2-D SEISMIC INTERPRETATION AND ROCK PHYSICS ANALYSIS OF DHERMUND AREA, UPPER INDUS BASIN, PAKISTAN

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ABSTRACT

The main purpose of the study is delineation of structure and hydrocarbon potential leads for future prospects. This is achieved by the analysis of migrated seismic lines. Seismic data interpretation includes identification and marking of the different lithological horizons after correlation with the well data. The same seismic data was also used to analyze the rock physical parameters and 2-D seismic modeling. Rock physical analysis is done on the basis of the computed value of poison ratio, bulk modulus, shear modulus, Vp Vs ratio and density along the seismic lines. These properties determine the rock characters in the subsurface.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

The Dhermund area is located about 119 km (74miles) to the southwest of Islamabad (Latitude: 32° 56' 41.28"to 32° 56' 41"N, Longitude: 72° 10' 11" to 72° 10' 10.56"E), Altitude is 1669 feet (508 m). The area is accessible via motorway (M2 section) from the Balkassar interchange and is approachable via Talagang-Chakwal Road, the study area is shown in figure 1.1.

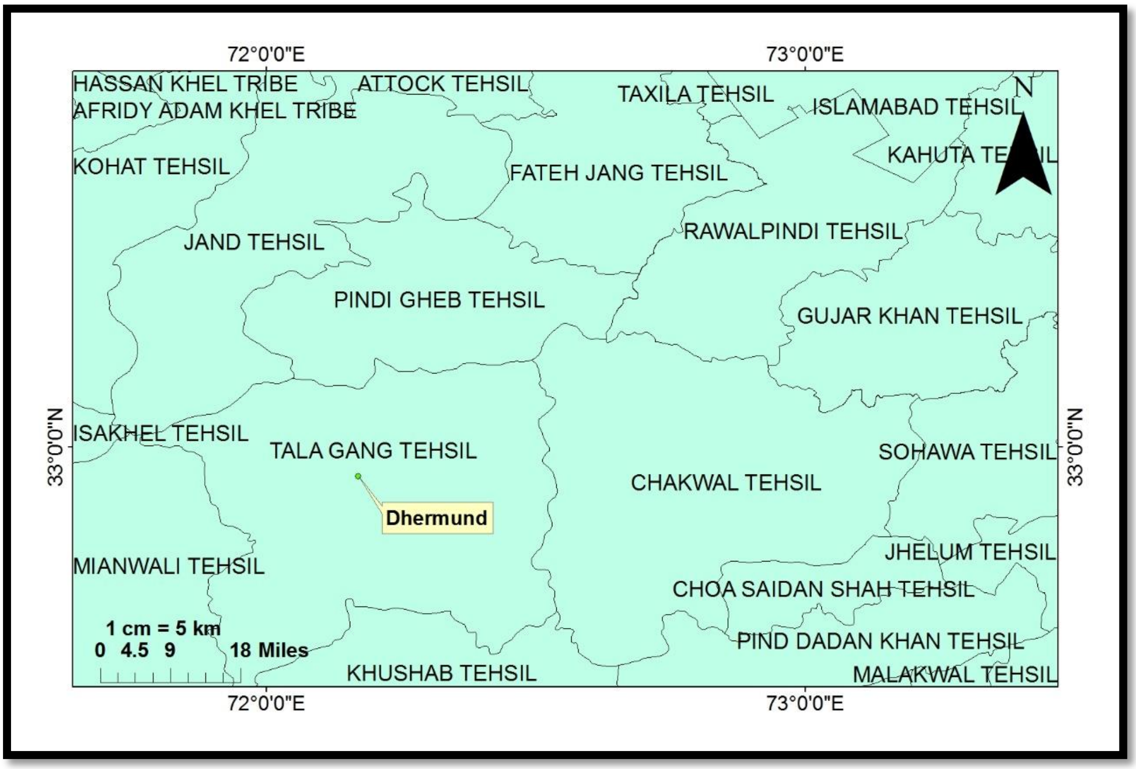


Figure 1.1. Map showing location of the area (ArcGis Map).

The Dhadambar-01 well lies in the Potwar sub-basin which is one of the oldest oil provinces of the world, where the first commercial discovery was made in 1914 at Khaur. So far, about 150 exploratory wells have been drilled of which most could not reach target depths due to operational problems related to extremely high-pressure water in mollasse deposits, thus were prematurely abandoned. This abnormal pressure is related to rapid deposition/burial of molasse deposits, which is further aggravated by structural complexities (Bender and Raza, 1995).

1.2 Objectives

The main objectives of this study are follows

(i) Seismic data interpretation.

(ii) To identifying and analyze prospective structure that may be present in the area on the time contour and depth contour map.

(iii) Analyzing rock physics and engineering properties to vertical and lateral variation in velocities strength of the subsurface material study the stratigraphic setting of the area and to observe hydrocarbon potential.

1.3 Base map

Base map helps to determine at what shot points the seismic section are to be tied and which of our seismic lines is the control lines; that which has a well. Seismic base map show the position and relationship of the seismic line as well as the shot points.

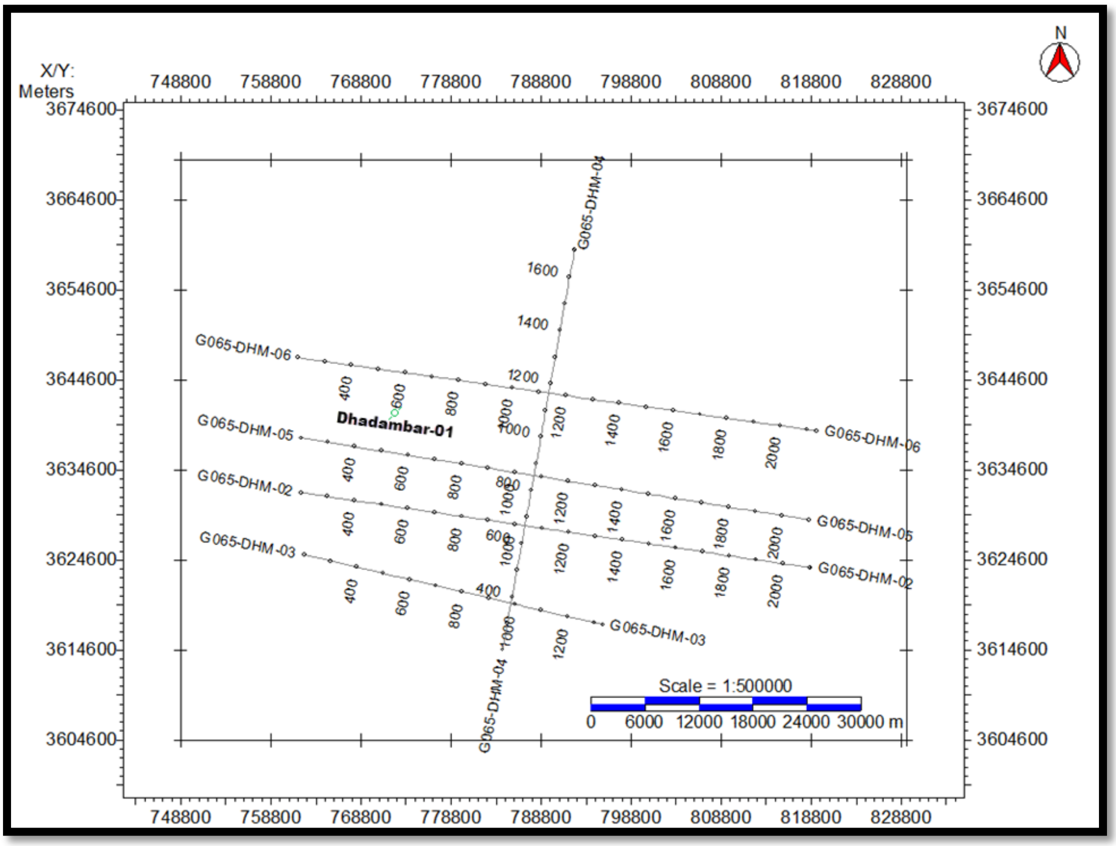


Figure 1.2. Base map of the study area.

1.4 Data used

Following seismic lines have been acquired from Land Mark Resources, Pakistan (LMKR) with the permission of Directorate General of Petroleum Concessions (DGPC).

(i) 065-DHM-02(Dip)
(ii) 065-DHM-03(Dip)
(iii) 065-DHM-04 (Strike)
(iv) 065-DHM-05(Dip)
(v) 065-DHM-06(Dip)

1.5 Methodology

In structure analysis study of reflector geometry on the basis of reflection time. In structure analysis the main objective is to search out traps containing hydrocarbons. The most common structural features associated with the oil, are anticline and faults. In Dhermund area compressional regime resulted in the formation of trust faults and anticlinal structures. Structural maps are constructed to display the geometry of selected reflection events.

Interpretation of Dhermund area involves following steps,

(i) Making of time versus depth chart.
(ii) Reflector identification.
(iii) Mark of prominent reflector.
(iv) Tracing the mark reflector on all available five seismic lines.
(v) Making depth contour maps.

CHAPTER 2

GEOLOGY AND STRATIGRAPHY OF THE AREA

2.1 General physiography

The Potwar sub-basin is located in the western foothills of Himalayas in northern Pakistan. It includes the Potwar Plateau, the Salt Range, and the Jhelum Plain. It is bounded in the north by main Boundary Thrust-MBT (recently the term MBT has been challenged (Iqbal and Bannert, 1998; Iqbal et al., 2007). The Potwar sub-basin is filled with thick Precambrian evaporates overlain by relatively thin platform deposits of Cambrian to Eocene age followed by thick Miocene Pliocene molasses. This whole section has been deformed by intensive Himalayan orogeny in Pliocene to Middle Pleistocene (Jaswal, 1990; Jadoon et al., 1997).

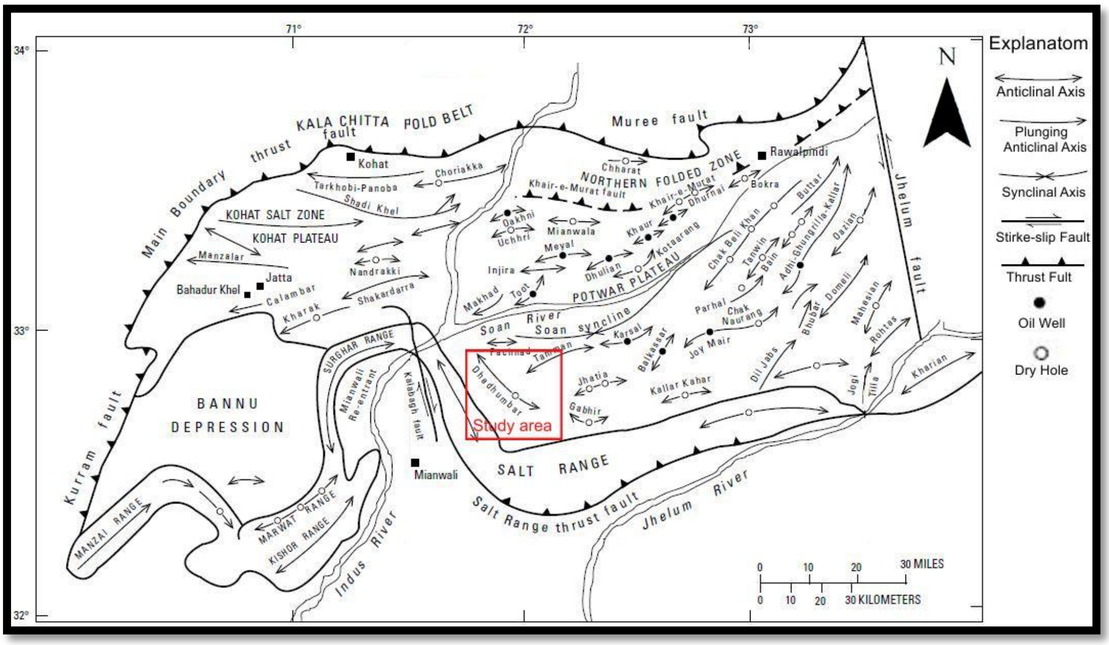


Figure 2.1. Structural map of the study area (Shami and Baig, 2002).

Surface geological features at some parts of the Potwar Plateau mismatch the subsurface geometry due to complexities involved at the upper and middle crustal levels and figure 2.1 showing geological map of the study area (McDougall and Hussain, 1991).

2.2 Geology of the Potwar sub basin

The Potwar Plateau and the Salt Range are part of the Himalayan foreland fold-and -thrust belt, a product of ongoing collision between Eurasian and Indo-Pakistani Plates. The Potwar Plateau is a large depression thrusted southward over the northwesterly dipping flank of the Sargodha high, along a basal decollement in the Eocambrian evaporate sequence of the Salt Range Formation. In the western and central Salt Range / Potwar Plateau, deformation primarily consists of southward verging thrusting along the main Salt Range thrust whilst in the eastern Salt Range / Potwar Plateau, thrusting and crustal shortening has given rise to intense folding and complex imbrication. (Jadoon et al., 1997).

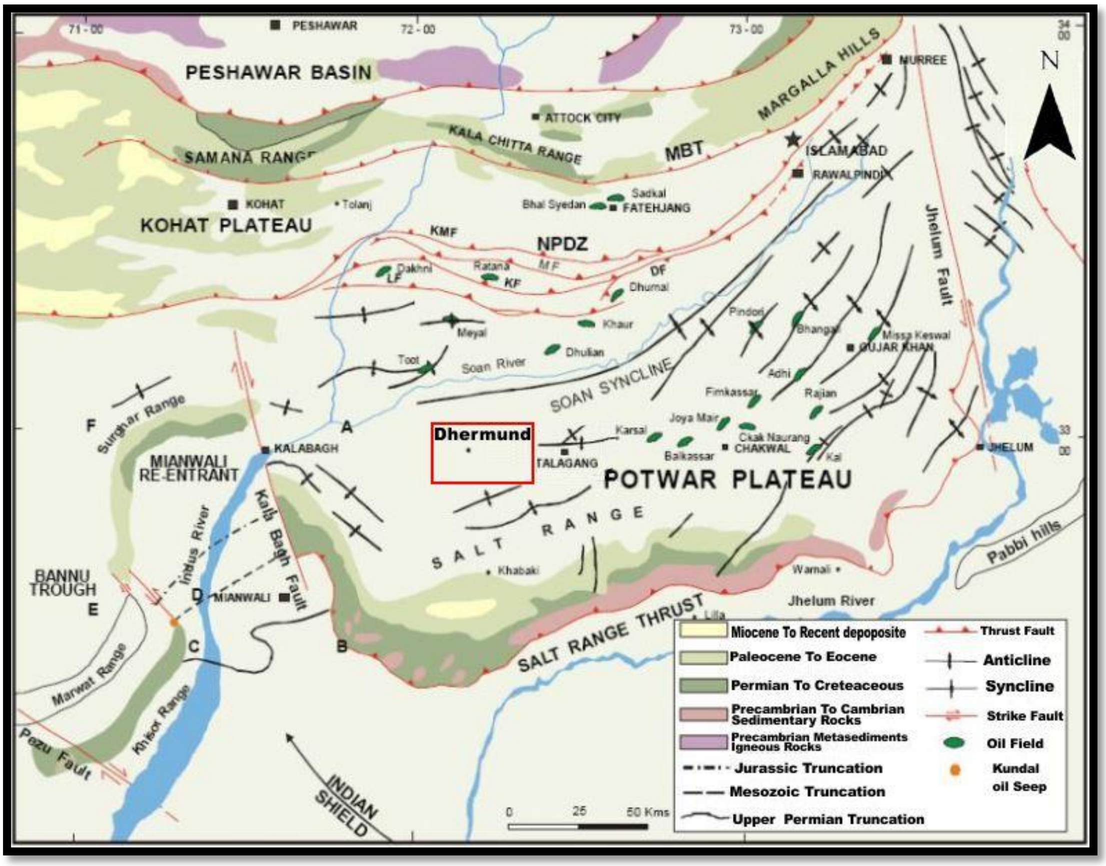


Figure 2.2. Geological map of the Potwar Plateau (Khan et al., 1986).

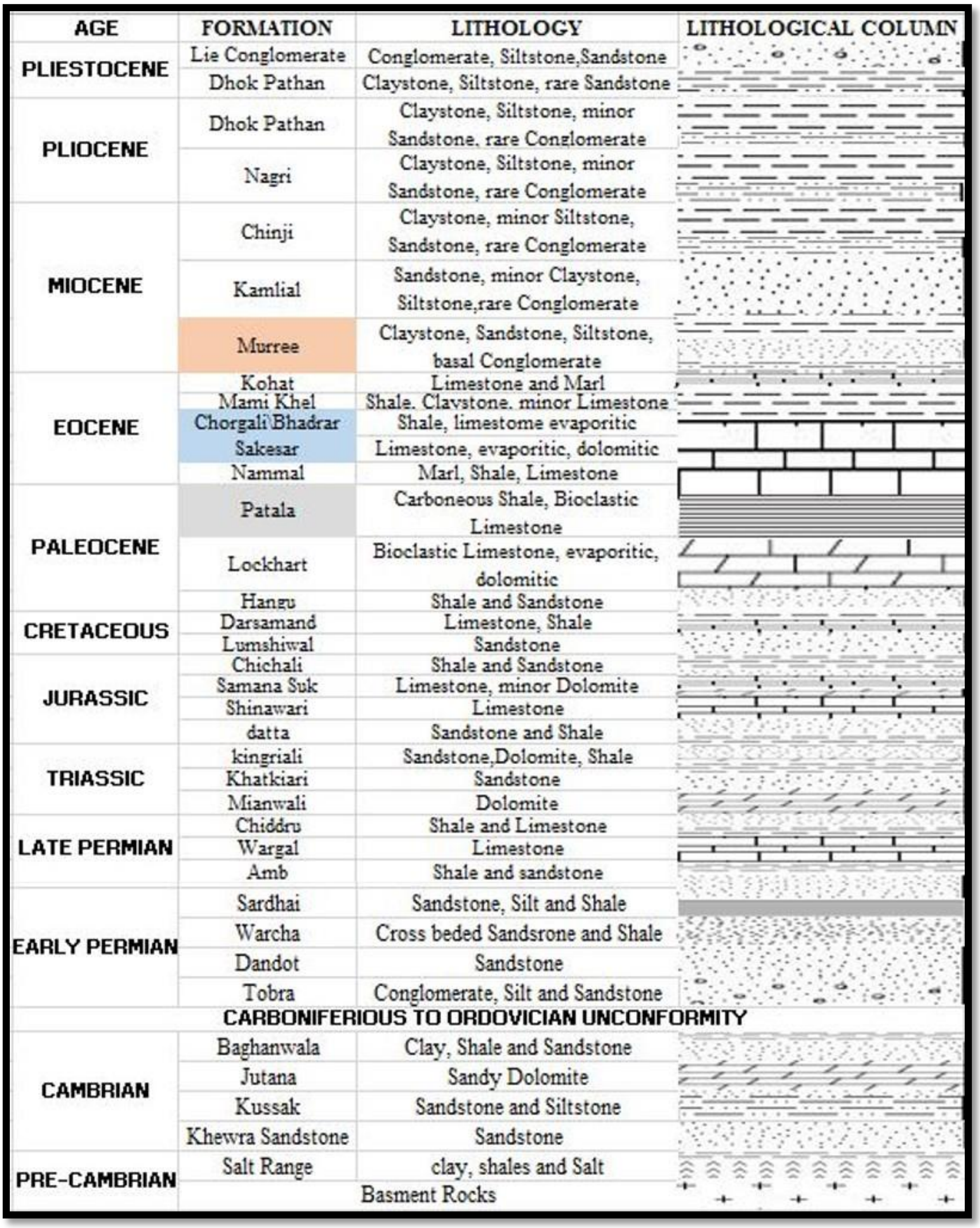
Anticlinal structures in the Potwar sub-basin have generally sub-latitudinal orientation and the structural complexity increases in the north due to proximity of collision zone as manifested by the existence of highly complex Northern Potwar Deformed Zone (NPDZ) with its southern boundary marked by Soan syncline. Generally, structures are progressively more tightly folded and more complexly faulted while going from south to north. The folds in this part of the area are isoclinal and imbricated / overturned with Tertiary sediments exposed in the crests of these structures. Cross sectional balancing studies by various authors show that thrust stacks of ramp anticlines have accommodated most of the shortening in the NPDZ. A triangle zone has also been formed by shallow decollement (within Neogene) in the foothill of Khairi Murat Ridge (Jadoon et al., 1997).

The structural style of the central, western and eastern parts of Potwar sub-basin suggests a marked difference. In the central and western parts of Potwar, the deformation appears to have occurred by south-verging thrusting, whereas in the eastern part the deformation is mainly in northeast-southwest with tight and occasionally overturned anticlines separated by broad synclines. This difference may be related to lesser thickness of salt in the Infracambrian in the eastern area and very low dip of the basement (1°-1.5°) as compared to central Potwar (2° to 3°). Major anticlinal and synclinal features are bounded by major thrusts and back thrusts trending almost E-W in the northern part, while in eastern part fault trend is almost NESW. The paleomagnetic studies have shown that originally the structural trends developed perpendicular to the transport direction and subsequently acquired the present alignment because of tectonic rotation as manifested by strike-slip nature of the left lateral Jhelum strike-slip fault (or Jhelum Basement Fault of Bannert and Raza 1992). In central Potwar, structures are mainly fault bounded mostly by thrusts and back thrusts, while at some places; asymmetric anticlines are bound by a single fault. Based on the seismic interpretation, the structures in Potwar area may be divided into: Pop-up anticlines,Triangle zones, Snake-head anticlines, Salt cored anticlines Excluding the above conventional structures the network of transects also depicts and confirms existence of sub-thrust closures situated in Kal/Rajian, structure beneath Toi Banda and in adjacent Nashpa and under Mandrakes fault in the Kohat area (Jadoon et al., 1997).

2.3 Stratigraphy of the Potwar area

The stratigraphy of the Potwar plateau is established from outcrops as well as from the well log sections (Kemal, 1991; Jaswal et al., 1997). In the subsurface, the Potwar Plateau preserves the sediments from Precambrian to Quaternary age, while surface expressions of these formations are exposed in the Salt Range. Detail account on each stratigraphic unit, its sedimentological record and regional distribution is beyond the scope of this study, therefore, a table summarizing brief details of each unit is given in table 2.1 (Kemal,1991; Jaswal et al., 1997; Kadri,1995).

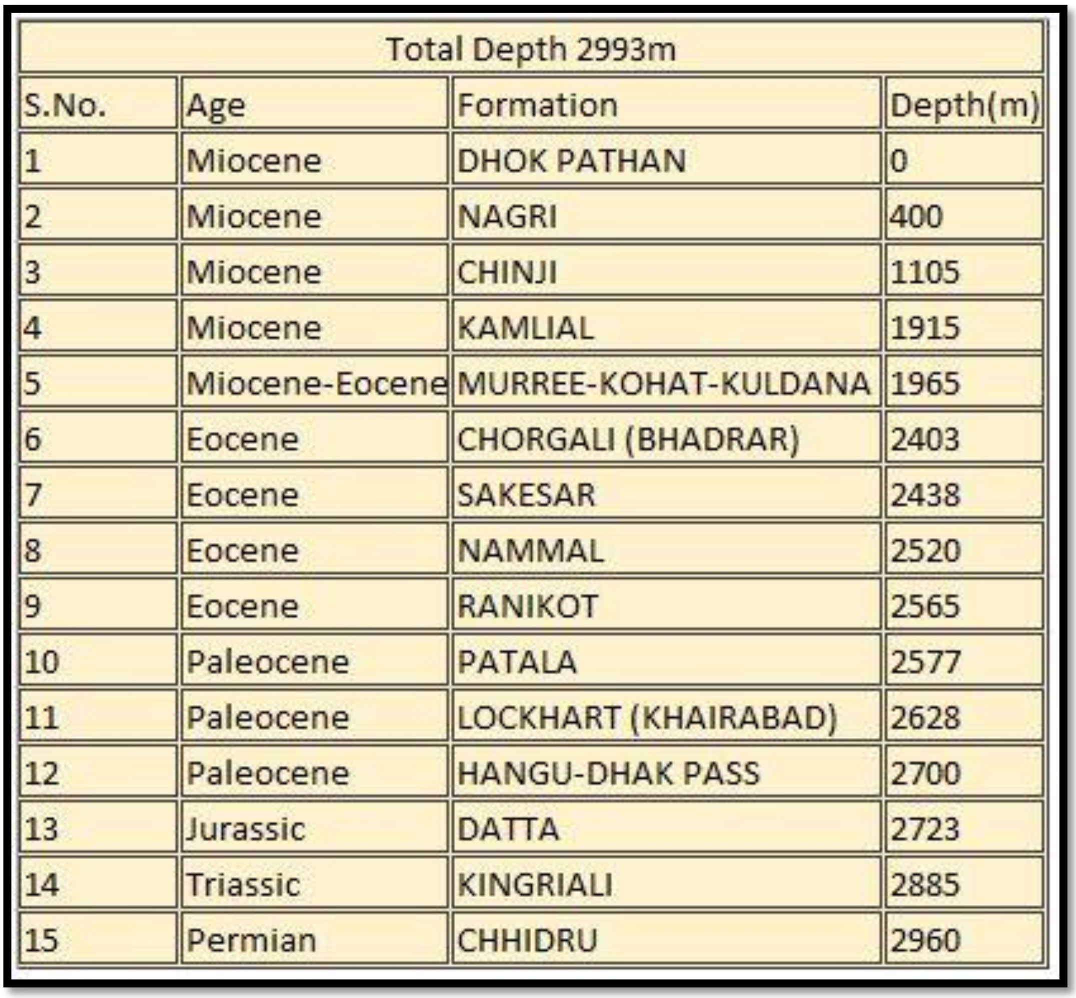
Table 2.1. Generalized stratigraphic column of the Potwar Plateau Upper Indus Basin (after Kemal, 1991).



AGE	FORMATION	LITHOLOGY	LITHOLOGICAL COLUMN
PLIESTOCENE	Lie Conglomerate	Conglomerate, Siltstone,Sandstone	
	Dhok Pathan	Claystone, Siltstone, rare Sandstone	
PLIOCENE	Dhok Pathan	Claystone, Siltstone, minor Sandstone, rare Conglomerate	
	Nagri	Claystone, Siltstone, minor Sandstone, rare Conglomerate	
MIOCENE	Chinji	Claystone, minor Siltstone, Sandstone, rare Conglomerate	
	Kamlial	Sandstone, minor Claystone, Siltstone,rare Conglomerate	
	Murree	Claystone, Sandstone, Siltstone, basal Conglomerate	
EOCENE	Kohat	Limestone and Marl	
	Mami Khel	Shale, Claystone, minor Limestone	
	Chorgali\Bhadrar	Shale, limestome evaporitic	
	Sakesar	Limestone, evaporitic, dolomitic	
	Nammal	Marl, Shale, Limestone	
PALEOCENE	Patala	Carboneous Shale, Bioclastic Limestone	
	Lockhart	Bioclastic Limestone, evaporitic, dolomitic	
	Hangu	Shale and Sandstone	
CRETACEOUS	Darsamand	Limestone, Shale	
	Lumshiwal	Sandstone	
JURASSIC	Chichali	Shale and Sandstone	
	Samana Suk	Limestone, minor Dolomite	
	Shinawari	Limestone	
	datta	Sandstone and Shale	
TRIASSIC	kingriali	Sandstone,Dolomite, Shale	
	Khatkiari	Sandstone	
	Mianwali	Dolomite	
LATE PERMIAN	Chiddru	Shale and Limestone	
	Wargal	Limestone	
	Amb	Shale and sandstone	
EARLY PERMIAN	Sardhai	Sandstone, Silt and Shale	
	Warcha	Cross beded Sandsrone and Shale	
	Dandot	Sandstone	
	Tobra	Conglomerate, Silt and Sandstone	
CARBONIFERIOUS TO ORDOVICIAN UNCONFORMITY			
CAMBRIAN	Baghanwala	Clay, Shale and Sandstone	
	Jutana	Sandy Dolomite	
	Kussak	Sandstone and Siltstone	
	Khewra Sandstone	Sandstone	
PRE-CAMBRIAN	Salt Range	clay, shales and Salt	
	Basment Rocks		

2.4 Borehole stratigraphy

Table 2.2. Borehole stratigraphy of Dhadambar-01.



Total Depth 2993m			
S.No.	Age	Formation	Depth(m)
1	Miocene	DHOK PATHAN	0
2	Miocene	NAGRI	400
3	Miocene	CHINJI	1105
4	Miocene	KAMLIAL	1915
5	Miocene-Eocene	MURREE-KOHAT-KULDANA	1965
6	Eocene	CHORGALI (BHADRAR)	2403
7	Eocene	SAKESAR	2438
8	Eocene	NAMMAL	2520
9	Eocene	RANIKOT	2565
10	Paleocene	PATALA	2577
11	Paleocene	LOCKHART (KHAIRABAD)	2628
12	Paleocene	HANGU-DHAK PASS	2700
13	Jurassic	DATTA	2723
14	Triassic	KINGRIALI	2885
15	Permian	CHHIDRU	2960

2.5 Petroleum prospect

In the 1970’s and 1980’s wells were drilled at Dhadambar-1, Dhermund-1, of which were dry holes. Dhadambar-1 well is placed in the potwar plateau, general geology of the area described in the start of the chapter. Dhadambar-1 is a dry well with total depth 2993 m. Chorgali Formation and Sakesar Limestone of Eocene age were primary targets of drilling, Patala Formation was source rock and Murree Formation act as seal (Bender and Raza, 1995).

2.5.1 Source rocks

Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources (BGR) Hanover, Germany have identified a number of source rock in this area. These investigations suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main contender for sourcing the Dhadumbar-01 and other Potwar oil fields (Bender and Raza, 1995). In potwar basin, Patala shale of Paleocene have proven as main source rocks. Organic shales were partly deposited in anoxic conditions prevailing Paleocene due to buckling of the basin floor. These shales are regarded as attaining maturity for oil generation during the Miocene. These shales have average values of TOC as 1.57 and Hydrogen Index as 2.68 (Porth and Raza, 1990). Also the oil to source correlation indicates that most of the oil produced in Potwar Sub-basin has been sourced through Patala Formation. Other potential sources in the area are organic rich shales of Eocambrian, Cambrian, Permian and Jurassic age (Kadri, 1995).

2.5.2 Reservoir rocks

The fractured carbonates of Sakesar and Chorgali Formations of Eocene epoch are the major producing reservoirs in Dhadumbar, Balkassar and Joya mair. Other reservoir rocks within the Potwar Basin includes the Khewra Sandstone (Cambrian), Tobra Formation (Permian), Amb Formation (Late Permian), Datta Formation (Jurassic), Lockhart Limestone (Paleocene), Patala Formation (Paleocene) and Murree Formation (Miocene). All these horizons have proved to be oil bearing in different fields within the Potwar Basin. The main producing reservoirs are the Cambrian sandstones and fractured Paleogene carbonates. (Bender and Raza, 1995).

2.5.3 Traps and seals

The clays and shales of the Murree Formation provides efficient vertical and lateral seal to Eocene reservoirs. Traps have been developed due to thin-skin tectonics, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt in the Potwar sub basin (Kadri, 1995).

2.5.4 Migration and generation

Generation of hydrocarbons most likely begin in Late Cretaceous time for Cambrian through Lower Cretaceous source rocks and again from Pliocene time to the present for younger source rocks. The Salt Range Potwar Foreland Basin (SRPFB) with an average geothermal gradient of 2 Cº/100 m is producing oil from the depth of 2750-5200 m (Shami and Baig, 2002). Migration is primarily over short distances up dip and vertically into adjacent reservoirs and through faults and fracture associated with plate collision and thrusting (OGDC, 1996).

CHAPTER 3
SEISMIC INTERPRETATION

3.1 Introduction

Seismic interpretation is analysis of the processed seismic data to predict the subsurface geology and structures. Seismic interpretation processes are divided into two categories, structural and stratigraphic interpretation. In this study structural seismic interpretation is carried out, which is directed toward the creation of different structural maps of the subsurface from the observed arrival times. Because Dhermund lies in sub basin Potwar (compression regime), which is intensely folded and thrusted area due to nearest location to Main Boundary Thrust and Salt Range Thrust, so here structures are well developed as compare to stratigraphy that’s why only structural seismic interpretation is done.

3.2 Control line

The well Dhadumber-01 lies out of the grid between dip line G065-DHM-06 and G065-DHM-05 but is nearer to the G065-DHM-06 so correlate on that line.

3.3 Choosing of horizon

On the basis of nearby fields data, two formations can act as reservoirs in this region which according to literature were before deformation deposits, and enough time has passed to deposited these formations that they are now sufficiently charged by the source rock (Patala Formation), based on the literature review and the data from the nearby producing fields, they are

(i) Chorgali Formation (Eocene)
(ii) Sakesar Limestone (Eocene)

3.4 Reflector marking

In the study area (Dermund, Potwar) from the well tops data two formations delineated which were acting as reservoir, that are Eocene Chorgali Formation and Sakesar Limestone. Initially solving the velocity windows (using petrophysica software) for each seismic line which gives average velocity for each millisecond and take mean of that average velocity at each millisecond; then "s=vt/2*1000" is applied to get the depths for each point. In formula "v" is mean average velocity, "t" is time and they are divided by "2" because one way time were required and "1000" from millisecond to second conversion. For the Formation depth you need to bring the kelly bushing and seismic reference datum on the same elevation because otherwise varying elevation will result into erroneous depth values. The elevation of kelly bushing is subtracted from the well tops values of specific Formation then this value is added to the value of seismic reference datum. Then time versus depth chart is made for control line from which possible accurate time is picked against the calculated depth. That picked time is then used for reflector or horizon marking. Because our study well is not lying on the grid, so we pick the horizon from its signature on the seismic section.

3.5 Time versus depth chart

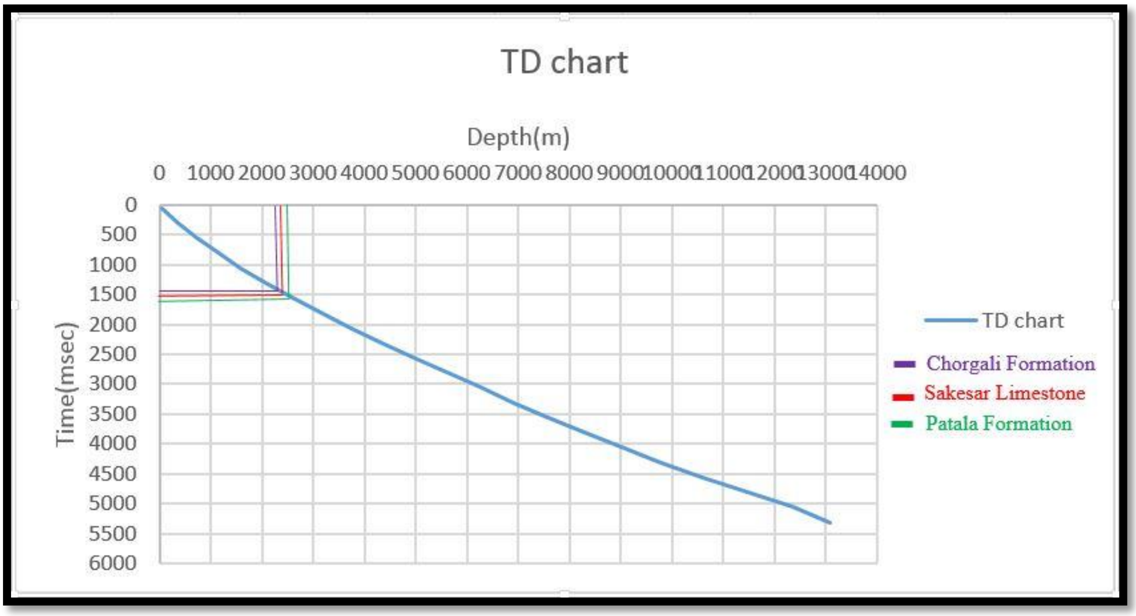


Figure 3.1. Time versus depth chart.

3.6 Tie points

After marking the selected horizons on the mentioned line, the other lines were tied by overlapping shot points of the lines and horizons were marked on them accordingly.

3.7 Seismic line

Seismic line is a collective representation of all the traces recorded on a single respective line. Each seismic line has its own header, having the basic information about the acquisition and the processing. The main objective here is picking and marking of the correct horizons and also marking the fault if there is any.

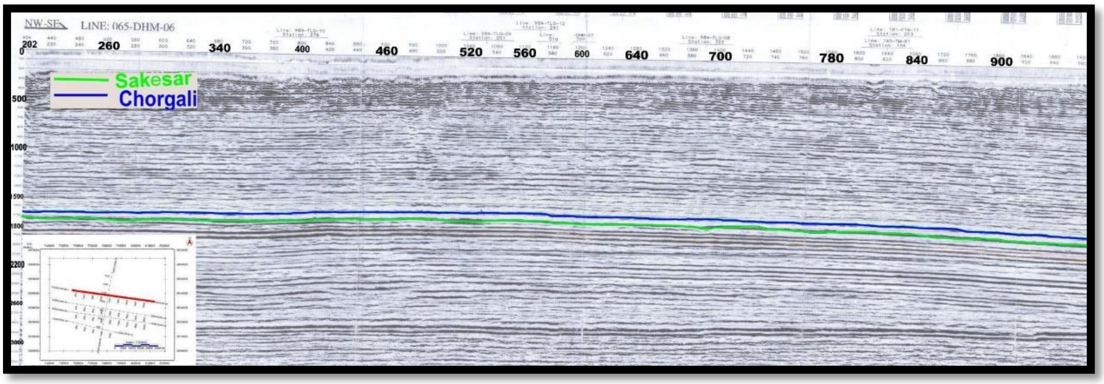


Figure 3.2. Seismic line 065-DHM-06.

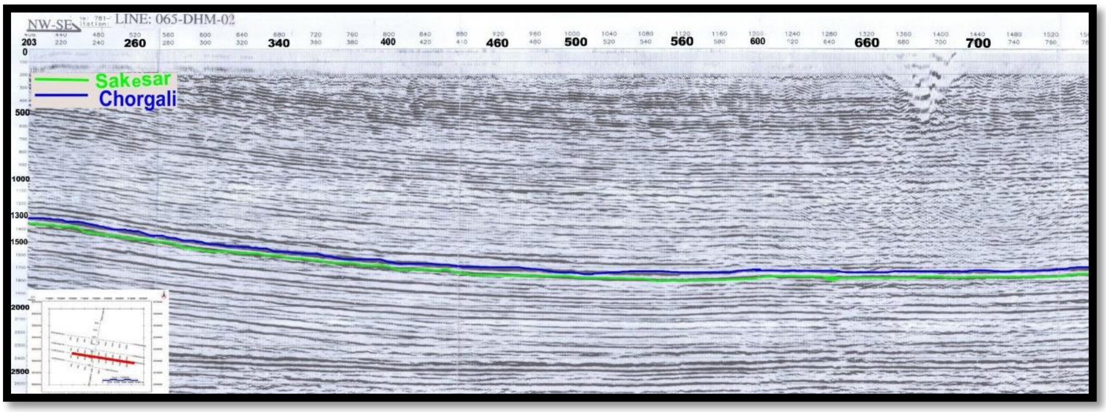


Figure 3.3. Seismic line 065-DHM-02.

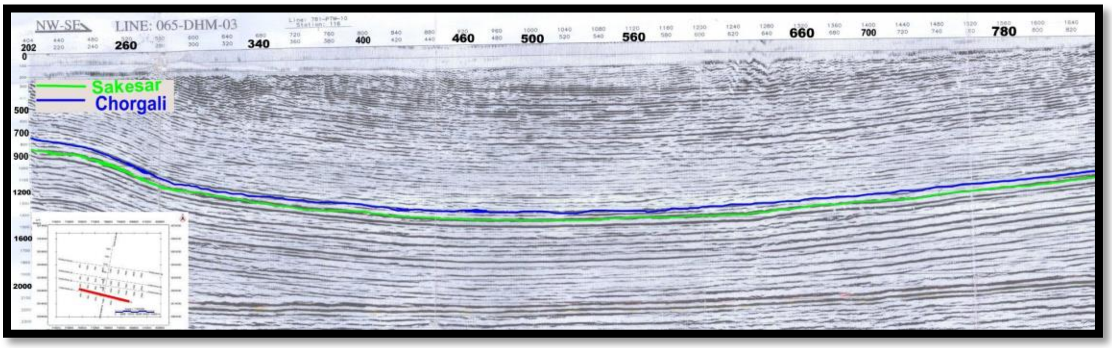


Figure 3.4. Seismic line 065-DHM-03.

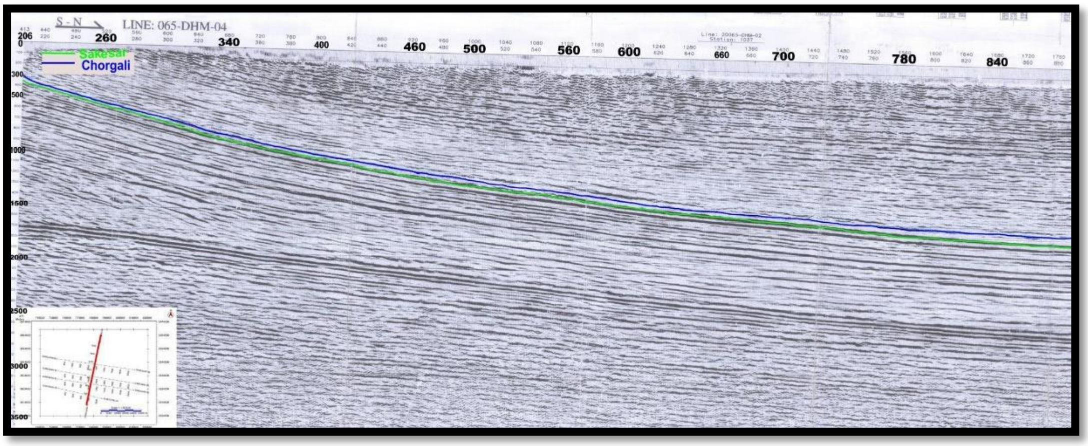


Figure 3.5. Seismic line 065-DHM-04.

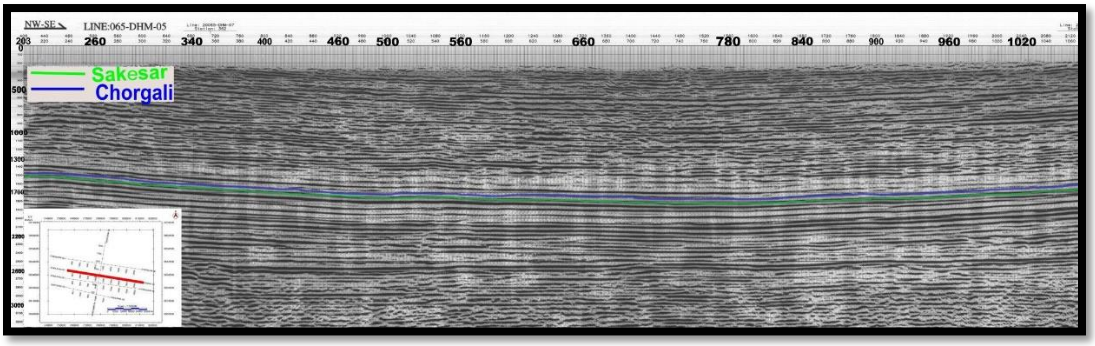


Figure 3.6. Seismic line 065-DHM-05.

These are the interpreted seismic lines where to two formations were mark. The blue color is showing Chorgali Formation and green color is showing Sakesar Limestone. On the base map well is lying out of the grid so well is correlated to the DHM-06 and carrying this seismic line as control line. On the interpreted seismic lines no major fault were observe whereas synclinal structure were observe on the seismic lines.

3.8 Time contour maps

To make a time contour map it is important to interpret more than one seismic lines. Along with seismic line 065-DHM-06 there are four other seismic lines (065-DHM-05, 065-DHM-04, 065-DHM-03, and 065-DHM-04) were utilized to make sure time contour maps.

The time contour maps are made by following procedure

(i) Respective time of the each selected horizons were taken at each shot point and arranging a excel file with latitude and longitude of every shot point with corresponding time of the horizon.

(ii) Make a grid of this excel file in Surfer software and generate contour maps.

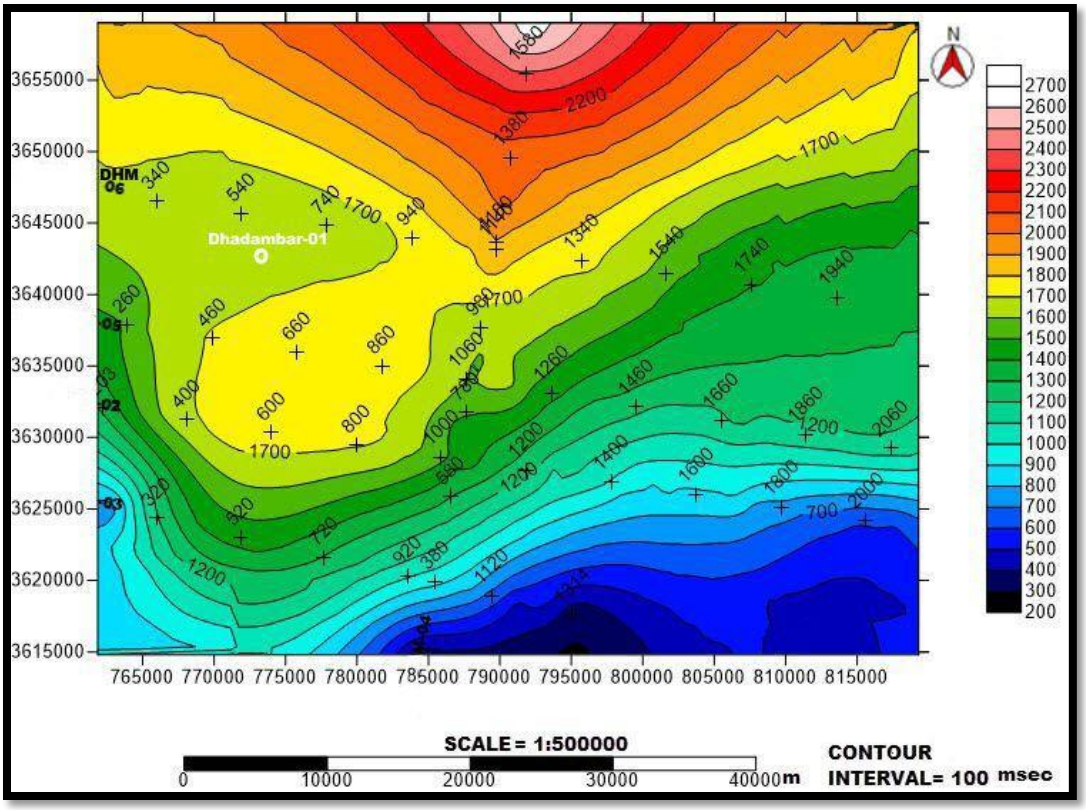


Figure 3.7. Time contour map of Chorgali Formation.

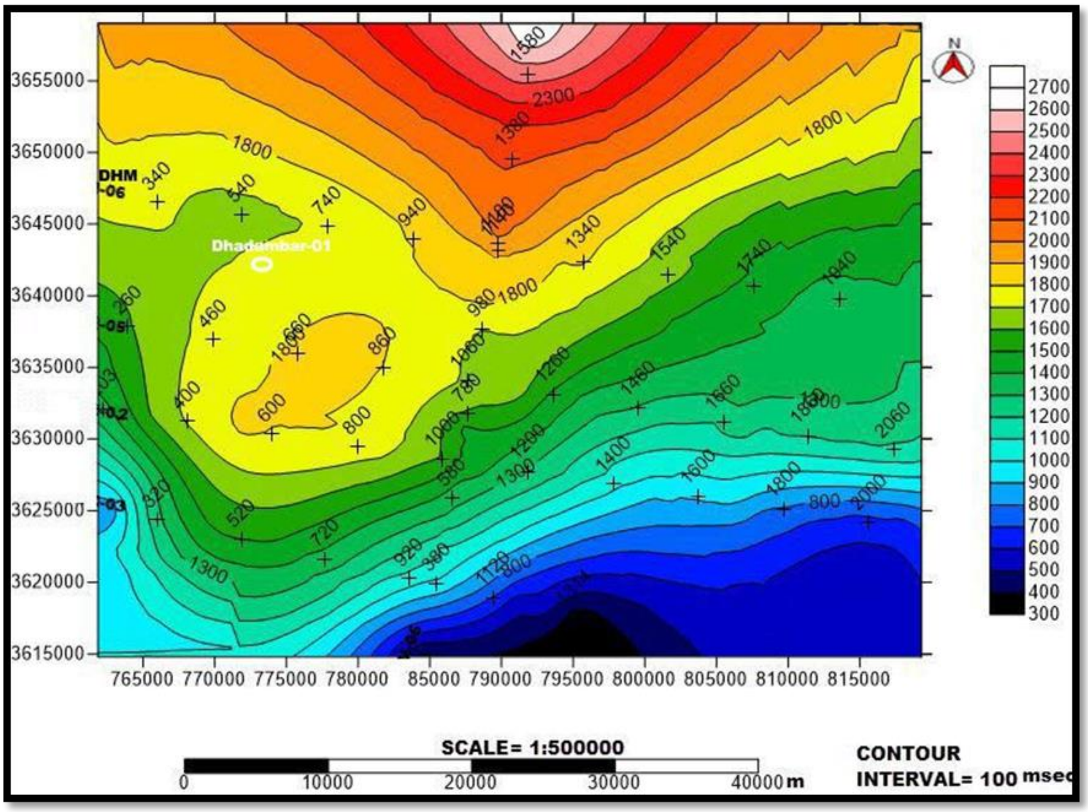


Figure 3.8. Time contour map of Sakesar Limestone.

Figure 3.7 and 3.8 are showing variations in the time of subsurface Chorgali Formation and Sakesar Limestone. The darkish-black color showing minimum time, while red to white color showing maximum time. While moving from south to north the time is increasing indicating the depth is increasing because more time is required for the signal to travel from the deeper side. At the south the contours are closer to each other showing steeper slope, while north ward at the central region the slope is relatively gentle. The same trend can be observed on the interpreted seismic lines as well. The nearest contour line to the well point is 1700 msec.

3.9 Velocity contour maps

The velocities used for the determination of the depth of each reflector are estimated with the help of average velocity contour map. The method of generating velocity contour map is same as that of time contour map but instead of time, velocity is used.

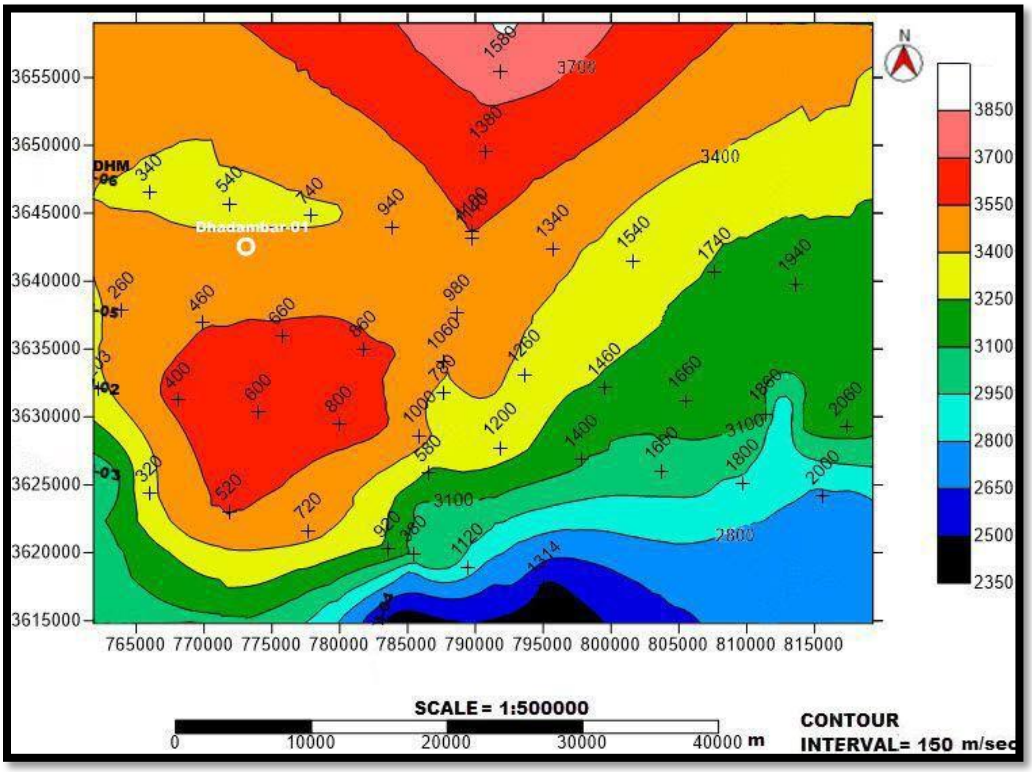


Figure 3.9. Velocity contour map of Chorgali Formation.

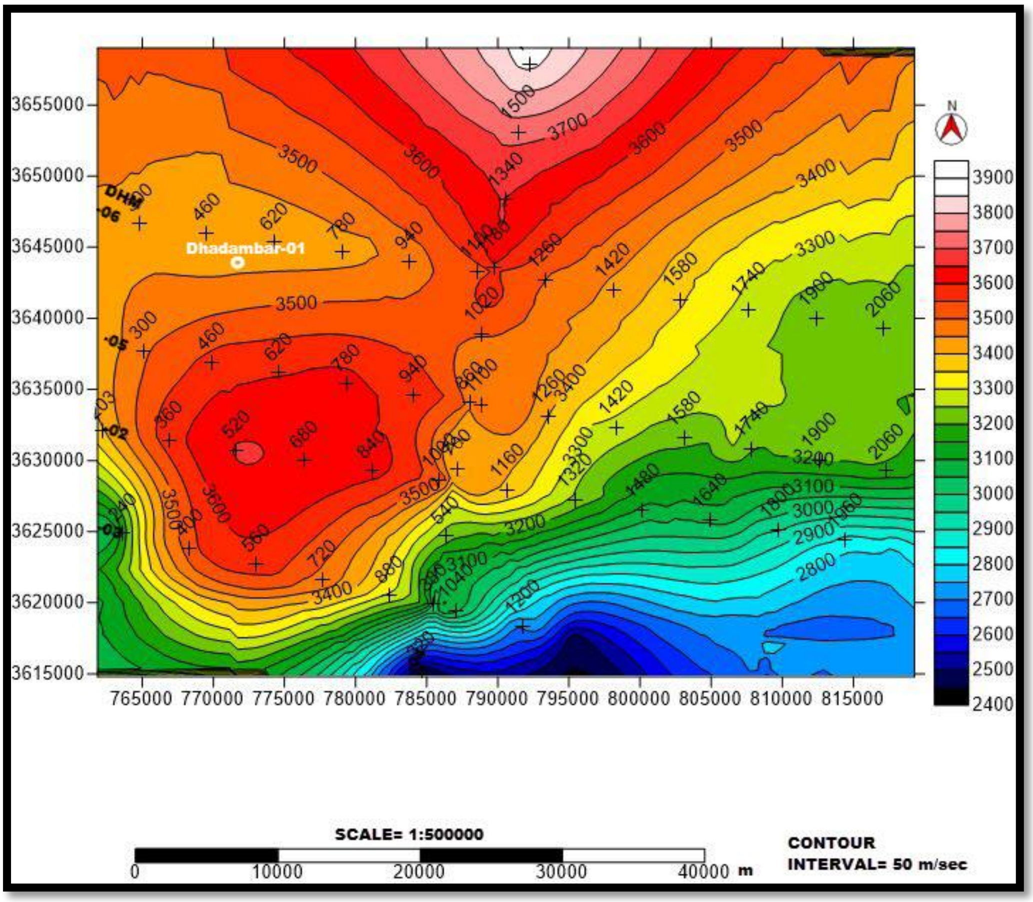


Figure 3.10. Velocity contour map of Sakesar Limestone.

Figure 3.9 and 3.10 shows the velocity contour maps of Chorgali Formation and Sakersar Limestone. From south to north velocity is increasing, while from east to west the color variations are showing normal behavior but at the end in western side velocity follow the reverse trend. In the figure 3.11 see depth is increasing north ward so the velocity is also increasing, but at northwest ward along the DHM-06 sudden decrease occurs in velocity it due to the depth, or it can be due to the presence of the fluids because in the presence of the fluids velocity decreases. The average velocity value for the Chorgali Formation is 3100 m/sec and that for the Sakesar Limestone is 1500 m/sec. In figure 3.9 the nearest contour line to the well point is 3400 m/sec while in figure 3.10 the nearest contour line to the well point is 3450 m/sec.

3.10 Depth contour maps

Depth contour maps are showing depth of the reflector on map. Generation of the map is same like time contour map, here depth is put instead of time.

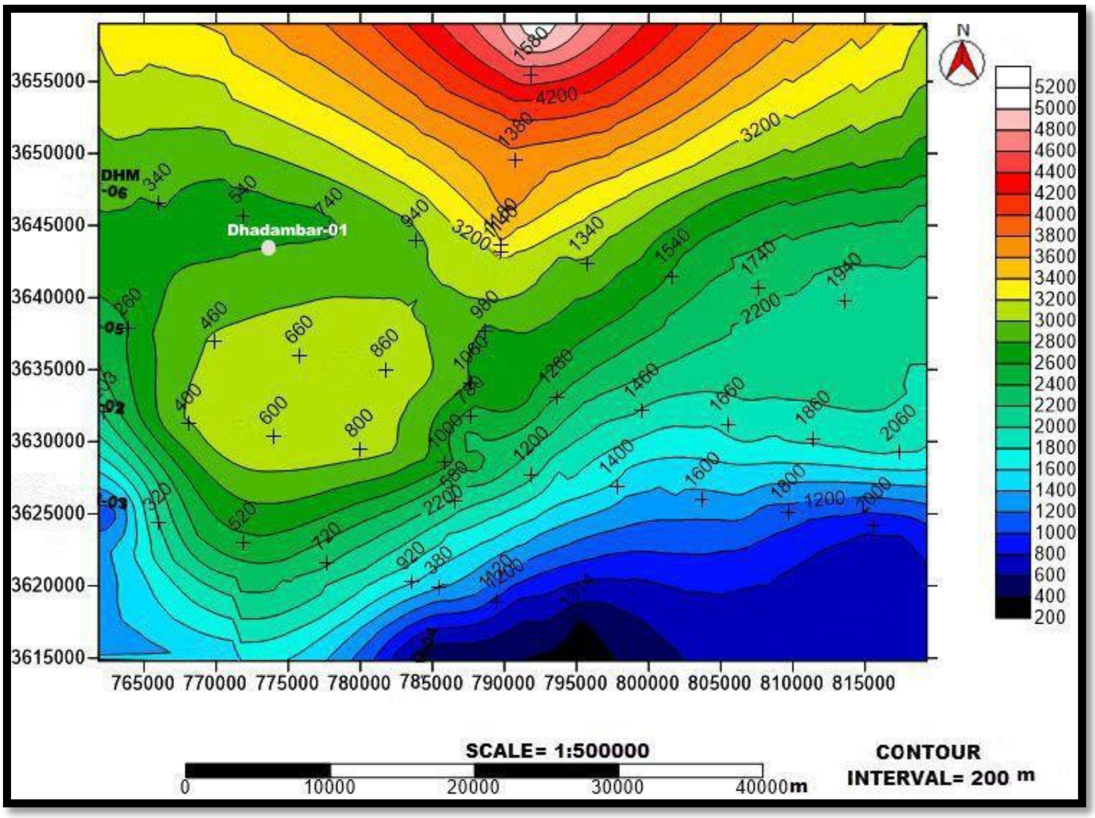


Figure 3.11. Depth contour map of Chorgali Formation.

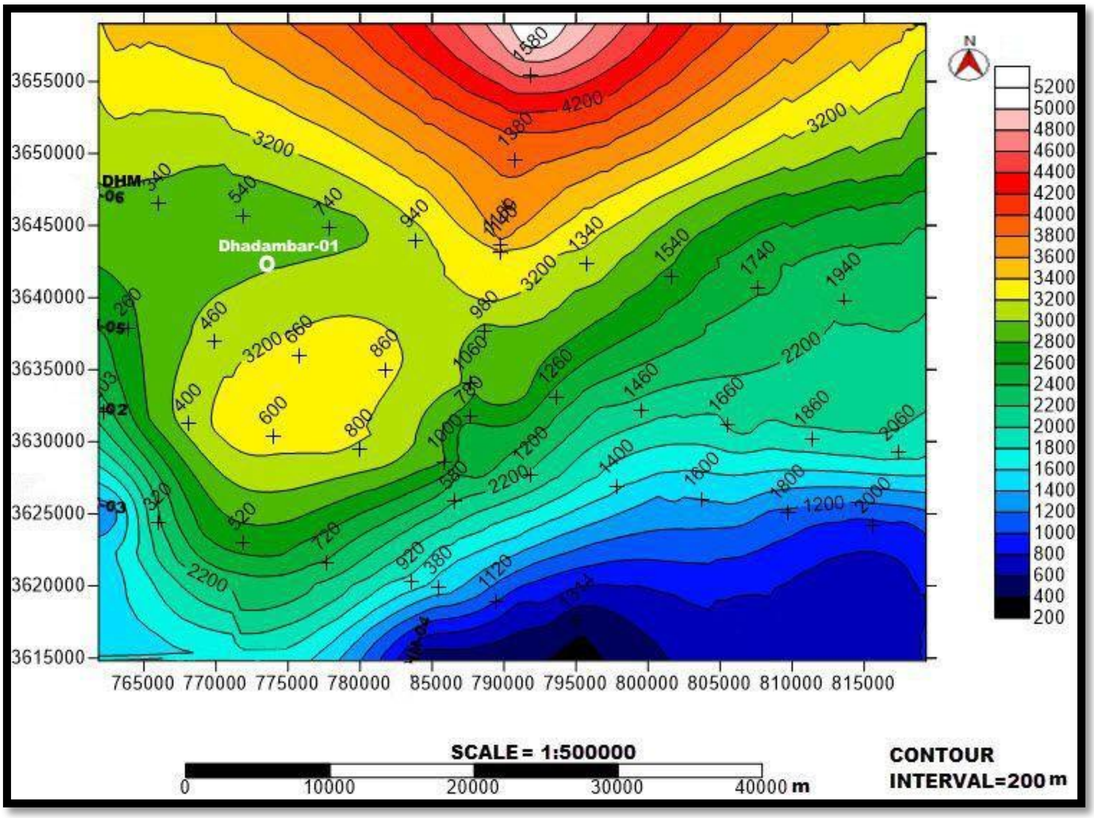


Figure 3.12. Depth contour map of Sakesar Limestone.

Figure 3.11 and 3.12 shows depth contour maps of Chorgali Formation and Sakesar Limestone. The color variations showing the change in the depth. From south to north depth is increasing indicating deepening, while moving from east to west the depth values is normally increasing and then along the extreme western side of contour map the values are decreasing showing relative shallowing. Also at south-southwest contours are close to each other which are showing and confirming abrupt deepening, while moving towards north at central region of the contour maps contours are wider indicating relatively gradual change in the depth, which are reflecting the glimpse of the time contour maps. Nearest contour line value to the structure is 3000 m.

CHAPTER 4
ROCK PHYSICS

4.1 Introduction

Rock physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility; properties that will affect how seismic waves physically travel through the rocks. The rock physicist seeks to establish relations between these material properties and the observed seismic response and to develop a predictive theory so that these properties may be detected seismically.

Establishing relationships between seismic expression and physical rock properties therefore requires

(i) Knowledge about the elastic properties of the pore fluid and rock frame.
(ii) Models for rock-fluid interactions. This is the domain of rock physics (Dewar et al., 2001).

Rock physics uses sonic logs, density logs and also dipole (shear velocity) logs if available. Rock physics aims to establish P-wave velocity (Vp), S-wave velocity (Vs), density and their relationships to elastic moduli κ (bulk modulus), μ (rigidity Modulus), porosity, pore fluid, temperature, pressure, etc. for given lithologies and fluid types. Rock physics talks about velocities and elastic parameters, because these are what link physical rock properties to seismic expressions. Rock physics may use information provided by the petrophysicist, such as shale volume, saturation levels, and porosity in establishing relations between rock properties or in performing fluid substitution analyses (Mavko et al., 2009).

Rock physics allows the interpreter to put “rock properties together with seismic horizons.” (Peters, 2001). Information about porosity, pore-fill, and lithology becomes available to augment the seismic interpretation (Dewar et al., 2001).

4.2 Elastic parameters

An elastic modulus, or modulus of elasticity is the mathematical description of an object or substances 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 region (Askeland and phule, 2006). In rock physics analysis following parameters were use:

(i) Vp
(ii) Vs
(iii) Density
(iv) Bulk modulus (K)
(v) Shear modulus (μ)
(vi) Young's modulus (E)
(vii) Lame's modulus (λ)
(viii) Poisson's modulus (σ)
(ix) Vp / Vs

4.3 Elastic moduli for homogeneous and isotropic materials

4.3.1 P-wave

P means Primary Waves as they are fast and arrive first. They are also called longitudinal or compressional waves, as particle motion is parallel to wave propagation. The ground is alternately compressed and dilated in the direction of propagation. These waves can travel through any type of material. In Solids twice as fast as S Waves.

$$\mathbf{Vp} = \mathbf{1.16} \times \mathbf{Vs} + \mathbf{1.36} \qquad \text{(Khan, 2009)}$$

4.3.2 S-wave

S means Secondary Waves as they arrive after the P Waves. They are also called transverse or shear waves, as particle motion is perpendicular to wave propagation. The ground is displaced perpendicularly to the direction of propagation. In the case of horizontally polarized S waves, the ground moves alternately to one side and then the other. They travel only through solids, as fluids (liquids and gases) do not support shear stresses. Their speed is about 60% of that of P waves.

$$\mathbf{Vs} = (\mathbf{Vp} - \mathbf{1.36})/\mathbf{1.16} \qquad \text{(Khan, 2009)}$$

4.3.3 Density

Density is defined as mass per unit volume. Seismic velocities depend upon density as density increases velocity will also increase and vice versa.

$$\text{p} = \mathbf{0.31} \times \mathbf{Vp^{0.25}}$$ (Dobrin and Savit, 1988)

Where

p = density.

4.3.4 Bulk modulus

The bulk modulus (K) of a substance measures the substance's resistance to uniform compression. It is the ratio of volume stress to volume strain. It is defined as the pressure increase needed to affect a given relative decrease in volume. It describes the material's response to uniform pressure. For a fluid, only the bulk modulus is meaningful (Khan, 2009).

$$\mathbf{K} = \text{p} \times (\mathbf{Vp^2} - \frac{\mathbf{4}}{\mathbf{3}}\mathbf{Vs^2})$$ (Mavko et al, 2009)

Where

K = bulk modulus
p = Density
Vp = P-Wave Velocity

4.3.5 Shear modulus

Shear modulus or modulus of rigidity (μ), is defined as the ratio of shear stress to the shear strain (angle of deformation). It is concerned with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force (such as friction). It describes the material's response to shearing strains (Khan, 2009).

$$\mu = \text{p} \times \mathbf{Vs^2}$$ (Mavko et al, 2009)

Where

μ =Shear modulus
ρ =Density
Vs=S wave Velocity

4.3.6 Young’s modulus

Young's modulus or modulus of elasticity (E) is a measure of the stiffness of an isotropic elastic material. It is the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds. It describes the material's response to linear strain (Khan, 2009).

$$\mathbf{E = \frac{9K\mu}{3K + \mu}} \qquad \text{(Mavko et al, 2009)}$$

Where

E= Young's modulus
k= bulk modulus
μ= Shear modulus

4.3.7 Lame’s constant

The Lame’s Constant (λ) has no physical interpretation, but it serves to simplify the stiffness matrix in Hooke's law. It is also called Lame’s First Parameter (Khan., 2009).

$$\boldsymbol{\lambda = K - \frac{2\mu}{3}} \qquad \text{(Mavko et al, 2009)}$$

Where

K= bulk modulus
μ= Shear modulus

4.3.8 Poisson’s ratio

Poisson's ratio (**σ**) is the ratio of transverse strain (normal to the applied load) to longitudinal strain (in the direction of the applied load). When a sample of material is stretched in one direction, it tends to contract (or rarely, expand) in the other two directions. Conversely, when a sample of material is compressed in one direction, it tends to expand (or rarely, contract) in the other two directions. Poisson's ratio is a measure of this tendency (Khan, 2009).

$$\boldsymbol{\sigma = 0.5 \times \frac{Vp^2 - 2Vs^2}{Vp^2 - Vs^2}}$$ (Mavko et al, 2009)

Where

σ = Poisson's ratio
Vs = S wave Velocity
Vp = P-Wave Velocity

4.3.9 P-Wave modulus

P-wave modulus (M) or longitudinal modulus is the ratio of axial stress to axial strain in a uniaxial strain state (Khan, 2009).

$$\mathbf{M = K + \frac{4\mu}{3}}$$ (Mavko et al, 2009)

Where

M= P-wave modulus
K= bulk modulus
μ= Shear modulus

4.3.10 Vp Vs ratio

Vp Vs ratio is sensitive to the presence of the hydrocarbons. Vp Vs ratio decreases in case of the hydrocarbons. Any decrease in these values will directly predict the presence of less dense fluids (hydrocarbons or brine water). It is denoted by gamma and it is dimension less quantity.

$$\frac{\mathbf{Vp}}{\mathbf{Vs}} = \sqrt{\frac{\mathbf{K}}{\mu} + \frac{\mathbf{4}}{\mathbf{3}}}$$ (Mavko et al, 2009)

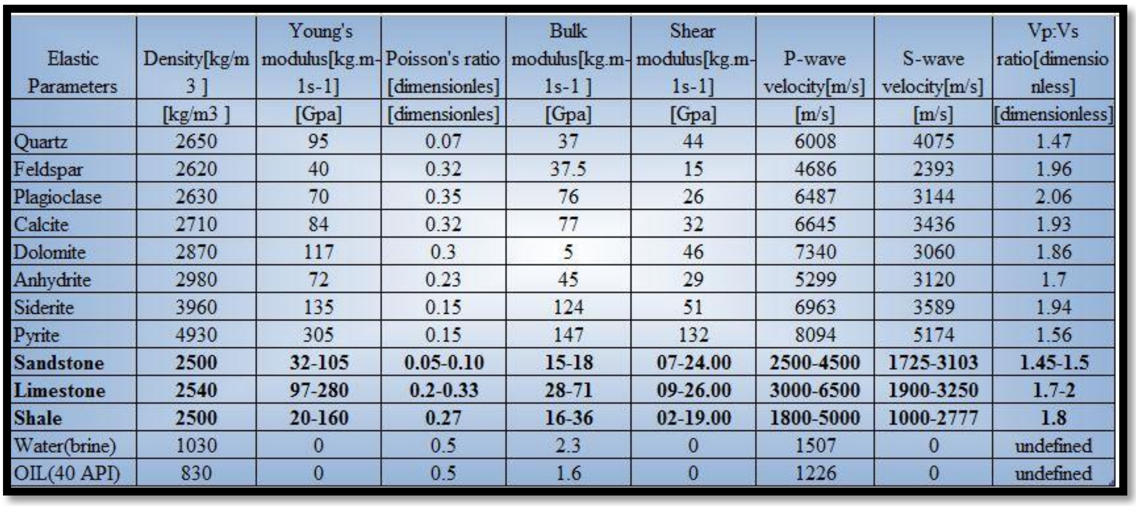
Where

K= bulk modulus
μ= Shear modulus

4.4 Rock physics parameters contours

Contours of each parameter for each reflector are made which show how these parameters change along the reflectors.

Table 4.1. Ranges of rock physics parameters (modified from agilegeoscience).



Elastic Parameters	Density[kg/m 3]	Young's modulus[kg.m-1s-1]	Poisson's ratio [dimensionles]	Bulk modulus[kg.m-1s-1]	Shear modulus[kg.m-1s-1]	P-wave velocity[m/s]	S-wave velocity[m/s]	Vp:Vs ratio[dimensionless]
	[kg/m3]	[Gpa]	[dimensionles]	[Gpa]	[Gpa]	[m/s]	[m/s]	[dimensionless]
Quartz	2650	95	0.07	37	44	6008	4075	1.47
Feldspar	2620	40	0.32	37.5	15	4686	2393	1.96
Plagioclase	2630	70	0.35	76	26	6487	3144	2.06
Calcite	2710	84	0.32	77	32	6645	3436	1.93
Dolomite	2870	117	0.3	5	46	7340	3060	1.86
Anhydrite	2980	72	0.23	45	29	5299	3120	1.7
Siderite	3960	135	0.15	124	51	6963	3589	1.94
Pyrite	4930	305	0.15	147	132	8094	5174	1.56
Sandstone	**2500**	**32-105**	**0.05-0.10**	**15-18**	**07-24.00**	**2500-4500**	**1725-3103**	**1.45-1.5**
Limestone	**2540**	**97-280**	**0.2-0.33**	**28-71**	**09-26.00**	**3000-6500**	**1900-3250**	**1.7-2**
Shale	**2500**	**20-160**	**0.27**	**16-36**	**02-19.00**	**1800-5000**	**1000-2777**	**1.8**
Water(brine)	1030	0	0.5	2.3	0	1507	0	undefined
OIL(40 API)	830	0	0.5	1.6	0	1226	0	undefined

4.4.1 Vp

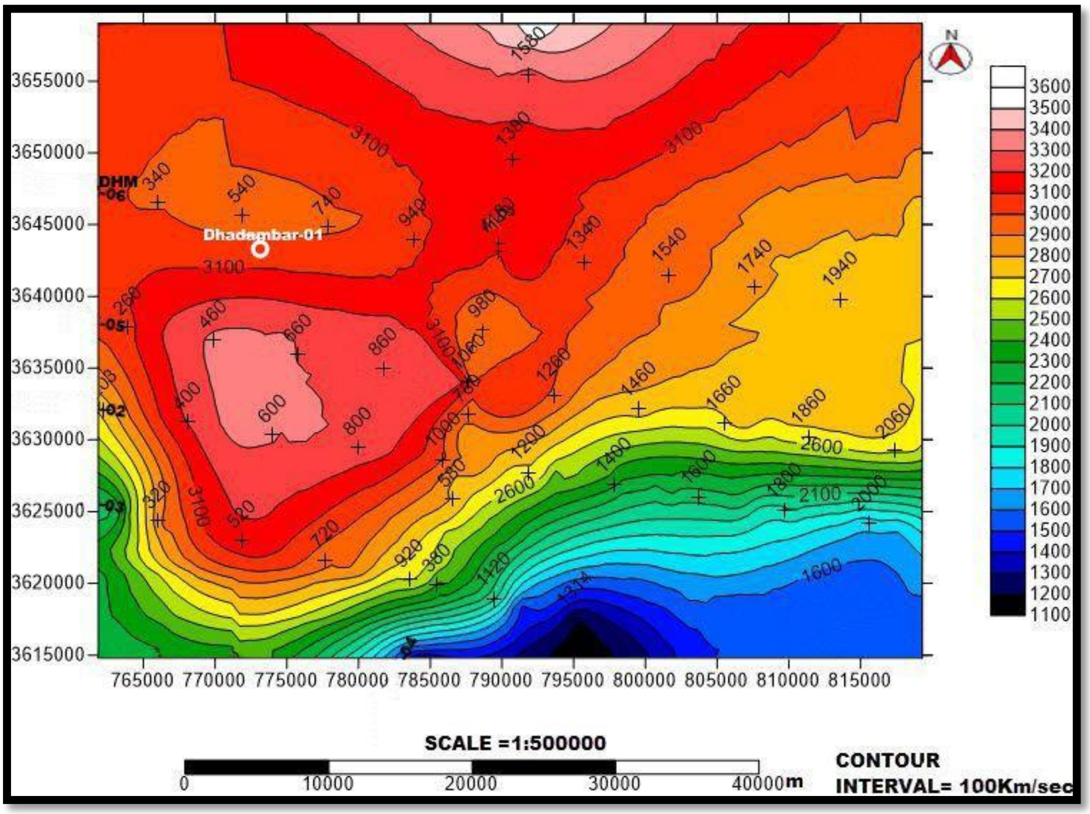


Figure 4.1. Vp contours of Chorgali Formation.

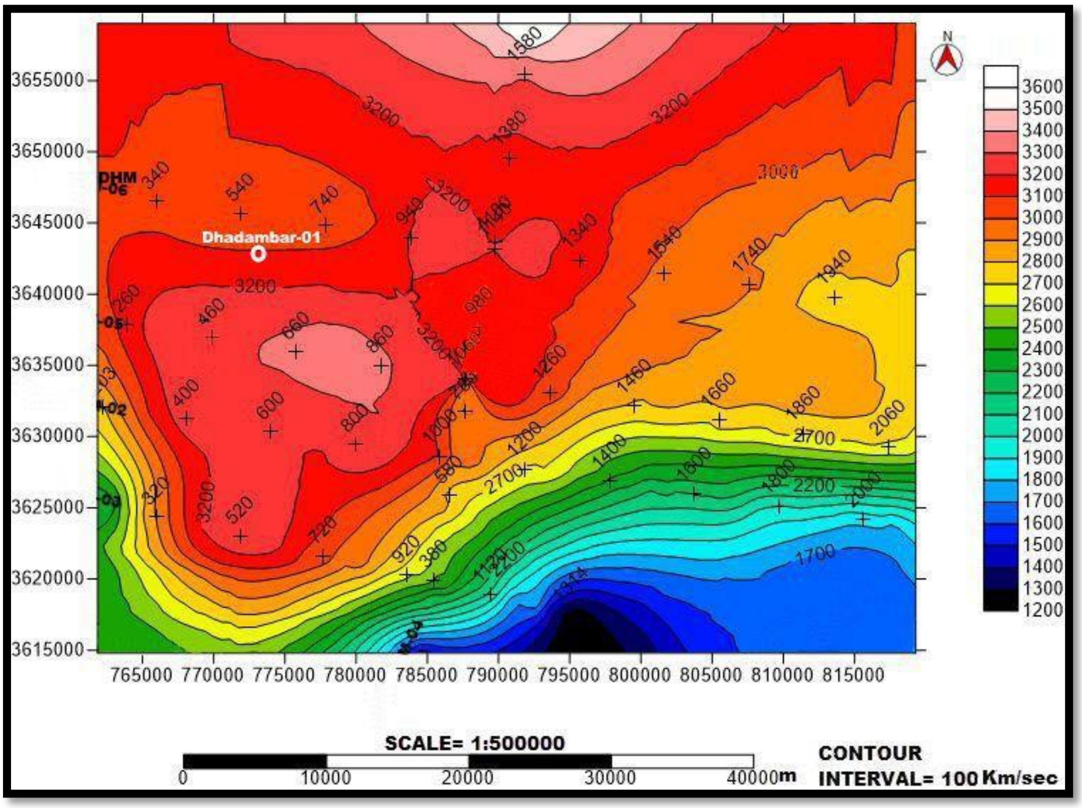


Figure 4.2. Vp contours of Sakesar Limestone.

Velocity increases with depth. In figure 4.1 and 4.2 the Vp of Chorgali Formation and Sakesar Limestone are increasing as moving from dark blue color towards the red color which shows that depth is increasing from south to northward. As depth is increasing then value of Vp will also increase. Velocity increased at DHM-02 and DHM-05 (3000-3300 km/sec) and (3200-3300 km/sec), and along northwestward at DHM-06 the value of Vp decreased (2900-2800 km/sec) and (3100-3000 km/sec) in both figure 4.1 and 4.2 respectively which may shows the presence of fluids.

4.4.2 Density

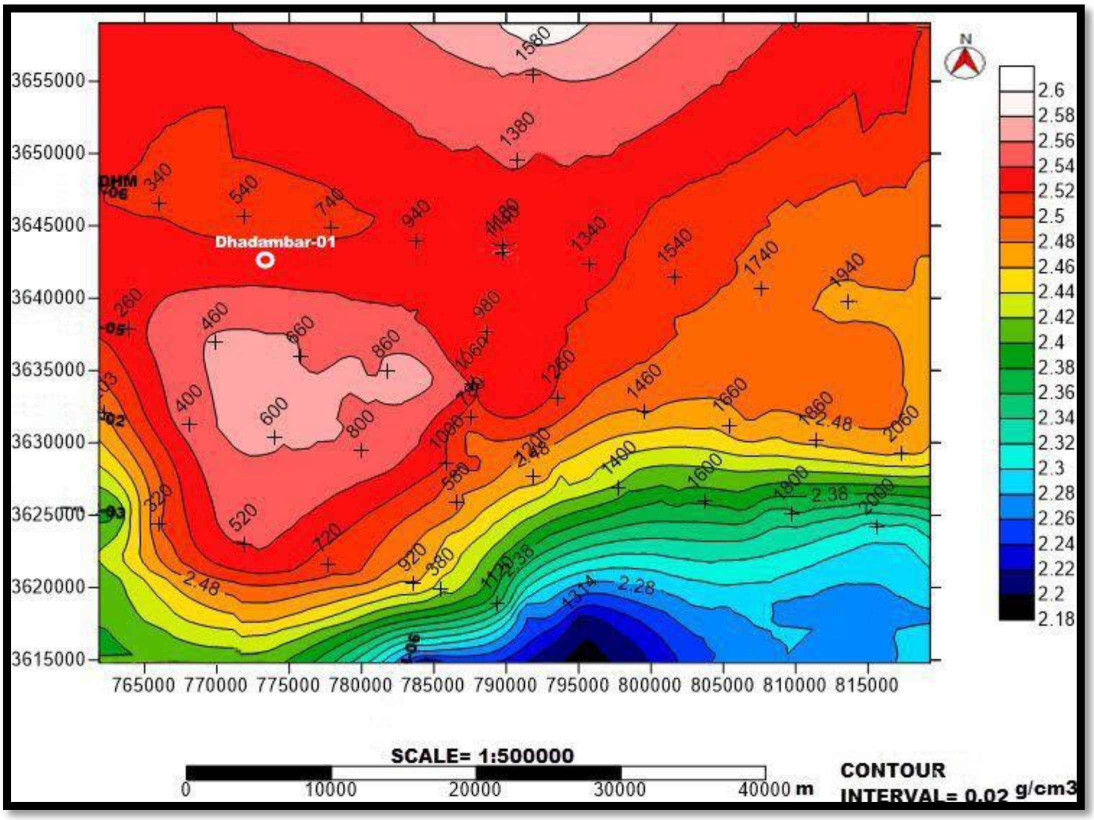


Figure 4.3. Density contours of Chorgali Formation.

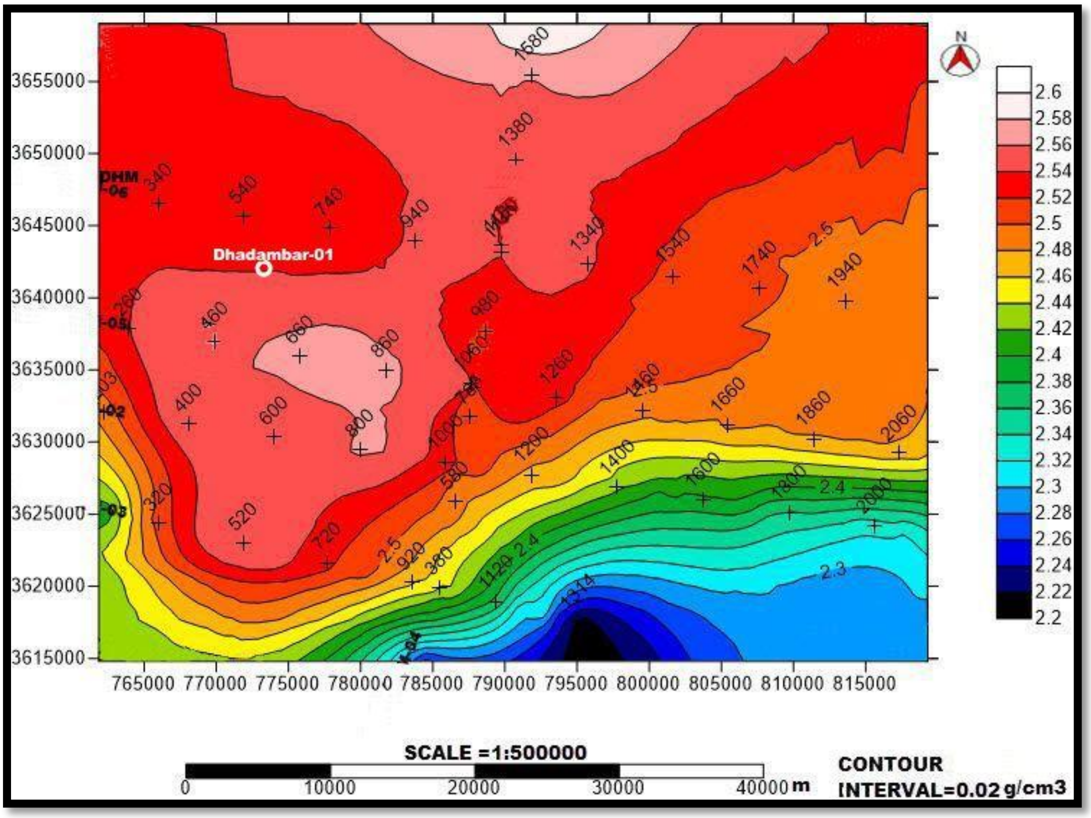


Figure 4.4. Density contours of Sakesar Limestone.

Fluids are less dense than the sedimentary rocks. As fluids are present then density will be decreases. As can be seen in figure 4.3 and 4.4 the density is increasing from south to north (shallow to deep) portion in both figures. At southwestward between DHM-02 and DHM-05 the density ranges from 2.50-2.58 and 2.52-2.58 while at northwestward along the dhadambar-01 well the density is lightly decreased from 2.54-2.50 and 2.54-2.52 in figure 4.3 and 4.4 respectively which may be the indication of presence of the fluids. At southward the contours are close enough due to which density values varies sharply but as move toward north the contours become broader and density values increased moderately.

4.4.3 Bulk modulus

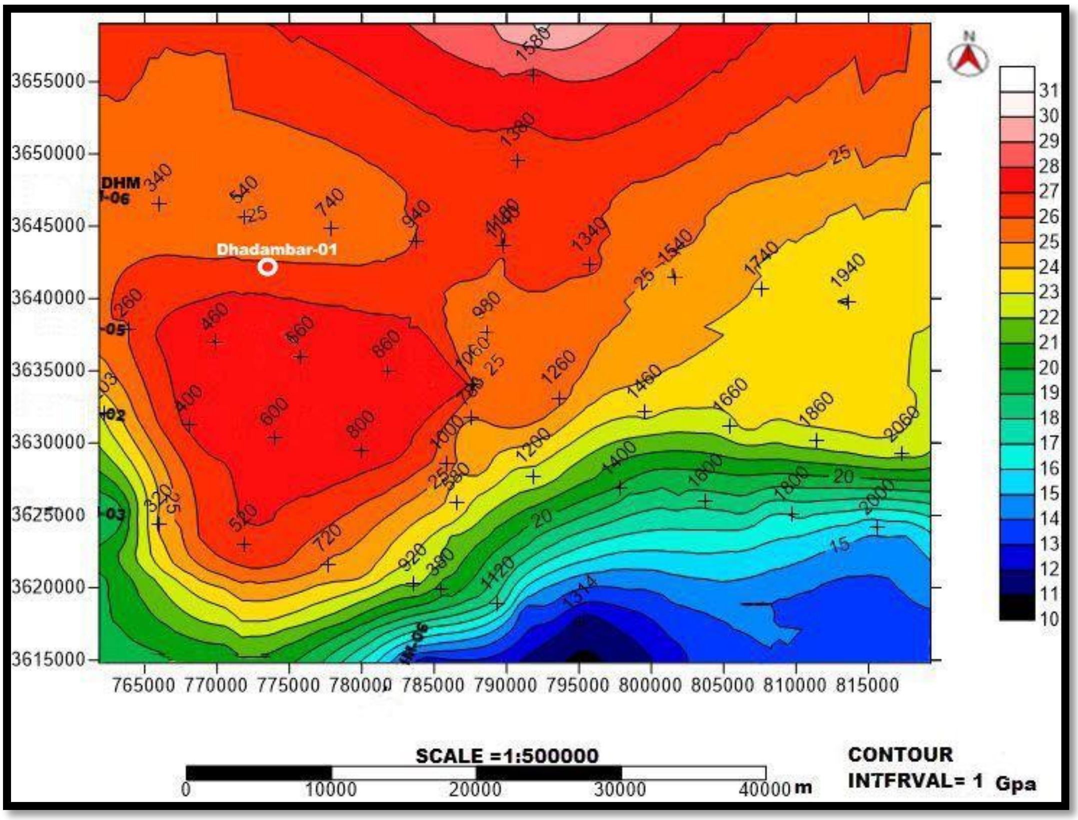


Figure 4.5. Bulk modulus contours of Chorgali Formation.

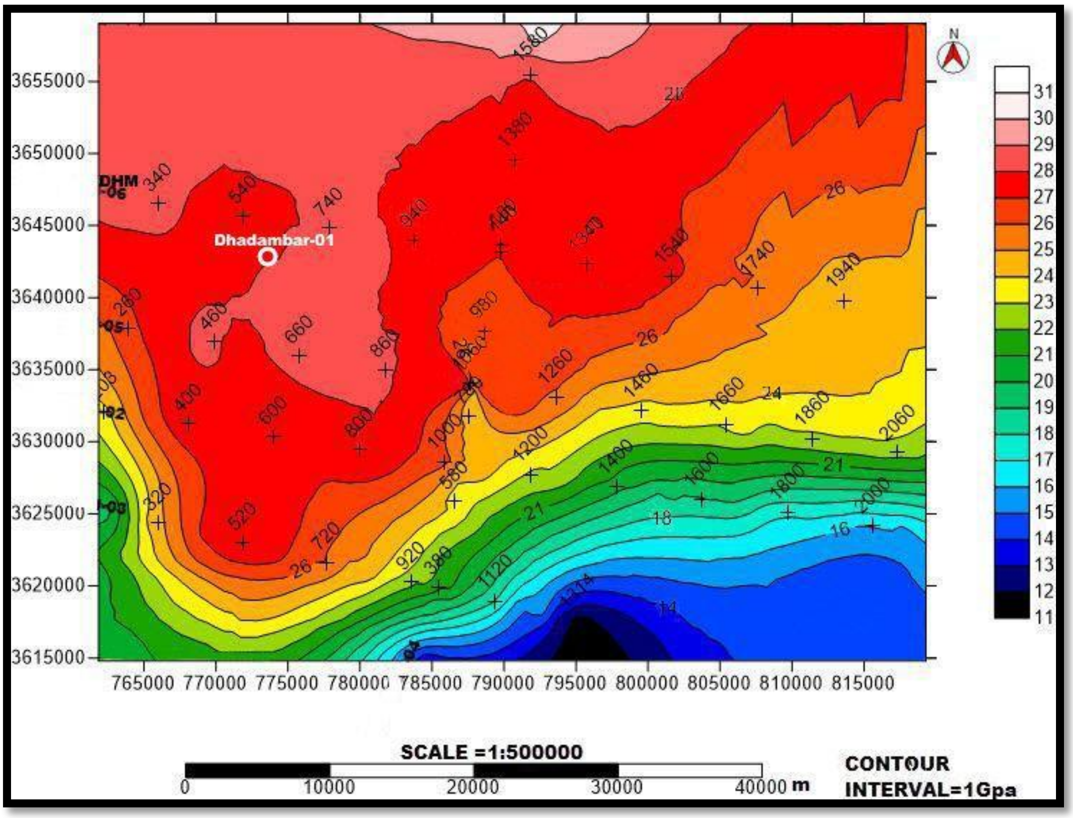


Figure 4.6. Bulk modulus contours of Sakesar Limestone.

For fluids the bulk modulus is meaningful. The bulk modulus decreases due to the fluid filled porosity. In figure 4.5 and 4.6 southward the contours are close to each other which indicate the sharp variations in the bulk modulus of the Chorgali Formation and Sakesar Limestone, and northward the contours becomes wider which shows that bulk modulus gradually increases. Southwestward along the DHM-05 and DHM-02 in figure 4.5 the bulk modulus value increased (26-27Gpa), and along the DHM-06 the bulk modulus value decreased (26-25Gpa). While in figure 4.6 northwestward along the DHM-06 near the well point the value of bulk modulus decreased (28-27Gpa) which may indicate the presence of the fluids.

4.4.4 Shear modulus

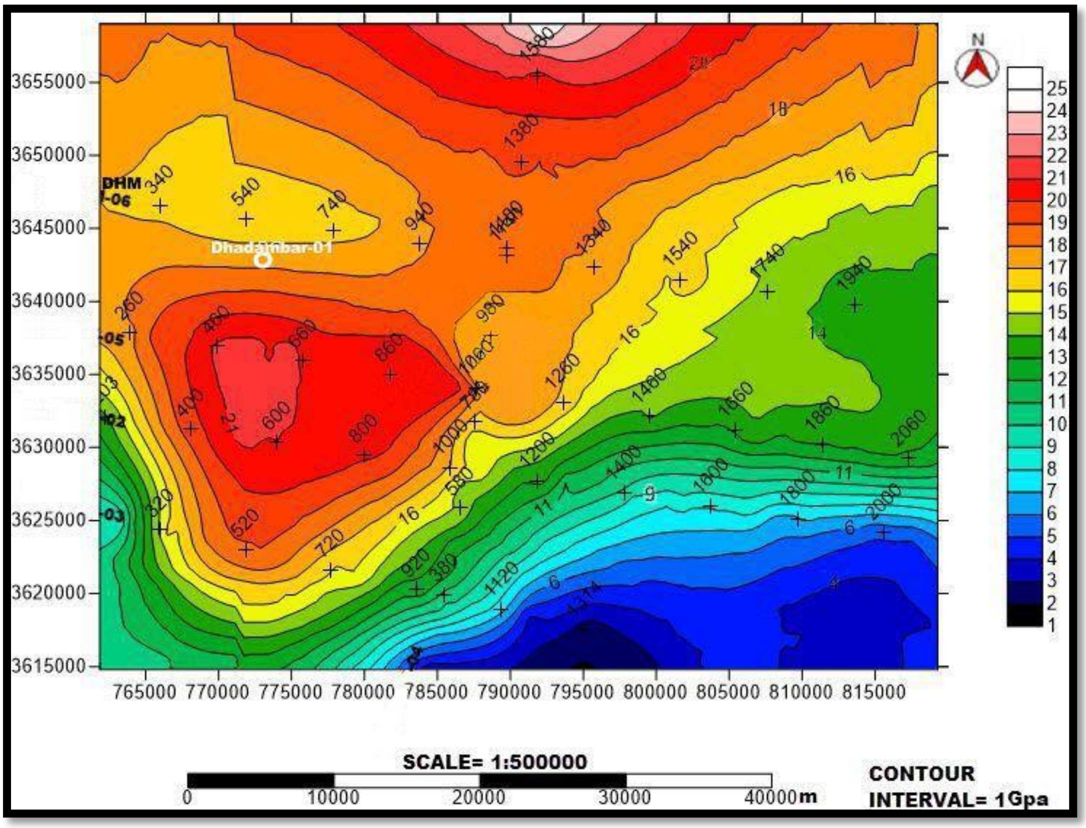


Figure 4.7. Shear modulus contours of Chorgali Formation.

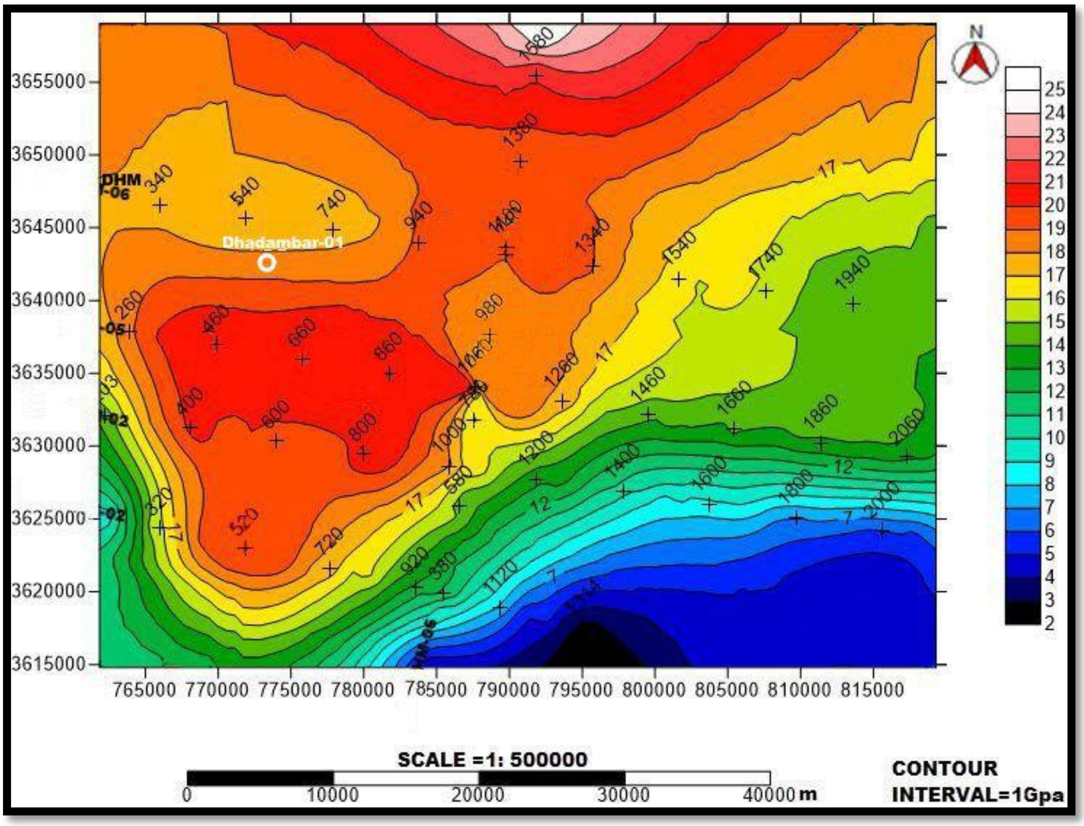


Figure 4.8. Shear modulus contours of Sakesar Limestone.

In figure 4.7 and 4.8 the shear modulus of Chorgali Formation and Sakesar Limestone are increasing as moving from dark blue color towards the red-white color which shows that depth is increasing from south to northward. As depth is increasing then value of shear modulus will also increases. Along southwestward at DHM-02 and DHM-05 the value of shear modulus is increase (20-21Gpa) and for figure 4.8 increase (19-20Gpa) which is normal increase, and northwestward along DHM-06 in both above figures the value of shear modulus decreased (17-16Gpa) which may be the indication of presence of the fluids. Nearest contour line value to the well point is 18 Gpa.

4.4.5 Poisson’s ratio

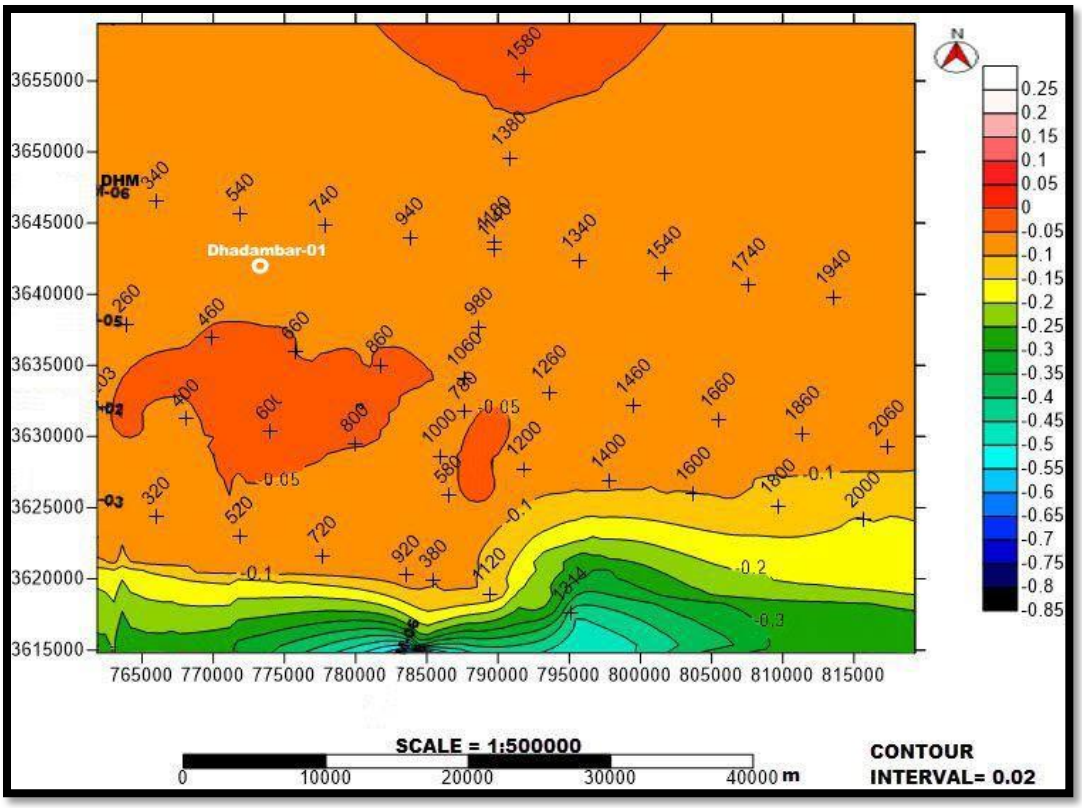


Figure 4.9. Poison ratio of Chorgali Formation.

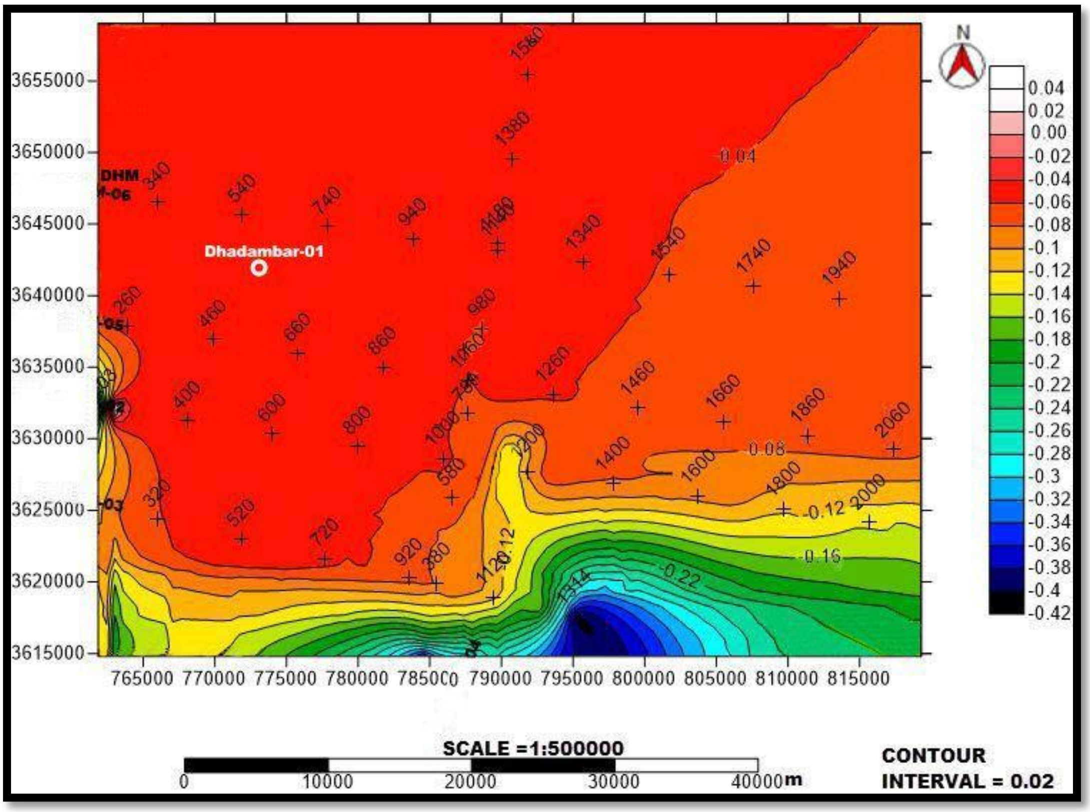


Figure 4.10. Poison ratio of Sakesar Limestone.

Increase in the poison ratio indicates the presence of fluid in the pore spaces of the formation. In figure 4.9 and 4.10 the poison ratio is increasing from south to northward ranging (-0.6 – 0.15) and (-0.42 to -0.02) respectively. In figure 4.9 along southwestward at DHM-02 and DHM-05 the poison ratio increased (-0.1 to -0.05) which may indicate the presence of the fluid.

4.4.6 Vp Vs ratio

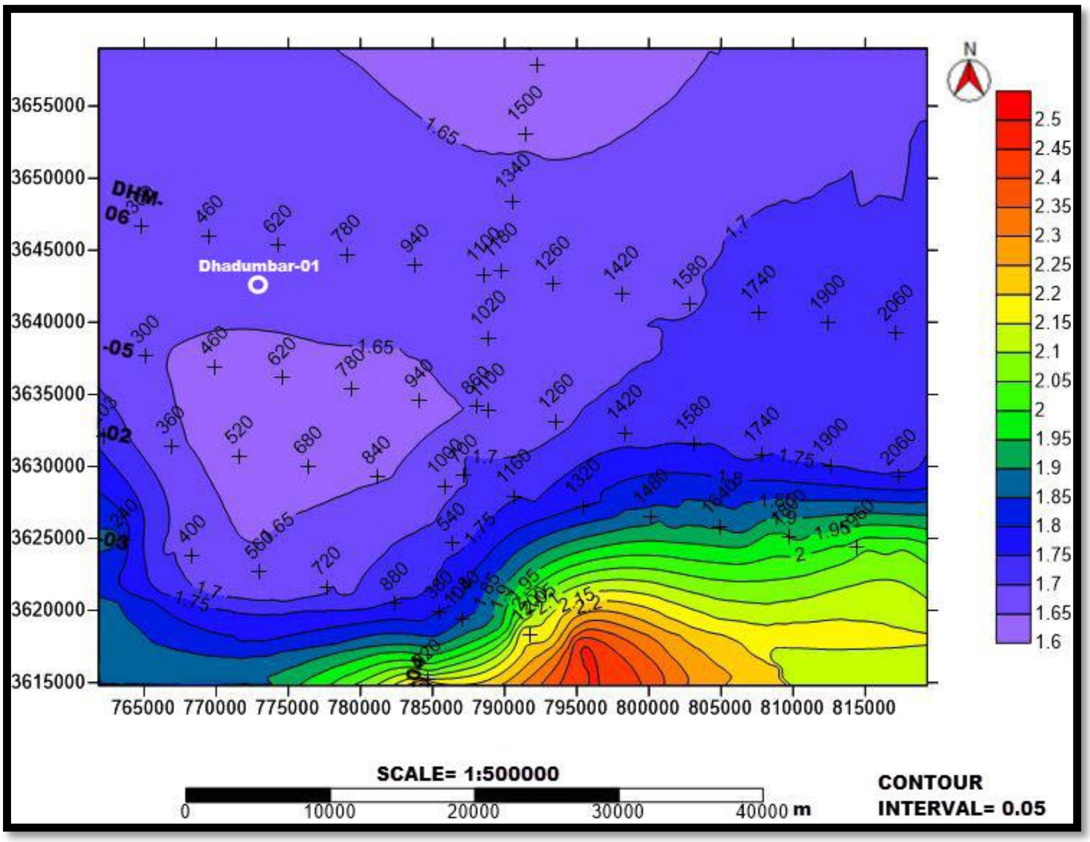


Figure 4.11. Vp Vs ratio contours of Chorgali Formation.

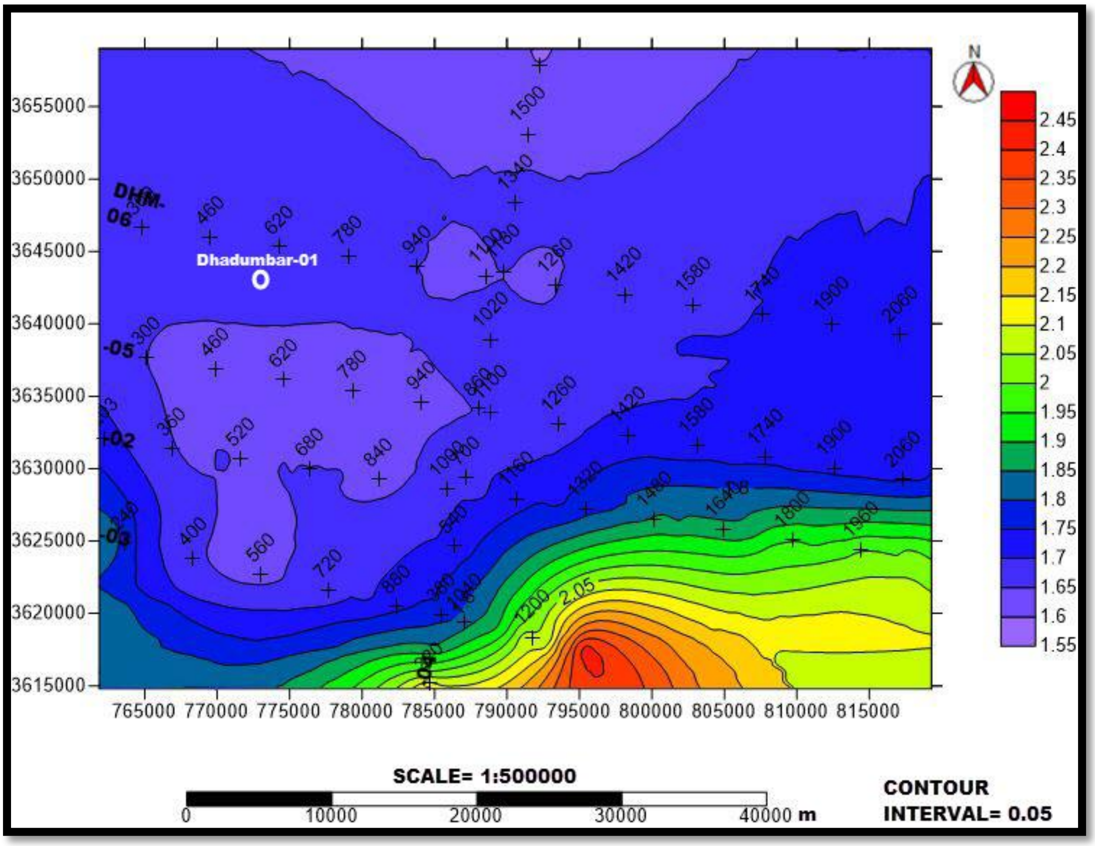


Figure 4.12. Vp Vs ratio contours of Sakesar Limestone.

Shear wave travel time is helpful in determining mechanical rock properties, while compressional wave is sensitive to the saturated fluids type. The Vp/Vs is good to identifying fluid type the ratio decreases indicates the fluid presence. In figure 4.11 and 4.12 with the depth Vp/Vs also decreased. Along the DHM-02 and DHM-05 the Vp/Vs decreased (1.7-1.6) that may indicate presence of the fluids. Along the southward the contour is close to each other which show that Vp/Vs is sharply varing, and as move towards northward at central portion in both figures the contours are wider which show that Vp/Vs is gradually changing.

CONCLUSIONS

(i) Interpretation of the contour maps of the seismic data confirm the time on the horizons. Moving from south towards north on the contour map increase in the depth can be observed. At central area of the contour map both at south and north contours are close to each other indicating steeper slope here and at the middle portion of the map contours are relatively away from each other showing gentler slope. As we say earlier that with the depth velocity increased, that is also confirmed from the velocity contour maps of the both formations.

(ii) No major fault have been observed on the interpreted subsurface horizons although minor faults may present and can be identify by magnifying or by very close look and the major structure that observed on the seismic lines is syncline.

(iii) The rock physics evaluations of the both formations indicate the presence of the fluids, especially near the area on the grid where the well lies. But unfortunately well data was not provided so amount of the hydrocarbon cannot be estimated.

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