2D SEISMIC INTERPRETATION AND STRUCTURAL DELINEATION OF MIANWALI AREA, UPPER INDUS BASIN, PAKISTAN

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of BS in Geophysics

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ABSTRACT

Main purpose of this dissertation is to evaluate the structure and hydrocarbon potential using seismic and well log data of Isa Khel area (Mianwali), Upper Indus basin, north western Punjab, Pakistan. The upper Indus basin is a compressional tectonic regime exhibiting reverse faulting. The area is bounded by Sirghar range in the north and west; Kalabagh thrust in the east, Salt range thrust in the southeast where as Khisor range in the south. The area follows the geology of the Nammal Gorge. The targeted formations ranged from late Permian to early Jurassic. For structural enhancement, five migrated seismic lines were used; 915-MWI-82, 915-MWI-100 and 905-MWI-71 (dip lines), 905-MWI-64 and 905-MWI-69 (strike lines). Time and depth contours of three horizons, Samana Suk formation, Datta formation and Wargal limestone were generated which confirmed the anticlinal pop-up structures in the subsurface. Mechanical properties calculated through rock physics also provide support to the probability of potential zones at the level of Samana Suk and Datta formation. Although potential reservoir zones were marked, hydrocarbon potential cannot be known due to lack of availability of complete log data of Isa Khel – 01. Time and depth sections confirm low relief anticline structure formed by four way fault closure. Elastic moduli calculated through rock physics also provide ample support to the delineated structure, although the presence of fluid is not confirmed at any level of target horizon. Although potential reservoir zone were marked, hydrocarbon potential cannot be known due to lack of availability of complete log data of Isa Khel – 01.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Study area

The study area is located in the Isa Khel Tehseel of Mianwali District northwestern Punjab. The study area lies between the latitudes of 32.5^{o} N to 33^{o} N and the longitudes of 71^{o} E to 71.5^{o} E. Tectonically the area is included in the Upper Indus Basin of Pakistan. Since the area in north is a continuation of Pothohar Plateau and the Salt Range, it was assumed that it could hold possible prospect zones owing to the remarkable petroleum system of the Potwar sub basin. Hence in 1990 and 1991 the seismic survey of the area was conducted by the OGDCL, also an exploratory well was drilled namely Isa Khel-01 later in 1993. The well location is 32.8724537^{o} N and 71.4137078^{o} E. The operation was not very successful hence the well was abandoned for further exploration.

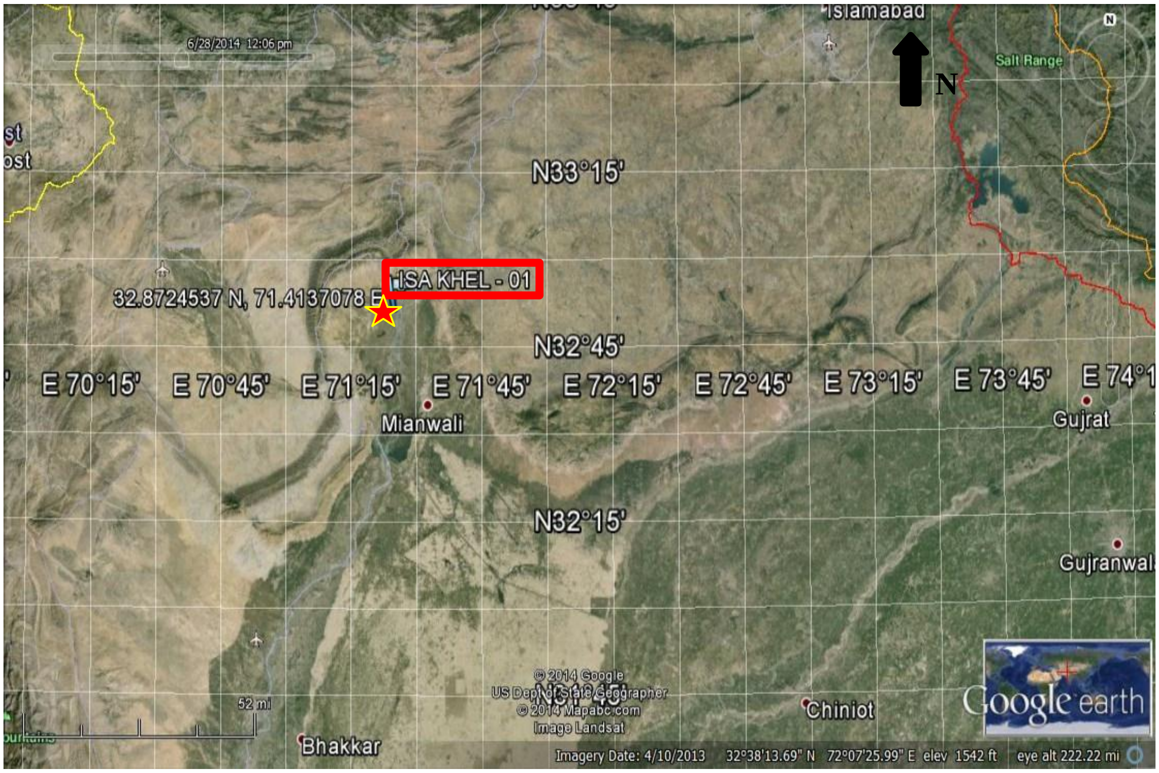

Figure 1.1 Location of study area (Google Earth).

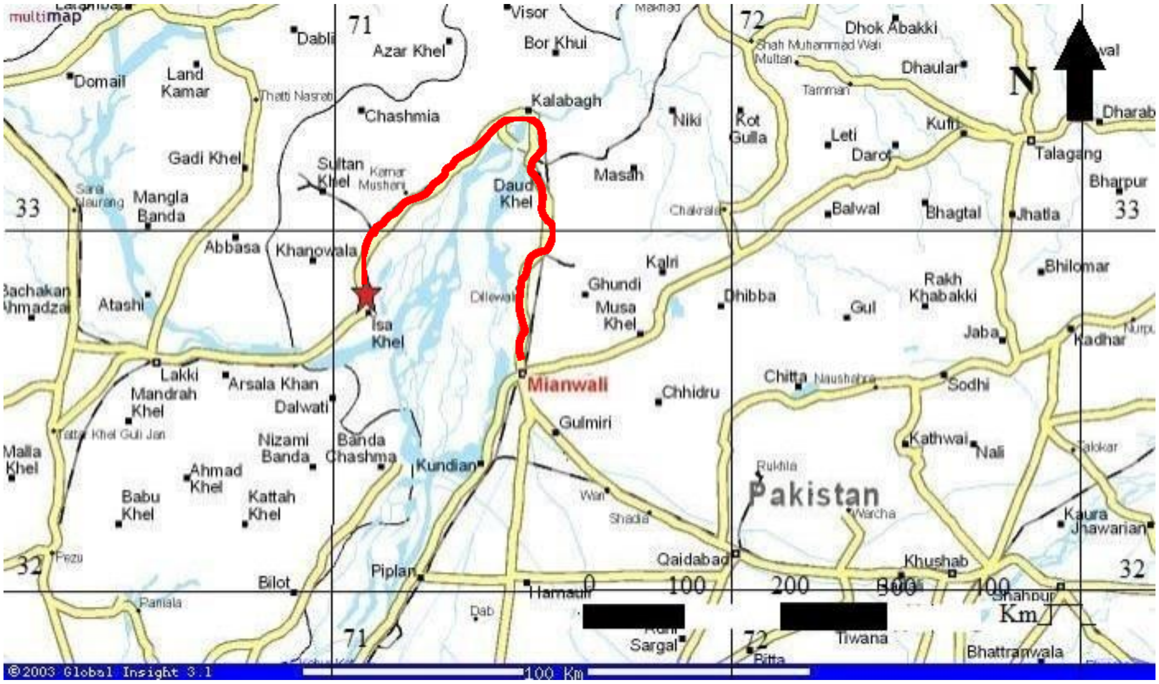

Figure 2.2 Accessibility map of study area. Dotted line shows the road map stretching 87kms from Mianwali city to Isa Khel tehseel.

1.2 Purpose of the study

This dissertation has the following objectives:

(1) To observe and confirm the structural features of the subsurface using seismic techniques.

(2) To carry out rock physical analysis.

(3) To reflect on the hydrocarbon potential of the Isa Khek-01 well using petro physical analysis.

1.3 Data source

The Seismic reflection data of the study area is provided by the Directorate General of Petroleum Concession (DGPC) Pakistan. The attempted output of the thesis research is the application of 2-D Structural analysis based on Integrated Techniques of Seismic and Well log on Well-01 Isa Khel, Pakistan. The provided data is as follows:

(1) Base map.

(2) Seismic cross-sections (05 seismic lines).

(3) Geological well log data of Isa Khel-01.

1.4 Base map

A seismic base map is one which shows the position and inter-relationship of the seismic lines as well as the shot points and data acquisition points of an area. It helps to determine at what shot points the seismic sections are to be tied and which of our seismic lines is the control line; that which has a well or the most proximal to it.

Below is the base map of the study area.

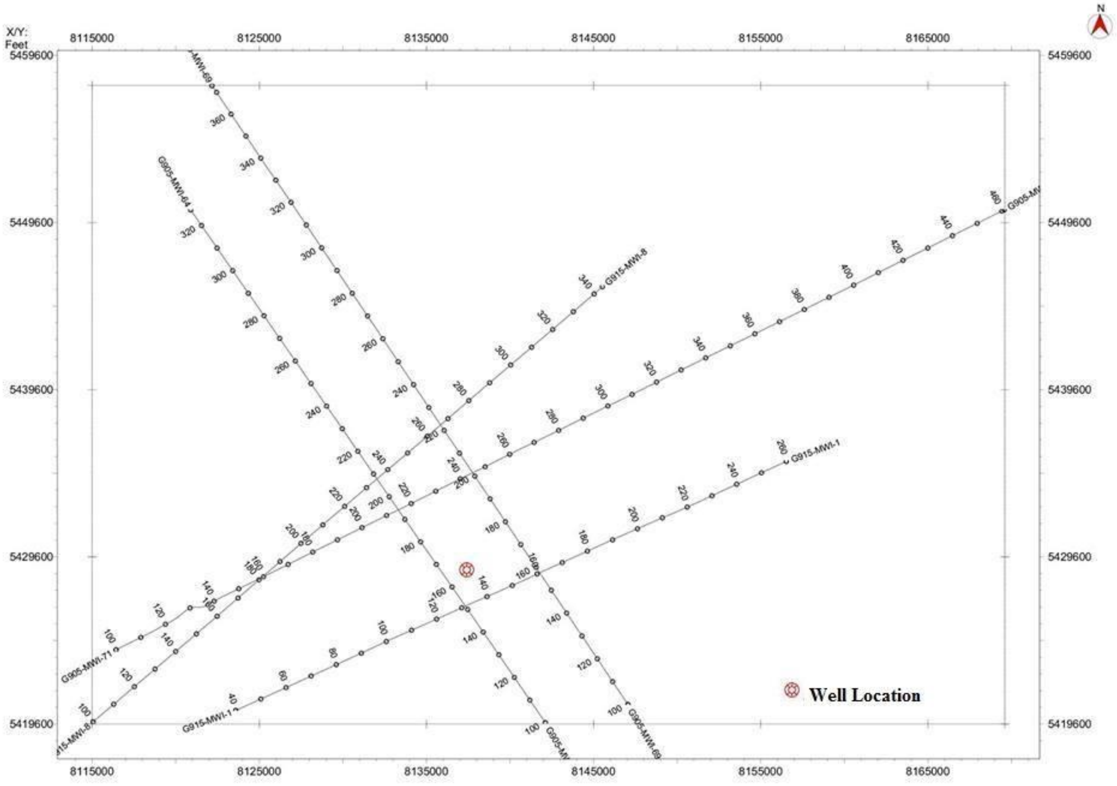

Figure 1.3 Base map of the study area (Courtesy LMKR)

1.5 Migrated seismic lines

Seismic surveying is the most accurate tool for subsurface imaging since seismic lines give a very accurate image which is further enhanced by seismic data processing. The data comprises of the following lines:

Table 1.1 Seismic lines provided for interpretation.

Line name	Line type	Line orientation
905-MWI-71	Dip Line	SE-NW
915-MWI-100	Dip Line	SE-NW
905-MWI-64	Strike Line	SE-NW
905-MWI-69	Strike Line	SE-NW
915-MWI-82	Dip Line	SE-NW

1.6 Well data

Following well and its respective logs were provided:

Table 1.2 Well logs provided to study.

Well name	Log types
Isa Khel well-01	Gamma ray log Density log Neutron log SP log Calliper log Resistivity log

1.7 Methodology

The methodology involves the following steps;

(1) Solving the velocity windows and calculating average velocity and depth.

(2) Marking of faults and horizons.

(3) Time and depth picking.

(4) Creating time and depth contour maps and 3D depth surfaces.

(5) Rock physical analysis by making contour maps of elastic modules in order to confirm the lithologies.

(6) Petrophysical analysis and calculation of net pay and movable hydrocarbons in the zone of interest.

CHAPTER 2

GEOLOGY AND TECTONICS

2.1 Overview

Indus basin is the largest sedimentary basin of Pakistan, stretching about 1600km along its axis and being 300km wide, with a NE-SW orientation. It mostly comprises of normal to moderate dipping structures while some steeply dipping structures are also present, exposing the basement rocks mainly as Sargodha Highs in NE and Naggar Parker Highs in SE. The compression regime of the tectonic plates causes the basin division into Upper and Lower Indus basin (Kazmi and Jan, 1997).

Sargodha High divides the Upper Indus Basin and Lower Indus Basin. Upper Indus Basin is further classified into Kohat sub-Basin and Potwar sub-Basin whereas Lower Indus Basin is further classified as Central Indus Basin and Southern Indus Basin, divided at Jacobabad High.

2.2 Potwar Basin

2.2.1 Introduction

The Potwar Basin is an onshore basin situated in northern Pakistan. A major portion of the hydrocarbon exploration activity in Pakistan is concentrated in this region due to its suitability for source, seal and reservoir rocks.

Potwar Basin, having being originated from a time in history when the Tethyan ocean dominated the area, is one of the oldest oil producing basins in the region. These palaeo-conditions made the area an ideal location for the preservation of phytoplanktons when the Tethyn Sea retreated and its subsequent conversion and preservation as hydrocarbons reserves. Although the northern area of Pakistan represents one of the most structurally deformed areas of the world, being the site for collision of Eurasian and Indian Plate, much of the sedimentary deposits in the Potwar Plateau have been preserved i.e in situ deposition of the sediments is still present. Hence most of the productive reservoir, coincident with the undisturbed sedimentary deposits of the region, belong to Eocene and Palaeocene carbonates although more recent exploration are some deeper targets zones of Permian formations.

Area north of Punjab plains is occupied by a major thrust known as Himalayan Frontal Thrust (HFT) along which lies Salt Range which occurs on the northern slopes of the Indian Shield. Nammal Gorge is located on the western part of Salt range. In Nammal gorge the strata from late Permian Wargal Limestone to Eocene Murree Formation are exposed. The area is structurally characterized by features like cross bedding, ripple marks; plumose structures, flute casts, burrows and some joints and fractures are present.

Economically Nammal gorge is very important. Large quantities of Limestone, Sandstone and silica sand are being extracted from the gorge. The quarries of limestone present here are fulfilling the needs of cement factories as well as construction purposes.

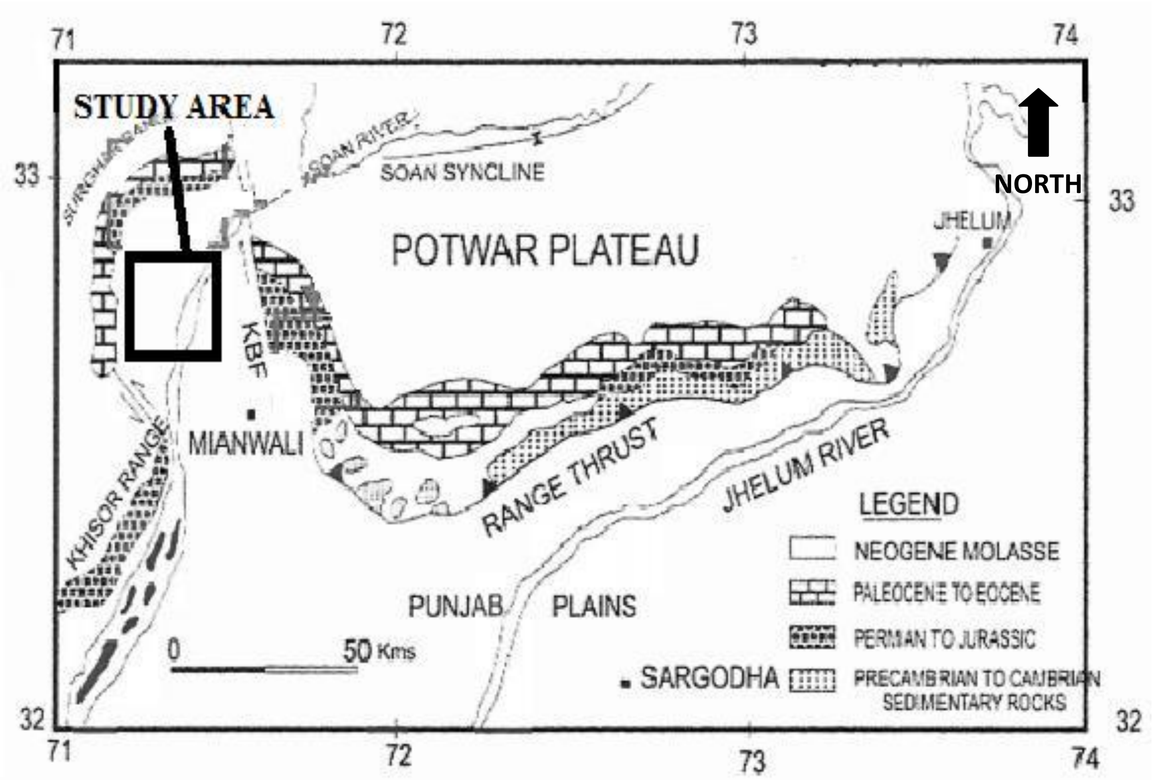

Figure 3.1 Generalized tectonic map of Potwar Region (Ahmed et. al., 2013)

2.2.2 Tectonics and structure style

The Salt range is the active frontal thrust zone of the Himalayas in Pakistan. About 1km offset of the basement normal faults acted as a buttress that caused the central Salt range-Potwar plateau thrust sheets to ramp to the surface, exposing Mesozoic and Paleozoic strata. The frontal part of the thrust sheet was folded passively as it overrode the sub-thrust surface on a ductile layer of Eocambrain salt. Lack of internal deformation of the rare part of the thrust sheet is due to decoupling of sediments from the basement along this salt layer. Cross-section balancing demonstrates at least 20to 23 km of shortening across the ramp. The rate of Himalayan convergence that can be attributed to under-thrusting of Indian basement beneath sediments in the Pakistan foreland is therefore at least 9-14mm/year about 20%-35% of the total plate convergence rate. The salt range is the surface expression of the leading edge of the decollement thrust that resulted from sediment decoupling from the northward drifting basement of Indian shield and essentially a complex salt anticlinorium with a series of salt anticlines. The youngest Salt range thrust appears 1.6 to 3.2 million years ago. The collision changes the sedimentation style from shallow neritic environment to fluvial system. The evaporites sequence is an effective zone of decoupling allowing thrusting to extend more than 100km south of MBT without involving basement. The salt layer permitted the rapid propagation of the basal detachment frontal ramp at the southern termination of the basin. Deformation produce horizontal shortening by folding and faulting, diapiric emplacement of evaporites and uplifting of the Salt range. The Salt range is terminated by the Jhelum strike-slip fault in the east and its western boundary is marked by Kalabagh strike-slip fault. The monocline structure of the Salt range represents rocks belonging from the Cambrian to recent in age.

2.2.3 Stratigraphy

The following lithologies are exposed at Nammal gorge:

1. Sakesar limestone
2. Nammal formation
3. Patala formation
4. Lockhart limestone
5. Hangu formation
6. Chichali formation
7. Samana suk formation
8. Shinwari formation
9. Data formation

10. Kingriali formation
11. Tridian formation
12. Mianwali formation
13. Chiddru formation
14. Wargal formation

Wargal Limestone

The name “Wargal limestone” was approved by the Stratigraphic Committee of Pakistan proposed by Teichert (1966) to the unit formerly known as “Middle Products limestone” of Waagen (1879) and “Wargal group of Noetling (1901). Its type section is Wargal village in the central salt range. Lithologicaly the formation is composed of limestone and dolomite of light grey to medium grey,brownish grey and olive green colors. In Zaluch nala the formations lithology is divided into 10 parts which shows alternate beds of sandstone, limestone and dolomite. The formation is 183m thick in Zaluch nala while in Marwat and Khisor ranges it is about 174m.The contact of Wargal limestone with underlying Amb formation is confirmable while upper contact with Chiddru formation is transitional.

Datta Formation

The name Datta formation was introduced by Danil chick and Shah (1967) for the “variegated stage” of Gee (1945). The formation is mainly of continental origin and consists of variegated colored sandstone, shale, siltstone and mudstone with irregularly distributed calcareous dolomitic, carbonaceous, ferruginous glass sand and fireclay horizons. The fireclay is present mainly in the lower part. At type locality the formation is 212m thick but increases to 230m in Punnunala to the west and over 400m in Sheikh Badin Hills. In Nammal gorge area the thickness is 150m which reduces further as we move towards east. The formation overlies unconformably on the Kingriali formation in Salt range and Trans Indus ranges while in Hazara it rests unconformably over the Precambrian Hazara formation. The upper contact with Shinawri formation is gradational.

Samana Suk Formation

Davies (1930) introduced name “Samana Suk” for the Jurassic limestone in Samana range formerly named as “Kioto Limestone” of Middle miss (1896) and Cotter (1933) and “Daulat mar Limestone” of Calkins and Matin (1968). The name Samana Suk is derived from the peak of this name in Samana Range. In the type locality the formation consists of grey, medium to thick bedded limestone with subordinate marl and shale intercalations. The limestone is oolitic and in Hazara and Kala Chitta it includes some dolomitic and ferruginous sandy, oolitic beds but these are absent here in Nammal area. The formation is widely distributed in western salt range, Kohat, Trans Indus ranges, Hazara and Kala Chitta. At the type locality thickness is 186m while in Bagnotar section Hazara it is 366m.The lower contact is transitional with Shinawari formation while upper contact with Chichali formation is disconformable.

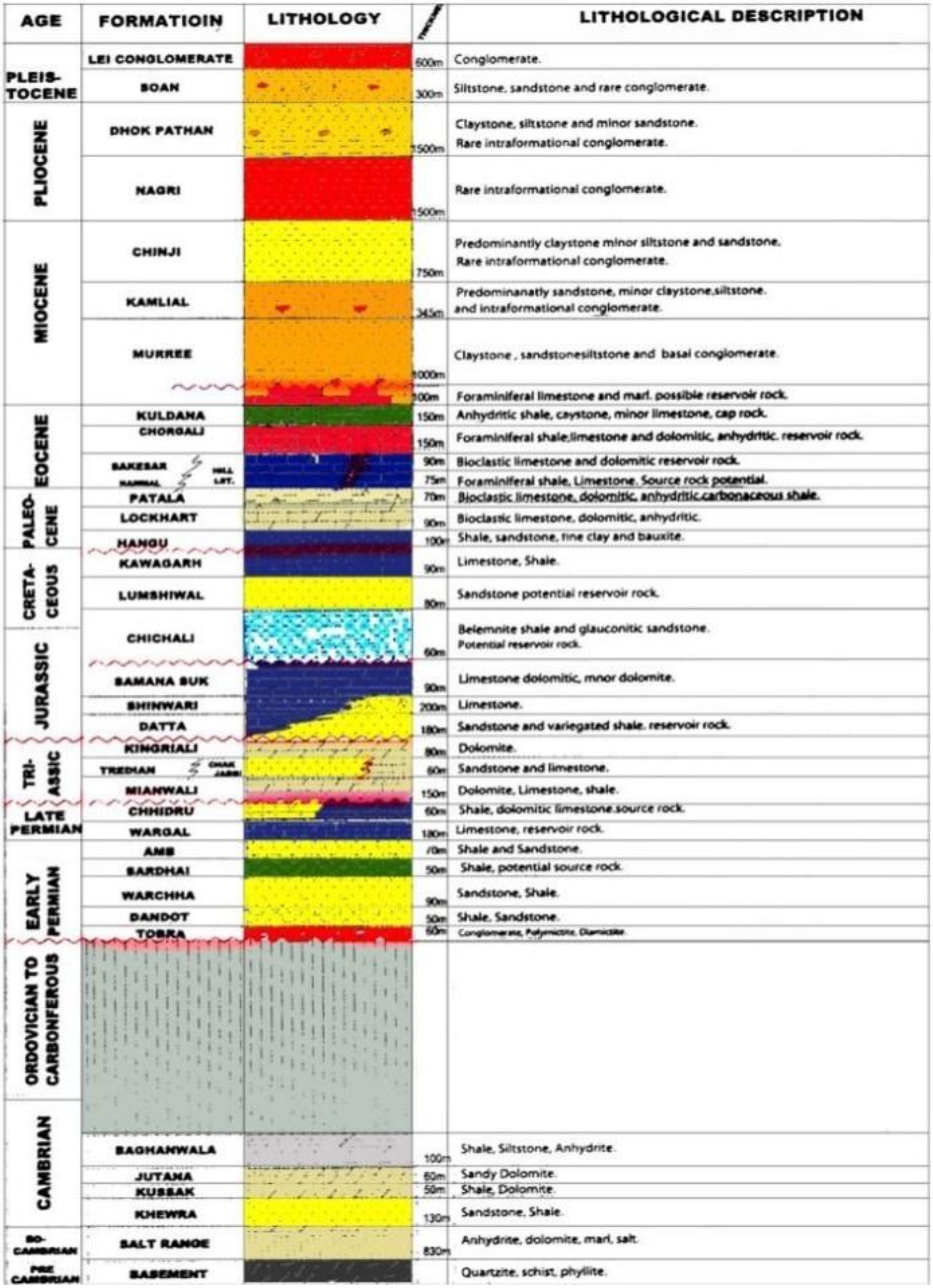

Figure 2.2 Generalized stratigraphy of Potwar Sub-Basin (Ahmed et, al., 2012)

2.3 Borehole stratigraphy

The study well Isakhel-01 is drilled to the depth of 4680 m. The well initially reveals Soan Formation at about 85m depth and ends with exposing Khewra Sandstone at a depth of 4350m. Noteworthy formations encountered include Patala Shale, Smanasuk Formation, Datta Formation, all of which are part of petroleum plays in producing fields.

Table 2.1 Borehole stratigraphic succession of Isakhel well-01

Formation top	Formation top age	Formation top value (m)	Thickness (m)
ALLUVIUM	Recent	0.00	85.00
SOAN	Pliocene	85.00	241.00
DHOK PATHAN	Pliocene	326.00	717.00
NAGRI	Pliocene	1,043.00	1,353.00
CHINJI	Miocene	2,396.00	414.00
SAMANA SUK	**Middle Jurassic**	**2,810.00**	**130.00**
SHINAWRI	Middle Jurassic	2,940.00	138.00
DATTA	**Early Jurassic**	**3,078.00**	**208.00**
KINGRIALI	Late Triassic	3,286.00	114.00
TREDIAN	Middle Triassic	3,400.00	91.00
MIANWALI	Early Triassic	3,491.00	101.00
CHHIDRU	Late Permian	3,592.00	76.00
WARGAL	**Late Permian**	**3,668.00**	**109.00**
AMB	Late Permian	3,777.00	76.00
SARDHAI	Early Permian	3,853.00	72.00
WARCHA	Early Permian	3,925.00	132.00
DANDOT	Early Permian	4,057.00	85.00
TOBRA	Early Permian	4,142.00	73.00
KHISOR	Middle Cambrian	4,215.00	51.00
JUTANA	Middle Cambrian	4,266.00	54.00
KUSSAK	Middle Cambrian	4,320.00	34.00
KHEWRA SANDSTONE	Early Cambrian	4,354.00	326.00

2.4 Petroleum geology of the area

2.4.1 Hydrocarbon potential

The presence of reservoir favourable features such as continental margins, thick marine sedimentary sequence, potential source, reservoir and cap rocks is evident from the many successful exploration ventures of the area. The target horizon was of Eocene age which was missing in the drilled hole therefore well was drilled up to Khewra sandstone of the Cambrian age. After that, target was changed up to the level of Permian age.

2.5 Petroleum play

Geologic components and processes necessary to generate and store hydrocarbons, including a mature source rock, migration pathway, reservoir rock, trap and seal. Appropriate relative timing of formation of these elements and the processes of generation, migration and accumulation are necessary for hydrocarbons to accumulate and be preserved. Kohat-Potwar Fold belt is a prolific hydrocarbon province and has many confirmed petroleum systems.

2.5.1 Source rock

From Potwar Sub-basin Patala shales of Palaeocene have a TOC between 0.5-3.5% (Kadri, 1995) . Also, the relatively high maturity of these shales makes them an excellent source rock.

2.5.2 Reservoir rocks

The significant reservoirs rocks in Upper Indus Basin are Eocene carbonates (Chorgali/Bhadrar-Sakesar formation) and Paleocene carbonates (Lockhart Formation). Also Sandstone of Jurassic (Datta Formation) is reservoir in many fields in Potwar basin and Kohat Basin e.g. Chanda oil field. Also Dhurnal, Tool and Meyaal fields are fed by both Samana Suk and Datta. Samana Suk occurs as a reservoir in Nand pur field and many others of the Karak area. Wargal Formation carbonates reservoir of Permian age is the reservoir in Dhurnal and Adhi fields.

2.5.3 Cap rock

A cap rock is a relatively impermeable rock commonly shale, anhydrite or salt that forms a barrier or seal above and around a reservoir rock so that fluids cannot migrate beyond the reservoir. The formations capable of acting as seal horizons in our area could be Chinji formation for Samana suk owing to the fact that it is a clay stone which are renowned for their efficient gas trapping. While for Wargal it would probably be the Chiddru formation, also Mianwali formation is a proven cap rock in the area. Datta’s shales acts as a cap for its self.

2.5.4 Trap

Both structural and stratigraphic traps are possible in the Potwar. Eastern Potwar represents thrusted and salt cored anticlines and local pop ups. In this area, anticlinal features strike generally east-northeast to west-southwest and are approximately parallel to the plate-collision zone.

CHAPTER 3

SEISMIC INTERPRETATION

The main purpose of the thesis is to identify the structural features upon which the well was drilled. Basically there are two main approaches to analyze seismic data; Stratigraphic correlation and Structural correlation.

Stratigraphic analysis encompasses interpretation of genetically related sedimentary sequences which characterize variations in the sedimentary depositional environments. However the structural approach visualizes the potential structures that can withhold hydrocarbons and thus an integral part in the petroleum play of the region, commonly known as "Structural Traps" (Keary, 1988). We applied the structural technique.

3.1 Well region

Mianwali lies in a compressional regime thus intense reverse faulting is observed in the seismic data of this region. The shallow parts are generally less faulted but the deeper you go the more intense faults you observe. Also the fault throws increase dramatically in the lower horizons.

3.2 Reflector Marking

From the formation tops we delineated the formations which were best fit for acting as reservoirs; this was done in accordance with the well tops. Initially solving the velocity windows for each seismic line which gives depths in terms of time and then correlating this value with the well top's depth value for the specific formation. For this you need to bring the Kelly Bushing and Seismic reference datum on the same elevation because otherwise varying elevations will result into erroneous depth values. The elevation of Kelly bushing is subtracted from the well tops value of a formation then this value is added to the value of Seismic Reference Datum. The resultant depth is the one upon which "s=vt/2" is applied to get the depths of formations.

3.3 Control Line

MWI-64 was the control line owing to its proximity to the Isa Khel 01 well.

3.4 Marking of Horizons

We found 3 formations eligible to act as reservoirs in this region based on the data from nearby producing fields, namely:

1. Samana Suk formation
2. Datta formation
3. Wargal Limestone

3.5 Marking of Faults

All the lines displayed major and minor faulting indicated by discontinuity in strata at certain locations. As faults form a variety of traps for accumulation of hydrocarbons; delineating them is the major and foremost concern of an interpreter.

3.6 Interpreted seismic sections

Three reflectors Samana Suk (red), Datta (green) and Wargal (yellow) were marked on the sections under study by using Microsoft Paint software. Scanned images were loaded into the software and were being manually marked.

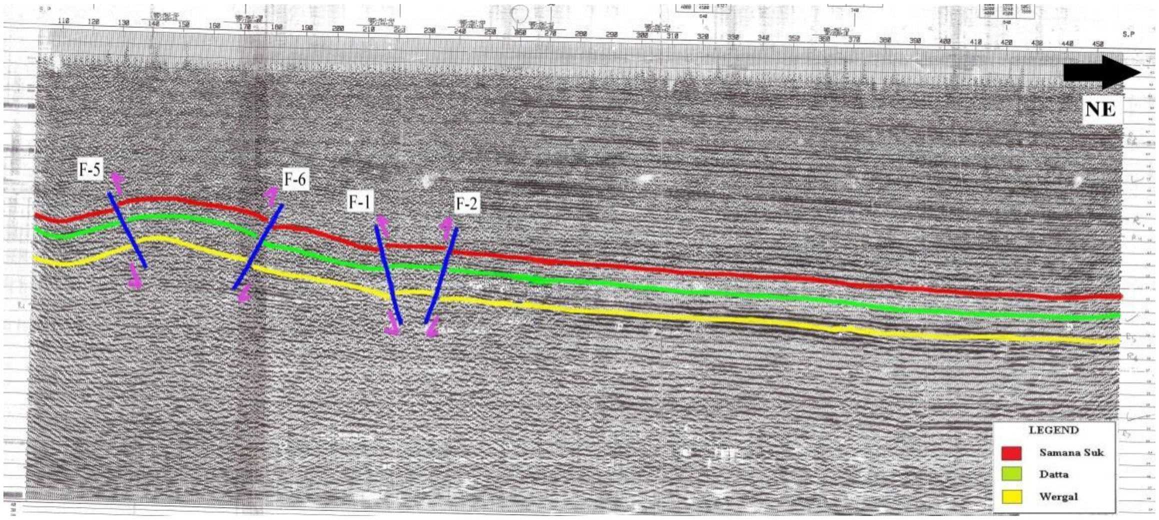

Figure 3.1 Horizons and faults on a dip line 905-MWI-71

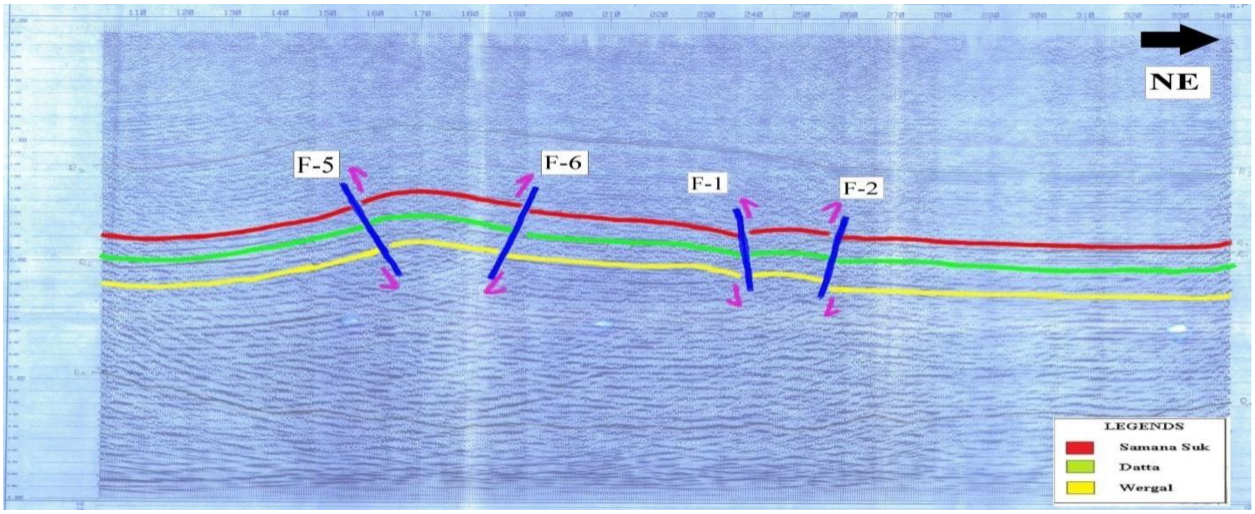

Figure 3.2 Horizons and faults marked on 915-MWI-82

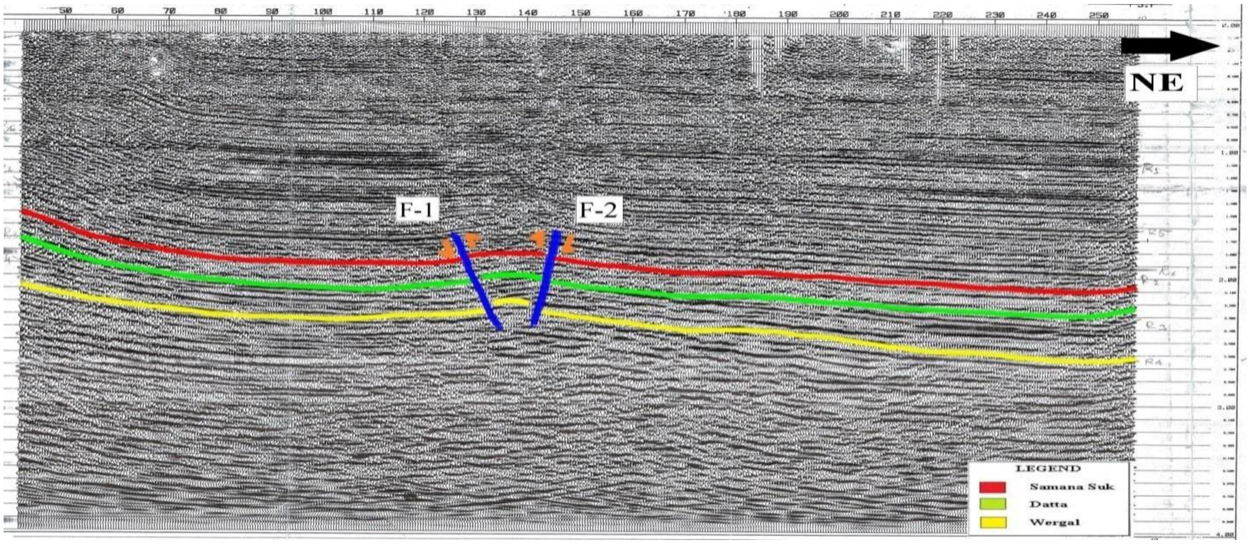

Figure 3.3 Horizons and faults on a dip line 905-MWI-100

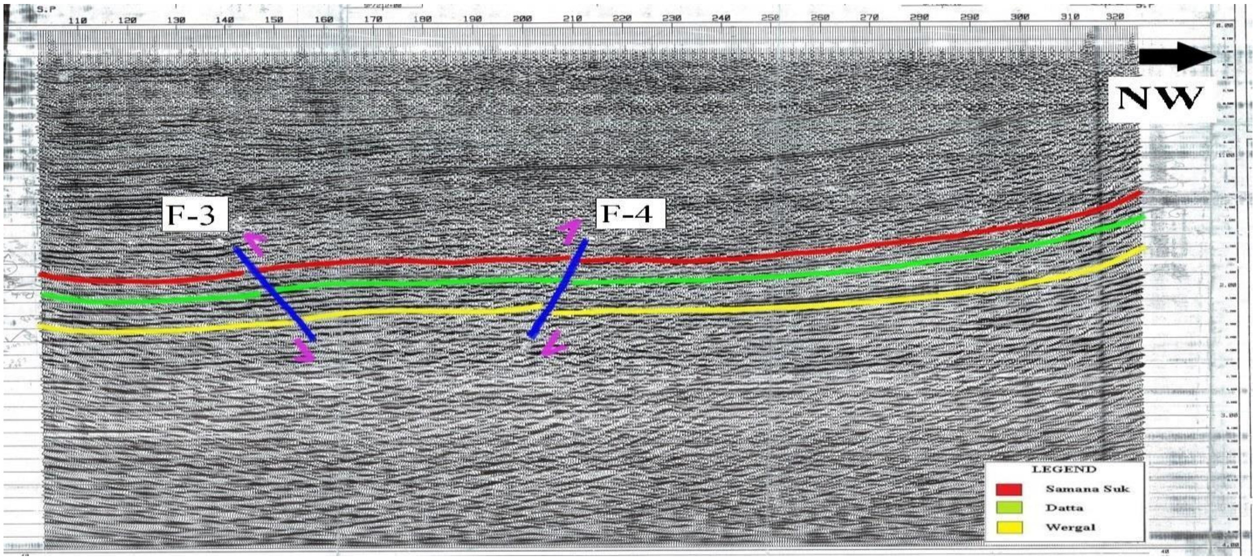

Figure 3.4 Horizons and faults on a strike line 905-MWI-64

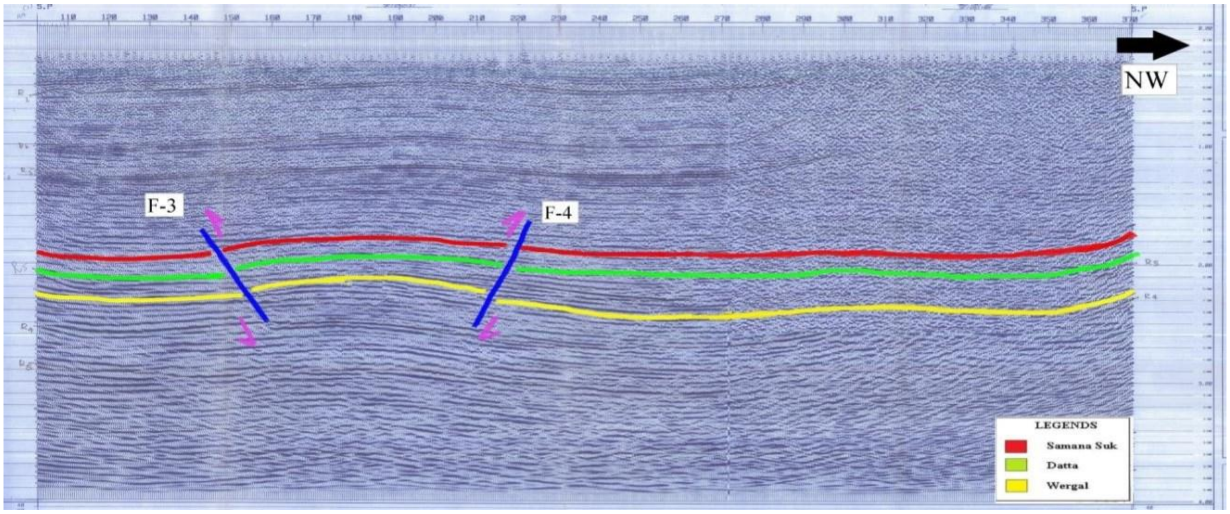

Figure 3.5 Horizons and faults on a strike line 915-MWI-69

3.7 Seismic time sections

The time section clarifies the subsurface picture of reservoir horizons (TWT on Y-axis) against the shot points (on X-axis), as obtained on the seismic sections. The time for each of the reflector is marked from the seismic section and plotted against the shot points.

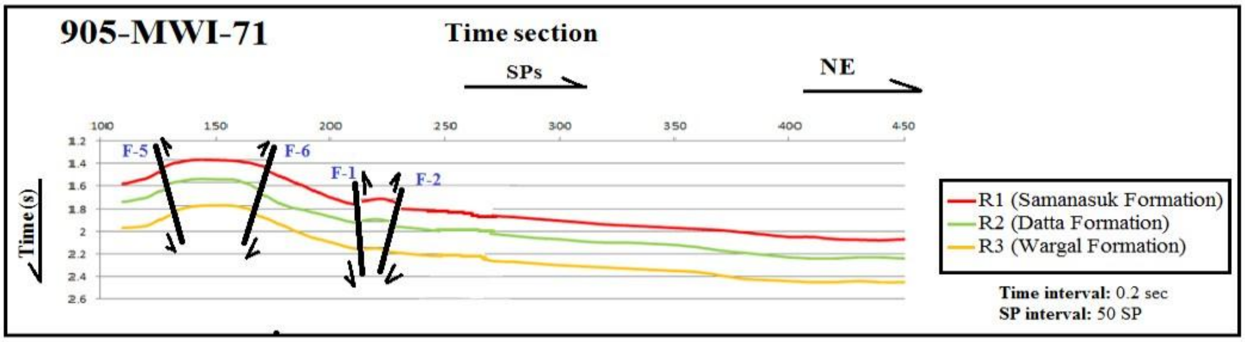

Figure 3.6 Time section of seismic line 905-MWI-71.

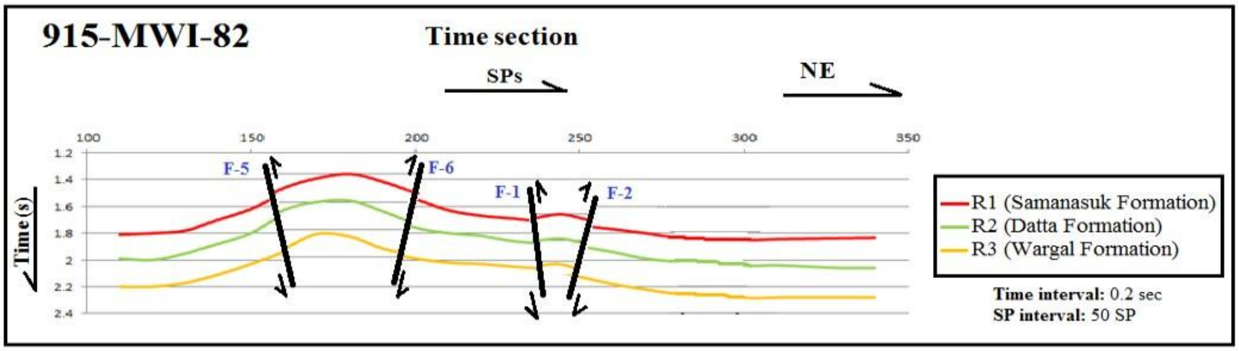

Figure 3.7 Time section of seismic line 915-MWI-82.

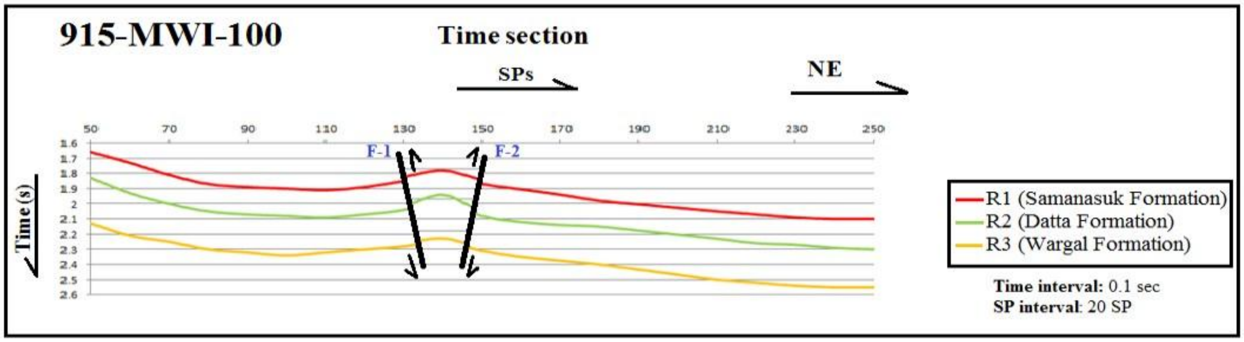

Figure 3.8 Time section of seismic line 915-MWI-100.

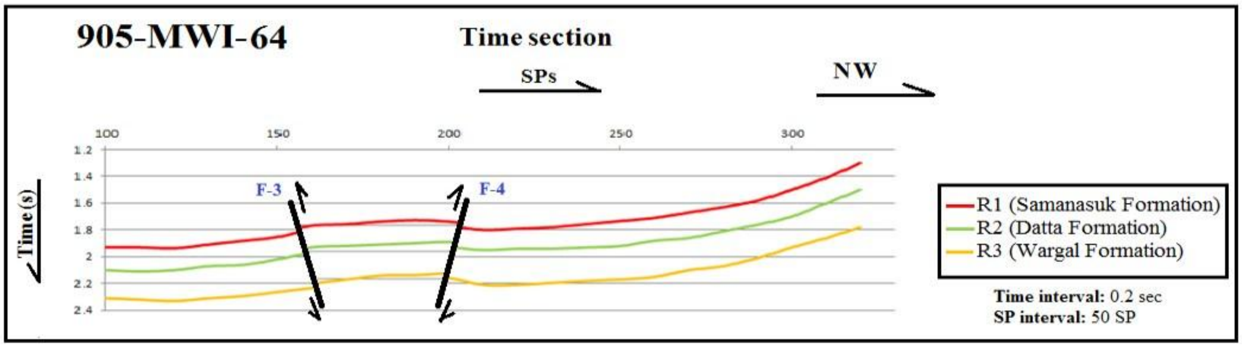

Figure 3.9 Time section of seismic line 905-MWI-64.

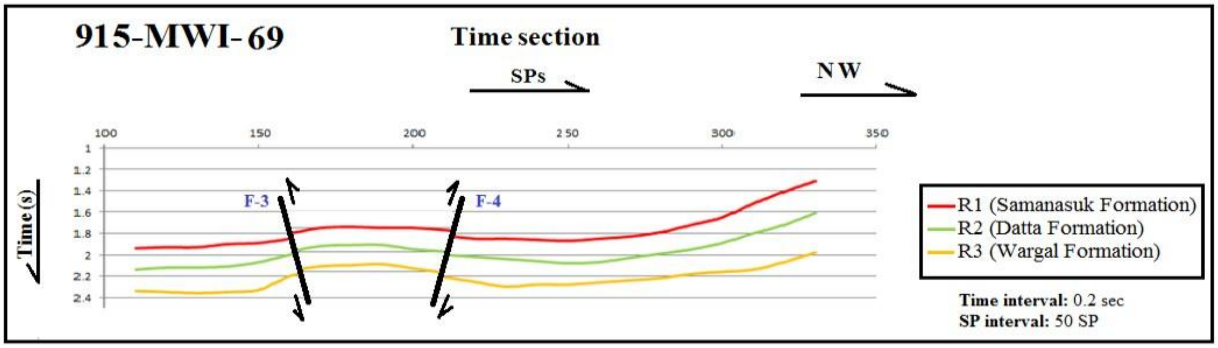

Figure 3.10 Time section of seismic line 905-MWI-69.

3.8 Seismic depth sections

The depth section provides the configuration of reflectors in similar way as it is in the time section. To determine the depth, the initial step is to read times of each reflector from seismic section. Using the appropriate velocity values and time, the depth of each reflector is calculated as follows:

$$\textbf{Depth} = (V \times T)/2$$

Where,

V= velocity of respective reflector (m/s)

T= two way travel time of each reflector (sec)

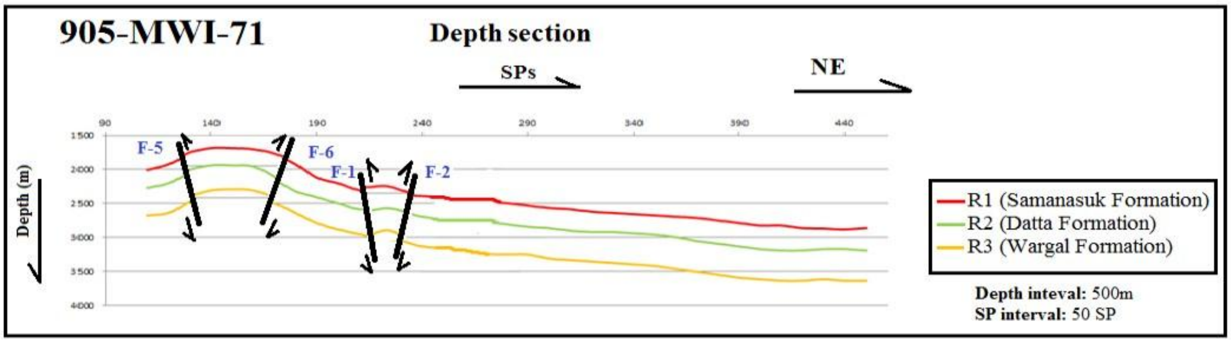

Figure 3.11 Depth section of 905-MWI-71.

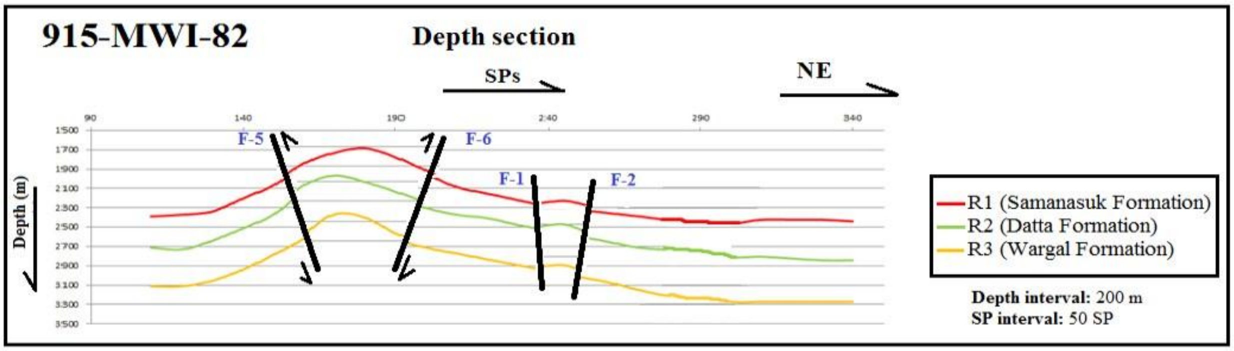

Figure 3.12 Depth section of 915-MWI-82.

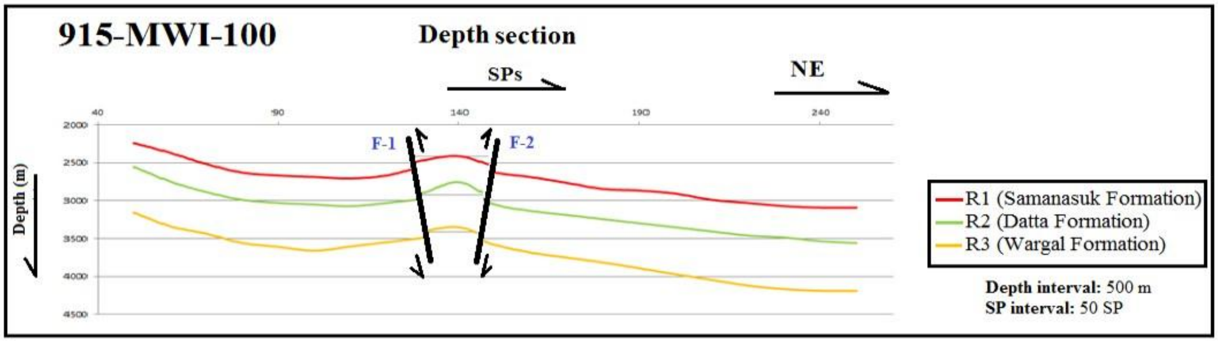

Figure 3.13 Depth section of 915-MWI-100.

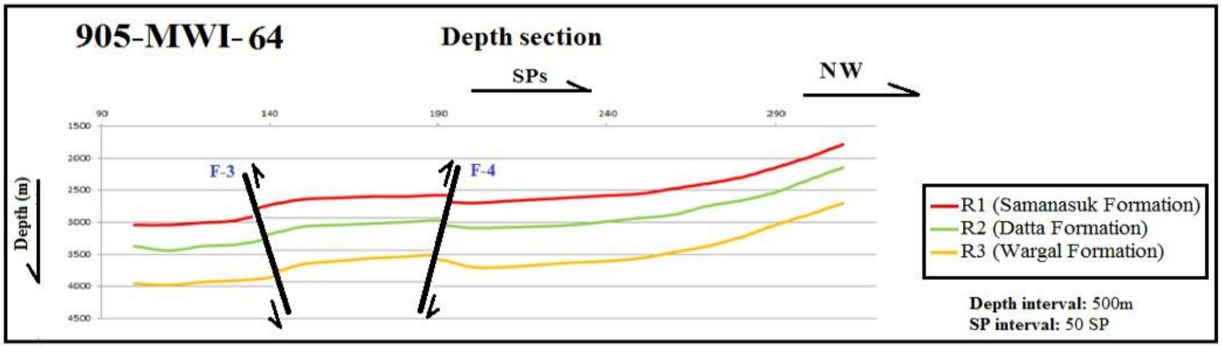

Figure 3.14 Depth section of 905-MWI-64.

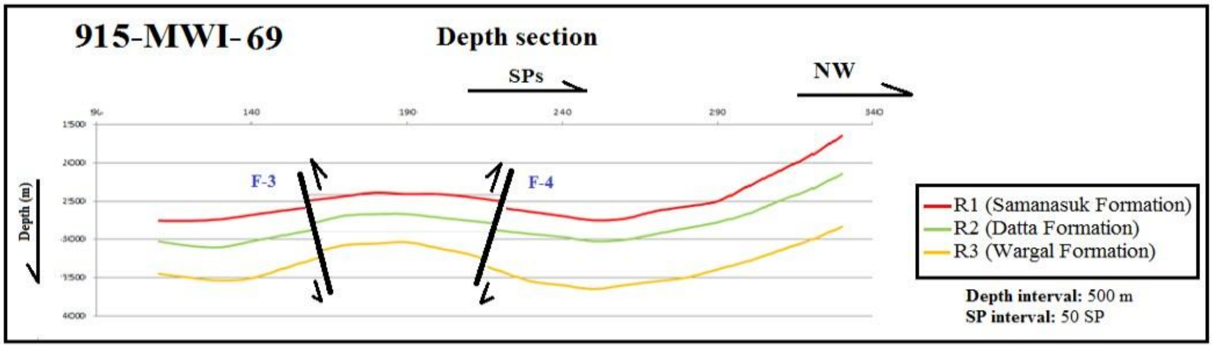

Figure 3.15 Depth section of 915-MWI-69.

3.9 Time contour maps

For making the time maps the times are read directly from the sections and so are immediately available for mapping. TWT contours represent contour lines having the same time values. These values represent the time consumed by the seismic wave from source to travel in the subsurface, strike a reflector and then reflect back to the surface.

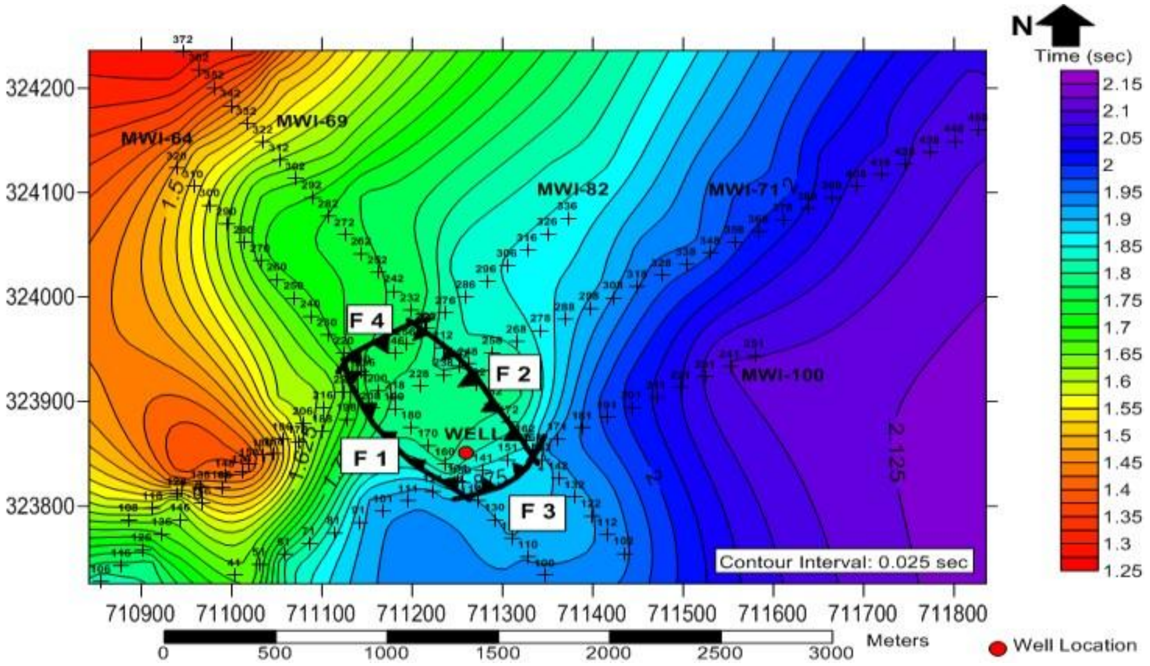

Figure 3.16 Time contour map of Samana Suk Formation.

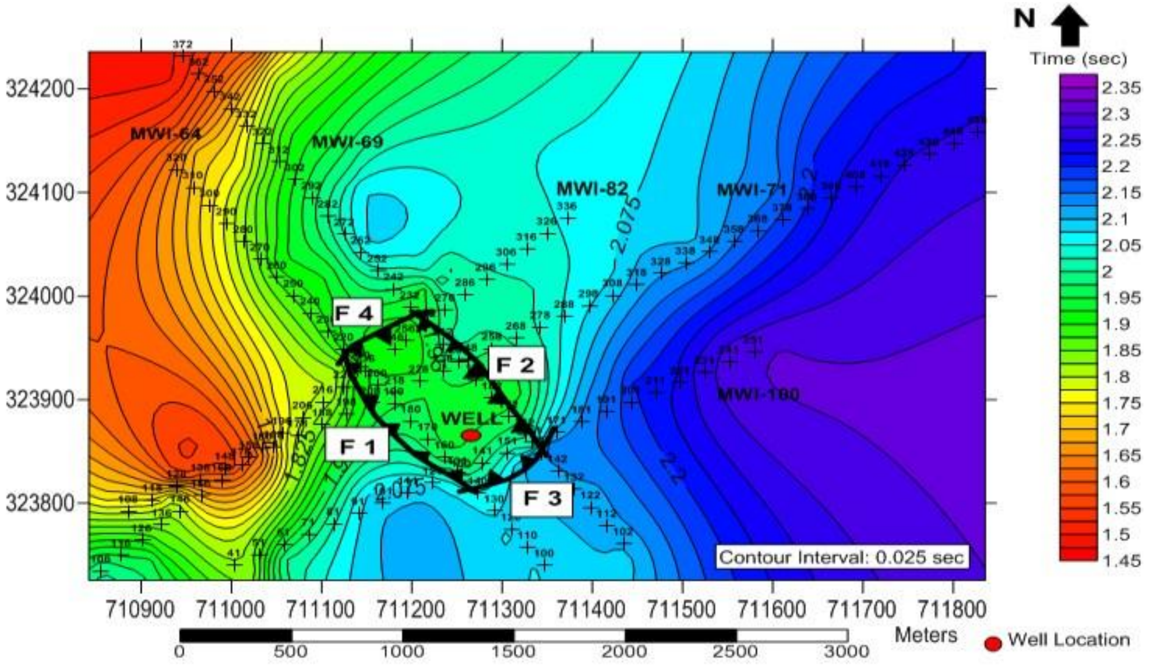

Figure 3.17 Time contour map of Datta Formation.

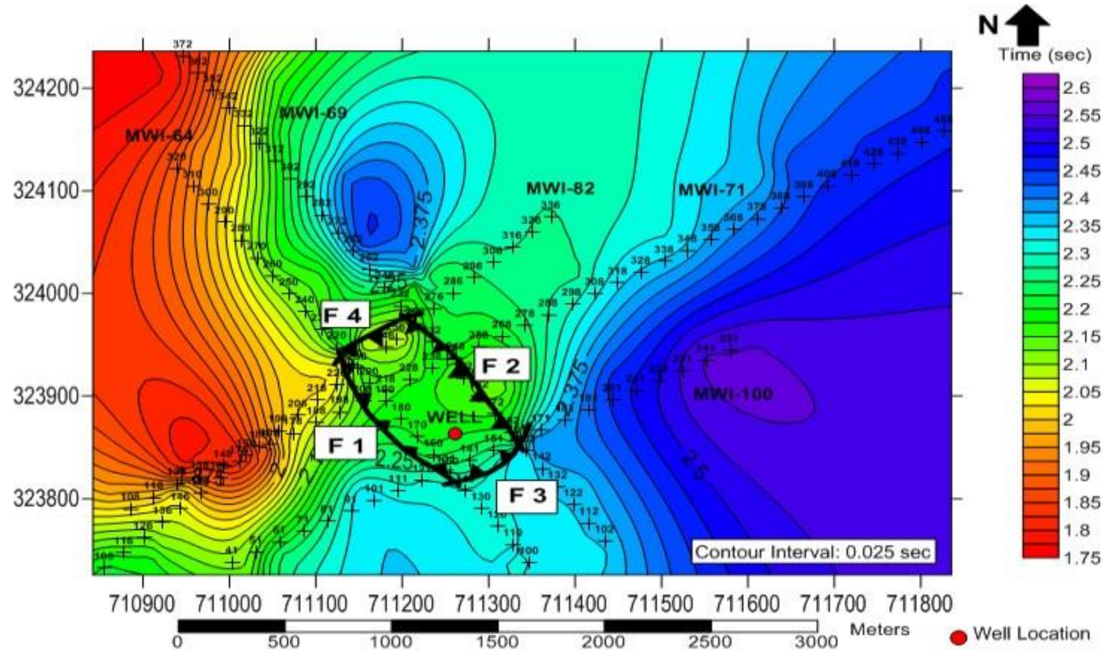

Figure 3.18 Time contour map of Wargal Formation.

3.10 Depth contour maps

Depth contour map represents the horizon in units of depth i.e. meters. This gives more accurate position of the horizon in the subsurface.

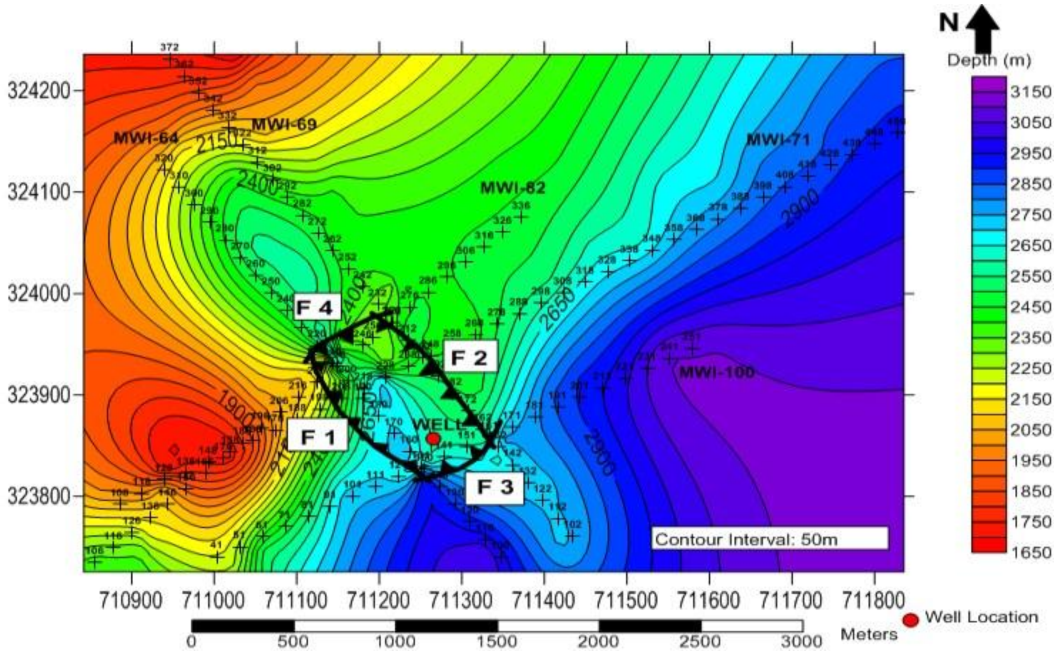

Figure 3.19 Depth contour map of Samana Suk Formation.

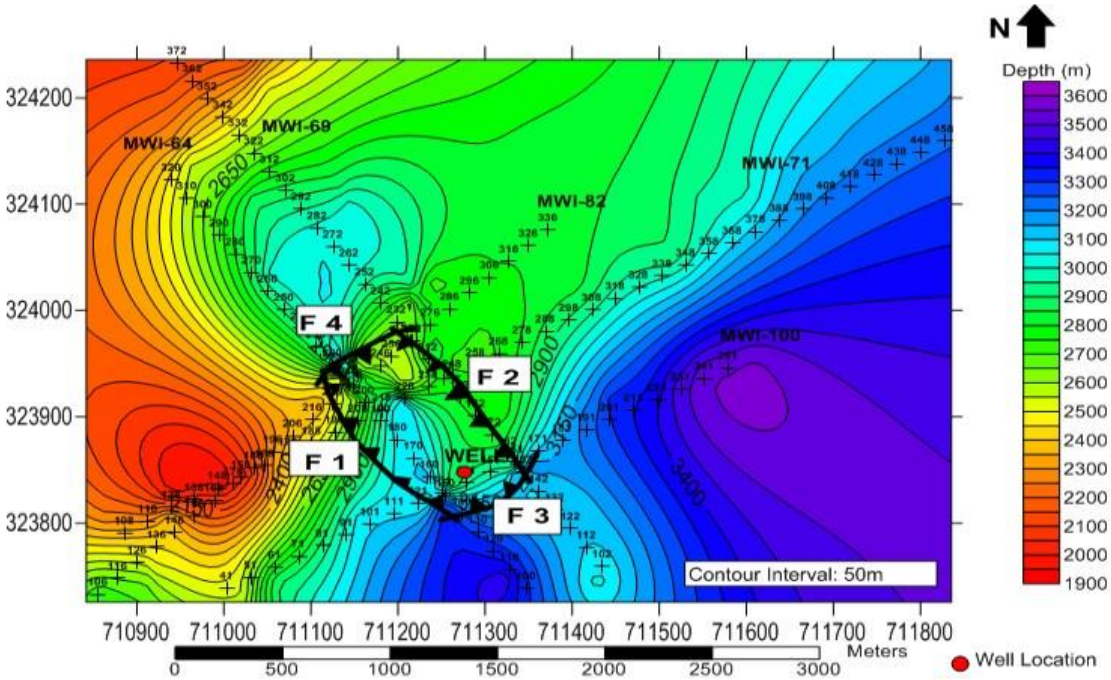

Figure 3.20 Depth contour map of Datta Formation.

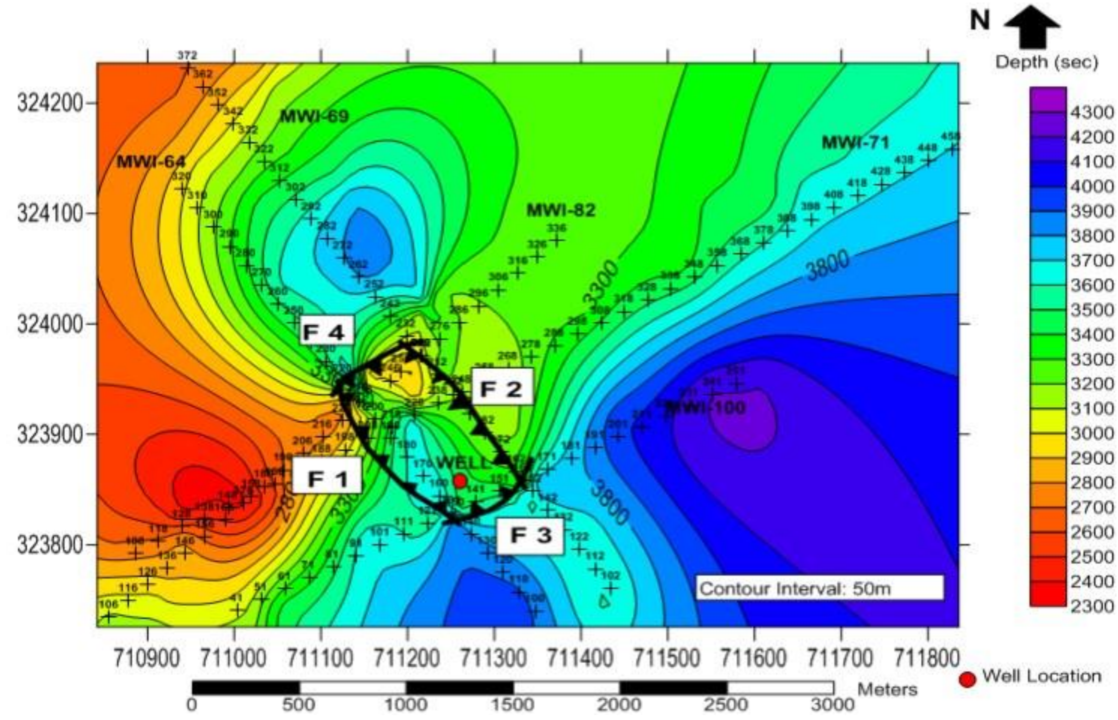

Figure 3.21 Depth contour map of Wargal Formation.

3.11 3-D Depth surfaces

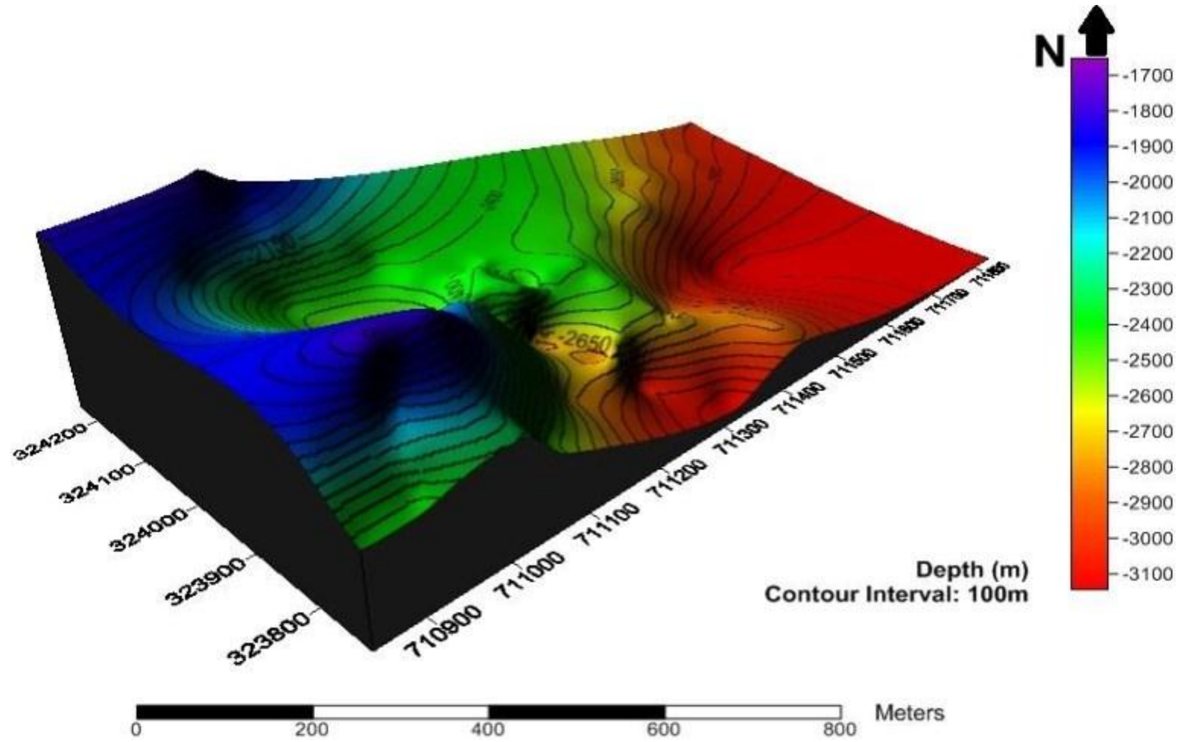

Figure 3.22 3-D depth surface of Samana Suk Formation.

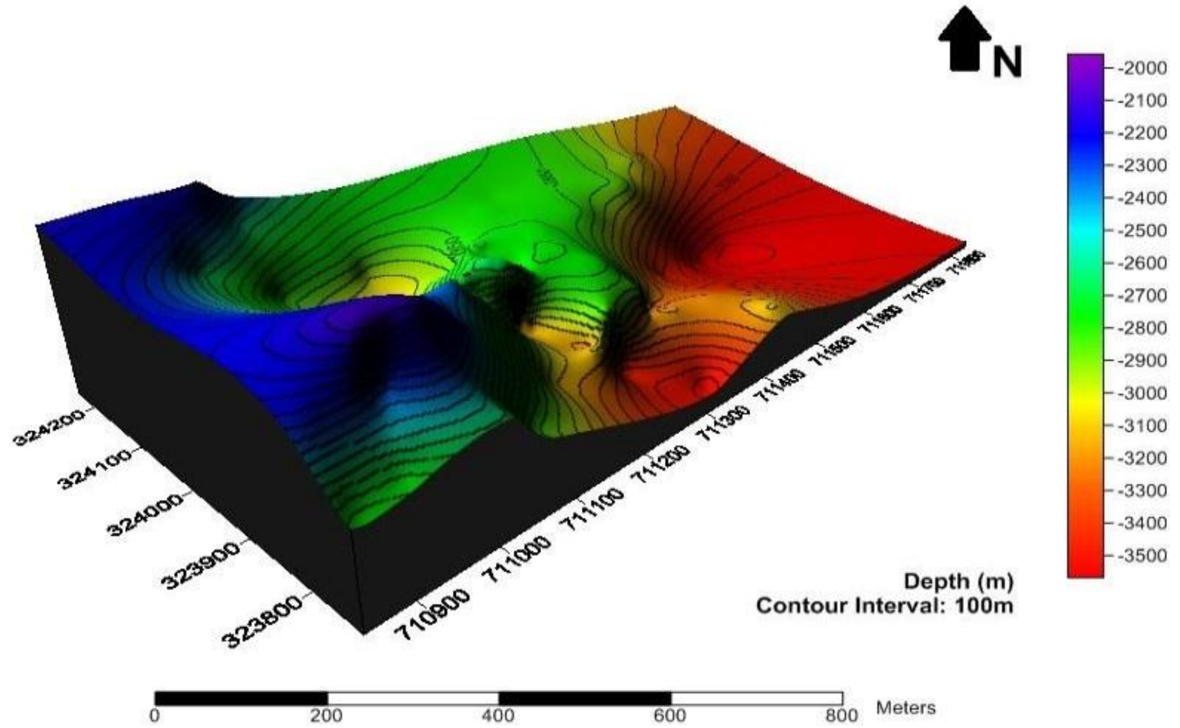

Figure 3.23 3-D depth surface of Datta Formation.

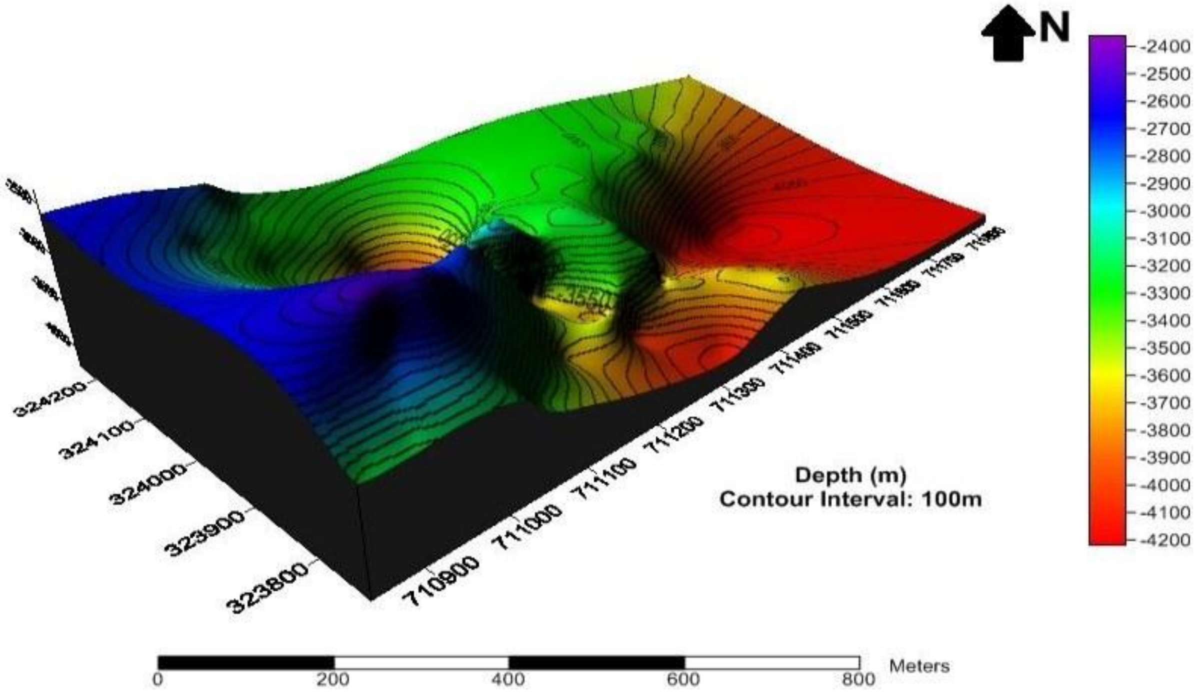

Figure 3.24 3-D depth surface of Wargal Formation.

CHAPTER 4

ROCK PHYSICS

4.1 Introduction

Rock Physics provides the connections between elastic properties measured at the surface of the earth, within the borehole environment or in the laboratory with the intrinsic properties of rocks, such as mineralogy, porosity, pore shapes, pore fluids, pore pressures, permeability, viscosity, stresses and overall architecture such as laminations and fractures. Rock Physics provides the understanding and theoretical tools required to optimize all imaging and characterization solutions based on elastic data. The techniques can be used for rock physics modeling i.e. to predict the elastic (seismic) properties from the geology or for rock physics inversion i.e. to predict geology from elastic (seismic) observations.

Reservoir characterization, especially reservoir monitoring has become integral part of Exploration and Production strategy. The goal of reservoir characterization is to see how the hydrocarbons are distributed in the reservoir. Among the many parameters use to describe the reservoir, the main ones are porosity, fluid saturation and permeability. In the reservoir monitoring, the objective is to find out how reservoir change with time during production and enhanced recovery efforts. Thus rock physics may help us understand the behavior of reservoir and non-reservoir zones.

Rock physics modelling is the process of finding a rock physics model that is consistent with the available well and core data. Thus using rock physics data we may be able to correct some of the problems encountered well log data as well as better calibrate and authentic the seismic responses of the subsurface.

4.2 Objectives

As a discipline, rock physics establishes a relationship between the seismic signal and the petrophysical properties in the subsurface. Through this connection, we seek to “extract” information about the petrophysical and geometrical properties, which gives rise to the recorded and observed seismic signal.

4.3 Elastic parameters

An elastic modulus is the mathematical description of an object or substance's tendency to be deformed elastically (i.e. non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation zone.

Following elastic moduli have been discussed with respect to the study area.

4.3.1 Bulk modulus

The bulk elastic properties of a material determine how much it will compress under a given amount of external pressure. The ratio of the change in pressure to the fractional volume compression is called the bulk modulus of the material. Thus the bulk modulus is a measure of the ability of a substance to withstand changes in volume when under compression on all sides. The bulk modulus is denoted by K and is stress divided by strain.

The mathematically representation is given below.

$$\mathbf{K= Stress/\ Strain}$$

$$\mathbf{K= \Delta P/\ (\Delta V/V)}$$

Where:

ΔP= Change in pressure.

V= Original volume.

ΔV= Change in volume.

If a material under goes no volume change ($\Delta V=0$) when subjected to compressive stress (ΔP), the material is said to be incompressible ($K = \infty$). Conversely, materials that are easy to compress (K very small) undergo large changes in volume (large $=\Delta V$) when subjected to relatively small compressive stresses (small ΔP) (Lillie, 1998).

The bulk modulus of a solid influences the speed of sound and other mechanical waves in the material. It also is a factor in the amount of energy stored in solid material in the Earth's crust. This buildup of elastic energy can be released violently in an earthquake, so knowing bulk moduli for the Earth's crust materials is an important part of the study of earthquakes. The bulk modulus is a factor in the speed of seismic waves from earthquakes.

4.3.2 Shear modulus or modulus of rigidity

It describes the ability of material to resist shearing. It is denoted by G or μ. A material that shows strong resistance to shearing ($\Delta L=0$) is very rigid ($\mu = \infty$). A fluid on the other hand has no resistance to shearing ($\Delta L= \infty$) and therefore lacks rigidity ($\mu =0$).

$$\mathbf{\mu = Stress/\ Strain}$$

$$\mathbf{\mu = (F/A)/\ (\Delta L/L)}$$

Where:

μ=Shear Modulus.

F/A= Force per unit area applied to the end of object.

L= Original Length of the object.

ΔL= Change in the length of the object (Lillie, 1998).

4.3.3 Young's modulus

Young's modulus, also known as the Stretch modulus or elastic modulus, is a measure of the stiffness of an elastic material. It is defined as the ratio of the stress along an axis over the strain along that axis in the range of stress in which Hooke's law holds. It is denoted by E.

The equation is given below:

$$\mathbf{E=Stress/Strain}$$

$$\mathbf{E= (F/A)/(\Delta L/L)}$$

Where:

E= Young’s modulus.

F/A= Force per unit area applied to the end of object.

L= Original Length of the object.

ΔL= Change in the length of the object (R.J.Lillie, 1989).

4.3.4 Poisson's ratio

Poisson’s ratio is named after Siméon Poisson, is the ratio between transverse strain to the longitudinal strain and it is a unit-less quantity. When a rod is compressed or stretched under applied stress then there is a change in it length as well as its width. This ratio of change in width to the change in lenhgth is called Poisson’s ratio. It is represented by υ or σ.

Negative seismic Poisson’s ratio anomaly indicates the presence of oil while wet sand will have almost no Poisson’s ratio anomaly.

$$\boldsymbol{\upsilon \text{ or } \sigma = (\Delta W/W)/(\Delta L/L)}$$

$$\boldsymbol{\upsilon \text{ or } \sigma = \text{Poisson Ratio}}$$

Where:

W= Original Width.

ΔW= Change in width.

L= Original Length of the object.

$\Delta L/L$= Change in the length of the object

4.3.5 Lame’s Constant

It is denoted by λ and illustrates the relationship between the four constants described above and represented as :

$$\lambda=K - (2\ \mu/3)$$

4.4 Depth vs. Modulus Graphs

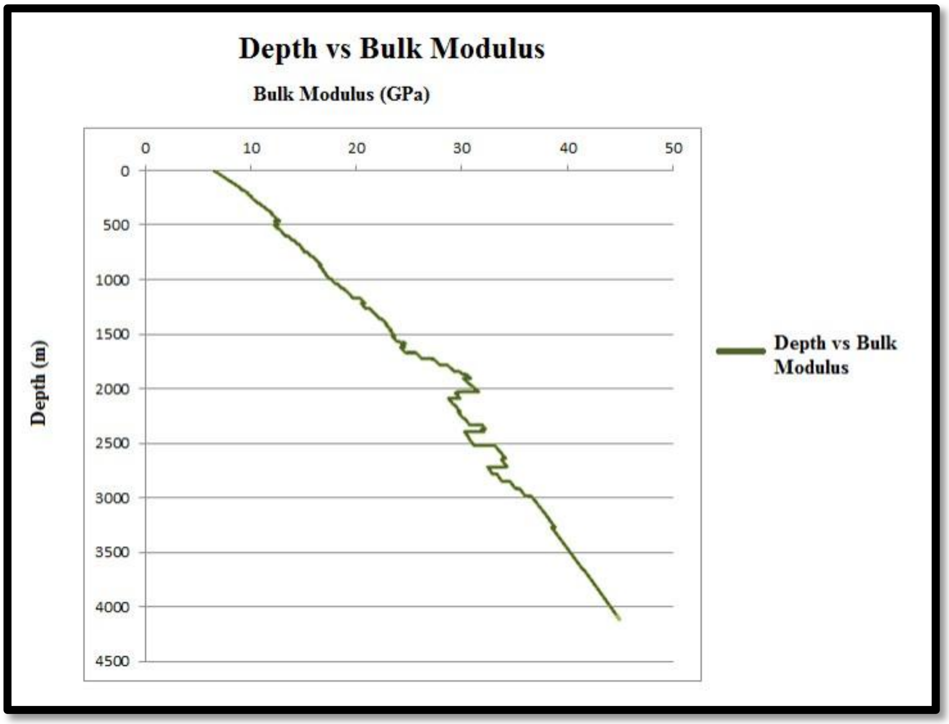

Figure 4.1 Depth vs Bulk Modulus plot.

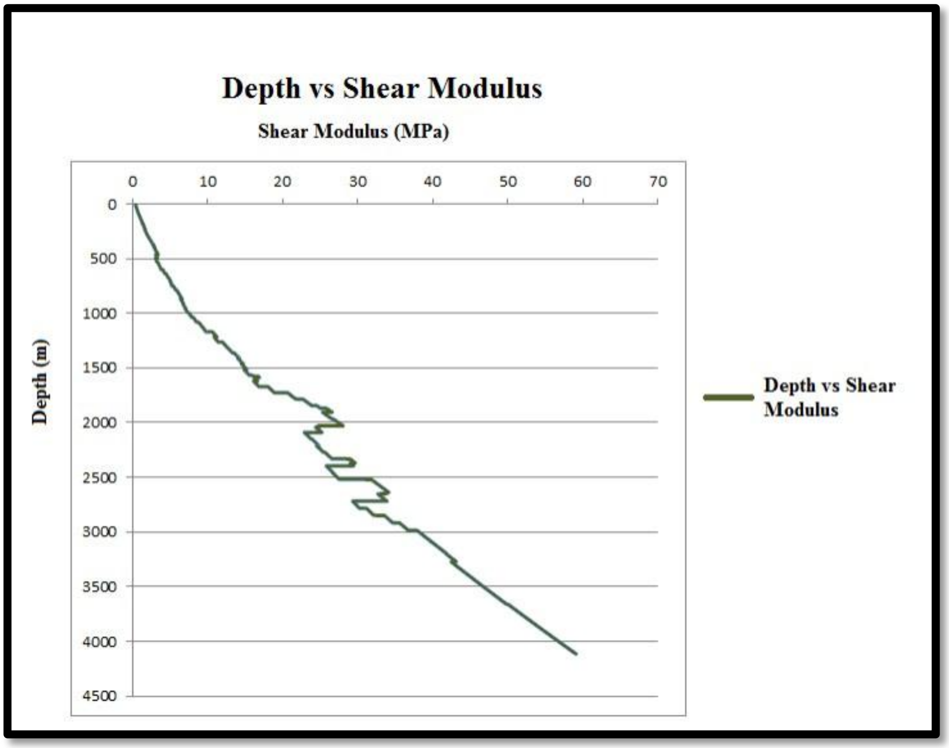

Figure 4.2 Depth vs Shear Modulus Plot.

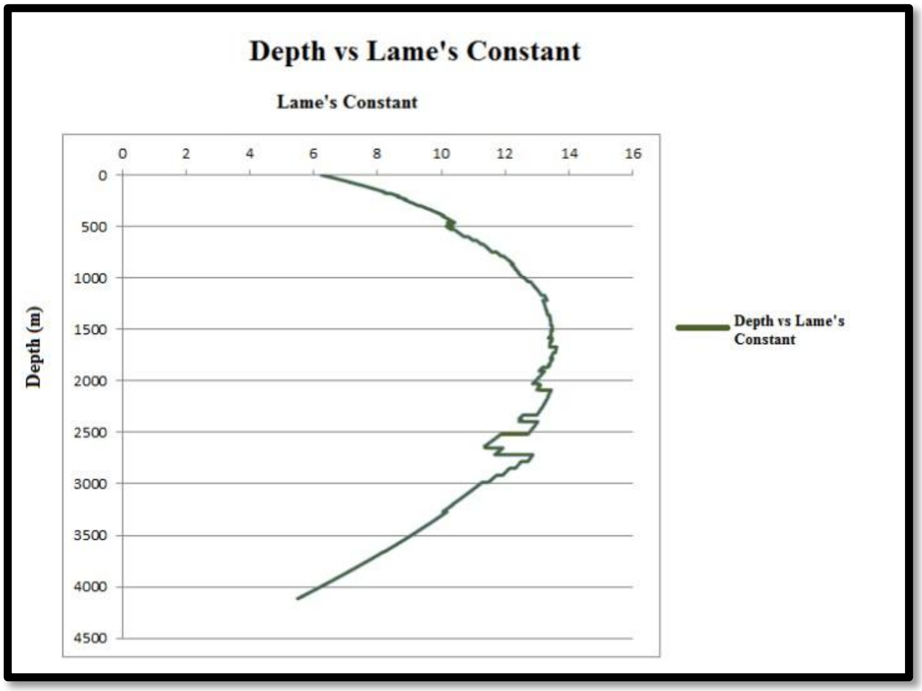

Figure 4.3 Depth vs Lame’s Constant Plot.

4.5 Modulus contour maps

BULK MODULUS

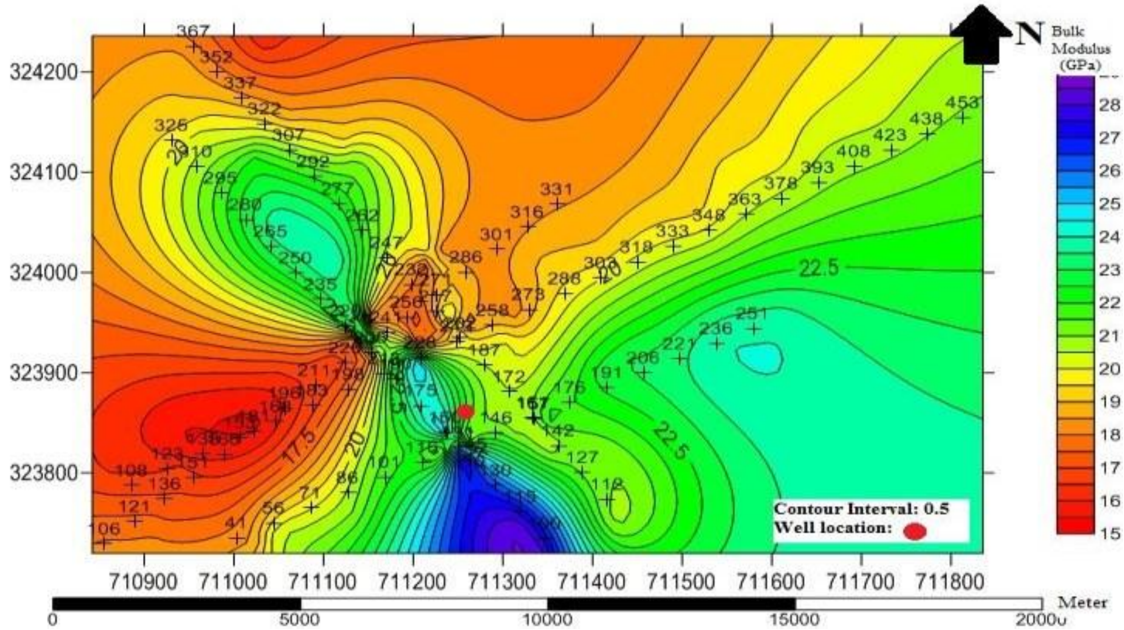

Figure 4.4 Bulk Modulus contours of Samana Suk Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

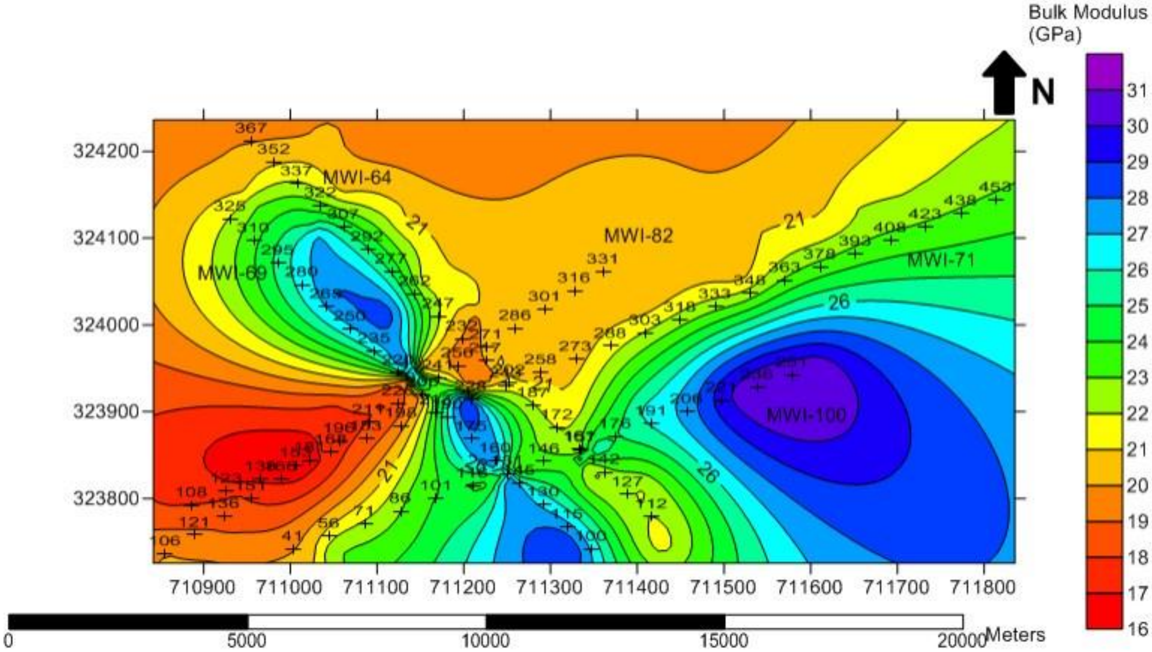

Figure 4.5 Bulk Modulus Contours of Datta Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Sandstone.

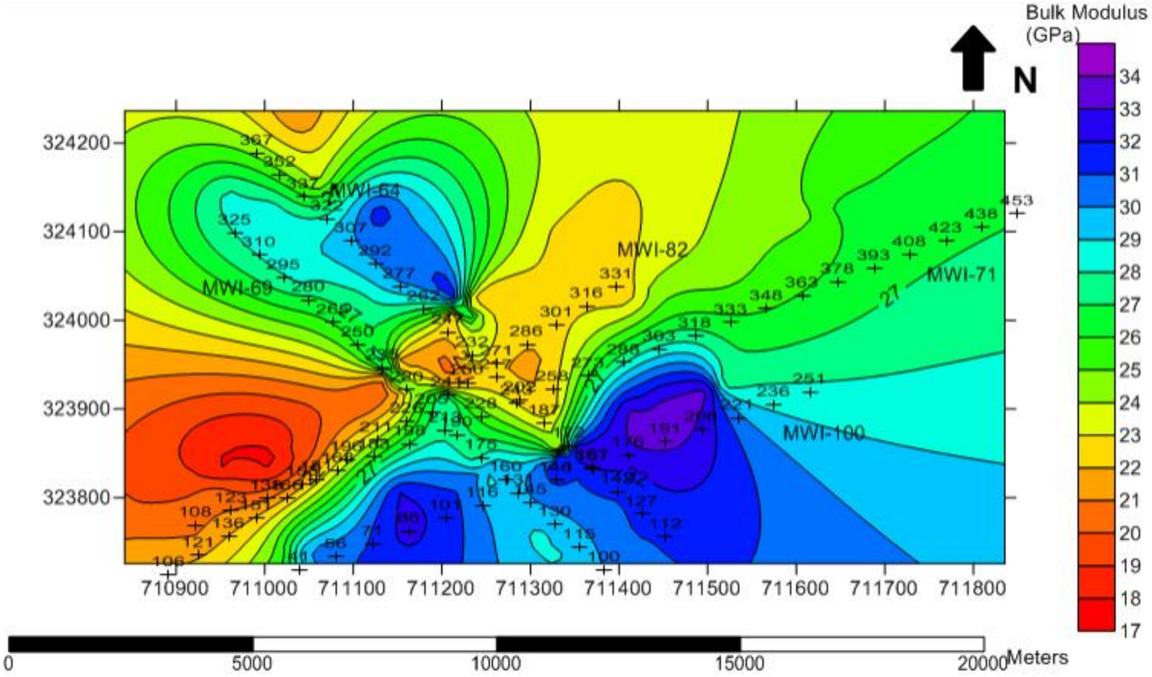

Figure 4.6 Bulk Modulus contours of Wargal Limestone.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

SHEAR MODULUS

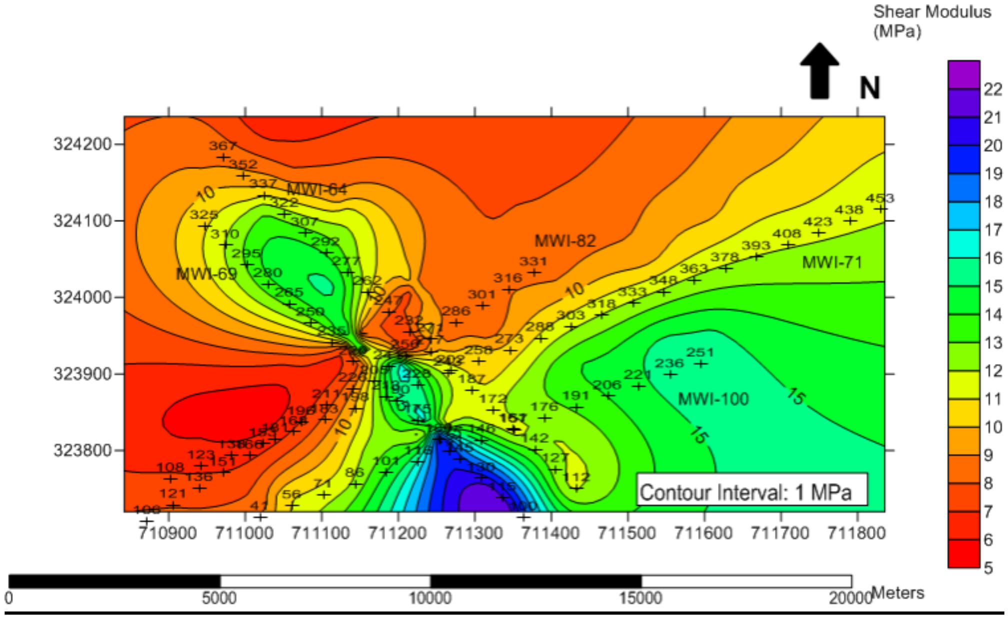

Figure 4.7 Shear Modulus contours of Samana Suk Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

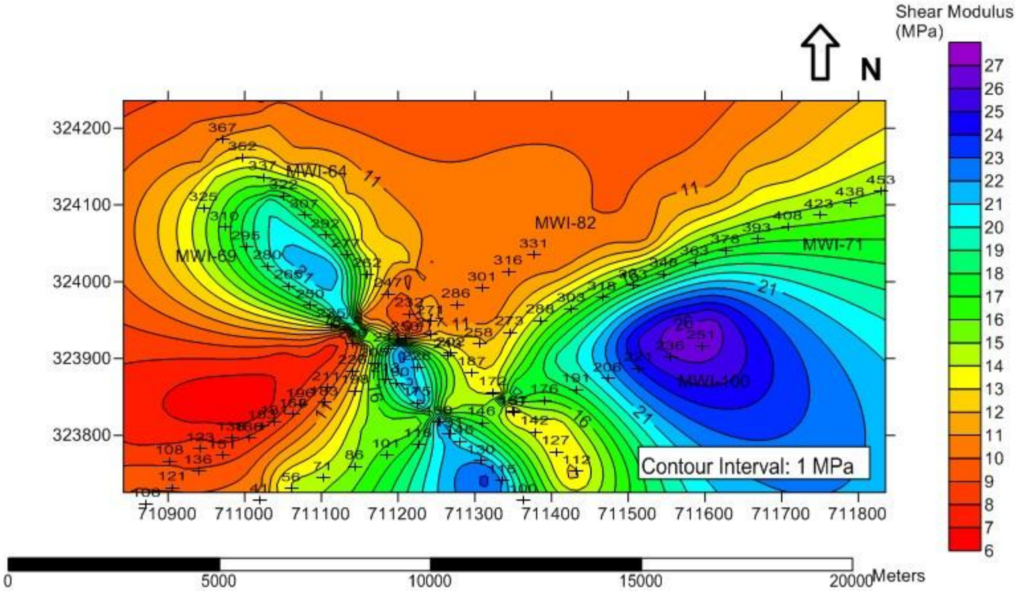

Figure 4.8 Shear Modulus contours of Datta sandstone Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Sandstone.

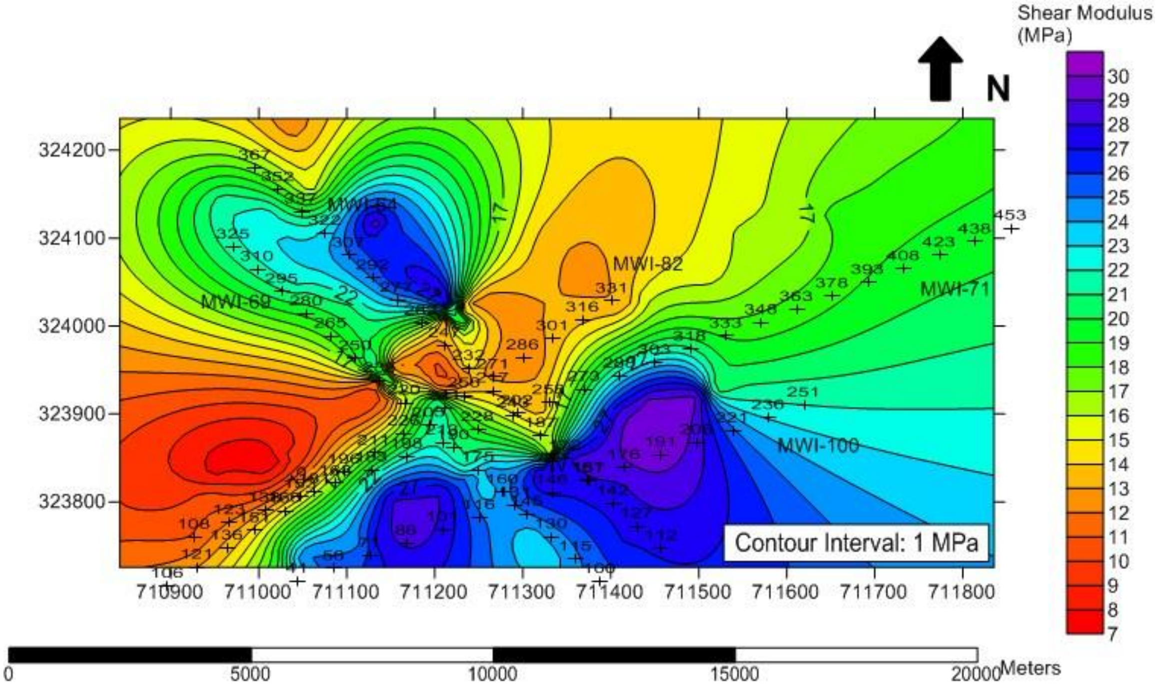

Figure 4.9 Shear Modulus contours of Wargal Limestone.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

POISSON'S RATIO

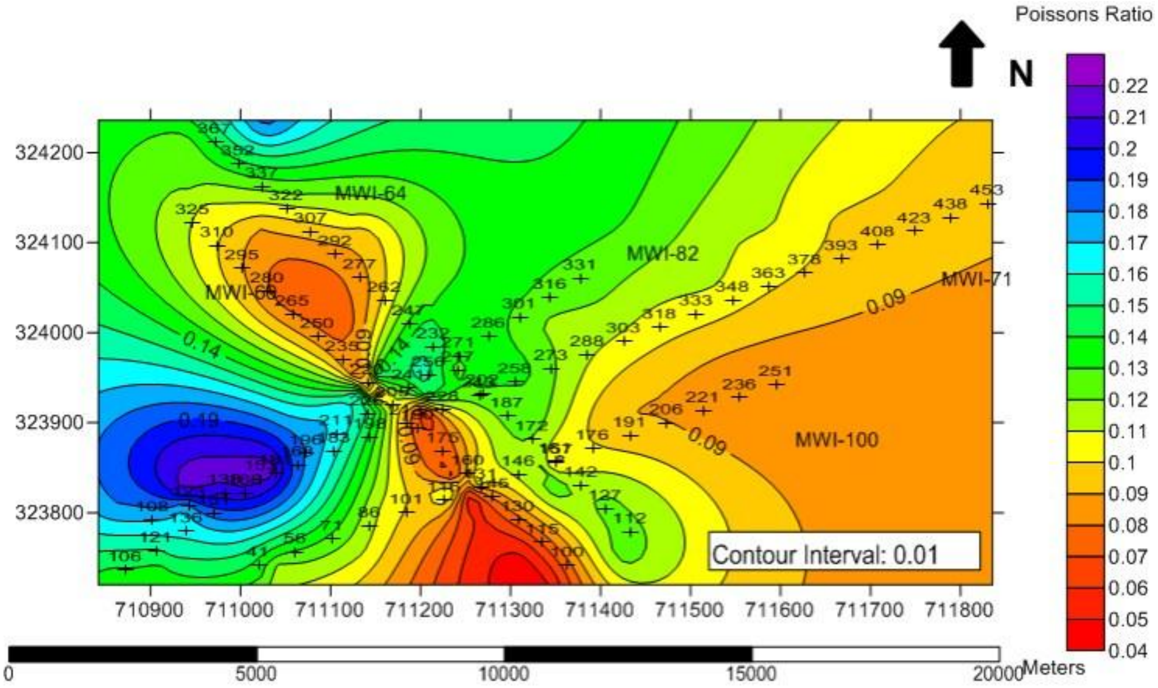

Figure 4.10 Poisson's ratio contours of Samana Suk Formation.

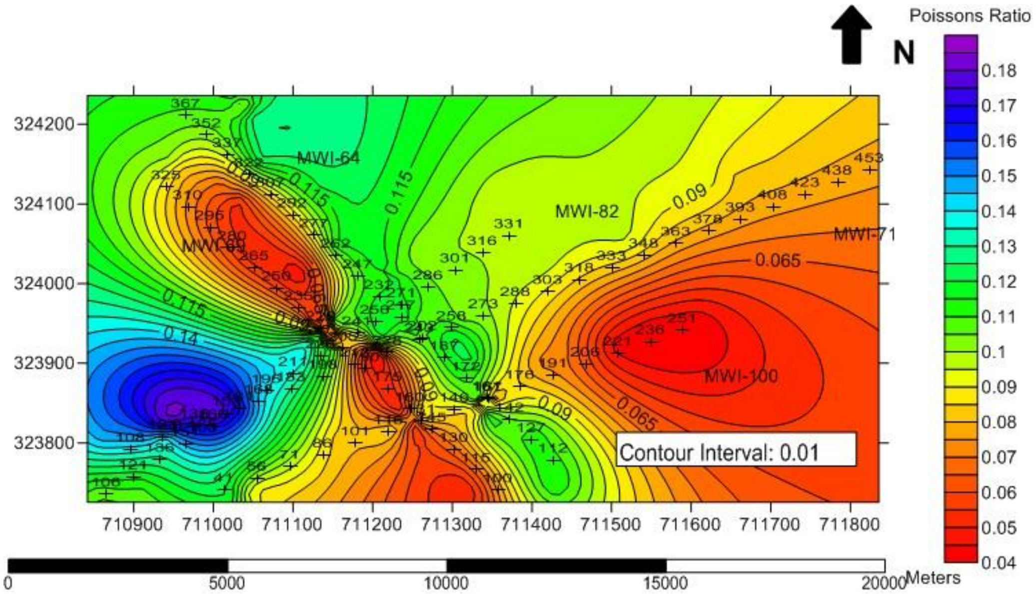

Figure 4.11 Poisson’s ratio contours of Datta Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Sandstone.

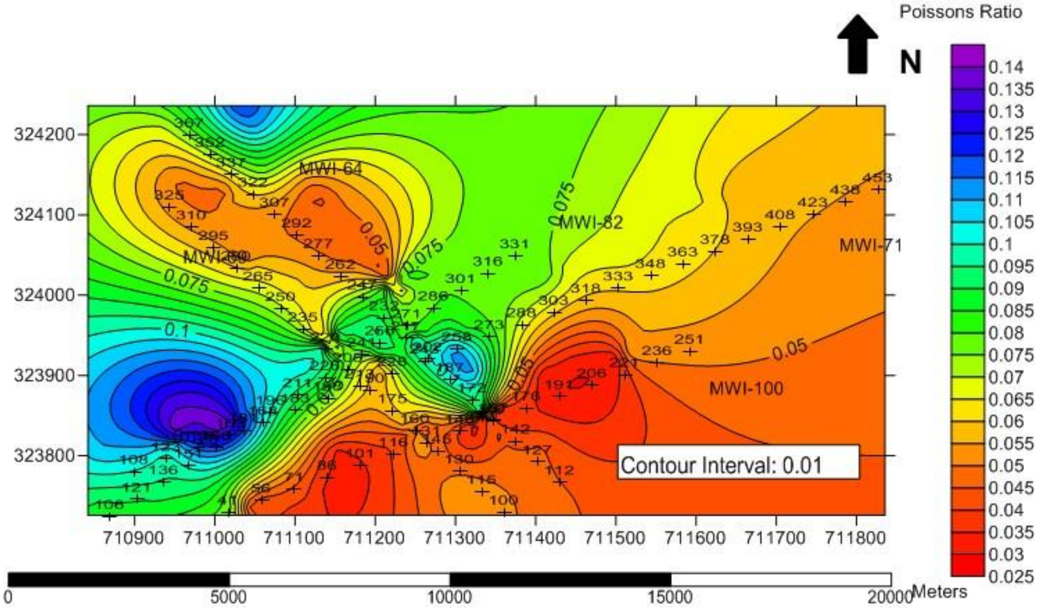

Figure 4.12 Poisson’s ratio contours of Wargal Limestone.

Values fall well within the specified range and thus the lithology is confirmed to Limestone.

LAME'S CONSTANT

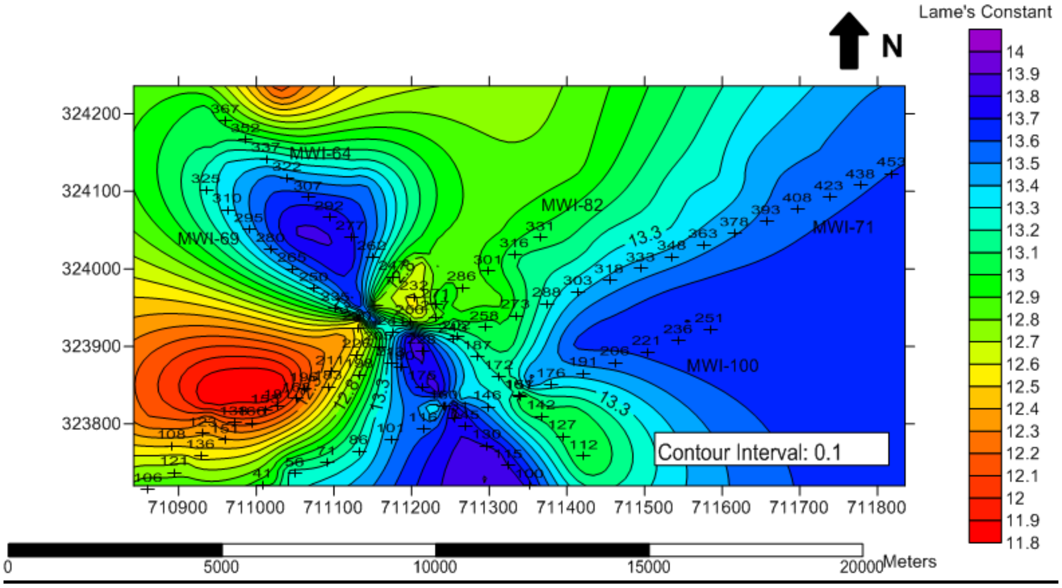

Figure 4.13 Lame's constant contours of Samana Suk Formation.

Values fall well within the specified range and thus the lithology is confirmed to Limestone.

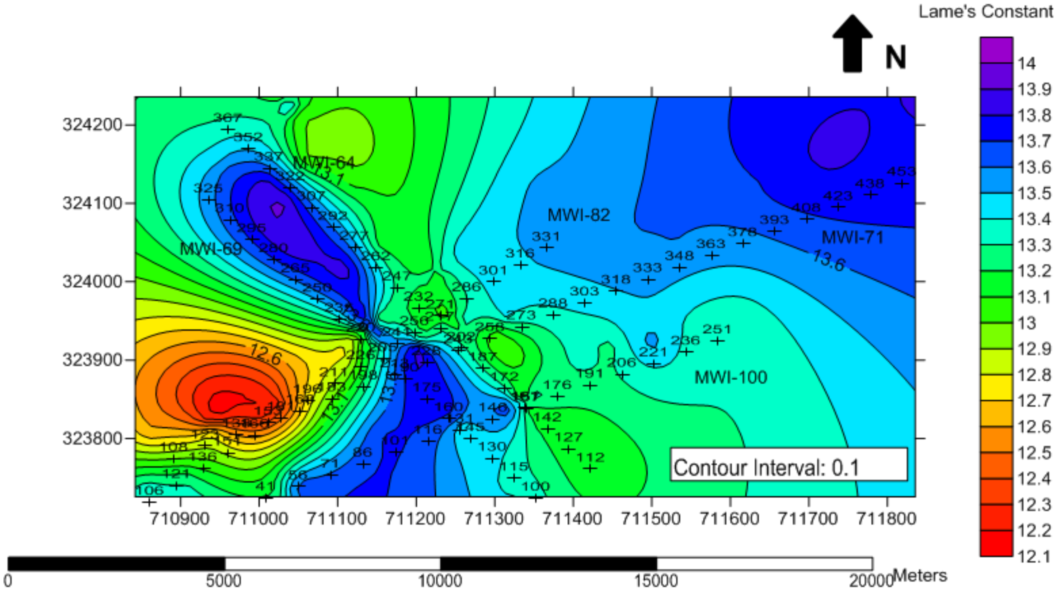

Figure 4.14 Lame's constant contours of Datta Formation.

Values fall well within the specified range and thus the lithology is confirmed to Sandstone.

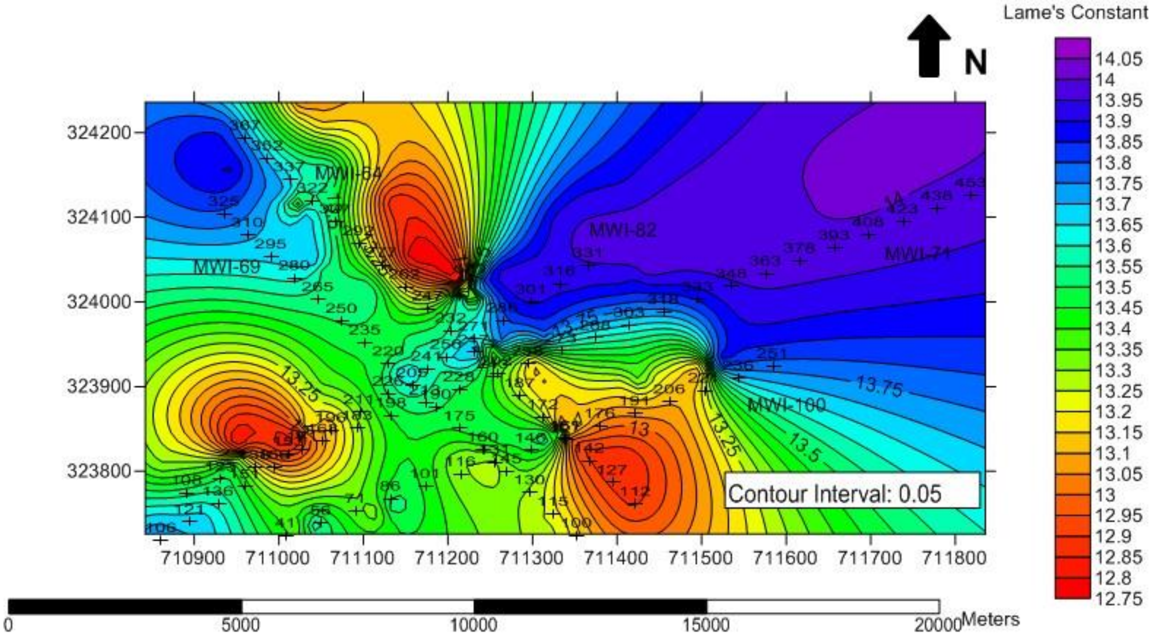

Figure 4.15 Lame’s constant contours of Wargal Limestone.

Values fall well within the specified range and thus the lithology is confirmed to Limestone.

YOUNGS MODULUS

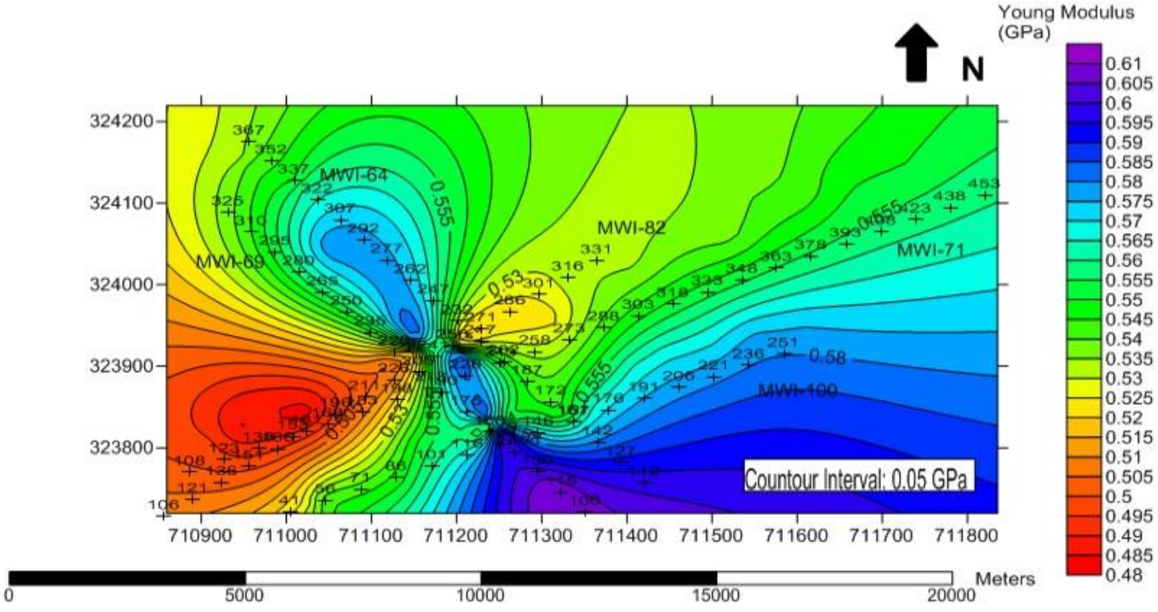

Figure 4.16 Young’s modulus contours of Samana Suk Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

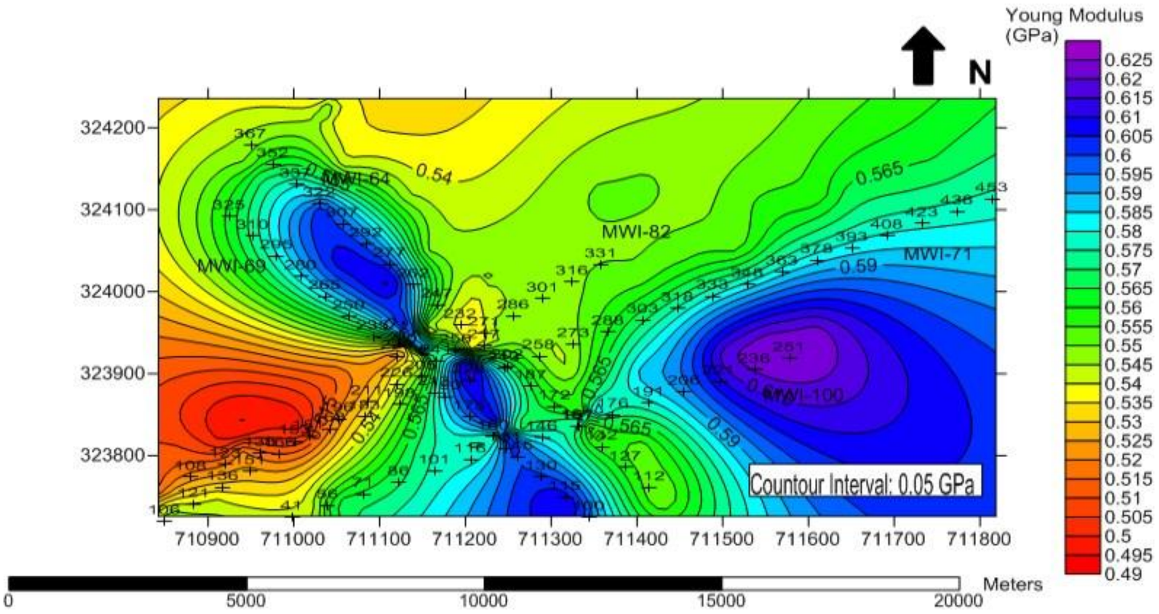

Figure 4.17 Young’s modulus contours of Datta Formation.

Values fall well within the specified range and thus the lithology is confirmed to be Sandstone.

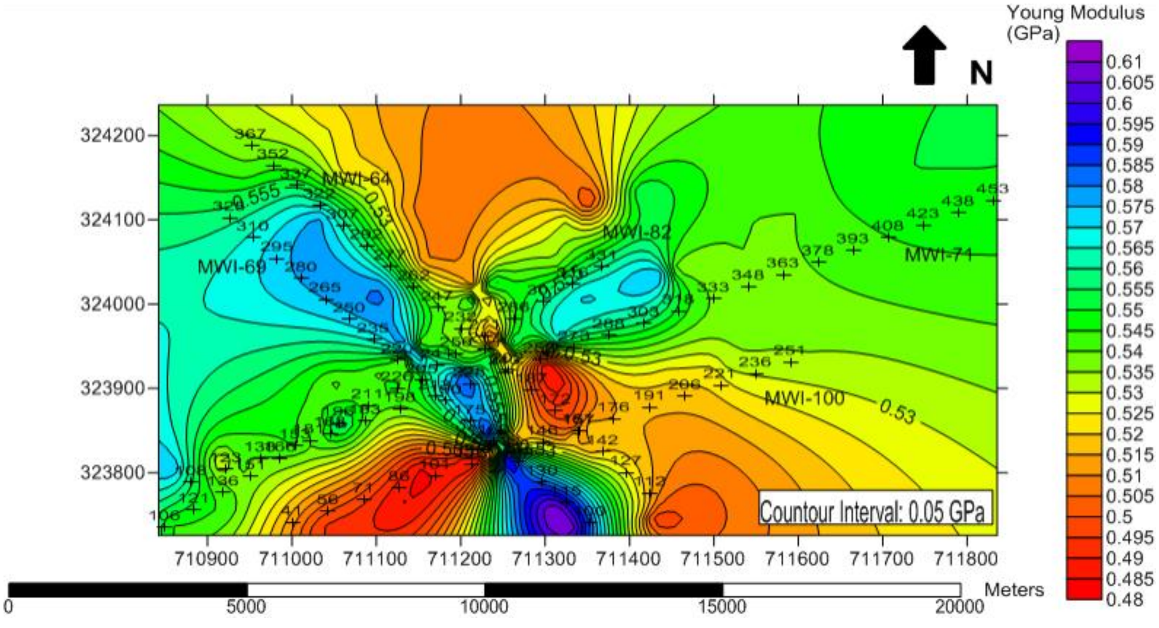

Figure 4.18 Young’s modulus contours of Wargal Limestone.

Values fall well within the specified range and thus the lithology is confirmed to be Limestone.

CONCLUSIONS

1) The study area lies in compressional regime with reverse faults trending from NE to SW having lesser throws.
2) The faults dipping towards north are Frontal thrust faults with southward dipping splays forming an anticlinal pop-up structure.
3) Time and depth sections also confirm low relief anticline structure formed by four way fault closure and the well is placed on the southern side of the structure.
4) Elastic moduli calculated through rock physics also provide ample support to the delineated structure, although the presence of fluid is not confirmed at any level of target horizon.
5) Although potential reservoir zone were marked, hydrocarbon potential cannot be known due to lack of availability of complete log data of Isa Khel – 01.

RECOMMENDATIONS

(a) If the full log data of well Isakhel-01 was provided then log interpretation and accurate reserve estimation could be done.

(b) If reprocessing had been applied on acquired seismic data than accuracy and resolution of seismic events and reflections would be high that ultimately results in convenient and more accurate seismic data interpretation.

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