. According to their study, there is a new approach about the modeling of dog-leg severity (DLS) while drilling a well directionally. This is called a Three-Point Contact method. Mud Motor manufacturers give a dogleg capacity of motors neglecting effects such as weight on bit, stabilizer and borehole contact. The conventional Three-Point Contact method is shown in Figure 2.13.

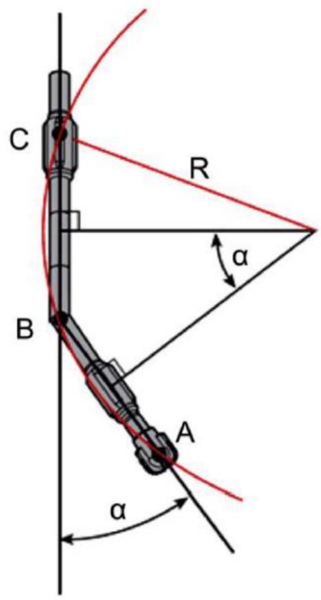


Figure 2.13. Conventional Three-Point Contact Method (Gharib & Kirkhope, 2017)

In this figure, there are three points which are point A (bit), point B (Bending point on Mud motor) and Point C (integral blade stabilizer above mud motor). According to Karlsson, Brassfield and Krueger, Equations 2.15 and 2.16 are used to calculate the dog-leg severity seen in Figure 2.14. *(Karlsson, Brassfield, & Krueger, 1985)*. These formulas are as follows.

$$R = \frac{28.65}{\alpha} \times (AB + BC) \qquad (2.15)$$

$$DLS = \frac{200 \times \alpha}{AB+BC} \qquad (2.16)$$

R is a radius of curvature (ft)(1 m=3.28 ft), AB is a distance from bit to bend of mud motor (ft)(1 m=3.28 ft), BC is a distance from bend of mud motor to stabilizer above of motor(ft)(1 m=3.28 ft), α is a bend angle (°) which is adjusted on motor before drilling operations and DLS is a dogleg severity (°/100 ft) or (°/30 m)

Up to this point, weight on bit, hole clearance, type of bottom hole assembly (BHA) have been neglected. However, these parameters affect the dog-leg severity; when the dog-leg severity changes, the direction and deviation of wellbore also change. In this article, these effects have been detailed. Bottom hole assembly classification depends on number of stabilizers and location of them. If one does not use mud motor any stabilizers on the bottom hole assembly, the BHA is defined as slick BHA. Three-point contact method does not work well at this condition. To evaluate the behavior of BHA, one need to consider the first the stabilizer located above mud motor and sleeve stabilizers on mud motor. If there is no stabilizer above mud motor, the third point to withstand is not certain. According to Karlsson and Brassfield, bending effect created by weight on bit affects the direction as increasing inclination or decreasing inclination (Karlsson et al., 1985). Figure 2.14 shows the effect of weight on bit.

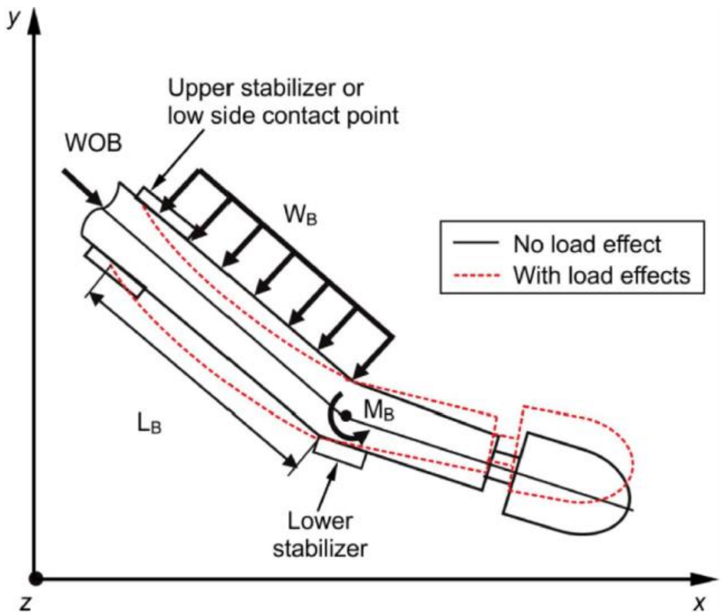


Figure 2.14. Bending Effect (Karlsson et al., 1985)

In Figure 2.14, WOB is the weight on bit applied while drilling, W_B is side load, M_B is moment, L_B is the length from the first stabilizer to the second stabilizer on the bottom hole assembly. Looking closely to this figure, one can say that when WOB increases, inclination tends to increase. Karlsson and Brassfield have studied the cases where there is a stabilizer above mud motor or not in their study. If stabilizer gauge is full gage (equal to hole size), bending affects dog-leg less *(Karlsson et al., 1985).* Moreover, hole enlargement has a slight effect on the three contact point method. When the hole diameter is bigger than the bit diameter, clearance between stabilizers and hole wall increases. This causes more bending on motors and effects inclination.

Marchand and Kalantari investigated build rate estimation in their study *(Marchand & Kalantari, 2013)*. Build rate is the change in inclination as mentioned in terminology. They compared a simple build rate estimation method and the industry's standard method. In other words, there are two methods to calculate build rate which are the bit tendency method as a simple build rate estimation and three-point geometry method as an industry's standard method. When these researchers compared them, they found that bit tendency method is more reliable than the three-point geometry because the three-point contact method does not respond well when there is no stabilizer located above mud motor. Moreover, the bit tendency method includes the effect of bit type and design, weight on bit, side force generated at the bit. This increases the accuracy of it to estimate the build rate.

The infleunce of rotary drilling assemblies has been studied in terms of building or dropping effects *(Jogi, Burgess, & Bowling, 1988).* According to this article, weight on bit, the number of stabilizers, location of the stabilizer, drill collar stiffness, borehole inclination and curvature, hole size, rotary speed, formation strength and formation dip have very important roles to predict the build and drop tendency of the bottom-hole assembly. In the build section while drilling directionally, side force applied to the bit is negative which means that side force affects bottom-hole assembly to reduce inclination. In the drop section, side force was accepted as zero which means that it acts to keep inclination. According to above researchers, the most important feature of designing bottom-hole assemblies is the location of the first few stabilizers. If one uses under gauge stabilizer as a sleeve stabilizer just above the bit, the BHA tends to decrease inclination and, if one adds a second stabilizer after one collar length which is also under gauge, the effect of this BHA is less mentioned. This BHA is called hold bottom-hole assemblies. The third stabilizer located on bottom-hole assemblies does not have a significant effect. If there is one under gauge stabilizer located just above the bit and one under gauge integral blade stabilizer located above two or more collar size, one can have building effect BHA but if one starts to move stabilizer located just above the bit through to the second stabilizer, the result is that the building effect turns to drop effect. If BHA has one stabilizer located above two collars size, this BHA has a dropping effect. The following Figure 2.15 describes briefly the importance of stabilizer for controlling orientation. *(Michael J. Economides, Larry T. Watters, 1998)*

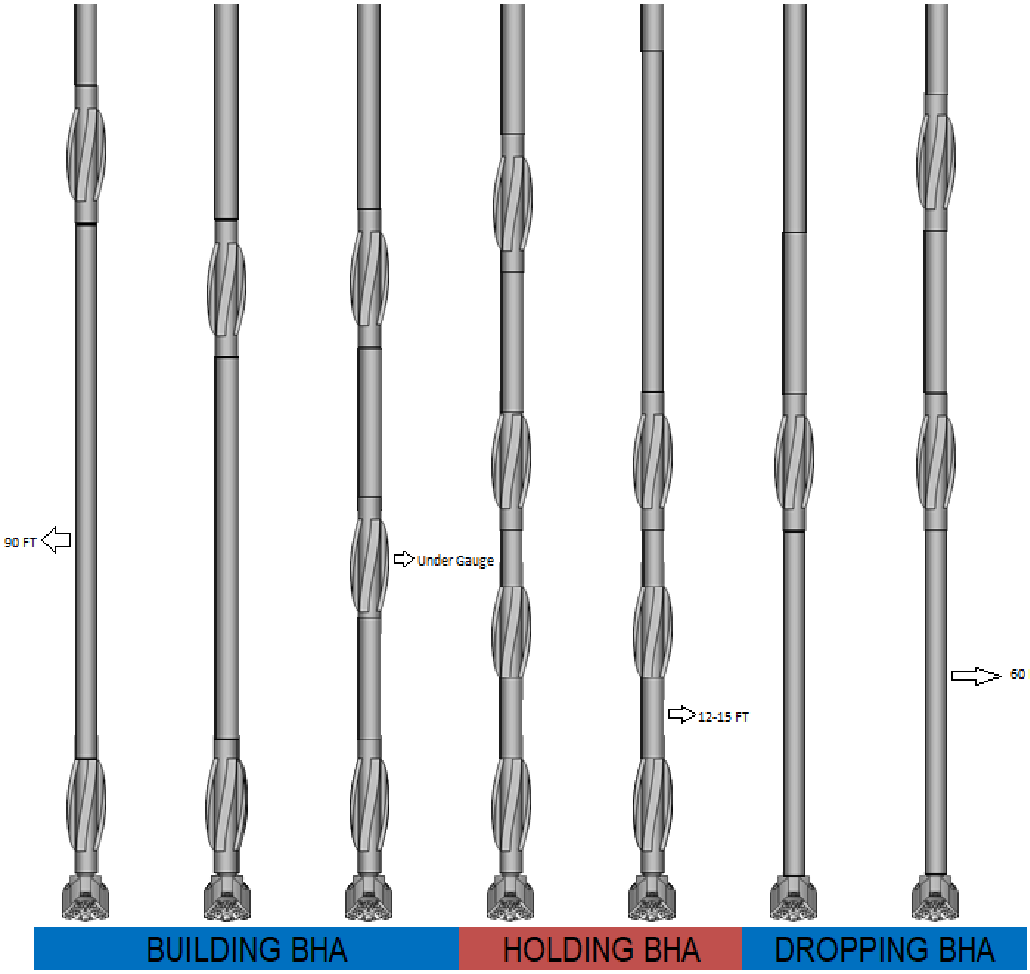


Figure 2.15. Stabilizer Effect to Orientation

According to Jogi, Burgess, Bowling, weight on bit affects the tendency of BHA slightly *(Jogi et al., 1988)*. Researches have detailed WOB in different wells that have different wellbore angles. For hold BHA, when the weight on is increased, BHA acts to increase inclination very slightly.

Pehlivantürk, Angelo, Ashok and Oort investigated a new guidance system for directional drilling *(Pehlivantürk et al., 2019)*. There are lots of uncertainties about directional drilling; therefore it is very difficult to predict the result in drilling operations. In this study, sliding drilling has been detailed to fit on a geometric optimal path. Directional drillers generally use rotary steerable system or mud motor technology to give a direction. The formulation for the guidance system changes extremely between these two technologies because orientation to give direction is done differently between them. Even if there are lots of technologies developed in recent years for directional drilling. However, it is impossible to make predictions about the wells' deviation and to create a well plan with neglecting the importance of drill string design and bit rock interaction. There are no procedures that can be taken as a guaranteed for drilling engineers since directional drilling operations are not repeatable. Actually, in this article, directional drilling has been considered as an art rather than a science.

Lubinski and Woods have examined the factors affecting the wellbore inclination and dog-leg in rotary boreholes *(Lubinski & Woods, 1953).* According to them, when everything is uniform in the hole, the inclination and dog-leg do not change but it is impossible to find everything uniform in the drilling operations. Therefore, they created mathematical relationships to find the forces on the bit, the dog-leg tendency, and the hole inclination as a function of WOB, size of drill collar, stabilizers and dip of the formation which is also the main parameter of the present thesis. According to this study, when one considers a well which is not vertical, there is a point close to the bit which is called the tangency point. Above this point, drill string lies on the hole wall; below this point, if there is no weight on the bit, all forces applied to the bit come from the weight of string. This affects the movement of a bit to be vertical. When one has weight on the bit, another force applied to the bit occurs. This pushes the bit not to be in a vertical position. There are forces generated by weight on bit, weight on drill string, drill collar size, stabilizers location and gauge. If there is no bedding place in the formations drilled, this formation is called as isotropic. Bit deviation depends on the sum of force vectors mentioned above. Researches have tried different weight on the bit and different drill collar types in their experiments. They could not find any constant relationship for guessing the deviation. Formation dip angle changes the orientation of a well while drilling. According to them, even if there is an isotropic formation, vertical hole cannot be drilled perfectly because of the elasticity of the drill string. They explained the formation drilling anisotropy index which is the difference between drillability of the formation parallel and perpendicular to the bedding plane. They have showed the difference of inclinations in isotropic and anisotropic formations with graphs. According to results, they got three times greater inclination in the isotropic formation than in the anisotropic formation. When they increased the weight on the bit, they saw increasing inclination. When they investigated the effect of size of the drill collar and hole size, they realized that the significance of clearance between drill collar and the hole is more important than the effects of their size separately. In other words, the important parameter which affects the direction and deviation of the hole is the size of drill collars used with respect to the size of the hole. It was seen that the inclination of the hole increases more as the clearance between hole and drill collar decreases. Therefore, stabilizers are used in the lower part of the drill string to decrease clearance to increase the angle of inclination even for beds which have 30 ° angle. Moreover, changing of dip angle creates sudden change in the hole angle; for example, crossing unconformities causes instantaneous change of the angle. Lubinski and Woods explained the effect of crossing unconformities with the Equation 2.17;

$$\Phi = h \times \gamma \tag{2.17}$$

Φ is the instantaneous change of angle, γ is the formation dip and *h* is the anisotropy index. According to this formula, instantaneous change of the angle does not depend on weight on bit, drill collar size, hole size and also stabilizer location and size. It only depends on the formation. In the following figure (Figure 2.16), the orientation when going from inclined bed to horizontal bed is shown *(Lubinski & Woods, 1953).*

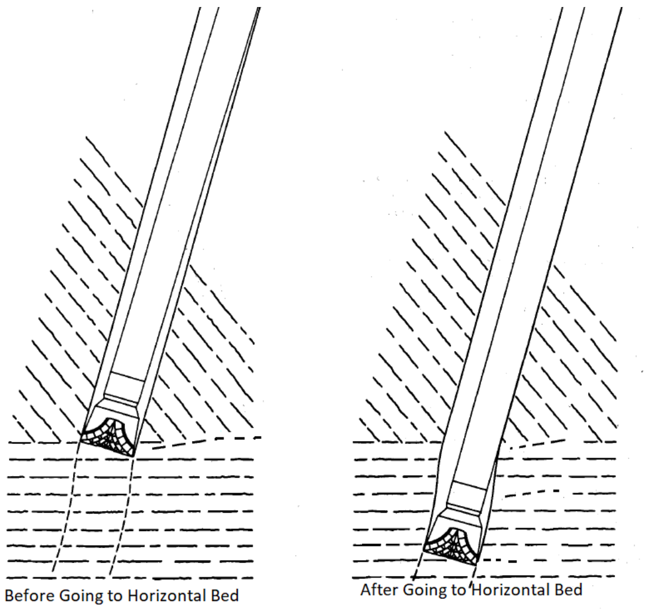


Figure 2.16. Orientation of Drill String from inclined bed to horizontal bed (Lubinski & Woods, 1953)

Menand, Mills and Suarez explained the importance of micro dog-leg on drilling performance by comparing continuous survey measurement and computer modeling *(Menand, Mills, & Suarez, 2016)*. Dog-legs are found in any vertical or deviated wells, it causes more torque and drag while drilling, over pull while pulling out of hole, key seating, stuck pipe and similar problems. Two favorite methods that are used to drill wells directionally shown in recent applications are mud motor and rotary steerable system. While drilling mud motor, sliding is done to give direction and after this rotary is done to follow the path created by sliding. There are micro dog legs while passing from sliding mode to rotary mode. This creates tortuosity. A Rotary steerable system also creates a micro dog leg less than mud motor. According to Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA), surveys are taken at an interval of the length of one stand or 30 m. This causes micro dog-legs to be eliminated. The following figure (Figure 2.17) shows the micro dog-legs while comparing continuous inclination surveying and inclination surveying at every 30 m *(Menand et al., 2016).*

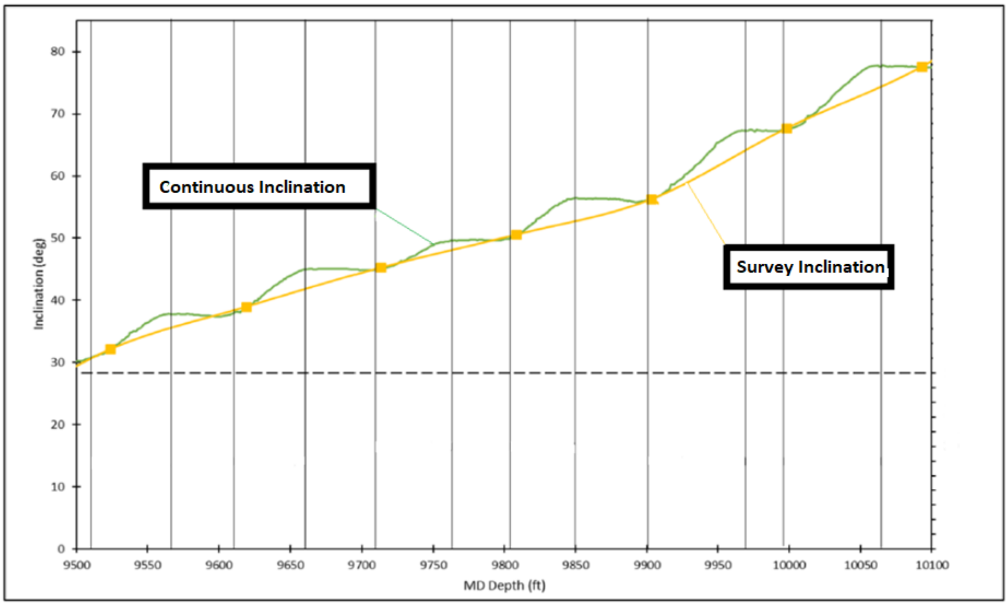


Figure 2.17. Difference Between Continuous Inclination and Survey Inclination (Menand et al., 2016)

Moreover, Menand, Mills and Suarez gave details about the bit behavior *(Menand et al., 2016).* Steerability and walk angle are the two parameters to describe the bit behavior. A bit steerability is the ability of the bit under the influence of the axial and lateral forces. These forces affect the ability of the bit to build and drop the angle. PDC type drilling bit is more affected by the axial and lateral forces. Therefore, controlling orientation with the PDC bit in the drilling operation is not easy. To see the formation effect, unconfined compressive strength logs can be taken. They also gave information about the walk angle which is the angle between the direction of the side forces and the direction of the lateral displacement of the bit *(Menand et al., 2016).* Tendency of the bit can be right, left and the same direction as the side force. Usage of the stabilizers to control the hole orientation has been investigated in detail by Woods and Lubinski *(Woods & Lubinski, 1955).* The importance of the stabilizer has not been known in the early studies. It has been realized that the stabilizer is the important portion of the drill string to drill a vertical hole and to control the hole deviation. The optimum place of stabilizer in the drill string depends on the hole size, drill collar size, weight on the bit and hole inclination. One cannot say that its location depends on formation dip and formation crookedness directly. This paper investigated the stabilizer's position on the drill string. If there is no stabilizer, drill collar lies on the hole wall which is an unwanted situation. If there is a stabilizer away from the drilling bit, drill collar can touch the hole wall. This configuration is better according to mathematical studies but in real life, it is not a good configuration. When the stabilizer is put close to the drilling bit, drill collar does not touch the wall. This is shown as an optimum position. When the weight on the bit is increased, the inclination of the hole tends to increase. More weight can be applied while drilling with adding one stabilizer to keep the angle constant. Moreover, when the larger diameter of drill collars are used in the BHA, more weight can be applied without affecting the angle.

Bhalla, Gong, Mckown created a program to predict the bottom hole assembly performance *(Bhalla, Gong, & McKown, 2008).* Inputs of this program are formation type, dip angle, size of drill collar, hole size, number and locations of the stabilizers. Outputs of it can be build, drop or hold tendency of the bottom of assembly for different weight on the bit.

Brakel and Azar worked on predicting wellbore behavior considering drilling bit dynamics and bottom hole assembly *(Brakel & Azar, 1989)*. According to them, direction of the well can be predicted by bottom hole assembly modeling; with the operating conditions as a controllable parameter and the formation characteristic as an uncontrollable parameter. They have investigated the bit rock interaction to study directional tendency. They compared polycrystalline diamond compact (PDC) bit and roller cone bit with building, holding and dropping assemblies. Moreover, they gave information about effect of the revolution per minute (RPM) on the bottom hole assembly behavior. They have also investigated the side forces applied on drilling bits to evaluate the tendency of PDC and roller cone bit while contacting with the formation at different weight on bit. Their predicting model worked well with hold BHA when compare with the field data. Their conclusion can be summarized as such: i. the rock bit interaction should be considered for prediction well path direction; ii. The inclination tendencies of roller cone and PDC bit are similar while azimuth effect of them is reverse especially in building and dropping BHA; iii. The roller cone bit has unstable behavior when faced with the formation because it has three cones; iv. PDC rock interaction is like a sine-wave behavior which is an unbalance force in a fix direction. According to Brakel and Azar, rotary speed affects the azimuth of the hole but its effect is not significant enough to be recorded *(Brakel & Azar, 1989).*

Bradley examined the factors affecting the borehole angle in vertical and deviated wells *(Bradley, 1975).* Controlling deviation of a borehole is very important because holes with high dog-leg can cause key seating, casing wear, stuck pipe, etc. To drill vertically, weight applied on the bit should be less but this causes a slow penetration rate. Therefore, controlling the wellbore angle has an important role for vertically and deviated wells. According to this article, two things which are the behavior of drill string under forces applied in well and drilling behavior in different formations are important for the deviation. When the weight on bit increases, the contact point on drill collar becomes closer to the bit. This increases the inclination. Moreover, Bradley indicates that orientation of wells are affected by the sum of the vectorial forces applied on BHA in uniform formations, but in anisotropic formations, the formation behavior affects the direction of well strongly *(Bradley, 1975).* The following figure (Figure 2.18) shows briefly the difference of direction at different formation constructions.

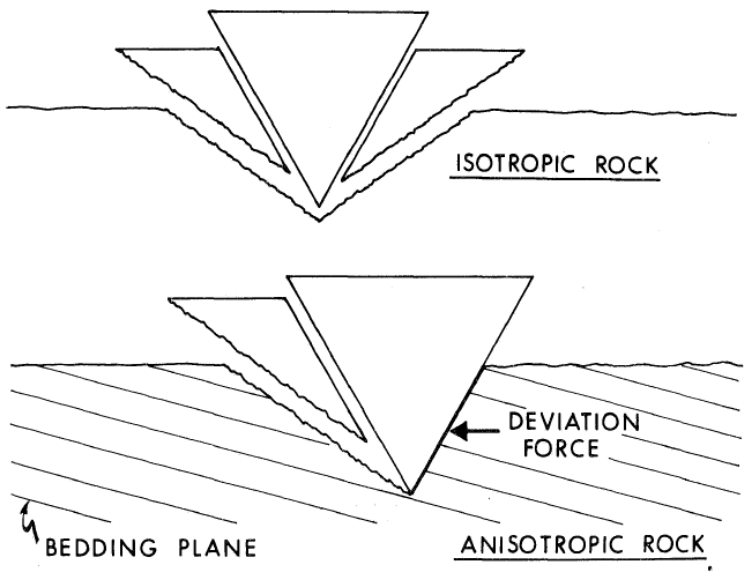


Figure 2.18. Orientation of Drilling in Isotropic and Anisotropic Rock, (Bradley, 1975)

Aadnoy (2002) proposed an analytical model to design the well path and the bottom hole assembly *(Aadnoy & Huusgaard, 2002).* According to this study, the most important parameters affecting bottom hole assembly behavior are stabilizer location and gauge, borehole inclination and curvature, weight on bit, drill collar stiffness, formation strength and anisotropy. Moreover, this study puts forward equations that can be used to have a bottom hole assembly with a minimum weight to be used in rotating and sliding drillings.

Maidla and Haci, investigated the sliding drilling to evaluate the effect on torque value *(Maidla & Haci, 2004).* There were two famous methods used for this purpose, which are the rotary steerable system and the motor/MWD system. In the rotary steerable system, the driller gives a direction while rotating but with the motor and MWD system, the driller gives the turn at the bit. Therefore, it is called as the sliding drilling. Orientation is harder in the sliding drilling than the other. The authors explained the principle of the sliding drilling. When weight is applied on the bit, the torque on the bit increases to the right of the direction of rotation. The force applied in the reverse direction of torque is called reactive torque. Reactive torque affects the tool-face orientation. Therefore, sliding is a challenging operation.

Effect of the formation anisotropy on directional tendency has been examined by Boualleg, Sellami, Menand, Ecole De Mines de Paris, Simon as shown in Equation 2.18 *(Boualleg, Sellami, Menand, & Simon, 2006).* Moreover, in this study, the gauge length of the bit and bit type, dip angle, number of the stabilizers and their positions and the bit steerability affect the deviations of the wellbores.

$$\text{Deviation} = \text{Func.}\,(\text{WOB}, \text{Form. Anisotropy}, \text{Wellbore Geo.}, \text{Bit}) \quad (2.18)$$

This paper examines the effect of formation anisotropy on the directional behavior. To evaluate the formation effect, laminated rock, which is a uniform formation and interbedded rock, where there is a sudden change in the rock's mechanical characteristics, have been studied. It was observed that when the bit cuts the uniform formation, there is no side force applied to the bit. If the bit enters from hard to soft or soft to hard formations, side force is generated. This effects the deviation. If the interface angle between the hard and soft rock is high (dip angle), it causes more significant forces and deviations. When the effect of the gauge length of bit has been investigated at the formation having 45° interface angle, they saw that deviation does not change suddenly and wellbore quality is obtained better. When, the parameters affecting side forces have been kept the same, they realized that side forces are generated mainly because of anisotropic behavior of the rocks. When they compare WOB and dip angle, they reached to the conclusion that the dip angle is more sensitive to the weight on bit. Following Figure 2.19 shows the effect of isotropic and anisotropic formations on build and drop angle for the different BHA design. As can be seen from this figure, in isotropic formation, the inclination changes with a constant rate; however, in anisotropic formation, one cannot say the same thing.

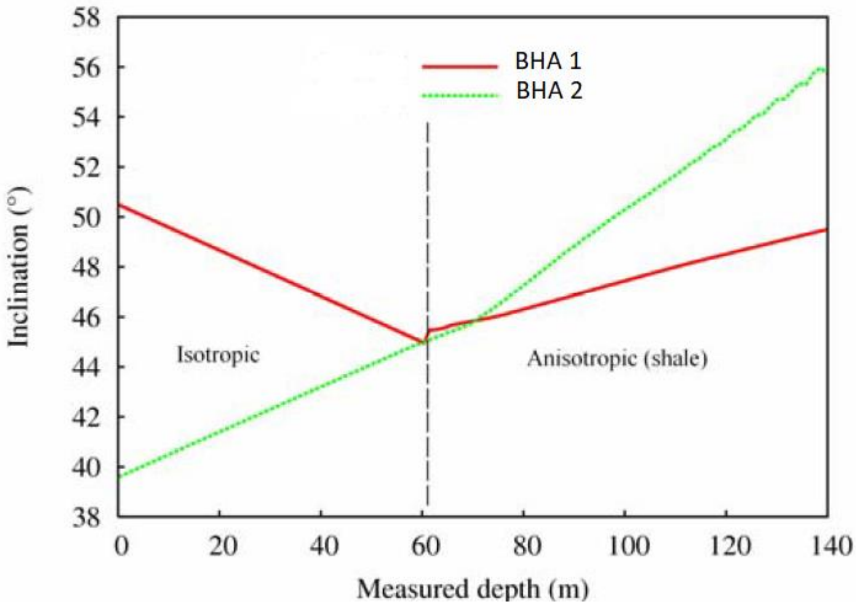


Figure 2.19. Effect of Anisotropy on Inclination (Boualleg et al., 2006)

The rock bit interaction in directional wells has been investigated by H-S and Ho *(Ho, 1987)*. For this purpose, there are various models developed in this study, which are inverse, forward modellings and modelling to generate drilling logs. The inverse modeling investigates the rock and bit anisotropy index with known formation dip, instantaneous drilling direction. The forward modeling explains the instantaneous drilling direction with known formation dip, rock and bit anisotropy index. The modeling to generate drilling logs is used to reach drilling dip log with known anisotropy index, instantaneous drilling direction. Drilling dip log will provide a true dip angle and true dip direction. As a result of this study, these modellings should work together to get the unknown values.

2.8 Review of the Adıyaman Region

Parameters affecting wellbore deviation in directional and vertical wells have been studied by different researchers. In the first part of Literature Review, weight on bit, stabilizer location and gauge, flow rate, bit behavior, formation stress, formation dip, drill collar stiffness, hole size, drill collar size, and hole inclination have been investigated in detail. In this part of the Literature Review, location, geological formation, general stratigraphy and structural geology of the Adıyaman Region will be examined.

2.8.1 Location of Adıyaman Province

Adıyaman is a province in the south-central of Turkey. It is located between Malatya, Kahramanmaraş, and Şanlıurfa Provinces. It covers 201.5 km^2 areas. Adıyaman Region is situated within the SE Anatolian Fold and Thrust Belt *(Rigo de Righi & Cortesini, 1964)*. Adıyaman is one of the productive areas in Turkey. Figure 2.20 shows the Adıyaman Region on Google Earth Map *(“Adıyaman Province,” 2019)*

Figure 2.20. Adıyaman Region on Map (“Adıyaman Province,” 2019)

Adıyaman is covered from North with East Anatolian Fault Zone, from South with Akçakale Graben and from East with Karacadağ Volcanic Province.

2.8.2 Geological Formation of the Adıyaman Region

Geological formation of the Adıyaman Region is related to a plate tectonics approach. Şengör and Yılmaz evaluated the plate tectonic which is that Palaeo-Tethyan and a Neo-Tethyan are the phases to evaluate the Tethyan of Turkey. During the Permo-Liassic interval, the south-dipping subduction zone of Palaeo-Tethys operates the Palaeo-Tethyan evaluation. The area of Turkey created by a part of the northern margin of Gondwana-Land, moreover Southeastern Turkey is placed along the north side of the Arabian plate of Gondwanaland during the Paleozoic Era *(Şengör & Yılmaz, 1981)*. Southern Anatolian thrust belt continues from Hakkari Province to Kahramanmaraş province until cut by the Eastern Anatolian fault. This thrust belt been occurred with closing area between Eurasia and Gondwana-Land. The collision of the continents caused the occurrence of this line. There are lots of folds occurred in Southern Anatolia due to this collision *(Perinçek, 1990)*. With the increase of jamming, faults have occurred. The Arabian plate compresses Anatolia to the West and to the North with the movement of the plates *(Perinçek, 1990)*. There are three geological zones in the region of SE (Southeast) Anatolia which are the Imbrication zone, the Arabian Zone and the Nappe Region *(Yilmaz & Clift, 1990)*. When these geological zones are compared, the Arabian Zone includes autochthonous and parautochthonous sedimentary succession which has started to accumulate in the early Paleozoic time. In the north of the Arabian platform, the region is affected by orogeny where folds and thrust belts occurred *(Yilmaz & Clift, 1990)*. The imbrication zone is located between the Arabian and Nappe Zone and it is separated by thrust faults. Figure 2.21 shows these zones.

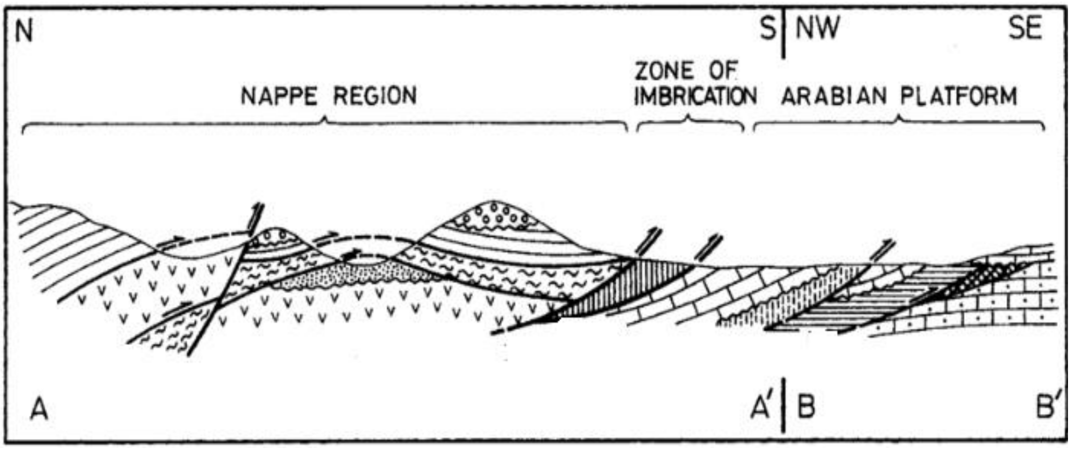


Figure 2.21. Geological Cross Section Across the Southeast Anatolian orogenic Belt (Yigitbas, Mart, & Gen, 1993)

The Imbrication zone includes thrust slices which cover succession that is occurred between the late Cretaceous to early Miocene sequence. The Nappe Zone has structurally highest tectonic units in the Southeast of Anatolia as seen in Figure 2.21.

According to Dinçer, The Southeast of Anatolia includes different geological ages and formation units. The following figure (Figure 2.22(a)) shows these units *(Dinçer, 1991)*. But, in the Adıyaman Region, Uppermost Cambrian to Ordovician units are missing because of Mardin-Kahta rising at the time of Caledonian (Devonian) and Hercynian (carboniferous) as seen in Figure 2.22 (b) *(Demirel, Yurtsever, & Guneri, 2001).* As seen in Figure 2.22 (a), The basement of the autochthonous unit of the southeast of Anatolia includes the Precambrian, Habur Groups and Lower Paleozoic Derik *(Best, J. A., Barazangi, M., Al-Saad, D., Sawaf, T. and Gebran, 1993).* According to Demirel (2001), the Zap Group has been accumulated in the eastern and western part of Turkey at the time of Upper Devonian to Early Carboniferous and the Late Permian Tanin Group has been deposited in the SE part of Turkey; after that Triassic-Lower, middle and upper sequences have been deposited as seen in Figure 2.22 (a) *(Demirel et al., 2001).* Diyarbakır unit in the Silurian and Lower Middle Devonian age is absent in the Southeastern of Turkey excluding Diyarbakır Province *(Perincek, D., Duran, O., Bozdogan, N. and Çoruh, 1991)*.

AGE		UNIT
PLIO-QUATERNARY		ALLUVIUM
MIOCENE	UPPER	ŞELMO
	LOWER	SİLVAN
OLIGOCENE		MİDYAT
EOCENE		
PALEOCENE		ŞIRNAK
CRETACEOUS	UPPER	KARADUT
		SAYINDERE
		KARABOĞAZ
		MARDİN
	LOWER	
TRIASSIC	UPPER	CUDİ
	MIDDLE	
	LOWER	ÇIĞLI
LATE PERMIAN		TANİN
EARLY CARBONIFEROUS		ZAP
DEVONIAN		
		DİYARBAKIR
SILURIAN		
ORDOVICIAN		HABUR
CAMBRIAN		DERİK
PRECAMBRIAN		

AGE	FORMATION	LITHOLOGY
PLIO-QUATERNARY		Alluvium
MIDDLE UPPER MIOCENE	ŞELMO	Conglomerate
LOW MIOCENE MID-UP OLIGOCENE	GAZİANTEP	Limestone
LOW OLIGOCENE LOWER EOCENE	HOYA	Limestone Dolomite
DANIAN-THANETIAN	GERMAV	Shale
UPPER MAASTRICHTIAN		
	BESNİ	Limestone
	TERBUZEK	Conglomerate
LOWER MAASTRICHTIAN	KASTEL	Shale
LOW MAASTRICHTIAN CAMPANIAN	SAYINDERE	Clayey Limestone
CAMPANIAN	KARABOĞAZ	Limestone, cherts diatomites
LOWER CAMPANIAN SANTONIAN	KARABABA	
LOWER TURONIAN UPPER CENOMANIAN	DERDERE	Sandy Limestone dolomitic Limestone
LOWER CENOMANIAN UPPER ALBIAN	SABUNSUYU	Dolomite Limestone
APTIAN-ALBIAN	AREBAN	Sandy Limestone Sandstone Limestone
LOWER PALEOZOIC		Shale-Sandstone

a) b)

Figure 2.22. a) Generalized columnar section of SE Anatolia (Dinçer, 1991), b) Generalized Stratigraphic Sequence in the Adıyaman Region (Demirel et al., 2001)

According to Ala & Moss, the Arabian Plate had exposed to tectonics forces extensionally to the Late Jurassic before the accumulation of the Mardin Carbonates *(Ala & Moss, 1979)*. After the extension by tectonics, subduction started in the Arabian Plate from the early or lower cretaceous age to late or upper cretaceous age (Önalan, 1988). Kastel Formation formed in the Southeast of Anatolia at the Campanian lower Maastrichtian age as seen in Figure 2.22 (b) *(Perinçek, 1980)*. From the Campanian to lower Maastrichtian, Karadut formation known as deep marine carbonate bur-stone overlapped throughout the northern Arabian Plate *(Sungurlu, 1974)*. According to Demirel (2001), shallow marine shelf and deep marine materials were accumulated because of the changing of sea level between two ages which are upper Maastrichtian and Upper Eocene *(Demirel et al., 2001)*.

According to Perinçek (1980), carbonates have been deposited in the Southeast of Turkey during the early Eocene transgression *(Perinçek, 1980)*. According to Seyrek (2008), the trough has developed to the east and west direction, WSW and ESE direction, during early Miocene age and in the middle Miocene age, this trough has disappeared *(Seyrek, 2008).* Continental deposition and tectonic movements occurred during the upper Miocene age in the Adıyaman Region. Thrusts and grabens created due to deposition and tectonic. Akçakale Graben is the graben occurred in the upper Miocene *(Tardu, T. Başkurt, T. Güven, A. Us, E. Dinçer, A. Tuna, M. E. Tezcan, 1987).* During the youngest period of tectonic actions which is the upper Miocene age in the Southeast of Turkey, stress occurred has been released *(Hempton, 2017).* In the Adıyaman region, strike-slip stress is the main stress occurred during to evaluation of Dead Sea Fault Zone and Eastern Anatolian Fault Zone at the age of upper Miocene *(Rotstein, 1984).* According to Seyrek, Bozova Fault, Kalecik Fault, Areban Thrust and Akçakale graben might be occurred during that time *(Seyrek, 2008).*

2.8.3 General Stratigraphy in the Adiyaman Region

Demirel explained the general stratigraphic sequence in the Adıyaman Region, as seen in Figure 2.22 (b). From up to down, formations can be sorted as Şelmo, Gaziantep, Hoya, Germav, Besni, Terbuzek, Kastel, Sayındere, Karaboğaz, Karababa, Derdere, Sabunsuyu and Areban *(Demirel et al., 2001).* These formations include a different type of lithologies. Geological units in the Adıyaman Region are classified by Bolat (2012) as Allochthonous Unit including Koçali and Karadut formations, Mardin Unit including Derdere and Karababa formations, Adıyaman Unit including Karaboğaz and Sayındere formations, Şırnak Unit including Kastel, Terbüzek, Besni and Germav formations, Midyat Unit including Gercüş and Hoya formations and Şelmo unit including Şelmo formation *(Bolat, 2012).* Figure 2.22 (a) designed by Dinçer (Dinçer, 1991) and Figure 2.22 (b) designed by Demirel *(Demirel et al., 2001)* show the units and formations in the Adıyaman Region explained by Bolat *(Bolat, 2012).* In this part, Germav and Kastel formations from Şırnak Group, Sayındere and Karaboğaz formations from Adıyaman Group, Karababa and Derdere formations from Mardin Group will be explained.

2.8.3.1 Şırnak Group

Şırnak group include thirteen separated formations which are Germav, Kastel, Terbüzek, Besni, Haydarlı, Kıradağ, Garzan, Üçkiraz, Sinan, Antak, Kayaköy, Belveren and Becirman *(Perincek, D., Duran, O., Bozdogan, N. and Çoruh, 1991)*. This group has been named as Şırnak since formations are seen on the surface in Şırnak Province *(Bolat, 2012)*. Şırnak group is located between the Adıyaman Group and the Midyat Group *(Seyrek, 2008)*. Germav and Kastel formations are investigated deeply.

2.8.3.1.1 Germav Formation

Germav formation has been named firstly as Kermav Formation by Maxson *(MAXSON, 1936).* After that, its name has been changed because of studies in Germav Village. Two different lithologies are found in Germav Formation which are marl and sandstone bands *(Sonel & Sarbay, 1988).* According to Perinçek (1980), different colored cemented sandstone and limestone are found in all Germav Formation. Conglomerates, shale, grey marls and interbedded limestone are found in the middle of Germav Formation. Moreover, marls and shales are found mostly at the bottom of Germav formation *(Perinçek, 1980)*. Depositional environment of the Germav Formation is a deep marine slope *(Dinçer, 1991)*.

2.8.3.1.2 Kastel Formation

Kastel is the other formation of Şırnak Group. Kastel Formation covers the Sayındere Formation as seen in Figure 2.22 (b) According to Sonel and Sarbay (1988), Kastel

Formation includes marls and shale *(Sonel & Sarbay, 1988).* Kastel is the oldest formation found in the Şırnak Group and the lithology sequence starts with marl at the bottom, continues with sandstones and shales, finalizes with marl, shale alternation at the top. Even if the contact point located at the bottom of Kastel Formation is the starting point of the Sayındere Formation in everywhere, it is impossible to generalize this kind of idea for the upper contact point *(Bolat, 2012).*

2.8.3.2 Adıyaman Group

Çoruh gave the name to this group as Adıyaman *(Çoruh, 1991)*. This group includes two different formations which are Sayındere and Karaboğaz. It is located between Mardin and Şırnak Groups.

2.8.3.2.1 Sayındere Formation

According to Seyrek, Gossage described this formation firstly in 1959 *(Seyrek, 2008*). The surface indication of this formation is found at the western side of the Sayındere River *(Yılmaz & Duran, 1997).* According to Sonel and Sarbay, Sayındere formation includes marly limestone and biomicrites *(Sonel & Sarbay, 1988).* Sayındere formations have clayey limestone *(Sonel & Sarbay, 1988).* Depositional environment of the Sayındere Formation is deep marine *(Dinçer, 1991)*.

2.8.3.2.2 Karaboğaz Formation

This formation was described by Tuna *(Tuna, 1973)* and the surface indication of this formation is found at the southern side of the Mountain Karababa *(Yılmaz & Duran, 1997)*. Depositional environment of the Karaboğaz Formation is deep marine *(Dinçer, 1991)*. According to Sonel and Sarbay, Karaboğaz Formation includes very porous limestone, and small, rounded, grains of cherts are found in it *(Sonel &*

Sarbay, 1988). There are plenty of organic matter to generate oil and natural gas in Karaboğaz Formation *(Sari & Bahtiyar, 1999)*.

2.8.3.3 Mardin Group

The name of this group has been given by Schmidt *(Schmidt, 1935)* and the surface indication of this formation is in the Mardin Province *(Yılmaz & Duran, 1997)*. Therefore, it is called as Mardin Group. This group has two formations which are Karababa and Derdere. The depositional environment of Mardin Group is beach, marine environment and also shallow marine, tidal environment *(Seyrek, 2008).*

2.8.3.3.1 Karababa Formation

In the Adıyaman Region, Karababa Formation is located between Karaboğaz Formation and Derdere Formation. Karababa Formation has limestone from lower to upper of thickness. At the bottom, argillaceous limestone is found, in the middle dolomitic limestone is found while cherty limestone is located at the top of the formation *(Yılmaz & Duran, 1997)*. Karababa Formation covers the Derdere Formation but there is no uniform distribution on it *(Tuna, 1973).*

2.8.3.3.2 Derdere Formation

Derdere Formation is located between Karababa and Sabunsuyu Formations in Adıyaman Province. Derdere formation has organic-rich limestone which can be thought as source rock, porous dolomites which can be thought as reservoir rock and micritic limestone which can also be thought as cap rock *(Coskun, 1996).*

2.8.4 Structural Geology in the Adıyaman Region

In this part of the thesis, structural geology in the Adıyaman Region has been investigated since the Adıyaman Region has a highly crooked area structurally. Bedding attitude, folds, unconformities and faults can be considered as subtopics for structural geology investigation.

2.8.4.1 Bedding Attitudes

Strike and dip of the bed are defined as attitudes of bedding. The definition of strike is a line created by the intersection of inclined bed with an imaginary horizontal plane and the definition of dip is an angle between inclined layer of earth material and an imaginary horizontal plane *(Grippo, 2011).* Figure 2.23 shows imaginative strike and dip *(Plummer & Carlson, 2008).*

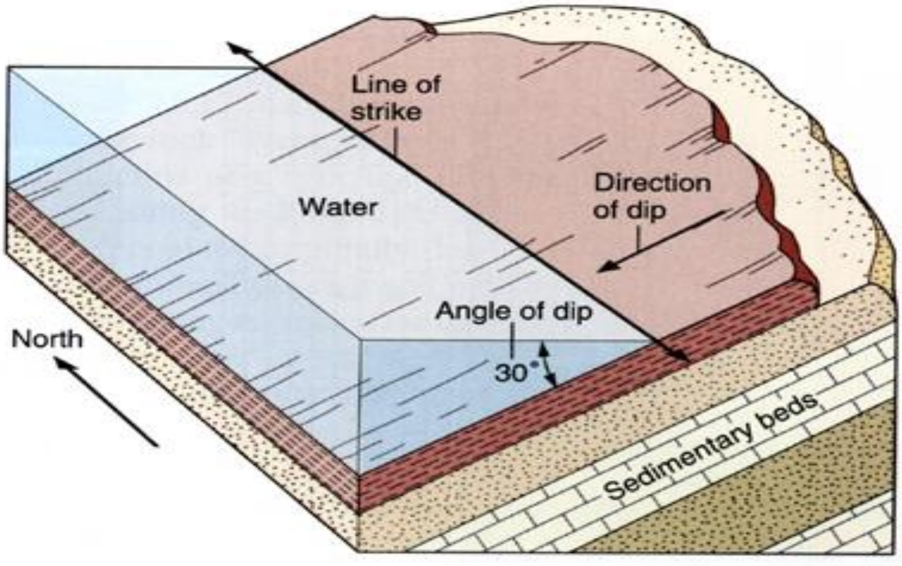


Figure 2.23. Diagram of Strike and Dip (Plummer & Carlson, 2008)

Seyrek (2008) chose three wells in his study to evaluate bedding and to see if there is a trend or not. First well was chosen from a syncline, the second was chosen form a bedrock of the fault while the third was chosen near to the thrust fault. Upper

Germav Formation and Midyat group have been drilled in these three wells. According to all dip-meters data from wells, all have almost NE direction of the strike even if they cut different formation. However, the dip directions of wells have changed. The dip direction of the layers drilled in the first well was from N to NW, other was from N to W while the dip direction of the layers drilled in the last well is the South *(Seyrek, 2008)*

2.8.4.2 Folds

When the earth material is under compressional stress, it is pushed inward from two sides. The rock changes its shape without breaking. This is called as folds. There are two common types of folds which are anticline and synclines. Anticline is a fold which rises as both sides of the rock are pushed inward, syncline is a fold which sinks as both sides of the rock are pushed inward. Anticline and syncline diagram is shown in Figure 2.24 (Newbill, 2014).

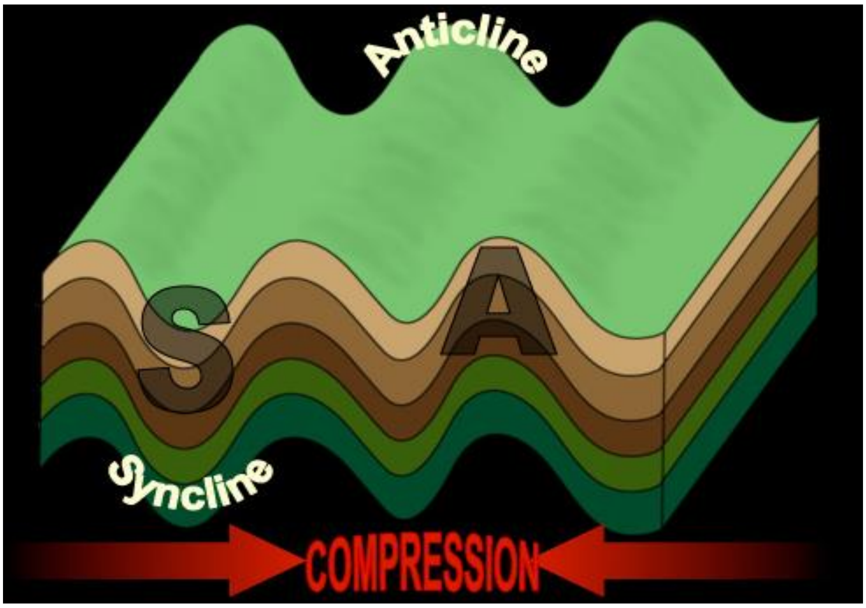


Figure 2.24. Diagram of Anticline and Syncline (Newbill, 2014)

Seyrek (2008) explained folds located in some parts of Adıyaman Province in his thesis. The Southeastern Anatolian folds as anticlines and synclines occurred in the

Paleocene age to upper Miocene age. The belt of the fold direction is from ENE to WSW. He investigated nine locations to evaluate the occurrence of anticlines and synclines. The locations have been selected on the line drawn from Çemberlitaş to Kızılcapınar direction. Most of anticlines have a strike direction from ENE (the east-northeast) to WSW (the west-southwest) while Alidağ anticline's strike direction from NE to SW and one more anticline has east to west strike direction. Some of anticlines and synclines are covered by thrust faults, some of them are bounded by strike-slip faults. In addition to the anticlines, the synclines are available at that region. One of them is located between Gebeli and Toptepe, other is between Akbulut village and Gözebaşı village in Adıyaman. Their strike direction changes from place to place. According to Seyrek (2008), the dip angle of flanks belonged to the anticline and the synclines are mostly different. Therefore, most of them are asymmetrical. In his study, one anticline and one syncline has symmetric flanks *(Seyrek, 2008)*.

Karakuş oil field which is located 29 km to the northwest of Adıyaman field is the most productive in the Adıyaman region. This field is on an anticline fold bounded by trust in the north and wrench faults in the south *(Karahanoglu & Ulu, 1998).*

2.8.4.3 Unconformities

The meaning of unconformities is that there is a non-depositional or buried erosional surface that distinguishes rock masses belonging to two different ages. The deposition of sediments should not be continuous to indicate unconformities. There are three types of unconformities which are angular, nonconformity and disconformity. An erosional surface separating steeply dipping rock layer below from slowly dipping layers above creates an angular unconformity. An erosional surface separating igneous, metamorphic rock below sedimentary strata above creates nonconformity. Erosional surface separating horizontal strata below from horizontal strata above creates disconformity *(Colorado School of Mines, 2019).*

According to Seyrek (2008), there are some unconformities in the Adıyaman region. The first of them is an unconformity between Cretecaus Mardin and Upper Cambrian Derik Groups. The transgression carbonates found in Mardin Group is located above the clastics found in Derik Group. According to him, this is commented as an angular type. Second of them is an unconformity between the upper Miocene Şelmo and Eocene Oligocene Midyat Group. This unconformity is also commented as an angular. The third unconformity is between Upper Miocene Şelmo and the Paleocene Upper Germav formations. According to Seyrek, last unconformity is between the Quaternary Alluvium and the Upper Miocene Şelmo formation *(Seyrek, 2008).*

According to Dinçer (1991), the unconformity is observed between two groups which are Cretaceous Mardin and Upper Cretaceous Karaboğaz formation *(Dinçer, 1991).*

The Sabunsuyu and Derdere Formations & Derdere and Karababa Formations are separated by unconformities *(Coskun, 1996).*

2.8.4.4 Faults

The definition of fault is a crack in the Earth's crust. When the earth material is under compressional or tensional stress, it is pushed inward or is pulled outwards from both sides so the rock breaks. Break crusts move the opposite sides of the fracture due to stress applied. There are three kinds of faults which are; strike-slip, normal and thrust fault. If the rocks slide in the opposite direction horizontally due to the applied force, there is no vertical movement. This is called as strike-slip faults. Movement of two blocks of crust outwards due to extension force or gravity causes normal fault. The thrust fault is known as the opposite of the normal fault. Movement of two blocks of crust inward due to compression force causes thrust fault. Normal faults create space while thrust fault stamps space out (Tikkanen, 2019).

The faults in Adıyaman have been occurred during the continent collision. According to Perinçek (1987), Adıyaman fault is the most important fault seen in there. Adıyaman fault is the left-lateral strike-slip fault (Perinçek, Günay, & Kozlu, 1987).

According to Khalifa, Çakir, Owen and Kaya (2019), the left lateral strike-slip fault is found in eastern Anatolia which occurred as a result of the collision between the Arabian and the Anatolian plates. Westward movement after collision occurred in the Anatolian side (Kalifa, Çakir, Owen, & Kaya, 2019). Figure 2.25 shows the faults located in the Southeastern Anatolia (Farr et al., 2007).

Adıyaman fault affects the porosity of the Mardin Group located near the city of Adıyaman province, Çemberlitaş, Çukurtaş, Bolukyayla and Karakuş field According to Coskun(1996), some structural zones from the direction of NW to SE occurred during the Mio-Pliocene due to the activity on transcurrent Adıyaman Fault. There are two structural zones in the Adıyaman Region that are formed by reservoir characteristic of the carbonates and oil migration from Kastel Basin to the North. The southern fault and the folded zones create a compression to cause this oil migration (Coskun, 1996).

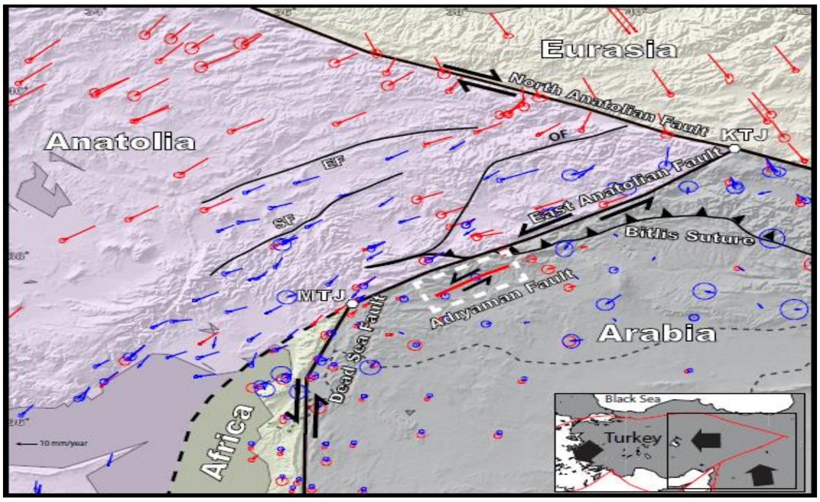


Figure 2.25. Images of Faults in Southeastern Turkey (Farr et al., 2007)

There is a thrust fault that is located close to the north of the Alidağ Mountain and the Southern Adıyaman fault cuts this fault.

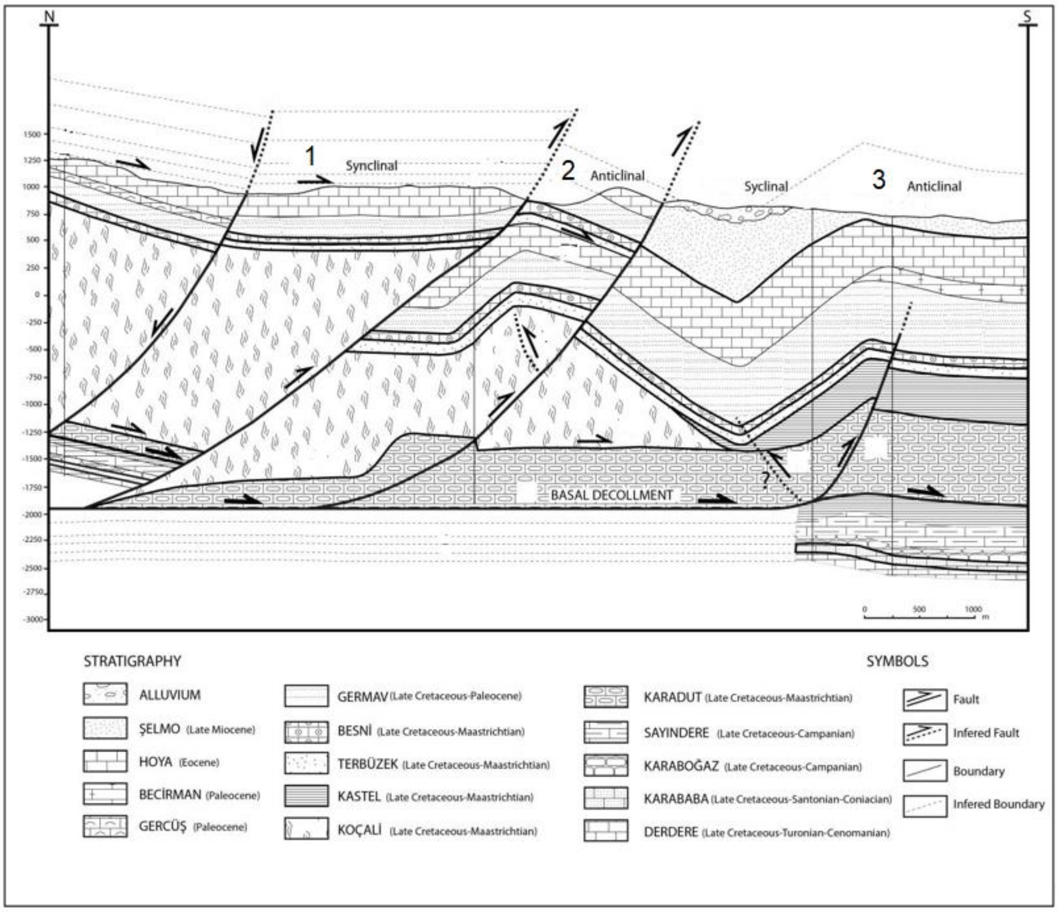


Figure 2.26. Geological Cross-Section Area of a part of Adıyaman Region (Tuncer, 2013)

Figure 2.26 shows the geological cross section area of a part of Adıyaman Region. As seen in Figure 2.26, structure can change in 0.5 km distances in Adıyaman Region. Synclinal 1 located in Figure 2.26 has 8 degrees North and 8 degrees South dipping angles while Anticline 2 has 35 degrees North, 15 degrees dipping and Anticline 3 has 35 degrees North, 8 degrees South dipping. There are a symmetric and asymmetric flanks (Tuncer, 2013).

CHAPTER 3

STATEMENT OF THE PROBLEM

Formation is one of the most important parameters for the direction and deviation of the wells. Even though most of the parameters affecting the direction of wells have been studied in many articles, the formation and its effect change from field to field.

The main aim of this thesis is to examine the effect of the formation to the orientation of the directional wells drilled in the Adıyaman Region, since the formation cannot be taken under control in drilling operations unlike the other parameters. Therefore, weight on the bit (WOB), the hole size, the stabilizer location and its gauge, flow rate, bit type, revolutions per minute, that is, controllable parameters have been held constant to see the effect of formation by comparing different wells.

The cost of the directional drilling operations is always higher than the operations where the directional drilling equipment is not used. If the directional drillers know the formation effect, they can arrange a work plan to finish early. In other words, the formation can help the orientation to the same side as planned. If the directional drillers know this action, they can configure all parameters except the formation.

The Adıyaman Region is one of the oil-producing places in Turkey. In this region, most of the wells are drilled directionally. So, the formation effect has been investigated between the wells to see if it has a trend or not. If there is a trend, it will decrease the drilling time and will reduce the cost of it. Moreover, this study evaluates which features of the formation, such as the stratigraphic properties and the structural properties of the formations, have more impact on the direction and deviation.

CHAPTER 4

MATERIALS AND METHODS

The materials used for the directional drilling operations and the methods to do sliding drilling and to calculate the deviation have been detailed in this chapter.

4.1 MATERIALS

The wells examined were drilled with the mud motor and with the measurement while drilling technology. Moreover, the stabilizers, the non-magnetic drill collar and the non-magnetic universal bottom-hole orientation sub are added to the drill string to manage the tendency of the bottom-hole assembly and to get correct surveys.

4.1.1 Drilling Bit

Different kinds of the drilling bits are available in the petroleum industry. Polycrystalline Diamond Compact (PDC) and Roller Cone bit are mostly used. In the Adıyaman Region, the wells with the size of $8^{1/2}$" (0.216 m) in diameter where the roller cone bit has been used were chosen to investigate the effect of the formation to the deviation. The roller cone bit is designed to crush rocks with a minimum amount of wear on the surface of cuttings. The roller cone bit was invented by Howard Hughes and it has conical cutters and teeth inserted. Steel milled tooth bits and carbide insert bits are the types of the roller cone bits (Schlumberger, 2020). According to International Association of Drilling Contractors (IADC), the roller cone bit is classified according to the formation characteristics. It has four digits' codes to separate each other. Table 4.1 shows how the roller cone bit is named.

Table 4.1. Roller Cone Denotation (Thomas, 2008)

Digits	**First**	**Second**	**Third**	**Four**
Codes	1==>8	1==>4	1==>7	Character

For the first digit; 1, 2, and 3 specify steel tooth bits with 1 for soft, 2 for medium and 3 for hard. 4, 5, 6, 7, and 8 specify tungsten carbide insert bits for varying formation hardness with 4 being the softest and 8 the hardest.

For the second digit; 1, 2, 3, and 4 help further breakdown of the formation with 1 being the softest and 4 the hardest.

For the third digit; the meaning of 1 is the standard open bearing roller bit, the meaning of 2 is standard open bearing bit for air drilling only, the meaning of 3 is the standard open bearing bit with gauge protection which is defined as carbide inserts in the heel of the cone, the meaning of 4 is roller sealed bearing bit, the meaning of 5 is roller sealed bearing bit with carbide inserts in the heel of the cone, the meaning of 6 is journal sealed bearing bit, the meaning of 7 is journal sealed bearing bit with carbide inserts in the heel of cone.

The fourth digit is an additional feature for the roller cone bits. For example, A is used for roller cone bits when it is suitable for the air application, D is used to control the deviation, X is a feature for the roller cone bit which is predominantly conical inserts. This list extends from A to Z *(Thomas, 2008).*

Figure 4.1 shows 5-3-7X IADC, $8^{1/2}$” (0.216 m) OD of roller cone bit used in the wells chosen to investigate the formation effect to the orientation in the Adıyaman Region *(Thomas, 2008).*

Figure 4.1. 8 1/2 "(0,216 m) OD of Roller Cone Bit (5-3-7X IADC) (Thomas, 2008)

4.1.2 Drilling Mud Motor

The Drilling Mud Motor has a stator and a rotor turning in it. Drilling fluid passes between the stator and the rotor, which generates an eccentric motion. The mud motor transfers an eccentric motion to the bit as a concentric power *(Rauf, Ahsan, & Azim, n.d.)*. The drilling mud motor has the following parts: a top sub, a power section, a driveshaft assembly, an adjustable assembly and a bearing assembly. The rotor and the stator are located in the power section of the mud motor which generates power. The driveshaft assembly transfers power generated by the power section to the drilling bit. The adjustable assembly is located between the driveshaft assembly and the bearing assembly which is used to adjust bend angle to achieve a required build rate while sliding. The bearing assembly is located between the adjustable assembly and the bit box where the drilling bit is connected. It transmits a rotational force that comes from the driveshaft assembly and supports trust and radial bending load *(DrillingFormulas.Com, 2018).* The sleeve stabilizer can be bound to the motor at the request of the directional drilling engineers. Figure 4.2 demonstrates the drilling mud motor.

Figure 4.2. Drilling Mud Motor

The parameters of the drilling mud motor used in the wells examined in this thesis are listed in Tables 4.2 and 4.3 *(Dyck, 2011).*

Table 4.2. Performance Specification of Drilling Mud Motor (Dyck, 2011)

NOV Drilling Mud Motor 6.75" (0,17 m) OD 7:8 Lobes 5 Stages	
Flow Range	300 – 600 GPM
Revolution	0.282 Rev / Gal
Speed Range	84 – 169 RPM

1 gallon = 3,785 liter

Table 4.3. Predicted Dog – Leg Rates, Degrees/30m (Dyck, 2011)

NOV Drilling Mud Motor 6.75" (0,17 m) OD 7:8 Lobes 5 Stages			
Bend Setting Degree, °	Slick BHA 8-1/2"(0.216 m) Hole	Single Stab. BHA 8-1/2" (0.216 m) Hole	Two Stab. BHA 8-1/2" (0.216 m) Hole
0.39	1.2 °/30 m	2.3 °/30 m	1.5 °/30 m
0.78	3.3 °/30 m	4.4 °/30 m	3.7 °/30 m
1.15	5.6 °/30 m	6.4 °/30 m	5.8 °/30 m
1.5	7.9 °/30 m	8.3°/30 m	7.9 °/30 m
1.83	10 °/30 m	10.1 °/30 m	9.7 °/30 m

The rotor and the stator configurations affect the torque and the speed outputs. When the number of lobes increase, the mud motor generates more torque. Maximum torque limit is limited by the mechanical strength of the stator material. Moreover, when weight on the bit is increased, the standpipe pressure seen on the surface rises. The motors have maximum differential pressure to work without stalling *(Jaeger & Doering, 2019)*

4.1.3 Measurement While Drilling Tool (MWD Tool)

The measurement while drilling (MWD) tool transmits the downhole collected data to the surface in almost real-time. This device uses sound waves for this procedure *(Ramsey, 2019).* The MWD tool can measure inclination, azimuth, temperature, shock, vibration, logs, pressure, torque and porosity. This depends on the configuration of sensors which are run into the hole. A typical measurement while drilling system uses mud pulse radio, electromagnetic waves and acoustic signals to transmit the data to the surface. General MWD tool includes sensors, data transfer devices, data receiving devices and data analysis module *(Li, Itakura, & Ma, 2014).* In this study, the mud pulse MWD system was used to get data from the bottom hole. There are two main sensors used in the MWD system which are an accelerometer and a magnetometer. These sensors create x, y and z vectors. The accelerometer uses the earth's gravitational vector relative to the tool axis, while the magnetometer uses the earth's magnetic field relative to the tool face. An inclination is calculated from the accelerometer values and an azimuth is calculated from the magnetometer values. The magnetometer sensors are affected by the materials with magnetic properties. Therefore, this sensor should be isolated to create a non-magnetic field. Figure 4.3 shows the diagram of the MWD system *(Gardner, 1997).*

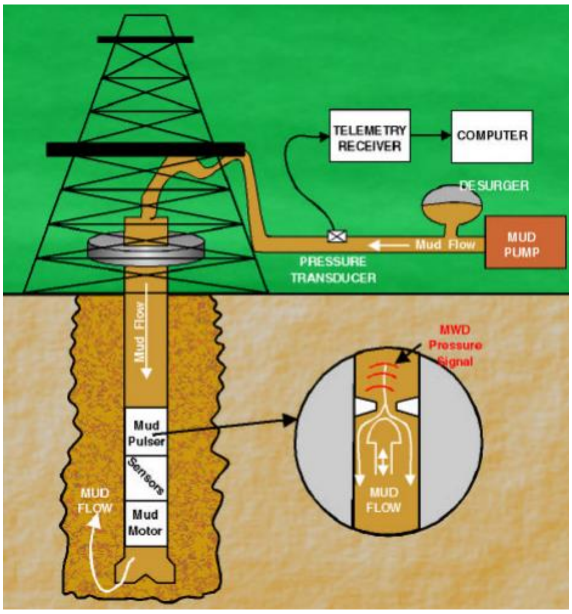


Figure 4.3. MWD System Concept Diagram (Gardner, 1997)

4.1.4 Stabilizers

There are two stabilizers that have been used in the directional drilling operations where data has been collected for this thesis. One of them is located on a mud motor, which is called a sleeve stabilizer with $8^{3/8}$" (0.213 m) of blade outer diameter (OD). The other is located just above the mud motor, which is called an integral blade stabilizer with $7^{3/4}$" (0.197 m) of blade OD. Figure 4.4 shows the stabilizers used in the bottom-hole assembly.

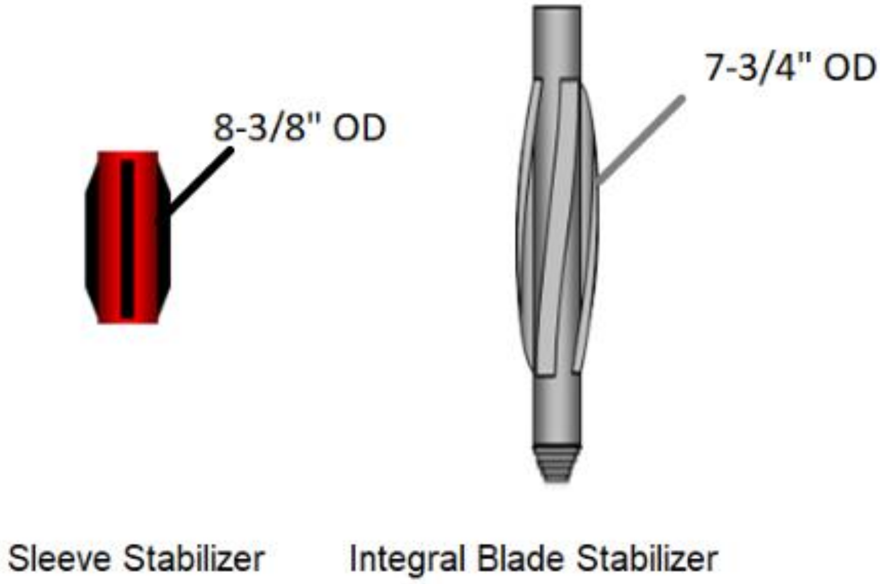


Figure 4.4. Sleeve and Integral Blade Stabilizers

4.1.5 Other Directional Drilling BHA Materials

Rotary bottom-hole assembly generally includes the bit, bit sub, stabilizers, drill collars and heavy-weight drill collars. The directional drilling bottom-hole assembly includes mud motor, MWD tool, specific stabilizers, non-magnetic drill collars, universal bottom-hole orientation sub, in addition to the rotary BHA. Here, the non-magnetic drill collars and the universal bottom-hole orientation sub are detailed. Firstly, both of them are not affected by magnetic field since, they are made of non-magnetic materials. Used non-magnetic drill collar has 6 ^{½}” (0.165 m) of outer diameter, $3^{1/4}$” (0.083 m) of inner diameter and 9.48 m of length. The MWD tool is run into the non-magnetic drill collar to get correct data and transfer it to the surface without being affecting from magnetic field. The universal bottom-hole orientation sub used has 6 ^{½}” (0.165 m) of outer diameter, $3^{1/4}$” (0.083 m) of inner diameter and 0.93 m of length. It is designed and used to establish the high side of the tool, which is essential to know the tool's orientation in the wellbore while drilling directionally. Moreover, the spiral drill collars have been used which have $6^{1/2}$” (0.165 m) of outer diameter, $2^{1/4}$” (0.057 m) of inner diameter and approximately 9.2 m of length. The heavyweight drill pipes have also been used which have 5” (0.127 m) of outer diameter, 3” (0.076 m) of ID and approximately 9.2 m of length.

4.1.6 Software for Calculation of Directional Drilling

The program is capable of calculating true vertical depth, dog-leg, north/south tendency, east/west tendency, tool-face, vertical section and distance to plan. This program has different calculation methods mentioned in the Literature Review Part as survey calculation methods to reach these results. This software uses three values that come from the MWD tool which are the measured depth, inclination and azimuth. By using them, others can easily be calculated. In addition to this, projection can be done with this program to find what value is wanted. The vertical section, north/south and east/west distances are calculated from the drilling rig location on the surface.

4.2 METHODS

The parameters and calculations have been detailed in this part of the thesis.

4.2.1 Parameters

There are quite a number of parameters that affect the deviation of the wellbore during drilling. These parameters have been investigated by different researchers as mentioned in the Literature Review part. According to them, the weight on the bit, the flow rate, the stabilizer gauge and the location on bottom-hole assembly, the formation, the bit type, the collar size, the hole size and the bottom-hole assembly design affect the deviation of the wellbore. In this thesis, the wells where the same parameters (WOB: 10-11 tones, flow rate: 450 gpm, RPM:40) are applied and the same equipments (8-3/8” of outer diameter sleeve stabilizer, 7-3/4” of outer diameter integral blade stabilizer, equal length of drill collars, roller cone drilling bit) are used in seven different wells to drill 8.5” (0.216 m) hole in diameter in drilling operations by directional driller, have been chosen to evaluate the effect of the formation to the deviation. These parameters are listed in Table 4.4. However, controlling the effect of the formation while drilling is impossible. As mentioned in the Literature Review part, lithology, folds, faults and unconformities change from well to well, even if the distance between the wells is less than 1 km as seen in Figure 2.26. Therefore, the formation effect to the orientation of a wellbore in the Adıyaman Region has been studied using 137 survey points from different lithologies of seven different directional wells. The formations detailed in this thesis are Germav, Kastel, Sayındere, Karaboğaz, Karababa and Derdere. Seven wells are chosen in the Adıyaman Region, their locations relative to each other are shown in the Figure 4.5. When the proximity of these wells to each other is compared, Well A, Well B and Well C are close to each other, Well D and Well E are also located close to each other. The remaining ones are also close to each other as shown in Figure 4.5.

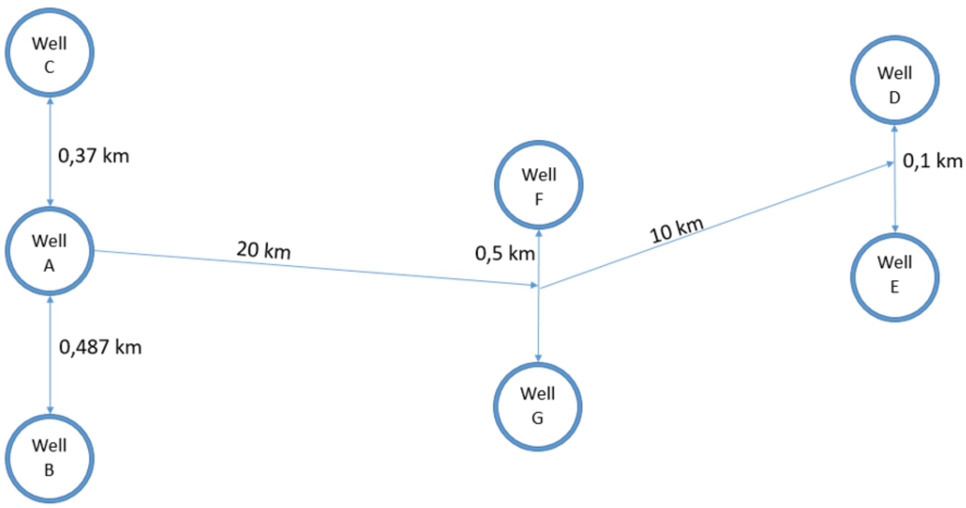


Figure 4.5. Location of Wells

The drilling operations in these wells have been completed with rotary and sliding drilling. Sliding drilling is used to change the angle and azimuth values to follow the plan determined before starting the drilling. The equipments mentioned in Materials part of the thesis are used for the sliding drilling. The directional drillers determine the mud motor bend angle by looking at the output of dog-leg rates of the mud motors according to their well plan. There is no effect of the mud motor bend angle to the hole orientation, it changes the length of the sliding drilling. After that, they decide the stabilizer gauge and size to control deviation in the rotary drilling. They also calculate the number of non-magnetic drill collars, drill collars, heavy-weight drill pipe and drilling jar location on BHA together with the engineers of the company. They also chose the drilling bit. The flow rate and weight on the bit are arranged to clean wellbore, to adjust deviation of the wells especially in soft formations and to safely drill faster with a high rate of penetration. Figure 4.6 shows the BHA design used in all wells examined in this thesis.

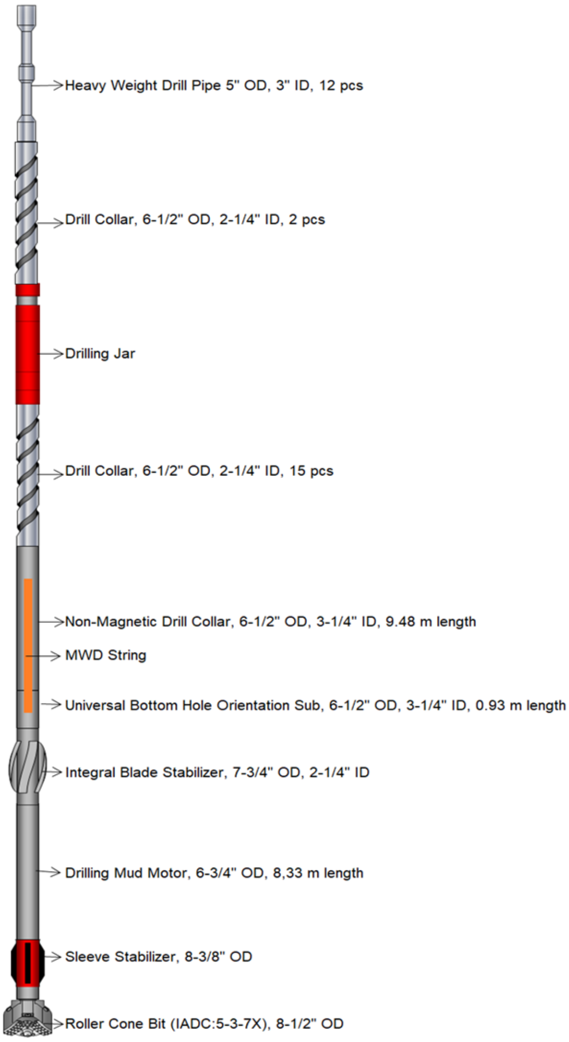


Figure 4.6. BHA Design Diagram

Parameters in the rotary and sliding drilling are given in Table 4.4.

Table 4.4. Controllable Working Parameters

Well Name	**Weight On Bit, Ton**	**Flow Rate, GPM**	**Motor Bend Angle, °**	**Rotary, RPM**
A	10-11	450	1.5	40
B	10-11	450	1.15	40
C	10-11	450	1.5	40
D	10-11	450	1.5	40
E	10-11	450	1.5	40
F	10-11	450	1.15	40
G	10-11	450	1.5	40

4.2.2 Calculations

All wells have been drilled in $8^{1/2}$" (0.216 m) of hole diameter with the same series of drilling bit, the same bottom hole assembly, the same applied weight on the bit, the same flow rate and the same revolution in the rotary drilling. These are in accordance with the required drilling plan. The directional driller uses the mud motor technology to follow this plan. They compare their position with respect to the plan. They also compare the vertical section which is a horizontal distance of the wellbore from the survey station to the position of the drilling rig. In this study, the formation effect to the orientation in the Adıyaman region has been investigated with keeping all of the other parameters the same as mentioned before. Surveys have been taken at equal intervals and have been evaluated in terms of the sliding and rotary drilling. If the position of a survey point is in accordance with the plan, there is no need for sliding drilling. Directional driller expects to keep inclination and azimuth values the same in isotropic formation with holding bottom hole assembly. If they need to catch the plan, the sliding drilling is made to adjust inclination and azimuth values. The North, the South, the East and the West distances to the drilling rig position are compared for every survey point. The used program mentioned in the Material part uses a minimum curvature method since it gives the most accurate results. The program calculates the dog-leg ratio, the tool-face, the North/South distance and the East/West distance values using the depth between two survey stations, azimuth and inclination values at that depths. In this study, all values taken from the wellbore in the field have been calculated and named as Realized Results. If there is no sliding drilling, inclination and azimuth should be the same so there are no tool-face and dog-leg values. However, in the sliding drilling, expected dog-leg is calculated using a motor bend angle from Table 4.3 and the tool-face is calculated to get desired inclination and azimuth values. These values are named as Intended Results in this study. After that, the difference on the North/South and the East/West deviation has been calculated with a minimum curvature method. Equations 4.1, 4.2 and 4.3 are used in the calculations *(Apostolov, 2017)*.

$$\beta = \cos^{-1}[\{(\cos(I1) \times \cos(I2) + \sin(I1) \times \sin(I2)\} \times \cos(A2 - A1)] \quad (4.1)$$

$$TF = \cos^{-1}\left(\frac{\sin(I2) - \mathrm{Sin}(I1) \times \cos(\beta)}{\mathrm{Cos}(I1) \times \mathrm{Sin}(\beta)}\right) \quad (4.2)$$

$$\mathrm{Lsliding} = \frac{\beta}{DLS} \quad (4.3)$$

β: Dog-Leg Angle (°)

TF: Tool-Face Angle (°)

Lsliding: Length of Sliding Section (m)

DLS: Dog-Leg Severity (°/30m) taken from table 4.3.

ΔMD: Measured depth between two survey location (m)

I1: Inclination at the upper survey (°)

I2: Inclination at the lower survey (°)

A1: Azimuth at the upper survey (°)

A2: Azimuth at the lower survey (°)

ΔNorth / ΔSouth and ΔEast/ΔWest calculations have been given in the Literature Review part. The MWD system gives us a tool-face. It comes from the accelerometer sensor. Equation 4.4 shows the calculation of Tool-face coming from the MWD system (Illfelder, Hamlin, Mcelhinney, & Energy, 2005).

$$\text{Toolface} = \tan^{-1}\left(\frac{\text{Gx}}{\text{Gy}}\right) \tag{4.4}$$

Toolface: Tool-face coming from MWD system (°)

Gx, Gy: Accelerometer components which are not parallel to the tool axis

The program which is used in the directional drilling operations supplies very quick responses. The following tables from Table 5.1 to Table 5.22 show the results to compare the deviations. For the realized results, inclination, azimuth and measured depth have been taken from the MWD system and they were input to the program. Program uses Equations 4.2 and 4.3, which give us a dog-leg, a tool-face, the North/South and the East/West distance from the wellhead. For the intended results, the directional drillers drilled wells with the sliding and rotational drilling methods. They calculated the length of the sliding depending on which dog-leg angle they want to get according to Equation 4.3. Moreover, the directional driller knew which a tool-face they worked. Inclination and azimuth values have been calculated with the help of the program whose calculation methods are based on Equations 4.1, 4.2 and 4.3. If the formation is isotropic and homogenous, inclination and azimuth values and the North/South, the East/West distance to the wellhead will be as calculated results. These results have been expressed as Intended Results. For example, for the first values in intended results for well A, the directional driller has drilled 8 m sliding drilling and a motor bend angle has been set as 1.5 ° before running into the hole. The output dog-leg of the mud motor is 7.9 °/30 m from Table 4.3. According to Table 4.3, the dog-leg angle is 2.11 °. (β=8 m x7.9 °/30 m). The tool-face was "-80" which means that the directional driller has worked 80 ° from the North to the West. By using these results, the inclination has been calculated as 4 ° and the azimuth has been calculated as 280 °. After entering the measured depth to the program, the North/South and the East/West distance to the wellhead which are 3.03 m (North) and -12.49 (West) m, respectively, with using a minimum curvature method mentioned in Literature Review part.

CHAPTER 5

RESULTS AND DISCUSSION

Seven wells have been examined to understand the behavior of the deviation. These wells have been drilled 8.5” (0.216 m) in diameter. The drilled interval of three wells which are A, B and C is between 1000 m and 2000 m. The drilled interval of two wells which are D and E is between 1800 m and 2300 m. The drilled interval of two wells which are F and G is between 2300 m and 2600 m. To summarize, the depth of all the wells whose inclination and azimuth values have been taken, are approximately to each other for the same lithology. In this part, the wells are examined one by one, by comparing the realized results and the intended (calculated) results. The direction of the North and the East is expressed as + (plus), the direction of the South and the West is expressed as – (minus) at all tables. Table 5.1, Table 5.2, Table 5.3, Table 5.4, Table 5.5, Table 5.6 and Table 5.7 show the realized results taken from wells.

The weight on the bit, the type of drilling bit, the revolution per minute, the flow rate, the bottom-hole assembly design, the stabilizer gauge and its location, the drill string stiffness, the hole size and the formation have been investigated by different researchers mentioned in Literature Review part. When increasing WOB, the build tendency of the BHA increases. Moreover, if the flow rate increases, the dropping tendency of the BHA increases especially in the unconsolidated formations. The stabilizers gauge and its location have a very important role to control the deviation of a wellbore. As mentioned in Method part of the thesis, the stabilizers have been located to create a holding effect in studied wells. All parameters except the formation can be controlled by the directional drillers. The effects of the parameters have been detailed and proved in different studies. In addition to them, the formations have a huge impact to control the deviation. The effect of the formation is also studied to show the importance of the directional drilling.

The results listed in Table 5.1 show the real values taken with the MWD sensors. These results include the effect of the parameters mentioned before include the formation. Inclination and azimuth values have been taken at equal interval, using these values, the North / South and the West / East distances according to the drilling rig, the dog-leg severity and the effective tool-face are calculated.

Table 5.1. Realized Results of Well A

Realized Result of Well A						
Slide Drilling,m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
8.00	4.40	273.04	2.92	-12.61	2.77	-82.65
8.00	5.98	256.65	2.63	-15.19	2.23	-51.54
8.00	7.21	236.66	1.28	-18.18	2.67	-71.99
9.50	8.27	219.61	-1.33	-21.03	2.60	-73.83
9.65	8.97	201.85	-5.04	-23.20	2.83	-84.16
6.70	10.29	197.68	-9.60	-24.83	1.54	-29.92
12.30	10.90	197.81	-14.51	-26.40	0.65	2.31
10.00	11.43	197.11	-19.86	-28.08	0.57	-14.69
9.50	11.70	194.82	-25.64	-29.73	0.53	-60.66
8.60	13.98	192.36	-31.80	-31.21	2.47	-14.69
9.70	16.44	191.30	-39.12	-32.74	2.61	-6.96
12.10	19.26	191.30	-47.96	-34.50	2.88	0.00
12.20	22.07	191.30	-57.99	-36.51	2.91	0.00
7.50	23.48	187.09	-69.07	-38.29	2.23	-51.09
0.00	22.77	187.09	-80.33	-39.69	0.74	180.00
4.00	23.33	186.73	-91.49	-41.04	0.60	-14.29
0.00	22.86	185.33	-102.99	-42.26	0.74	-131.20
4.00	23.21	186.91	-114.28	-43.47	0.73	61.21
2.50	22.77	187.09	-125.48	-44.84	0.46	171.00
3.00	23.05	188.16	-136.67	-46.34	0.52	56.58
3.00	22.77	189.72	-147.59	-48.06	0.71	115.47
4.00	23.04	190.07	-158.59	-49.98	0.32	26.93
5.50	23.74	189.55	-170.13	-51.97	0.74	-16.67

Table 5.1 (Continued)

0.00	23.04	189.72	-181.48	-53.90	0.73	174.57
5.70	24.18	188.84	-192.94	-55.77	1.23	-17.58
0.00	23.74	188.32	-204.39	-57.50	0.51	-154.60
0.00	23.65	188.49	-216.04	-59.22	0.12	142.88
0.00	23.74	188.32	-227.45	-60.91	0.12	-37.28
0.00	23.10	189.00	-239.04	-62.67	0.35	157.42
0.00	23.00	190.00	-250.62	-64.61	0.40	104.79

Table 5.2 Realized Results of Well B

Realized Result of Well B						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF. °**
16.50	13.37	311.18	13.44	-22.25	2.82	-19.70
12.70	16.53	311.88	18.41	-27.85	3.27	3.61
15.00	18.99	315.57	24.53	-34.22	2.80	26.35
6.00	19.35	317.97	31.37	-40.68	1.48	41.49
0.00	18.27	318.40	38.34	-46.92	1.13	172.89
1.30	17.41	317.15	44.92	-52.89	0.97	-156.59
6.50	17.50	317.51	51.21	-58.68	0.15	50.36
9.50	18.47	316.98	57.89	-64.87	1.00	-9.83
4.50	18.47	318.21	64.68	-71.06	0.40	90.58
1.50	17.94	318.74	71.36	-76.99	0.58	162.90
7.30	18.73	319.97	78.26	-82.90	0.91	26.68
0.00	17.50	320.49	85.07	-88.57	1.31	172.76
7.00	17.94	319.79	91.94	-94.31	0.50	-26.17
7.65	17.98	317.45	98.67	-100.24	0.74	-87.94
0.00	17.85	316.45	105.17	-106.31	0.35	-113.39
11.60	19.61	317.33	111.88	-112.58	1.87	9.54
0.00	18.55	318.21	118.89	-118.95	1.14	165.23
5.50	17.94	320.85	125.80	-124.85	1.06	127.68
7.00	18.47	322.96	132.93	-130.44	0.87	52.21
13.00	19.52	318.56	140.23	-136.41	1.84	-55.85
2.00	18.73	317.33	147.53	-142.99	0.89	-153.55
8.70	19.31	314.24	154.29	-149.58	1.20	-61.53
2.00	18.91	312.06	160.56	-156.27	0.88	-120.30

Table 5.2 (Continued)

8.50	19.52	311.88	166.95	-163.36	0.63	-5.63
6.00	19.61	314.52	173.59	-170.44	0.92	85.43
0.00	18.20	314.87	180.20	-177.12	1.46	175.57
5.00	18.03	313.64	186.49	-183.58	0.43	-114.55
2.00	17.17	313.06	192.60	-190.04	0.90	-168.75
0.00	16.18	313.29	198.27	-196.09	1.03	176.30
7.00	18.20	314.12	204.13	-202.22	2.13	7.32
0.00	17.91	314.61	210.42	-208.64	0.34	152.59
0.00	17.78	315.13	216.69	-214.94	0.21	129.46
0.00	17.73	314.45	222.06	-220.35	0.26	-103.88
0.00	17.75	314.50	225.47	-223.83	0.05	37.32

Table 5.3 Realized Results of Well C

Realized Result of Well C						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
8.00	9.50	278.86	-3.33	-13.38	2.67	-10.39
8.00	11.70	277.98	-2.56	-18.62	2.30	-4.64
9.70	14.42	274.82	-1.84	-25.17	2.89	-16.25
5.60	16.18	268.32	-1.66	-32.82	2.53	-47.43
11.70	18.73	265.33	-2.16	-41.50	2.80	-20.81
0.00	18.20	264.10	-3.00	-50.60	0.68	-144.26
2.00	17.67	266.03	-3.77	-59.57	0.82	132.64
0.00	17.06	264.98	-4.45	-68.20	0.71	-153.31
5.75	18.91	264.98	-5.24	-77.17	1.90	0.00
1.25	18.73	264.27	-6.12	-86.53	0.30	-128.50
3.90	19.17	266.56	-6.87	-95.88	0.90	60.47
2.10	19.43	267.08	-7.40	-105.49	0.32	33.71
0.00	18.38	267.61	-7.84	-114.87	1.10	170.96
6.00	19.26	267.26	-8.26	-124.22	0.92	-7.48
0.00	18.64	267.44	-8.69	-133.63	0.64	174.70
1.50	18.29	267.79	-9.08	-142.86	0.38	162.59
5.00	19.79	267.26	-9.49	-152.28	1.57	-6.83
0.00	18.99	267.79	-9.90	-161.95	0.84	167.85
0.00	18.03	268.67	-10.19	-171.09	1.04	164.19

Table 5.3 (Continued)

5.70	18.55	267.61	-10.49	-180.23	0.64	-33.11
5.00	19.79	266.38	-10.99	-189.74	1.35	-18.62
0.00	18.55	266.56	-11.58	-199.28	1.28	177.36
0.00	17.23	267.08	-12.07	-208.20	1.37	173.35
3.75	17.50	268.32	-12.42	-216.81	0.48	54.48
8.25	18.20	268.32	-12.68	-225.79	0.72	0.00
7.60	19.52	266.05	-13.15	-235.08	1.57	-30.15
0.00	18.29	266.73	-13.74	-244.51	1.29	170.17
6.50	18.64	264.45	-14.44	-253.58	0.84	-65.23
0.00	17.50	264.45	-15.32	-262.57	1.17	180.00
5.90	18.03	265.50	-16.09	-271.32	0.65	31.65
6.00	20.14	266.03	-16.78	-280.74	2.20	4.95
0.00	19.52	265.33	-17.52	-290.59	0.68	-159.37
2.50	19.26	266.38	-18.22	-300.20	0.45	127.21
1.50	19.08	267.26	-18.90	-312.39	0.27	122.33
0.00	18.90	267.26	-19.14	-317.47	0.35	180.00

Table 5.4 Realized Results of Well D

Realized Result of Well D						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	10.02	56.44	80.62	145.21	1.74	-147.32
6.00	10.46	59.25	83.27	149.43	0.71	50.01
8.30	12.75	64.18	86.01	154.57	2.58	25.85
6.00	13.19	68.39	88.57	160.42	1.10	67.09
5.50	14.68	68.57	91.09	166.81	1.57	1.75
0.00	14.41	67.00	93.80	173.44	0.50	-125.16
2.00	14.86	68.82	96.50	180.11	0.68	46.50
3.00	14.86	68.75	99.17	186.99	0.02	-90.03
0.00	15.04	64.53	102.06	193.67	1.17	-82.65
0.00	15.12	62.07	105.39	200.29	0.68	-84.06
0.00	15.00	61.00	108.30	205.66	0.39	-113.86
0.00	15.20	59.00	110.51	209.49	0.98	-69.97

Table 5.5 Realized Results of Well E

Realized Result of Well E						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
11.70	13.28	246.12	-43.02	-140.66	1.89	-73.64
14.50	15.65	236.45	-46.43	-146.80	3.59	-50.30
0.00	15.56	238.21	-50.60	-153.29	0.50	101.61
0.00	15.30	239.97	-54.52	-159.84	0.56	119.89
6.00	15.04	235.57	-58.50	-166.15	1.24	-104.84
0.00	14.95	236.45	-62.59	-172.22	0.26	111.99
0.00	15.04	237.68	-66.60	-178.41	0.35	74.80
0.00	14.86	238.21	-70.50	-184.64	0.24	143.04
5.00	14.95	245.24	-73.98	-191.11	1.90	90.55
4.00	13.81	246.29	-76.86	-197.52	1.24	167.62
5.10	14.25	252.10	-79.32	-203.99	1.55	75.48
0.00	14.42	254.38	-81.35	-210.75	0.62	74.35
0.00	14.51	255.61	-83.21	-217.67	0.33	74.27

Table 5.6 Realized Results of Well F

Realized Result of Well F						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	15.21	272.66	2.12	-252.58	2.17	164.85
8.00	16.09	269.89	2.29	-260.43	1.19	-41.68
4.00	17.50	269.52	2.25	-268.78	1.47	-4.51
0.00	17.74	269.77	2.18	-280.28	0.20	17.62
3.00	18.41	268.22	2.02	-289.27	0.85	-36.41
0.00	18.22	267.86	1.71	-298.38	0.23	-149.40
3.00	18.11	269.52	1.50	-307.42	0.55	102.79
0.00	17.90	269.19	1.39	-316.69	0.23	-154.25

Table 5.7 Realized Results of Well G

Realized Result of Well G						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	6.95	269.42	-54.19	-30.01	0.17	90.69
0.00	6.95	271.53	-54.17	-33.27	0.28	91.05
0.00	6.77	273.64	-54.01	-36.72	0.32	126.58
0.00	6.66	279.61	-53.63	-39.98	0.75	101.91
0.00	6.51	279.26	-53.43	-41.22	0.42	-165.19

Tables 5.8 to 5.14 show the values which are intended (calculated) results for the wells where realized values have been taken. The directional drillers follow the path determined originally to hit the target. To do this, they try to adjust the inclination and the azimuth values with the slide drilling mode. The manufacturer has a dog-leg ratio for their mud motors. The directional driller calculates the amount of the sliding drilling, the inclination, the azimuth and the tool-face values with Equations 4.1, 4.2, 4.3 and 4.4. However, they never get results like the calculated ones due to the resultant forces applied to the drilling BHA. When this resultant force is ignored, results happen as listed in tables named the Intended Results of the wells.

Table 5.8 Intended Results of Well A

Intended Result of Well A						
Slide Drilling,m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
8.00	4.00	280.00	3.03	-12.49	2.11	-80.00
8.00	5.90	257.50	2.65	-15.17	2.11	-53.00
8.00	6.80	239.50	1.41	-18.14	2.11	-75.00
9.50	7.74	218.50	-1.25	-20.91	2.50	-85.00
9.65	9.16	204.50	-5.04	-23.32	2.54	-75.00
6.70	9.66	192.30	-9.51	-24.56	1.76	-70.00

Table 5.8 (Continued)

12.30	11.30	182.30	-14.73	-25.70	3.24	-78.00
10.00	13.18	192.30	-20.35	-27.94	2.63	-30.00
9.50	12.86	187.30	-26.02	-29.38	2.50	-60.00
8.60	13.72	191.75	-31.75	-31.16	2.26	-20.00
9.70	16.37	190.82	-39.11	-32.70	2.55	-10.00
12.10	19.52	189.65	-48.04	-34.38	3.19	-11.00
12.20	22.34	189.72	-58.08	-36.37	3.21	-11.00
7.50	23.20	187.30	-69.00	-38.30	1.98	-55.00
0.00	23.48	187.09	-80.49	-39.71	0.00	0.00
4.00	23.75	186.65	-91.58	-41.04	1.05	-10.00
0.00	23.33	186.73	-103.09	-42.41	0.00	0.00
4.00	23.72	186.70	-114.40	-43.46	1.05	35.00
2.50	23.56	188.25	-125.64	-44.98	0.66	60.00
3.00	23.53	187.09	-136.79	-46.25	0.79	0.00
4.70	24.20	187.60	-147.96	-47.90	1.24	-10.00
4.00	23.65	188.50	-158.76	-49.85	1.05	-25.00
5.50	24.40	189.00	-170.29	-51.94	1.45	-18.00
1.00	23.74	188.92	-181.66	-53.85	0.26	-90.00
6.40	24.52	188.00	-193.04	-55.70	1.69	-25.00
2.50	24.50	187.50	-204.57	-57.44	0.66	0.00
0.00	23.74	188.32	-216.06	-59.21	0.00	0.00
3.00	24.00	187.00	-227.52	-60.78	0.79	-60.00
0.00	23.74	188.32	-239.20	-62.62	0.00	0.00
0.00	23.10	189.00	-250.66	-64.51	0.00	0.00

Table 5.9 Intended Results of Well B

Intended Result of Well B						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
16.50	13.86	314.20	13.66	-22.22	3.19	-5.00

Table 5.9 (Continued)

12.70	15.43	315.91	18.42	-27.46	2.46	32.00
15.00	18.72	317.70	24.60	-34.05	2.90	40.00
6.00	19.46	320.26	31.76	-40.27	1.16	50.00
0.00	19.35	317.97	38.75	-46.83	0.00	0.00
1.30	18.42	319.00	45.44	-52.66	0.25	50.00
6.50	18.58	317.90	51.66	-58.55	1.26	10.00
9.50	19.31	317.51	58.32	-64.69	1.84	0.00
4.50	19.19	318.25	65.05	-70.89	0.87	30.00
1.50	18.65	318.85	71.74	-76.81	0.29	50.00
7.30	19.22	320.20	78.61	-82.68	1.41	20.00
0.00	18.73	319.97	85.52	-88.51	0.00	0.00
7.00	18.82	320.49	92.39	-94.12	1.35	0.00
7.65	19.30	318.30	99.20	-100.12	1.48	-20.00
0.00	17.98	317.45	105.49	-105.99	0.00	0.00
11.60	19.92	317.52	112.18	-112.34	2.24	10.00
0.00	19.61	317.33	119.28	-118.90	0.00	0.00
5.50	19.56	318.76	126.23	-124.95	1.06	10.00
7.00	19.12	322.58	133.28	-130.27	1.35	35.00
13.00	20.49	318.74	140.65	-136.27	2.51	-35.00
2.00	19.77	317.64	147.98	-142.86	0.39	-50.00
8.70	20.26	315.60	154.78	-149.38	1.68	-20.00
2.00	19.65	313.86	161.03	-156.01	0.39	-20.00
8.50	20.45	312.90	167.41	-163.19	1.64	10.00
6.00	20.34	314.12	173.93	-170.30	1.16	45.00
0.00	19.61	312.52	180.54	-177.22	0.00	0.00
5.00	19.14	314.87	186.99	-183.42	0.97	0.00
2.00	18.41	313.64	193.08	-189.95	0.39	0.00
0.00	17.17	313.06	198.67	-195.99	0.00	0.00
7.00	17.42	314.46	204.26	-201.79	1.35	15.00
0.00	18.20	314.12	210.68	-208.44	0.00	0.00
0.00	17.91	314.61	216.92	-214.71	0.00	0.00
0.00	17.78	315.13	222.34	-220.05	0.00	0.00
0.00	17.73	314.45	225.71	-223.55	0.00	0.00

Table 5.10 Intended Results of Well C

Intended Result of Well C						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
8.00	8.95	278.20	-3.38	-13.25	2.11	-15.00
8.00	11.46	275.90	-2.69	-18.58	2.11	-10.00
9.70	14.10	275.25	-1.83	-25.09	2.55	-20.00
5.60	15.28	270.40	-1.53	-32.61	1.47	-55.00
11.70	18.98	265.00	-2.20	-41.56	3.08	-20.00
0.00	18.73	265.33	-2.93	-50.74	0.00	0.00
2.00	18.56	265.24	-3.87	-59.79	0.53	45.00
0.00	17.67	266.03	-4.40	-68.36	0.00	0.00
5.75	18.53	264.98	-5.25	-77.08	1.51	0.00
1.25	19.23	264.98	-6.09	-86.66	0.33	0.00
3.90	19.68	265.08	-7.01	-96.00	1.03	15.00
2.10	19.69	266.96	-7.43	-105.55	0.55	15.00
0.00	19.43	267.08	-7.91	-115.12	0.00	0.00
6.00	19.81	266.00	-8.39	-124.34	1.58	-20.00
0.00	19.26	267.26	-8.73	-133.77	0.00	0.00
1.50	19.00	266.92	-9.17	-143.03	0.40	-25.00
5.00	19.55	267.04	-9.52	-152.22	1.32	-10.00
0.00	19.79	267.26	-9.97	-162.14	0.00	0.00
0.00	18.99	267.79	-10.28	-171.32	0.00	0.00
5.70	19.44	267.50	-10.52	-180.45	1.50	-15.00
5.00	19.79	266.64	-10.99	-189.75	1.32	-15.00
0.00	19.79	266.38	-11.63	-199.57	0.00	0.00
0.00	18.95	266.56	-12.15	-208.51	0.00	0.00
3.75	18.18	267.08	-12.54	-216.97	0.99	0.00
8.25	19.60	265.94	-13.10	-226.11	2.17	-10.00
7.60	20.03	266.70	-13.30	-235.20	2.00	-17.00
0.00	19.52	266.05	-14.02	-244.79	0.00	0.00
6.50	19.73	264.31	-14.68	-253.83	1.71	-30.00
0.00	18.64	264.45	-15.55	-262.84	0.00	0.00
5.90	18.99	264.45	-16.39	-271.54	1.55	0.00
6.00	19.54	266.00	-16.98	-280.59	1.58	5.00
0.00	20.14	266.03	-17.68	-290.74	0.00	0.00
2.50	19.52	267.24	-18.36	-300.26	0.66	90.00

Table 5.10 (Continued)

1.50	19.22	267.90	-19.04	-312.43	0.40	100.00
0.00	19.08	267.26	-19.35	-317.49	0.00	0.00

Table 5.11 Intended Results of Well D

Intended Result of Well D						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	11.00	60.13	80.61	145.42	0.00	0.00
6.00	11.18	61.40	83.27	149.63	1.58	40.00
8.30	12.22	65.15	85.90	154.47	2.19	37.00
6.00	13.59	69.65	88.54	160.54	1.58	57.00
5.50	14.44	70.86	90.94	166.80	1.45	25.00
0.00	14.68	68.57	93.73	173.53	0.00	0.00
4.50	15.00	70.80	96.39	180.18	1.19	60.00
3.00	15.30	71.20	99.06	187.15	0.79	55.00
0.00	14.86	68.75	101.80	193.73	0.00	0.00
0.00	15.04	64.53	105.24	200.34	0.00	0.00
0.00	15.12	62.07	108.26	205.70	0.00	0.00
0.00	15.00	61.00	110.43	209.50	0.00	0.00

Table 5.12 Intended Results of Well E

Intended Result of Well E						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
11.70	13.88	242.00	-43.30	-140.69	3.08	-70.00
14.50	15.76	235.66	-46.49	-146.79	3.82	-50.00
0.00	15.65	236.45	-50.71	-153.25	0.00	0.00
0.00	15.56	238.21	-54.66	-159.84	0.00	0.00
6.00	15.37	234.31	-58.61	-166.17	1.58	-90.00
0.00	15.04	235.57	-62.65	-172.21	0.00	0.00
0.00	14.95	236.45	-66.65	-178.35	0.00	0.00
0.00	15.04	237.68	-70.55	-184.66	0.00	0.00

Table 5.12 (Continued)

5.00	14.92	243.10	-74.10	-191.04	1.32	90.00
4.00	13.96	245.24	-76.94	-197.52	1.05	180.00
5.10	14.27	251.20	-79.37	-203.98	1.34	70.00
0.00	14.25	252.10	-81.48	-210.67	0.00	0.00
0.00	14.42	254.38	-83.28	-217.63	0.00	0.00

Table 5.13 Intended Results of Well F

Intended Result of Well F						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	16.88	270.93	2.03	-252.92	0.00	0.00
8.00	16.70	271.74	2.43	-260.57	1.55	-10.00
10.00	18.00	269.89	2.28	-268.90	1.93	0.00
2.00	18.00	270.00	2.20	-280.36	0.39	15.00
5.50	18.70	269.77	2.14	-289.35	1.06	0.00
0.00	18.41	268.22	1.73	-298.43	0.00	0.00
3.00	18.51	269.40	1.49	-307.51	0.58	60.00
0.00	18.11	269.52	1.42	-316.74	0.00	0.00

Table 5.14 Intended Results of Well G

Intended Result of Well G						
Slide Drilling, m	**Inc °**	**Azi °**	**NS(m)**	**EW(m)**	**DLS °/30m**	**Toolface GTF, °**
0.00	6.95	268.02	-54.24	-30.01	0.00	0.00
0.00	6.95	269.42	-54.23	-33.27	0.00	0.00
0.00	6.95	271.53	-54.07	-36.77	0.00	0.00
0.00	6.77	273.64	-53.80	-40.03	0.00	0.00
0.00	6.66	279.26	-53.43	-41.24	0.00	0.00

Tables 5.15 to 5.21 show the values which are the difference between the NS and the EW directions in the different lithology taken from the each well investigated. The

realized values are the real values at that survey location and they include the resultant force of all parameters detailed by different researchers mentioned in Literature Review part. The intended values are the calculated values for the same survey location and they do not include any forces affecting the deviation. In this study, WOB, RPM, flow rate, BHA design, stabilizers gauge and location, type of drilling bit have been kept the same. Moreover, all the values have been taken from $8^{1/2}$” (0.216 m) diameter hole. So, the parameters except the formation were the same. If the resultant force and other vectorial forces are known, the force applied by the formation can be known relatively. Therefore, the difference between the realized values and the intended values can be thought as the formation effect in the Adıyaman Region and can be used to show if there is a trend or not. All values are shown with respect to the formation type. The average of them has been calculated for comparison between wells since surveys have been taken at equal interval.

Table 5.15 Deviation Calculation for Well A

Deviation Calculation for Well A						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Germav	-0.11	-0.12	0.070	-0.088	0.16049	0.18952
Germav	-0.02	-0.02				
Germav	-0.13	-0.04				
Germav	-0.08	-0.12				
Germav	0	0.12				
Germav	-0.09	-0.27				
Germav	0.22	-0.7				
Germav	0.49	-0.14				
Germav	0.38	-0.35				
Germav	-0.05	-0.05				
Germav	-0.01	-0.04				
Germav	0.08	-0.12				
Germav	0.09	-0.14				
Germav	-0.07	0.01				

Table 5.15 (Continued)

Germav	0.16	0.02				
Germav	0.09	0				
Germav	0.1	0.15				
Germav	0.12	-0.01				
Germav	0.16	0.14				
Kastel	0.06	-0.09	0.127	-0.127	0.04989	0.02867
Kastel	0.18	-0.16				
Kastel	0.14	-0.13				
Sayındere	0.14	-0.03	0.090	-0.053	0.04637	0.01479
Sayındere	0.13	-0.05				
Sayındere	0.03	-0.07				
Sayındere	0.06	-0.06				
Karaboğaz	0.02	-0.01	0.045	-0.070	0.025	0.06
Karaboğaz	0.07	-0.13				
Karababa	0.16	-0.05	0.100	-0.075	0.06	0.025
Karababa	0.04	-0.1				

Table 5.16 Deviation Calculation for Well B

Deviation Calculation for Well B						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Germav	0.22	-0.03	-0.380	-0.170	0.12	0.11
Germav	0.01	-0.39				
Germav	0.07	-0.17				
Germav	0.39	-0.41				
Germav	0.41	-0.09				
Germav	0.52	-0.23				
Germav	0.45	-0.13				
Germav	0.43	-0.18				
Germav	0.37	-0.17				
Germav	0.38	-0.18				
Germav	0.35	-0.22				
Germav	0.45	-0.06				
Germav	0.45	-0.19				
Germav	0.53	-0.12				

Table 5.16 (Continued)

Germav	0.32	-0.32				
Germav	-0.3	-0.24				
Germav	0.39	-0.05				
Germav	0.43	0.1				
Germav	0.35	-0.17				
Germav	0.42	-0.14				
Germav	0.45	-0.13				
Germav	0.49	-0.2				
Germav	0.47	-0.26				
Germav	0.46	-0.17				
Germav	0.34	-0.14				
Kastel	-0.34	0.1	-0.420	-0.030	0.08	0.13
Kastel	-0.5	-0.16				
Sayındere	-0.48	-0.09				
Sayındere	-0.4	-0.1	-0.340	-0.210	0.15	0.158
Sayındere	-0.13	-0.43				
Karaboğaz	-0.26	-0.2	-0.250	-0.215	0.02	0.015
Karabogaz	-0.23	-0.23				
Karababa	-0.28	-0.3	-0.260	-0.290	0.02	0.01
Karababa	-0.24	-0.28				

Table 5.17 Deviation Calculation for Well C

Deviation Calculation for Well C						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Germav	0.05	-0.13				
Germav	0.13	-0.04				
Germav	-0.01	-0.08				
Germav	-0.13	-0.21				
Germav	0.04	0.06	0.040	0.100	0.07	0.14
Germav	-0.07	0.14				
Germav	0.1	0.22				
Germav	-0.05	0.16				
Germav	0.01	-0.09				
Germav	-0.03	0.13				

Table 5.17 (Continued)

Germav	0.14	0.12				
Germav	0.03	0.06				
Germav	0.07	0.25				
Germav	0.13	0.12				
Germav	0.04	0.14				
Germav	0.09	0.17				
Germav	0.03	-0.06				
Germav	0.07	0.19				
Germav	0.09	0.23				
Germav	0.03	0.22				
Germav	0	0.01				
Germav	0.05	0.29				
Germav	0.08	0.31				
Germav	0.12	0.16				
Kastel	0.42	0.32	0.280	0.240	0.11	0.0864
Kastel	0.15	0.12				
Kastel	0.28	0.28				
Sayındere	0.24	0.25	0.260	0.247	0.03	0.021
Sayındere	0.23	0.27				
Sayındere	0.3	0.22				
Karaboğaz	0.2	-0.15	0.170	0.020	0.02	0.126
Karabogaz	0.16	0.15				
Karaboğaz	0.14	0.06				
Karababa	0.14	0.04	0.175	0.030	0.035	0.01
Karababa	0.21	0.02				

Table 5.18 Deviation Calculation for Well D

Deviation Calculation for Well D						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Sayındere	0.01	-0.21	0.030	-0.130	0.04	0.05
Sayındere	0	-0.2				
Sayındere	0.11	-0.1				
Sayındere	0.03	-0.12				

Table 5.18 (Continued)

Karaboğaz	0.15	0.01	0.110	-0,040	0.04	0.05
Karaboğaz	0.07	-0.09				
Karababa	0.11	-0.07	0.160	-0.100	0.07	0.04
Karababa	0.11	-0.16				
Karababa	0.26	-0.06				
Derdere	0.15	-0.05	0.090	-0.030	0.05	0.02
Derdere	0.04	-0.04				
Derdere	0.08	-0.01				

Table 5.19 Deviation Calculation for Well E

Deviation Calculation for Well E						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Sayındere	0.28	0.03	0.100	-0.020	0.06	0.03
Sayındere	0.06	-0.01				
Sayındere	0.11	-0.04				
Sayındere	0.14	0				
Sayındere	0.11	0.02				
Sayındere	0.06	-0.01				
Sayındere	0.05	-0.06				
Sayındere	0.05	0.02				
Sayındere	0.12	-0.07				
Sayındere	0.08	0				
Sayındere	0.05	-0.01				
Sayındere	0.13	-0.08				
Sayındere	0.07	-0.04				
Karababa	-0.24	-0.28				

Table 5.20 Deviation Calculation for Well F

Deviation Calculation for Well F						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Sayındere	0.09	0.34	-0.025	0.170	0.081	0.1
Sayındere	-0.14	0.14				
Sayındere	-0.03	0.12				
Sayındere	-0.02	0.08				
Karaboğaz	-0.12	0.08	-0.070	0.070	0.05	0.01
Karaboğaz	-0.02	0.05				
Karababa	0.01	0.09	-0.010	0.070	0.02	0.02
Karababa	-0.03	0.05				

Table 5.21 Deviation Calculation for Well G

Deviation Calculation for Well G						
Formation	**North(+) South(-), m**	**East(+) West(-), m**	**Mean N/S, m**	**Mean E/W, m**	**SD(σ) of N/S, m**	**SD(σ) of E/W, m**
Kastel	0.05	0	0.057	0.020	0.0047	0.02
Kastel	0.06	0				
Kastel	0.06	0.05				
Sayındere	0.17	0.05	0.085	0.040	0.085	0.02
Sayındere	0	0.02				

Table 5.22 shows the summary of all wells. For each well, the average deviations are shown with respect to the formation lithology. Angles listed in Table 5.22 were calculated with arctangent of ratio of the EW deviation to the NS deviation. For example, the meaning of the NW direction with 51.63 angle for Well A and lithology Germav is that the well has oriented from the North to the West with an angle of 51.63. The total length of the deviation for each well and lithology was calculated with the hypotenuse of the NS and the EW deviations.

Table 5.22 Summarizing of Wells Deviation

Well Name	Lithology	NS (m)	EW (m)	Direction	Angle, °
A	Germav	0.070	-0.088	NW	51.63
A	Kastel	0.127	-0.127	NW	45.00
A	Sayındere	0.090	-0.053	NW	30.26
A	Karaboğaz	0.045	-0.070	NW	57.26
A	Karababa	0.100	-0.075	NW	36.87
B	Germav	-0.378	-0.172	SW	24.42
B	Kastel	-0.420	-0.030	SW	4.09
B	Sayındere	-0.337	-0.207	SW	31.54
B	Karaboğaz	-0.245	-0.215	SW	41.27
B	Karababa	-0.260	-0.290	SW	48.12
C	Germav	0.042	0.099	NE	66.92
C	Kastel	0.283	0.240	NE	40.27
C	Sayındere	0.257	0.247	NE	43.86
C	Karaboğaz	0.167	0.020	NE	6.84
C	Karababa	0.175	0.030	NE	9.73
D	Sayındere	0.030	-0.126	NW	76.61
D	Karaboğaz	0.110	-0.040	NW	19.98
D	Karababa	0.160	-0.097	NW	31.14
D	Derdere	0.090	-0.033	NW	20.32
E	Sayındere	0.101	-0.019	NW	10.80
F	Sayındere	-0.025	0.170	SE	81.63
F	Karaboğaz	-0.070	0.065	SE	42.88
F	Karababa	-0.010	0.070	SE	81.87
G	Kastel	0.057	0.017	NE	16.39
G	Sayındere	0.085	0.035	NE	22.38

With using the data from Table 5.22, Figures from 5.1 to 5.12 have been prepared to see the deviation for each well and for each formation. Figures 5.1 to 5.7 show the behavior of orientation when drilling different formations in each well. These wells are located on the northwestern coastline of Ataturk Dam and the southwest of the East Anatolian fault line in the Adıyaman Region.

Although many of the parameters affecting the orientation of wells have been examined in the Literature Review part with the help of different articles, the parameters of the formation affecting the orientation and the geological development affecting the orientation in the Adıyaman Region should be investigated at this point for further discussions.

Figure 5.1 is divided into two parts for a clearer view of the charts. This figure shows the deviation values of Well A. Germav, Kastel, Sayındere, Karaboğaz, Karababa formations were cut, respectively. All of them have different lithologies and their hardness is different. While the depositional environment of all except Karababa formations is a deep marine environment, Karababa formation's depositional environment is the beach, tidal and shallow marine. Moreover, while Germav and Kastel formations have a very low porosity, Sayındere, Karaboğaz and Karababa formations have higher porosity than others. There are unconformities between the Upper Miocene Şelmo and the Paleocene Upper Germav, the Cretaceous Mardin and the Upper Cretaceous Karaboğaz mentioned before. Although some researches said that the unconformities affect the deviation, Well A seems not to be affected so much. Well goes to the Northwest in all formations. As seen in Table 5.22, the deviation angles for Well A for different formations are close to each other. The structural properties of the formation may affect the deviations in this well more than the stratigraphic properties of the formation.

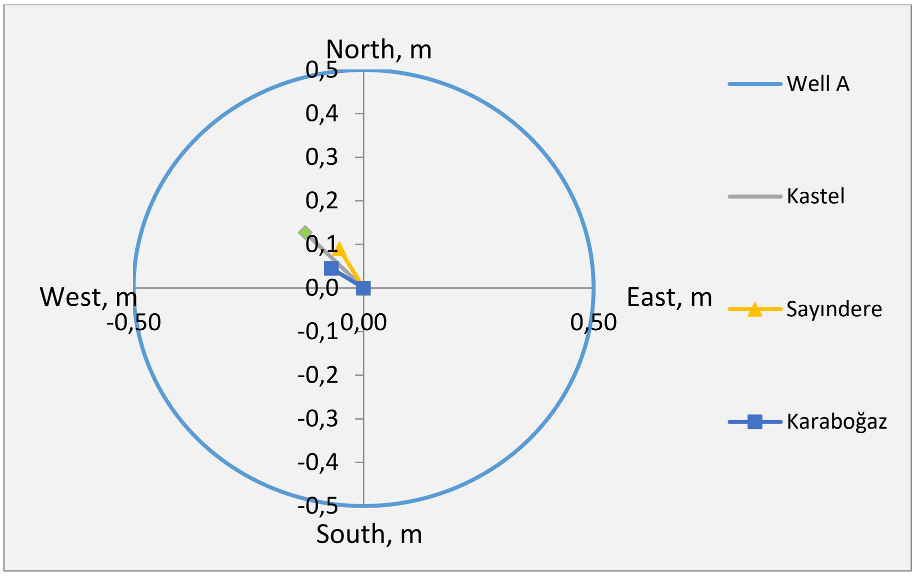


Figure 5.1(a) Graph of Deviation of Well A in Kastel, Sayındere and Karaboğaz Formations

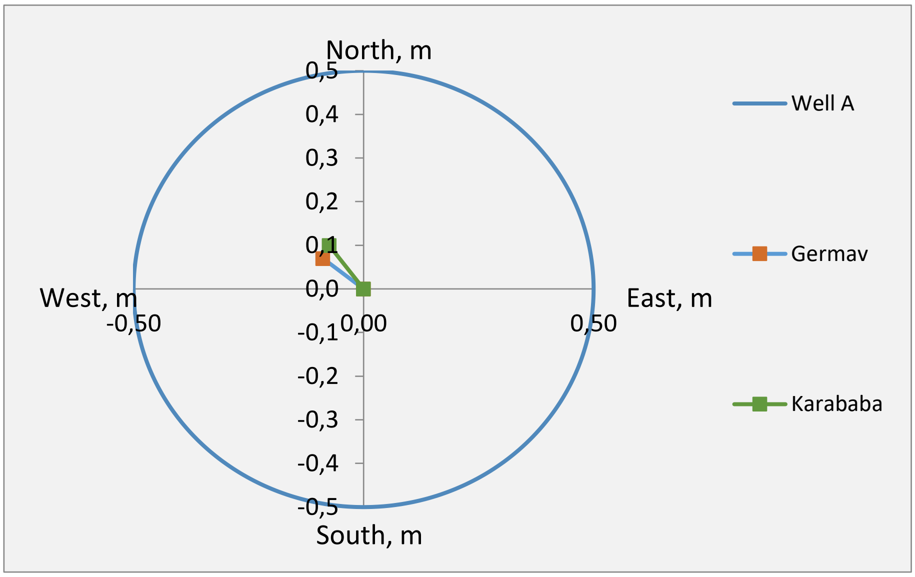


Figure 5.1(b) Graph of Deviation of Well A in Germav and Karababa Formations

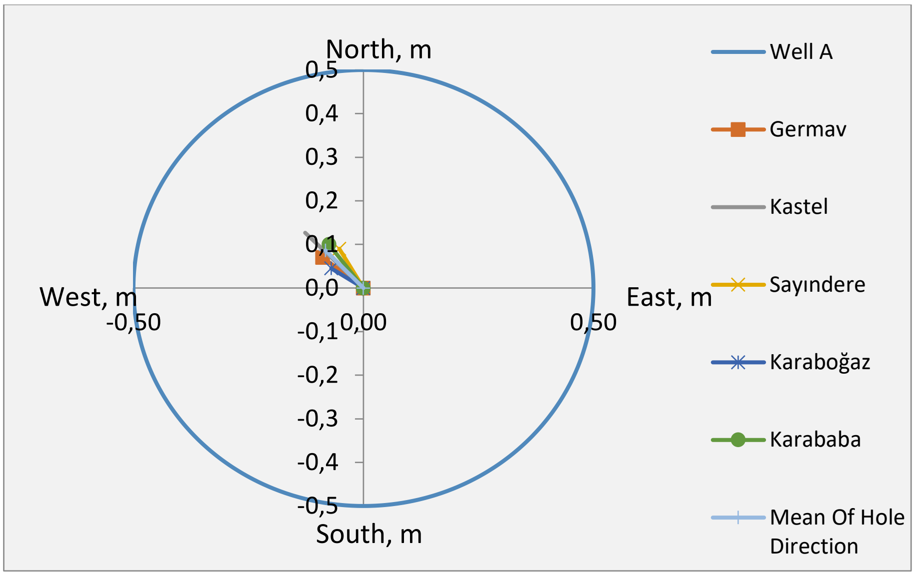


Figure 5.1. Graph of Deviation of Well A in Different Formations

Figure 5.2 shows the deviation values of Well B. Germav, Kastel, Sayındere, Karaboğaz, Karababa formations were cut, respectively. Everything mentioned about the lithology, the depositional environment, the porosity and the unconformities for Well A is the same for Well B. This well goes to the Southwest in all formations. As seen in Table 5.22, deviation angles for Well B increases from Kastel formation to the Karaba formation. However, there is no big effect to change the direction to another direction. Well A and Well B are close to each other. When comparing them, they deviate to the different directions. Bedding, folds or faults could be the reason for that because there are lots of folds, and faults in the Adıyaman Region. Seyrek (2008) investigated three wells in the Adıyaman Region. They are located on anticline, syncline and near thrust fault. All of them have the NE strike direction and have different dip directions. Moreover, most of the anticlines and synclines in Adıyaman have different dip angle and their flanks are asymmetrical. The structural properties of the formation such as bedding, may affect the deviations in this well more than the stratigraphic properties of the formation.

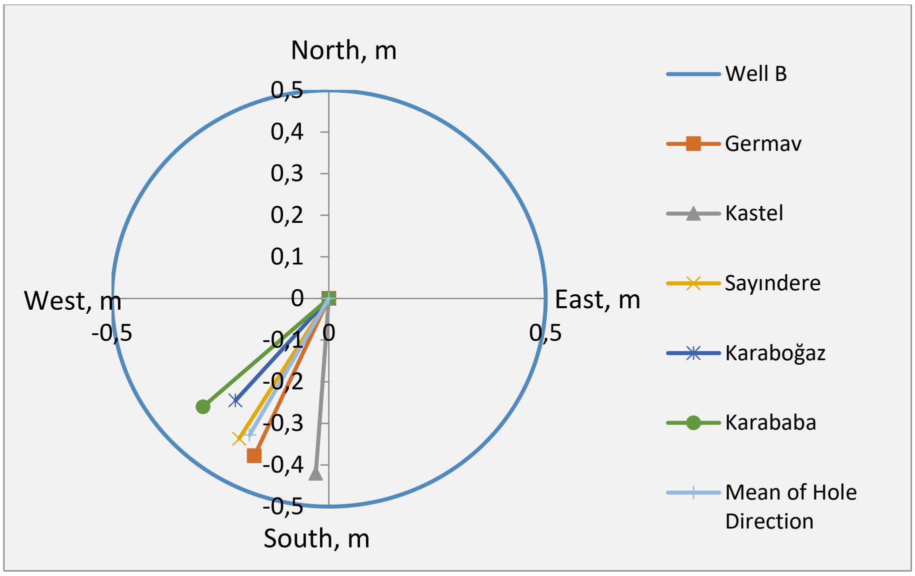


Figure 5.2. Graph of Deviation of Well B in Different Formations

Figure 5.3 shows the deviation values of Well C. Germav, Kastel, Sayındere, Karaboğaz, Karababa formations were cut, respectively. Everything mentioned about the lithology, the depositional environment, the porosity and the unconformities for Well A is the same for Well C. This well goes to the Northeast in all formations. As seen in Table 5.22, deviation angles for Well C changes from Germav formation to the Karababa formation. However, there is no big effect to change direction to another. Well A, Well B and Well C are close to each other, but the directions of the wells go to the NW, the SW and the NE, respectively. The explanation for this could be the same as Well A and B.

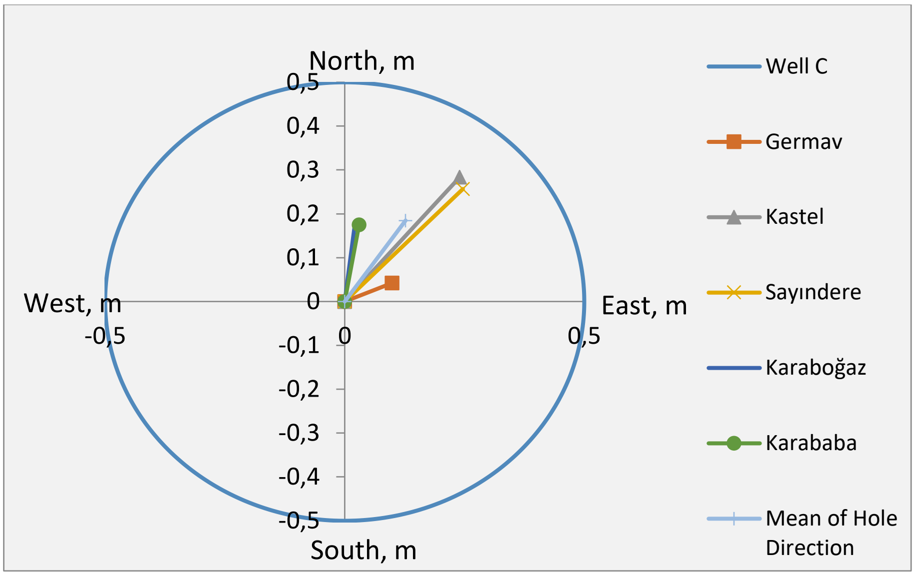


Figure 5.3. Graph of Deviation of Well C in Different Formations

Figure 5.4 shows the deviation values of Well D. Sayındere, Karaboğaz, Karababa and Derdere formations were cut, respectively. All of them have different lithologies and their hardness is different. While the depositional environment of Sayındere and Karaboğaz is a deep marine environment, Karababa and Derdere formation's depositional environment are the beaches, tidal and shallow marines. There are unconformities between the Cretecaus Mardin and the Upper Cambrian Derik Group, the Cretaceous Mardin and the Upper Cretaceous Karaboğaz, Derdere and Karababa formations mentioned before. The unconformities affect the deviation but this well seems to be not affected so much because the angles of deviation of Karaboğaz, Karababa and Derdere formations which have the unconformities while passing from one to another mentioned by different researchers, are close to each other. This well goes to the Northwest in all formations. The structural properties of the formation may affect the deviations in well D more than the stratigraphic properties of the formation.

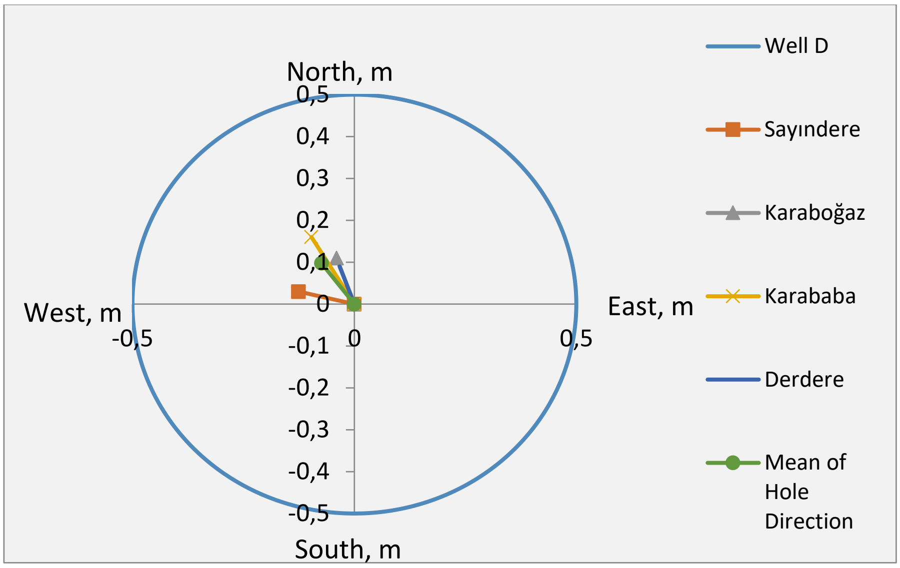


Figure 5.4. Graph of Deviation of Well D in Different Formations

Figure 5.5 shows the deviation value of Well E. Sayındere formation was cut. The lithology of Sayındere formation is marly limestone. The depositional environment of Sayındere is a deep marine environment. Well E is very close to well D. The well goes to the Northwest in Sayındere formation. Although Well D and Well E go to the same direction, Karaboğaz, Karababa and Dedere formations could not be cut at the same depth in Well E. According to geologist worked in Well E, a fault caused this reason. Well E is very close to the fault. According to Seyrek (2008), Bozova fault is located in Adıyaman. Well E is also close to Bozova fault. Therefore, structural properties of the formation such as faults may affect the deviations in Well E.

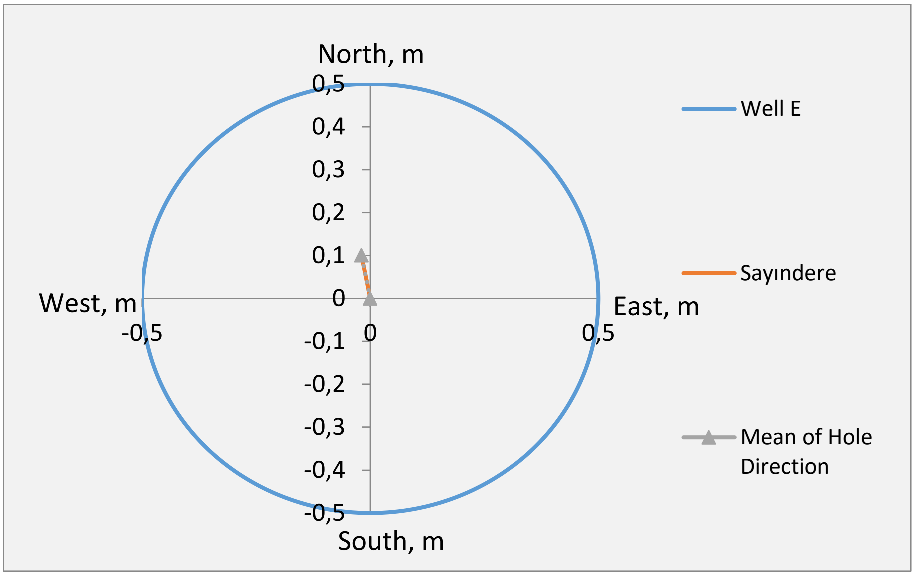


Figure 5.5. Graph of Deviation of Well E in Different Formations

Figure 5.6 shows the deviation values of Well F. Sayındere, Karaboğaz and Karababa formations were cut, respectively. All of them have different lithologies and their hardness is different like other wells mentioned before. The depositional environment of this well is mentioned in previous wells. There is an unconformity between the Cretecaus Mardin (Karababa formation) and the Upper cretaceous Karaboğaz. In this well, although the unconformity does not change the direction, it affects the deviation angle when compared with other wells. This well goes to the Southeast in all formations.

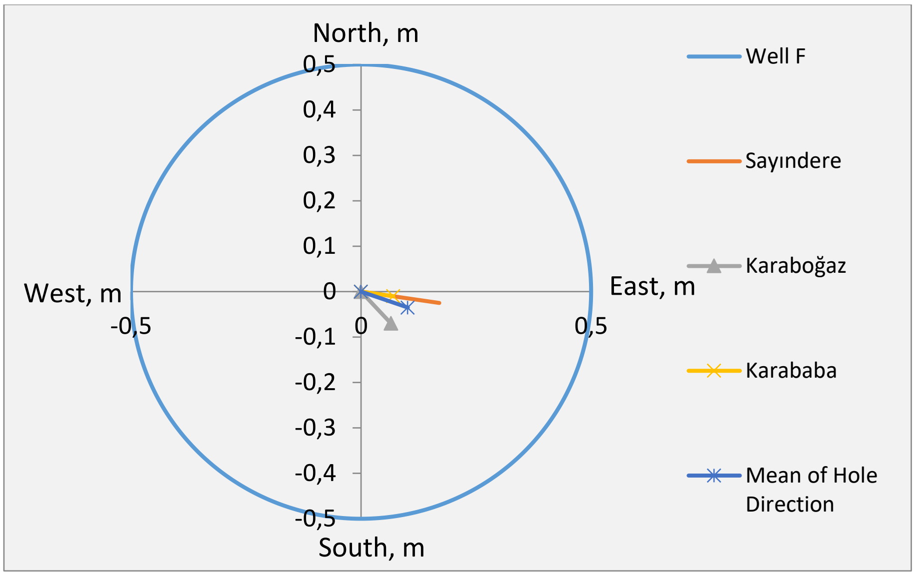


Figure 5.6. Graph of Deviation of Well F in Different Formations

Figure 5.7 is divided into two parts to distinguish lines on the charts. This figure shows the deviation values of Well G. Well G is close to Well F. Kastel and Sayındere formations were cut, respectively. While the lithology of Kastel formation is marl, shales, the lithology of Sayındere formation is marly limestone. Their porosity is different. There is no unconformity between them. The well goes the Northeast in Kastel and Sayındere formations. Therefore, the structural parameters such as bedding, folds or faults can take a more important role to determine the deviation of Well G.

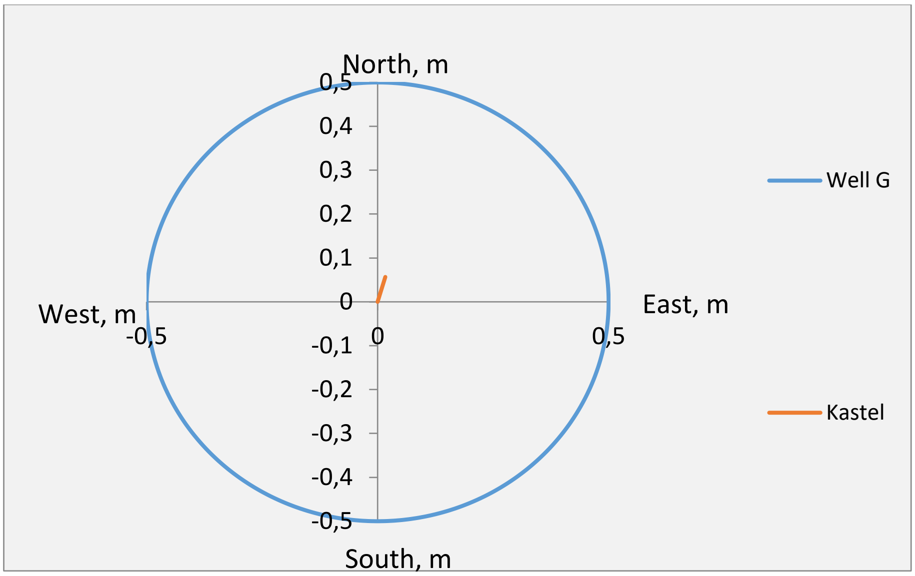


Figure 5.7(a) Graph of Deviation of Well G in Different Formations

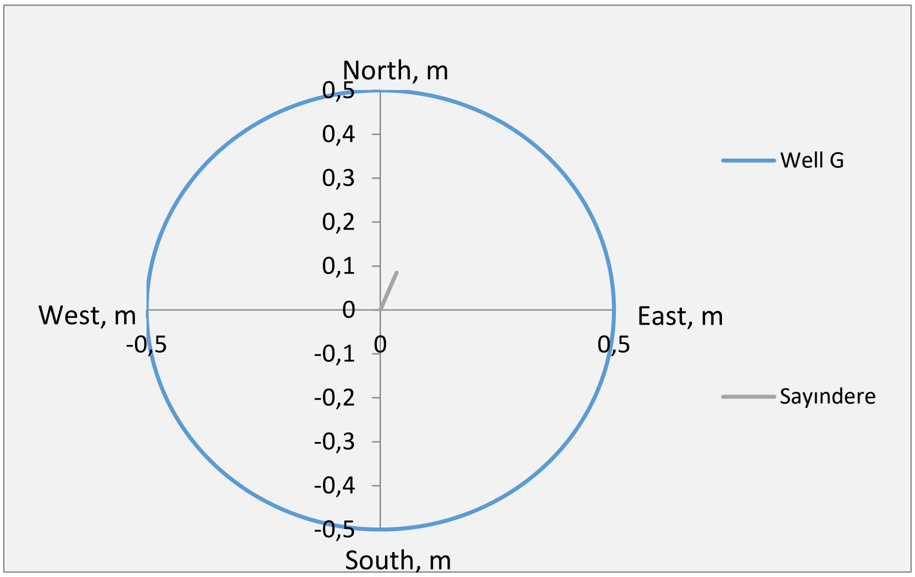


Figure 5.7(b) Graph of Deviation of Well G in Different Formations

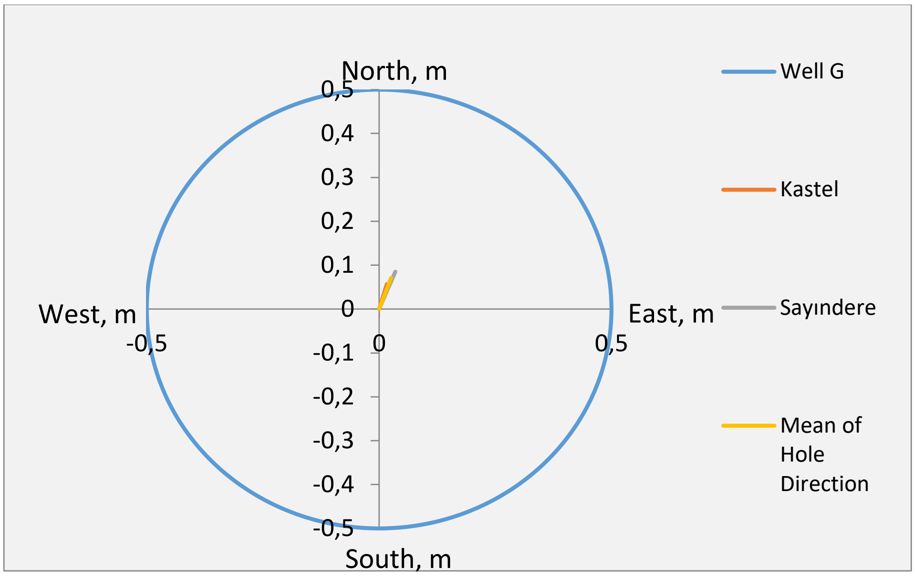


Figure 5.7. Graph of Deviation of Well G in Different Formations

Figure 5.8 shows the behavior of orientation when drilling the same formation in the different wells. Germav formation was cut in Well A, Well B and Well C at the same depth. These three wells are close to each other. Although they are close, the orientation in Germav formation is different as seen in Figure 5.8. The structural properties can change as expressed in the researchers mentioned in the Literature Review part. Moreover, the lithology does not affect the deviation as seen in Figure 5.8. Therefore, it is assumed that the structural properties of the formation in the Adıyaman Region can be more effective to determine the orientation.

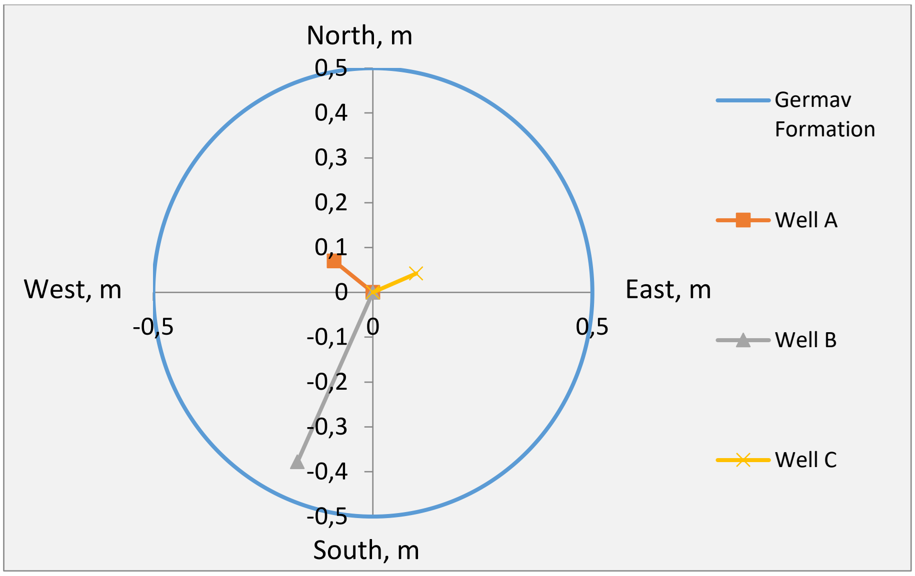


Figure 5.8. Graph of Deviation of Wells in Germav Formation

Kastel formation was cut in Well A, Well B, Well C and Well G shown in Figure 5.9. It is known that Well A, B and C are close and Well G is not close to others. Comments made for Figure 5.8 can also be made for Kastel formation.

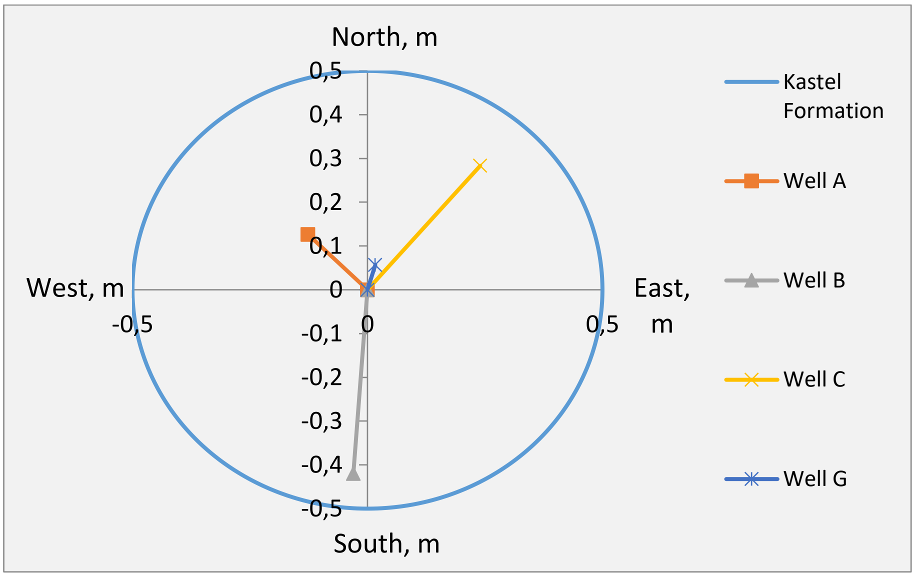


Figure 5.9. Graph of Deviation of Wells in Kastel Formation

Sayındere formation was cut in all wells examined shown in Figure 5.10. As previously known, Well A, B and C are close to each other, D and E are close to each other and F and G are also close to each other. Well A goes to the Northwest direction, Well B goes to the Southwest and Well C goes to the Northeast in Sayındere formation. Well D and Well E go to the same direction with different angles in Sayındere formation. It is known that the fault affected the orientation in Well E. Well F and G go to the different directions even if they are close to each other. The same comment can be made for all wells in Sayındere formation which is that lithology does not have a major influence on the deviation.

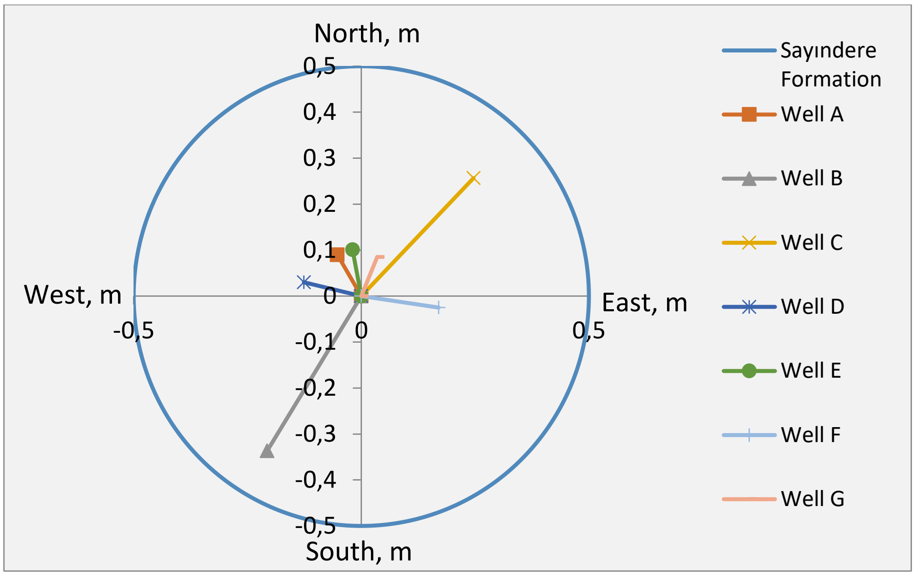


Figure 5.10. Graph of Deviation of Wells in Sayındere Formation

Karaboğaz formation was cut in Well A, B, C, D and F. As seen in Figure 5.11, lithology does not have a major effect to the deviation of the wells. Although, Well A, B and C are close to each other, these wells go to the different direction in the same formation. However, Well A and Well D go to the same direction which is the Northwest. To mention about unconformity is impossible in the same formations because unconformity occurs at different geological time. Therefore, the reason to see the different directions in Karababa formations cannot be the unconformity. Bedding attitudes, fault or folds can be the reason.

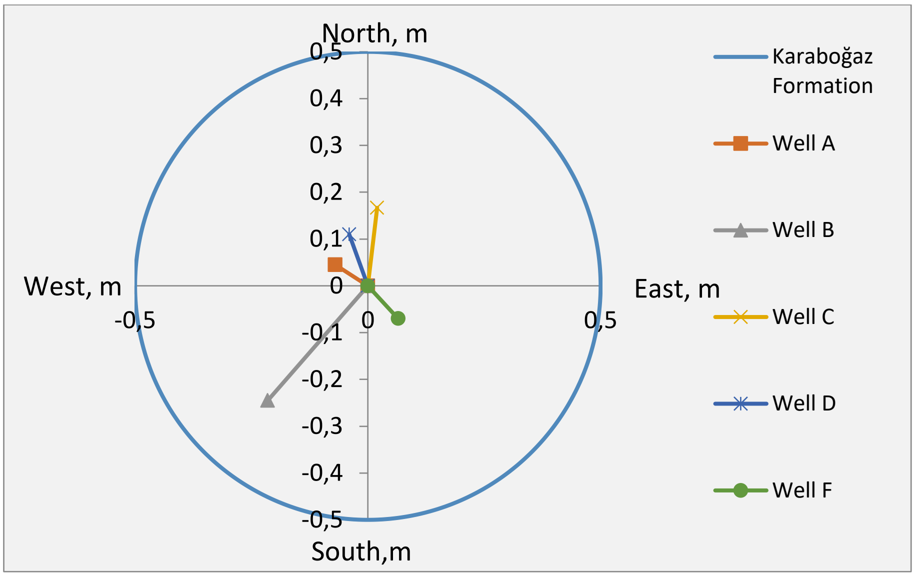


Figure 5.11. Graph of Deviation of Wells in Karaboğaz Formation

Karababa formation was cut in Well A, B, C, D and F. As seen in Figure 5.12, lithology does not have a major effect to the deviation of the wells. Although, Well A, B and C are close to each other, these wells go to the different direction in the same formation. However, Well A and Well D which are far apart, go to the same direction which is the Northwest. To mention about unconformity as parameter affecting the deviations is impossible in the same formations because unconformity occurs at different geological time. Therefore, the reason to see the different directions in Karababa formations cannot be the unconformity. Bedding attitudes, fault or folds can be the reason.

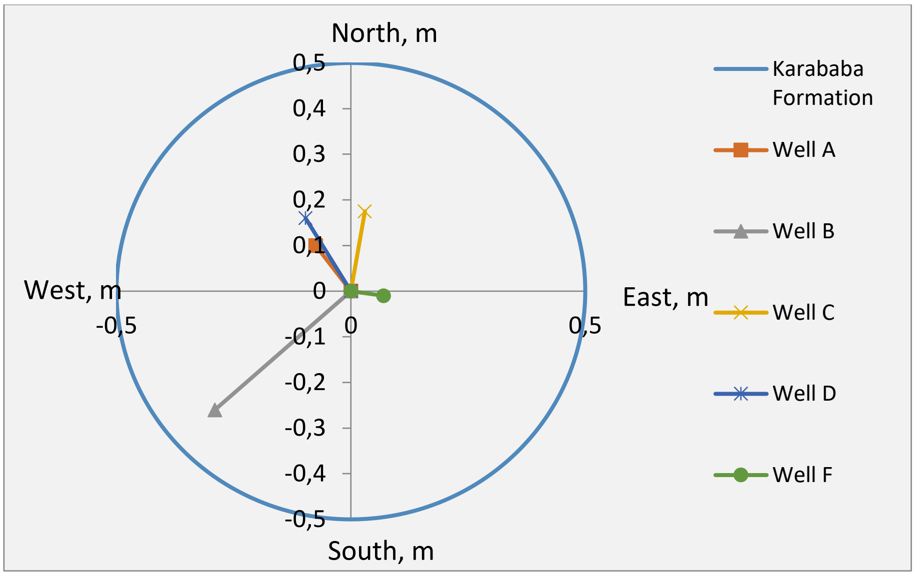


Figure 5.12. Graph of Deviation of Wells in Karababa Formation

Following Figure 5.13 shows the plan view and Figure 5.14 shows the section view of Well A to see the differences between realized and intended wells. In this thesis, data have been taken 8.5” (0.216m) hole in diameter. Therefore, values taken from surface to the beginning of section examined in this thesis have been considered same.

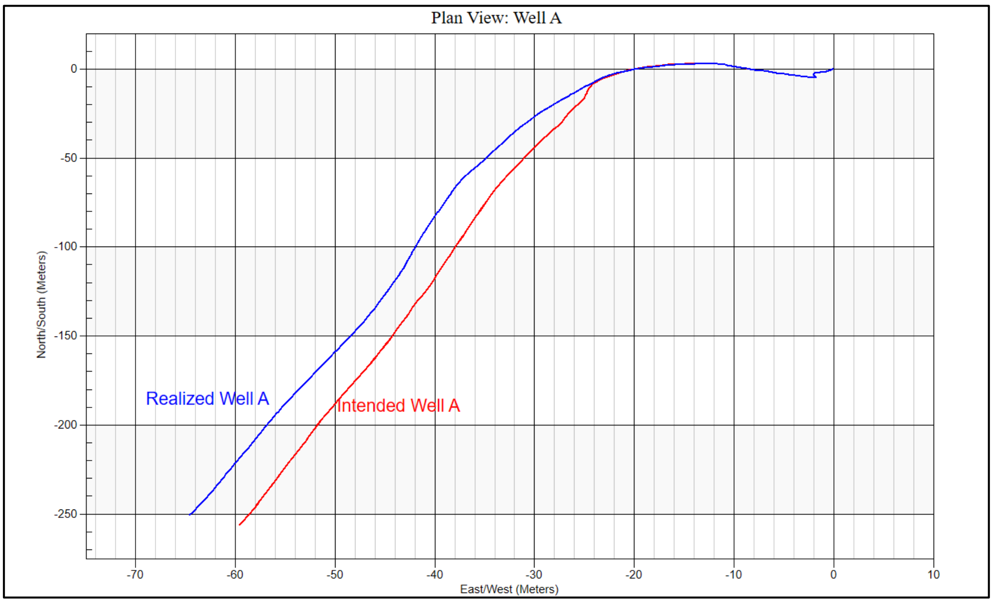


Figure 5.13. Plan View of Realized and Intended Well A

Plan view is defined as a path of the wells projected on paper with Cartesian coordinates showing the bore path in East, West, North and South directions.

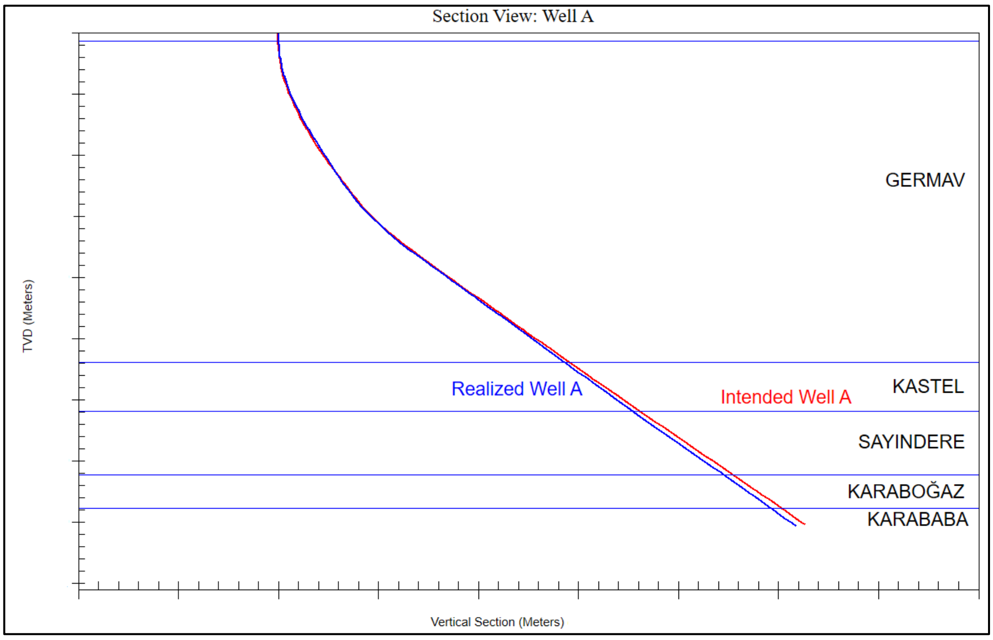


Figure 5.14. Section view of Realized and Intended Well A (Off Scale)

Section view is a graph showing the vertical section moves horizontally according to the wellhead regardless of direction. Plan view and section view of other six wells are located in the Appendix A and Appendix B.

CHAPTER 6

CONCLUSION

This study investigates the effect of the formation to the orientation of the directional wells in the Adıyaman Region by using 137 survey data taken from seven different wells in Germav, Kastel, Sayındere, Karaboğaz, Karababa and Derdere formations.

It is known that weight on the bit, flow rate, number of the stabilizers, their gauges and locations on the BHA, drilling bit type, hole size, BHA components such as drill collars, revolution per minute (RPM) in rotary drilling, and the formation properties are the parameters affecting the orientation and the direction of wells. However, the formation is accepted as the main parameter affecting the orientation. Thus, geological formation, stratigraphic and structural properties has been investigated in detail for the Adıyaman Region in this study.

All surveys taken from seven wells where the parameters that affect the orientation of the wells were taken as constants except the formation, have been processed to see the deviations and directions in them in order to compare the effect of the formation from well to well.

The following conclusions were obtained by comparing the real (taken from the surveys) and the intented (theoretical) values.

The Adıyaman Region has too much faults and folds occurred after collision of Eurasia and Gondwana-Land as mentioned in the Literature Review Part as seen in Figure 2.26. Moreover, strike-slip stress is the main stress in the Adıyaman Region. Most of the folds have asymmetric flank. The dip and strike direction and the angle of them changes from place to place even when they are so close to each other.

This study reveals that the direction and the deviation of the wells change in the same formations for different wells although the formation has the same lithology.

Moreover, it is impossible to have unconformities and different depositional environment in the same formation.

When a well is drilled in a certain wellhead location in the Adıyaman Region, the direction does not change from top to bottom of the section, the intensity is not affected too much and the formation does not affect the deviations in a considerable extent. Even the difference of the deviations between the lithologies were not significant to affect the directional drilling operations.

Although the locations of the wells in the Adıyaman Region are very close to each other seen in Figure 4.5, they follow different directions in different wells. There was no trend to decide the formation effect for each formation.

The stratigraphic properties does not have a significant effect on the orientation compared to the effect of structural properties of the formation in the Adıyaman Region.

To conclude, the results of this study enables the driller to decide the direction after the first few surveys. After the decision on the direction, the amount of sliding, the time to reach the target and the operational costs are reduced. With the help of this study, when the drilling direction changes while everything else is continuing as expected, the reason of that must be the other factors that affect the orientation, such as the stabilizer gauge, the bit gauge, the flow rate and the weight on the bit. Knowing the effect of the formation to the orientation helps to foresee the directional problems, to create a more successful projection to hit to the target, and to use more appropriate equipments such as different size stabilizers, different BHA components and thus to drill a well faster and in a more reliable fashion for the field engineers.

CHAPTER 7

RECOMMENDATIONS

This study examined the effects of the formation to the orientation of the directional wells in the Adıyaman Region. Because of the importance of the orientation in the directional drilling operations, the information about factors affecting the hole deviation (WOB, flow rate, stabilizers gauge and location, drilling bit type, BHA design and RPM), should be collected instantly to find the optimal values by simulating in addition to the effect of the formation. Moreover, the combined effect of all factors can be modeled for the accurate hole orientation estimation and thus optimization of all parameters will enable easier orientation control of the wells and allow drilling operations to be completed quickly and smoothly.

REFERENCES

Aadnoy, B. S., & Huusgaard, P. P. (2002). Analytical Models for Design of Wellpath and BHA. *Proceedings of the IADC/SPE Asia Pacific Drilling Technology Conference, APDT*, 207–219. https://doi.org/10.2523/77220-ms

Adıyaman Province. (2019). Retrieved from Google Earth website: https://earth.google.com/web/@37.81060813,38.34912085,740.13635173a,293917.5058413d,35y,0h,0t,0r/data=CkwaShJECiUweDE1MzMxMzdlYjZmMmEwZGY6MHhiYTc2NDIxOGU0ZjQ3MTg0GbZtc74z9EJAIemnSToUPkNAKglBZMSxeWFtYW4YAiAB

Ala, M. A., & Moss, B. . (1979). COMPARATIVE PETROLEUM GEOLOGY OF SOUTHEAST TURKEY AND NORTHEAST SYRIA. *Journal of Petroleum Geology*, *1*, 3–27.

Apostolov, K. (2017). Formulae in practice, Borehole planning and Toolface calculation. *BG Drilling Solutions*. Retrieved from https://coringmagazine.com/article/formulae-practice-borehole-planning-toolface-calculation/

Baker, & Hughes INTEQ Inc. (1995). Drilling Engineering Workbook A Distributed Learning Course. In *Baker Hughes INTEQ*.

Best, J. A., Barazangi, M., Al-Saad, D., Sawaf, T. and Gebran, A. (1993). Continental margin evolution of the Northern Arabian Platform in Syria. *American Association Petroleum Geologists Bulletin*, *77*(2), 173–193.

Bhalla, K., Gong, L., & McKown, G. K. (2008). Implementation of a bottom-hole assembly program. *Journal of Energy Resources Technology, Transactions of the ASME*, *130*(4), 0431011–0431016. https://doi.org/10.1115/1.3000123

Bolat, A. (2012). *Adıyaman İli Kuzeyinin Jeolojisi ve Petrol Potansiyeli*.

Boualleg, R., Sellami, H., Menand, S., & Simon, C. (2006). Effect of formations anisotropy on directional tendencies of drilling systems. *SPE/IADC Drilling Conference, Proceedings*, 295–304. https://doi.org/10.2523/98865-ms

Bradley, W. B. (1975). Factors Affecting the Control of Borehole Angle in Straight and Directional Wells. *JPT, Journal of Petroleum Technology*, *27*, 679–688. https://doi.org/10.2118/5070-PA

Brakel, J. D., & Azar, J. J. (1989). Prediction of wellbore trajectory considering bottomhole assembly and drill-bit dynamics. *SPE Drilling Engineering*, *4*(2), 109-118 16172. https://doi.org/10.2118/16172-pa

Colorado School of Mines. (2019). Colorado Geological Survey-Unconformities. Retrieved from Colorado School of Mines website: http://coloradogeologicalsurvey.org/colorado-geology/structures/unconformities/

Cooper, G. (2006). Directional Drilling Terminologies. Retrieved from http://viscosity-hydrochloric-acid.blogspot.com/2016/02/directional-drilling-terminologies.html

Çoruh, T. (1991). *Adıyaman civarında (XI. Bölge kuzeybatısı ve XII. Bölge) yüzeyleyen Kampaniyen-Tanesiyen istifinin biyostratigrafisi ve paleocoğrafik evrimi: TPAO Research Center, report no: 1656*.

Coskun, B. (1996). Tectonic Controls on the Evolution of Porosity in the Cretaceous Mardin Group Carbonates, Adiyaman Oilfields, SE Turkey. *Journal of Petroleum Geology*, *19*, 45–460.

Demirel, I. H., Yurtsever, T. S., & Guneri, S. (2001). Petroleum systems of the Adiyaman region, Southeastern Anatolia, Turkey. *Marine and Petroleum Geology*, *18*(3), 391–410. https://doi.org/10.1016/S0264-8172(01)00002-2

Devereux, S. (1998). *Practical Well Planning and Drilling*.

Dinçer, A. (1991). *Güneydoğu Anadolu Otokton Stratigrafi Birimleri*.

Directional Drilling- Chapter 12. (2007).

DrillingFormulas.Com. (2018). What are Positive Displacement Mud Motors in Drilling for Oil and Gas? Retrieved from http://www.drillingformulas.com/what-are-positive-displacement-mud-motors-in-drilling-for-oil-and-gas/

Dyck, T. (2011). *National Oilwell Varco Motor Handbook* (Seventh).

Farah, O. (2013). Directional Well design, trajectory and survey calculations, with a case study in Fiale, Asal Rift, Djibouti. *Programme Training Programme*, *27*(27), 34.

Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., … Alsdorf, D. E. (2007). The shuttle radar topography mission. *Reviews of Geophysics*, *45*(2), 1–33. https://doi.org/10.1029/2005RG000183

Gardner, W. R. (1997). High Data Rate MWD Mud Pulse Telemetry. *U.S. Department of Energy's Natural Gas Conference*, 0–26. Retrieved from http://www.netl.doe.gov/kmd/cds/disk28/NG2-4.PDF

Gharib, H., & Kirkhope, K. (2017). A modified three-point contact approach for dogleg severity modeling. *SPE Middle East Oil and Gas Show and Conference, MEOS, Proceedings*, *2017-March*(March), 1657–1672. https://doi.org/10.2118/183870-ms

Grippo, A. P. D. (2011). STRUCTURAL GEOLOGY and TECTONICS. Retrieved from Earth Sciences website: https://homepage.smc.edu/grippo_alessandro/struct2.html

Halliburton. (1997). *Petroleum Well Construction*. 1–903.

Hempton, M. R. (2017). *CONSTRAINTS ON ARABIAN PLATE MOTION AND EXTENSIONAL HISTORY OF THE RED SEA the north and (2) northwest propagation of extension associated with the medial Eocene reorganization of* ... (January). https://doi.org/10.1029/TC006i006p00687

Ho, H. S. (1987). *Prediction of drilling trajectory in directional wells via a new rock-bit interaction model.* (3). https://doi.org/10.1016/0148-9062(88)90280-x

Illfelder, H., Hamlin, K., Mcelhinney, G., & Energy, P. (2005). *A Gravity-Based Measurement-While-Drilling Technique Determines Borehole Azimuth From Toolface and Inclination Measurements*.

Jaeger, T., & Doering, K. (2019). Navi-Drill motor handbook. *Baker Hughes Company*, 230.

Jogi, P. N., Burgess, T. M., & Bowling, J. P. (1988). Predicting the Build/Drop Tendency of Rotary Drilling Assemblies. *SPE Drilling Engineering*, *3*(2), 177–186. https://doi.org/10.2118/14768-PA

Kalifa, A., Çakir, Z., Owen, L. A., & Kaya. (2019). Evaluation of the relative tectonic activity of the adıyaman fault within the arabian-anatolian plate boundary (Eastern Turkey). *Geologica Acta*, *17*, 1–17. https://doi.org/10.1344/GeologicaActa2019.17.6

Karahanoglu, M., & Ulu, N. (1998). Characterization of the Karababa C reservoir in the South Karakus oil field \ southeast Turkey. *Marine and Petroleum Geology*, *15*, 803–820.

Karlsson, H., Brassfield, T., & Krueger, V. (1985). PERFORMANCE DRILLING OPTIMIZATION. *Society of Petroleum Engineers of AIME, (Paper) SPE*. https://doi.org/10.2523/13474-ms

Li, Z., Itakura, K. I., & Ma, Y. (2014). Survey of measurement-while-drilling technology for small-diameter drilling machines. *Electronic Journal of Geotechnical Engineering*, *19*(Z2), 10267–10282.

Lubinski, A., & Woods, H. B. (1953). Factors affecting the angle of inclination and dog-legging in rotary bore holes. *Drilling and Production Practice 1953*, 222–250.

Maidla, E., & Haci, M. (2004). Understanding torque: The key to slide-drilling directional wells. *Proceedings of the Drilling Conference*, 553–560. https://doi.org/10.2523/87162-ms

Marchand, N., & Kalantari, M. (2013). A new approach for build rate estimation of downhole motors. *Proceedings - SPE Annual Technical Conference and Exhibition*, *6*(October), 4422–4426. https://doi.org/10.2118/166457-ms

MAXSON, J. H. (1936). *Geology and petroleum possibilities of the Hermis dome*.

Menand, S., Mills, K. A., & Suarez, R. (2016). Micro dogleg detection with continuous inclination measurements and advanced BHA modeling. *Society of Petroleum Engineers - Abu Dhabi International Petroleum Exhibition and Conference 2016*, *2016-Janua*, 1–14. https://doi.org/10.2118/183299-ms

Michael J. Economides, Larry T. Watters, S. D.-N. (1998). *Petroleum Well Construction* (John Wiley & Sons, Ed.).

Newbill, P. (2014). Geologic Structures. Retrieved from Radford University website: https://www.radford.edu/jtso/GeologyofVirginia/Structures/GeologyOfVAStructures4-2e.html

Oilfield Glossary. (2019). Rotary Steerable System.

Önalan, M. (1988). Geological evolution of the Kahramanmaraş Tertiary Peripheral Basin. *Geological Bulletin of Turkey, 31*, 1–10.

Pehlivantürk, C., D'Angelo, J., Cao, D., Chen, D., Ashok, P., & Van Oort, E. (2019). Slide drilling guidance system for directional drilling path optimization. *SPE/IADC Drilling Conference, Proceedings*, *2019-March*. https://doi.org/10.2118/194096-ms

Perincek, D., Duran, O., Bozdogan, N. and Çoruh, T. (1991). Stratigraphy and paleogeography evolution of the autochthonous sedimentary rocks in SE Turkey. *Proceedings of Ozan Sungurlu Symposium*, 274–305.

Perinçek, D. (1980). Sedimentation on the Arabian Shelf under the control of Tectonic Activity in Taurid Belt. *Proceedings of the 1st Petroleum Congress, Turkey*, 77–93.

Perinçek, D. (1990). Stratigraphy of Hakkari Province Southeast Turkey. *Turkish Association of Petroleum Geologist Bulletin*, *2*(1), 21–68.

Perinçek, D., Günay, Y., & Kozlu, H. (1987). New observations about the strikeslip faults in East and Southeast Anatolia. *The Seventh Turkish Petroleum Congress*, 89–103.

Plummer, C. C., & Carlson, H. D. (2008). *Physical Geology: 12th (twelve) Edition*. McGraw-Hill.

Ramsey, M. S. (2019). Effects on Drilling Efficiency and Rate of Penetration. In *Practical Wellbore Hydraulics and Hole Cleaning*. https://doi.org/10.1016/b978-0-12-817088-5.00004-6

Rauf, W., Ahsan, N., & Azim, R. A. (n.d.). *Design , Fabrication and Analysis of Positive Displacement Mud Motors*. 11.

Rig, L. (2015). *IADC DRILLING*.

Rigo de Righi, M., & Cortesini, A. (1964). Gravity tectonics in foothilt structure belt of SE Turkey, the petroleum system – from source to trap, L. B. Magoon and W. G. Dow. *Amerikan Association of Petroleum Geologist Memoir, 60*(48), 1596–1611.

Rotstein, Y. (1984). Counterclockwise rotation of the Anatolian block. *Tectonophysics, 108*(1–2), 71–91.

Sari, A., & Bahtiyar, I. (1999). Geochemical evaluation of the Besikli oil field, Kahta, Adiyaman, Turkey. *Marine and Petroleum Geology, 16*(2), 151–164. https://doi.org/10.1016/S0264-8172(98)00067-1

Schlumberger. (2020). Schlumberger Oilfield Glossary, Roller Cone Bit. Retrieved from https://www.glossary.oilfield.slb.com/en/Terms/r/roller_cone_bit.aspx

Schmidt, K. (1935). *First report over geological and paleontological, MTA compilation no. 1532*.

Şengör, C., & Yılmaz, Y. (1981). A systems analysis of political life. *Systems Research for Behavioral Science: A Sourcebook, 75*, 428–436. https://doi.org/10.2307/589063

Seyrek, E. (2008). *Post-Miocene Tectonic Evolution of Alidağ Anticline, Adıyaman, Turkey*.

Škrjanc, Ž., & Vulić, M. (2016). Comparison of the directional survey calculation methods applied on real well data. *Measurement: Journal of the International Measurement Confederation, 94*, 239–244. https://doi.org/10.1016/j.measurement.2016.08.002

Sonel, N., & Sarbay, N. (1988). *Definition of Petroleum Traps Around Narlı Using Seismic Methods*. *6*, 257–287.

Sungurlu, O. (1974). VI. Bölge kuzeyinin jeolojisi ve petrol imkanları. *Türkiye Ikinci Petrol Kongresi*, 85–107.

Tardu, T. Başkurt, T. Güven, A. Us, E. Dinçer, A. Tuna, M. E. Tezcan, Ü. Ş. (1987). Structural and stratigraphic aspects of Akçakale Graben and its HC potential. *Seventh Petroleum Congress of Turkey*, 36–49.

Thomas, T. (2008). *Iadc codes*. 59.

Tikkanen, A. (2019). Fault Geology. In *Britannica Encyclopedia*. Retrieved from https://www.britannica.com/science/fault-geology

TPAO. (2013). *TPAO Annual Report*.

Tuna, D. (1973). *VI. Bölge litostratigrafi birimleri adlamasının açıklayıcı raporu: TPAO. Report no:813*.

Tuncer, M. (2013). Balanced cross section of the northeast of Adıyaman, Turkey.

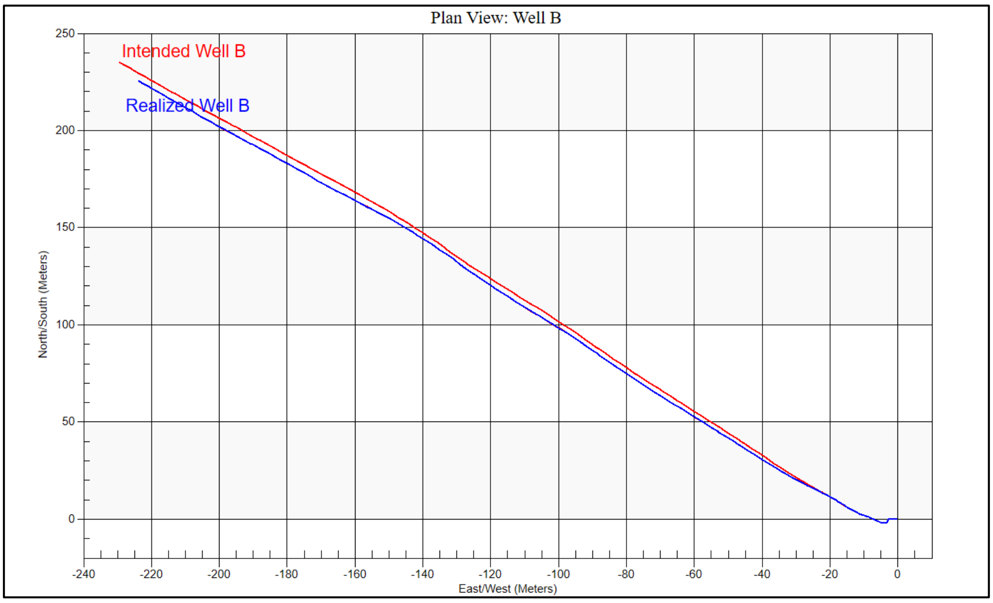
Woods, B. H., & Lubinski, A. (1955). Use of Stabilizers in Controlling Hole ~ e v i a t i o n '. *Spring Meeting of the Mid-Continent District*, (March).

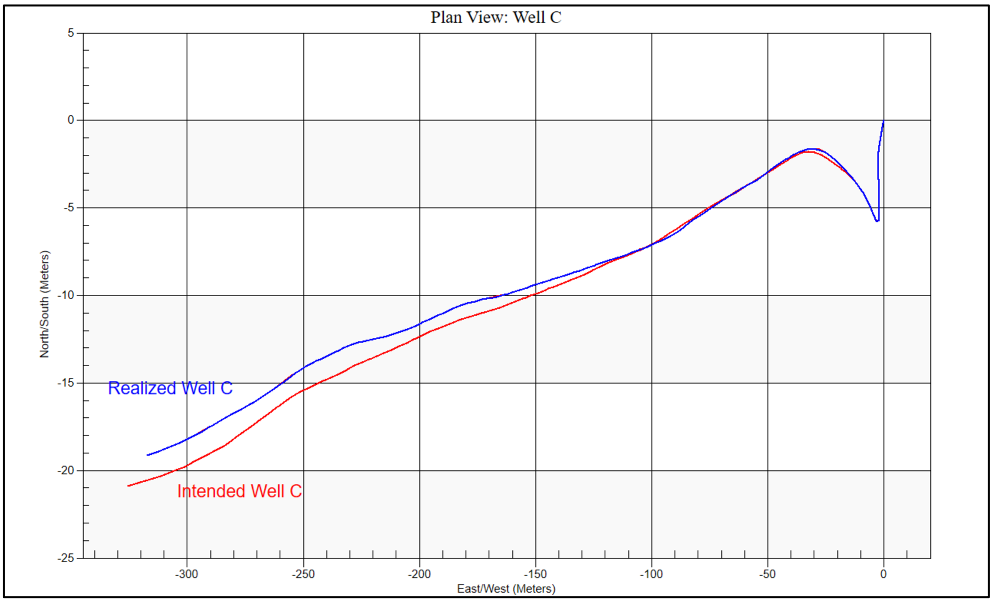
Yilmaz, Y., & Clift, P. D. (1990). *Allochthonous Terranes in the Tethyan Middle East : Anatolia and the Surrounding Regions [and Discussion]*. 611–624. https://doi.org/10.1098/rsta.1990.0093

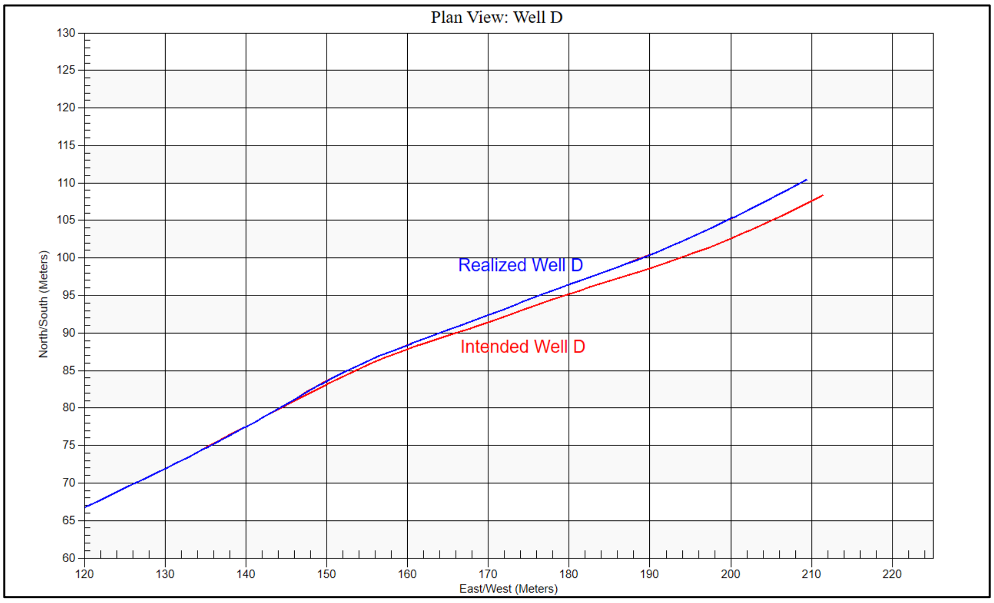
Yılmaz, E., & Duran, O. (1997). *Güneydoğu Anadolu Bölgesi Otokton ve Allokton Birimler Stratigrafi Adlama Sözlüğü*.

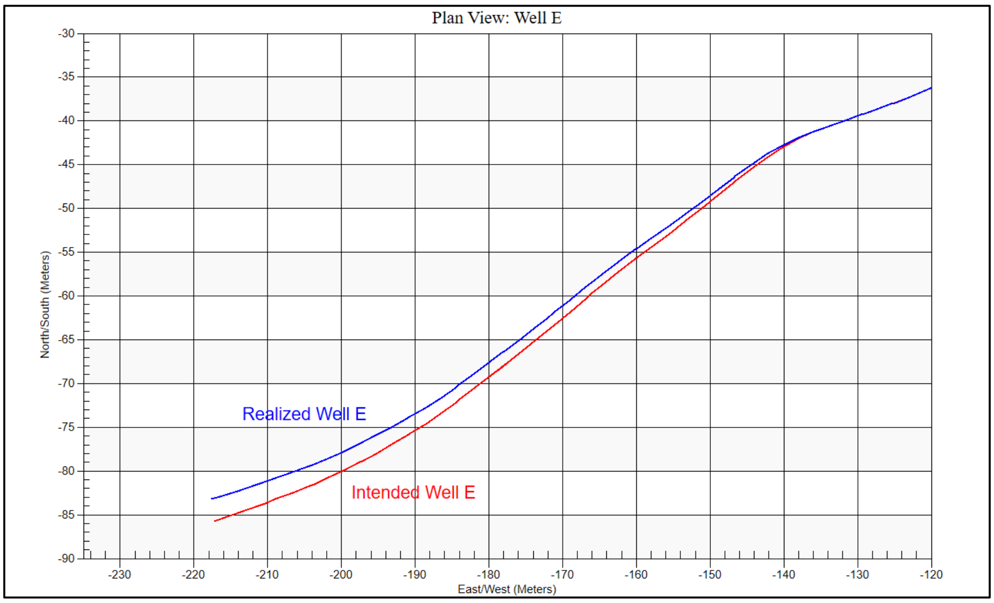
APPENDIX

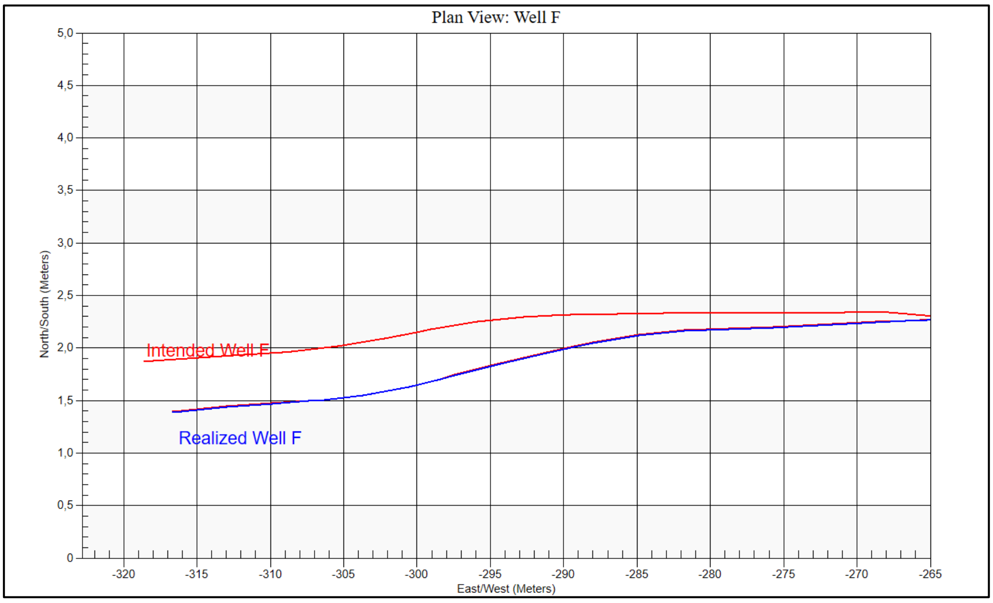
A. Plan View of Realized and Intended Wells

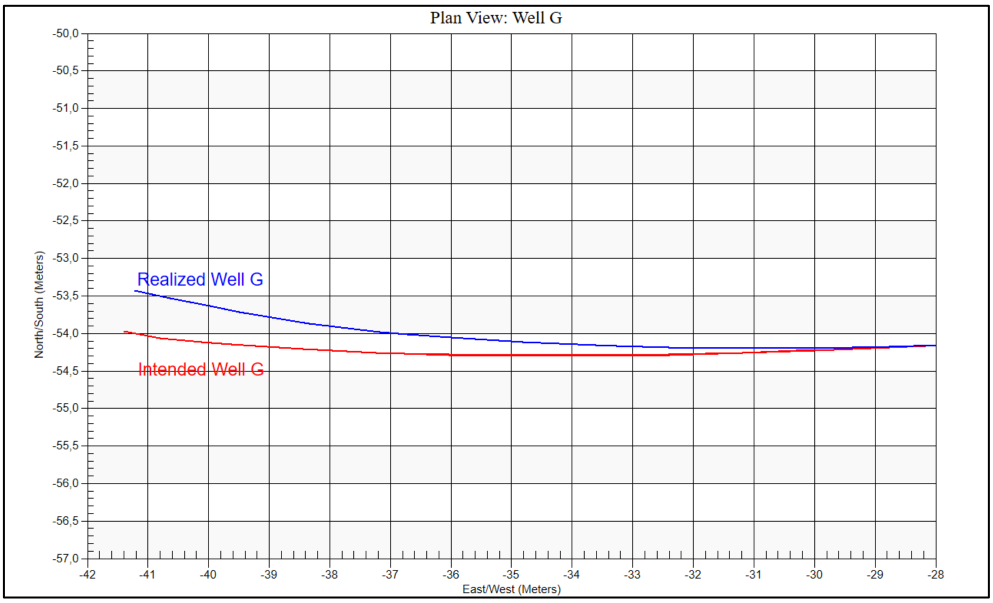




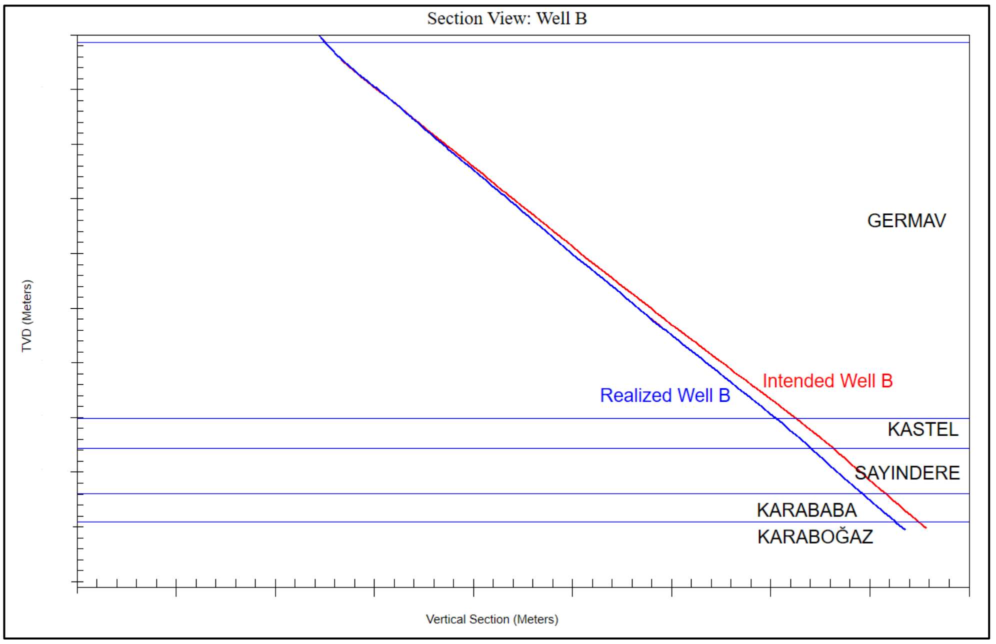

Plan View: Well D
Realized Well D
Intended Well D
North/South (Meters)
East/West (Meters)

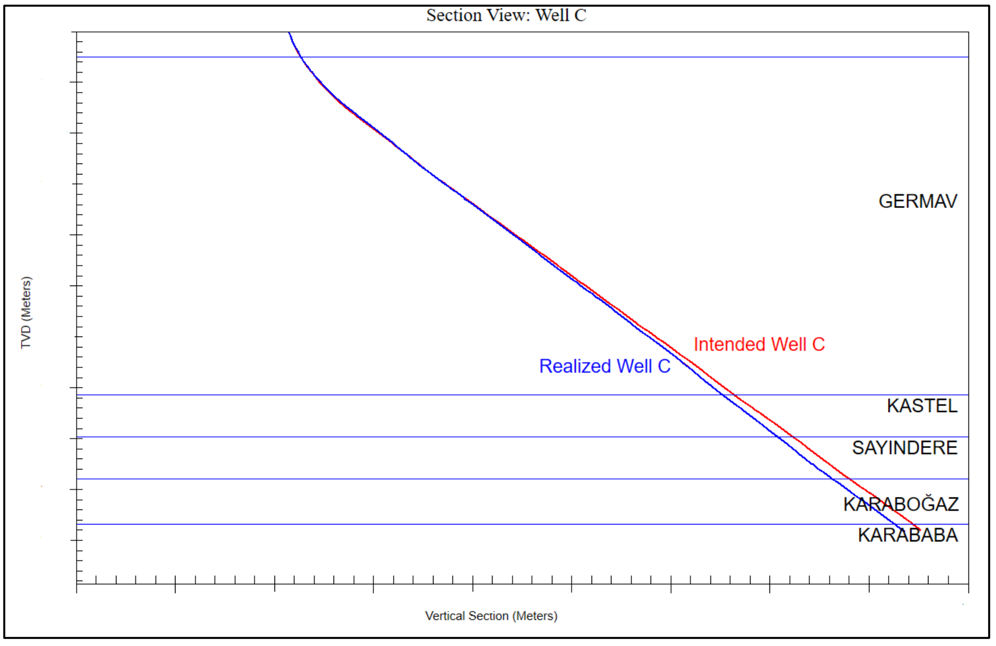

Plan View: Well E
Realized Well E
Intended Well E
North/South (Meters)
East/West (Meters)

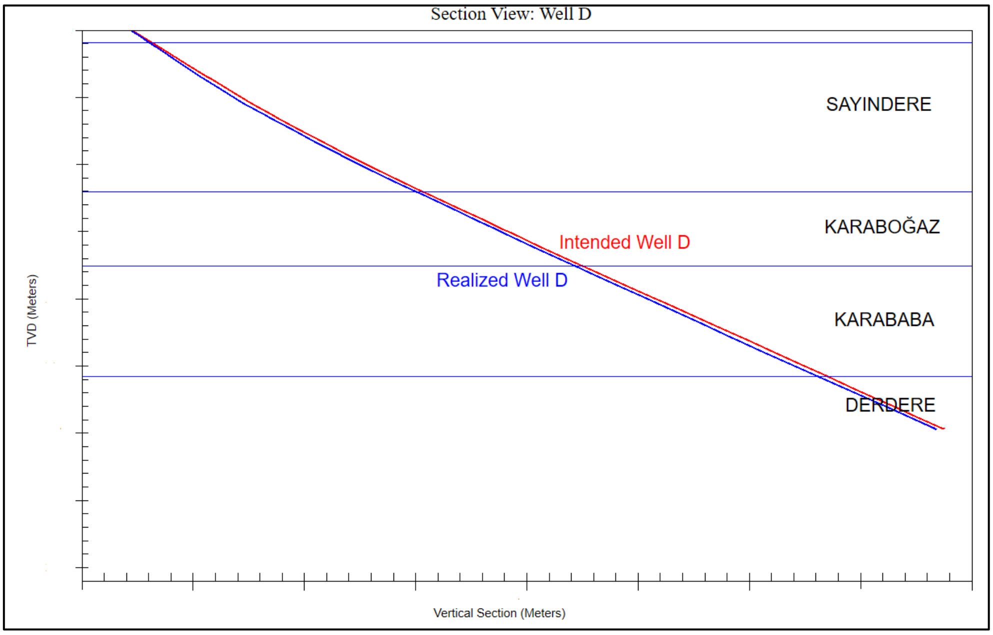

Plan View: Well F
Intended Well F
Realized Well F
North/South (Meters)
East/West (Meters)

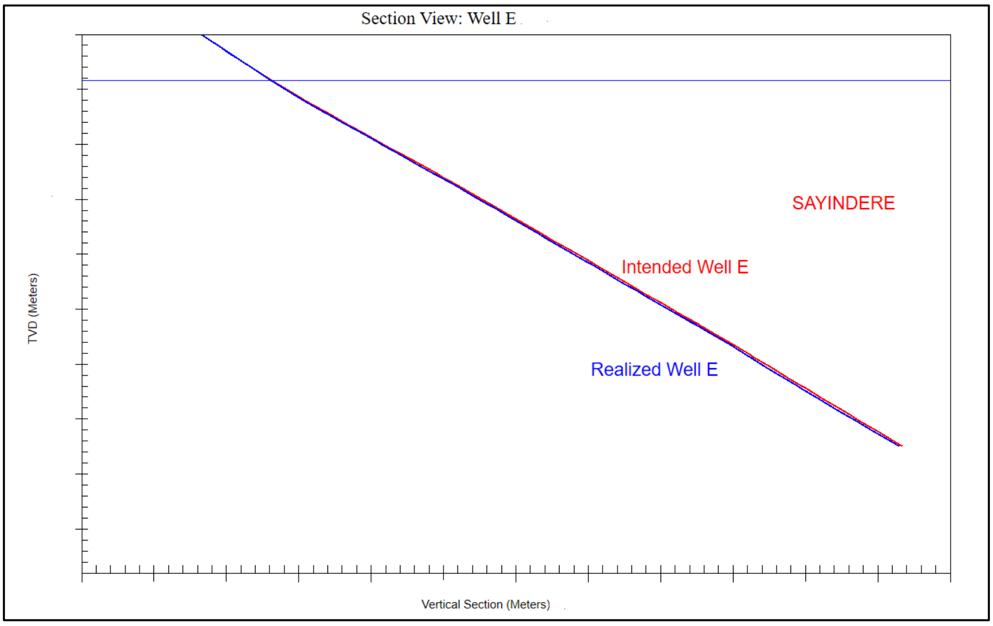

Plan View: Well G
Realized Well G
Intended Well G
North/South (Meters)
East/West (Meters)

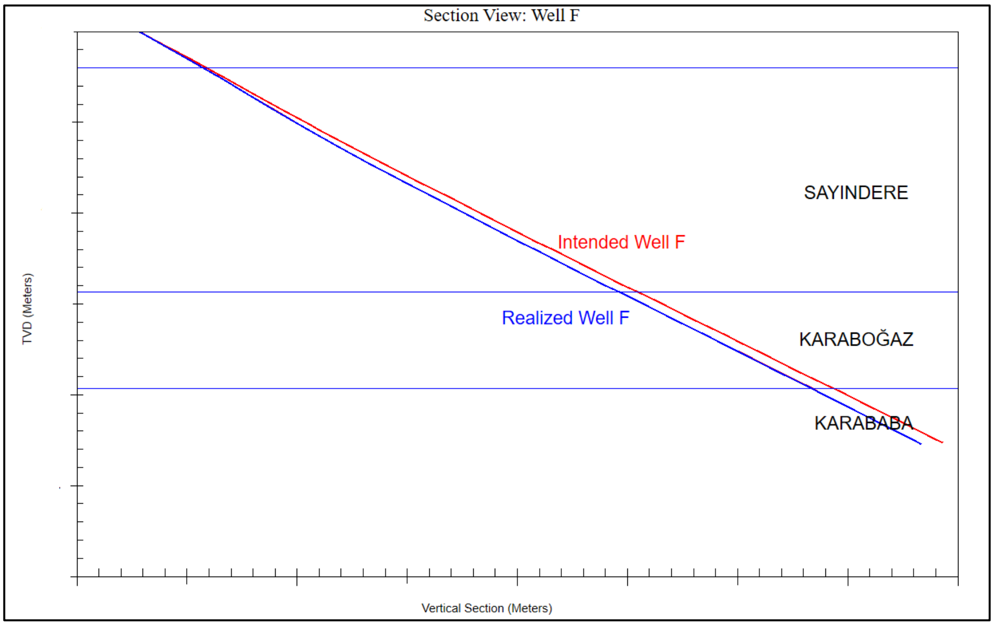
B. Section View of Realized and Intended Wells (Off Scale)

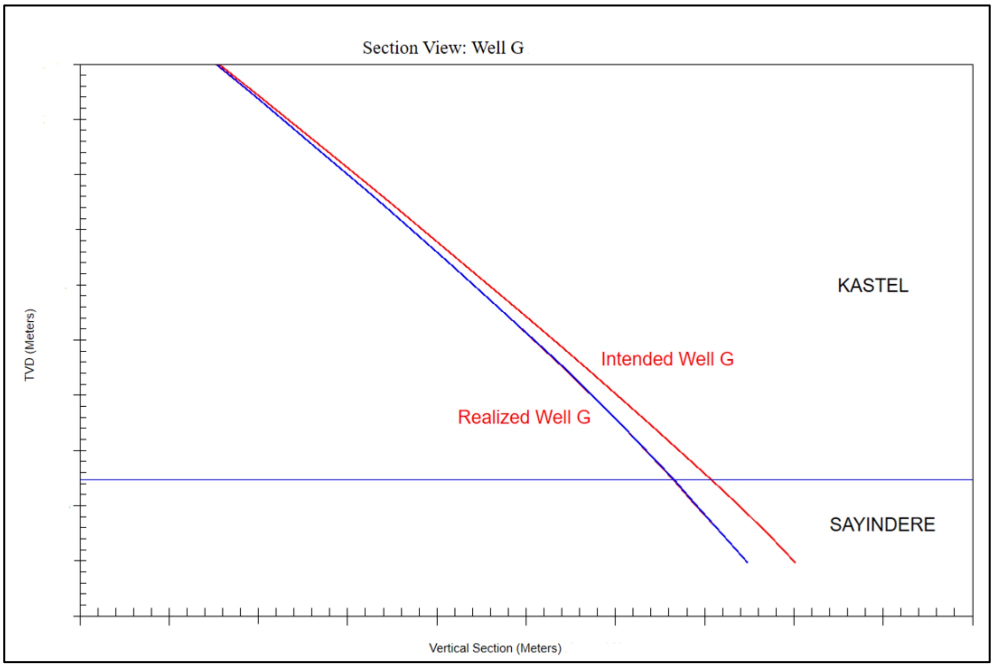





Section View: Well D
SAYINDERE
KARABOĞAZ
Intended Well D
Realized Well D
KARABABA
DERDERE
TVD (Meters)
Vertical Section (Meters)


Section View: Well E
SAYINDERE
Intended Well E
Realized Well E
TVD (Meters)
Vertical Section (Meters)


Section View: Well F
SAYINDERE
Intended Well F
Realized Well F
KARABOĞAZ
KARABABA
TVD (Meters)
Vertical Section (Meters)


Section View: Well G
KASTEL
Intended Well G
Realized Well G
SAYINDERE
TVD (Meters)
Vertical Section (Meters)