STRUCTURAL MAPPING OF FIMKASSAR OIL FIELD AND ITS CORRELATION WITH SUBSURFACE OIL PRODUCING STRUCTURAL UNITS, POTWAR SUB BASIN, PAKISTAN

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I DEDICATE MY THESIS TO MY FAMILY AND TEACHERS

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ABSTRACT

North Potwar deformed zone (NPDZ) is present in Upper Indus Basin Potwar plateau. The main source of deformation in this zone is Indian plate movement toward north. Potwar basin is the first oldest known basin for commercial hydrocarbon production; when the exploration was only on anticlinal and oil seepage basis (Khaur oilfield 1917).The study area is consisting of Fimkassar oil field and the seismic lines were collected from Landmark Resources (LMKR) with the permission of Directorate General of petroleum concession (DGPC) of Ministry of petroleum and natural resources Islamabad with the help of Earth and environmental sciences department Bahria University Islamabad. The study area consists of Fimkassar well-01, well-02 and well-03 and seismic lines G884-FMK-101, G884-FMK-103, G884-FMK-104, G884-FMK-105, G884-FMK-106, G884-FMK-107 and G884-FMK-108 of the Fimkassar oil field. The 2D seismic study was carried out at OGDCL data interpretation centre for the structural mapping of Fimkassar oil Field and its correlation with subsurface oil producing structure along with the formation contributing for hydrocarbon in deeper horizon of Northern Potwar Deformed Zone. With the help of seismic synform anticline was identified with two major faults trending north east and south west. Oil area was identified in the north east of structure and in the northern part of the known structure a relative smaller high at deeper level was also identified in the south western side of the structure. Time structure maps of the reflectors ware prepared for Chorgali Formation and Sakesar Limestone using two way time of the reflectors. Time structure map was converted into depth contour map for further clarity of the structure.

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LIST OF ABBREVATIONS

DGPC	-	Directorate General of Petroleum Concession
GPS	-	Global Positioning System
MBT	-	Main Boundary Thrust
MFT	-	Main Frontal Thrust
NPDZ	-	Northern Potwar Deformed Zone
PFTBZ	-	Potwar Fold and Thrust Belt Zone
SRPFB	-	Salt Range Potwar Foreland Basin
SPDZ	-	Southern Potwar Deformed Zone
SRT	-	Salt Range Thrust

CHAPTER 1

INTRODUCTION

1.1 General Introduction to the Study Area

Pakistan comprises of two major basins named as the Indus Basin and Balochistan Basin. These two basins, formed through different tectonic activities, are joined together along Chaman fault. The Indus Basin is further segmented into two main sub-basins: the Upper Indus basin and the Lower Indus Basin. The project area lies in the Northern Potwar Deformed Zone (NPDZ) of the Upper Indus Basin. The NPDZ is further divided into Sis Indus area and Trans Indus area which is commonly known as Kohat Sub-Basin. The Fimkassar field lies in the Sis Indus area Potwar Sub-Basin near Dhudial, district Chakwal. The basin is marked by compressional regime hence it consists of structure formed by thrust fault. The main structures found in the study area include the popup anticline along with triangular zones. The Fimkassar exhibits an anticlinal structure (Shami and Baig, 2002:124).

The Sis Indus Potwar region is very valuable foe hydrocarbons as various petroleum prospect zones are present and also it is firstly known commercially viable hydrocarbons area from Khaur which was traced by oil seep. This basin has various structural extending east to west direction and slightly tilting due to Jhelum fault, this area is duly known for oil prospecting. The various attempts have been made to find out the oil by structural mapping over Cambrian, Permian, Jurassic, Triassic, Paleocene and Eocene. For base Miocene epoch level a regional time structural map was developed to understand the structure vogue, fault varieties, decollement levels and tectonics, which are conformably for deeper horizons (Aamir et al, 2005:103). Because of higher movement involve in the basin. So, there is not a rhythmic movement coordinating sub-surface with surface. Therefore, the anticlinal structures appear on surface do not match with sub-surface. The most prominent example is Dhurnal oil field which is very prominent syncline on surface which was a major reason for leaving that structure unexplored for almost 100 years. Although, several oil companies were setting on the structure. The interpretation of seismic profiles by various workers shows the presence of double decollement especially in the eastern part. However, this decollement is 3 or 4 time in the northern limit of Potwar Sub Basin (Badley, 1985:266). The decollement present in the Potwar Sub Basin is low angle thrust that displaces the whole stratigraphic sequences towards south. Extreme south is represented by Salt range Thrust (SRT) (Shami & Baig, 2002:124-141). The various structure anamoly have found mainly due to southward movement of faults that was mainly caused by the soft salt movement activated by southward thrusting (Khan, et al, 1986:397).

1.2 Location and Accessibility of Study Area

The project field is located within eastern part of the Potwar Sub Basin district Chakwal Punjab, Pakistan. The Fimkassar oil field is the concession block of Oil and Gas Development Company Limited (OGDCL), which lies between Latitude 33° 04' 42"N and Longitude 72°56'50"E with an average elevation of 1696 feet (516km) from mean sea level (MSL). The project area is about 72km south of Islamabad and located near Dhudial, district Chakwal of Punjab province in Potwar Sub Basin region of Upper Indus Basin (Fig 1.1).

Figure 1.1 The location and accessibility map of the study area (Using Google Earth).

1.3 Literature Review

The Fimkassar structure was first explored by the Gulf Oil Company in 1980. The company drilled Fimkassar well (Fim-1X) and Fimkassar fractured carbonate reservoir included Chorgali and Sakesar Formation. The well was tested in Eocene and hydrocarbons were discovered with oil rate of 20 Barrels per B/day with little gas. After a few months of production it was observed by Gulf oil company that this well is non-commercial and they were not satisfied with production. Although, they attempted to increase the production and the field was then taken by OGDCL.

The OGDCL drilled a well (Fimkassar -1A) which was abandoned due to drilling complications in the Murree Formation, before reaching to the target depth. Later on re-entry was made in Fim-1X to side track it and was renamed as Fim-1ST. This side tracked well Fim-1ST successfully tested for commercial hydrocarbon in Sakesar Formation and lead to the discovery of the Fimkassar oil field in 1989.

In October 1989, the Fimkassar oil field came on regular production. At that time the initial reservoir pressure for Sakesar and Chorgali Formation was recorder as 5709 Pounds per square inches (PSI) with oil rate of 4000 bbls/day. Till June 2003, four (4) wells were drilled on Fimkassar structure. The wells Fim-1ST and Fim-2 both are the producers well while well Fim-3 is considered as water injection well. Because of the mechanical problem the fourth well Fim-1X was abandoned. The cumulative production as of 30 April, 2003 was about 12 MMSTB oil from the field. Similarly the cumulative water injection and production as of this date in the field was about more than 14 million barrels and 2 million barrels respectively (Jadoon et al, 2003:45).

In the past, different studies have been carried out on the Fimkassar oil field such as the reservoir’s net pay estimations and the Petrophysical studies on the basis of well log data (M. Ishfaque, et al, 2017:25-27). A combined study was carried out and reservoir simulation study was compiled to address the reservoir management problems to the field in order to recover the remaining resources from the field. Therefore, requirements of new wells were planned and an optimum recovery of oil from the field was made (Ahmad et al, 2003:613).

On the basis of Geophysical evaluation seismic data was interpreted and the depth structure map was prepared. Interpretation results reveal the following features: Fimkassar structure is an anticline feature formed as a result of compression tectonic. The structure rests in the hanging wall being separated by northeast-southwest trending thrust fault from its Chak Naurang counterpart, which is situated in the down thrown block. The throw of this fault is about 2300 meters. Such structures are the product of major detachment. This detachment level lies within the Pre- Cambrian salt. Two north-south trending reverse faults confine the Fimkassar structure on its northern and southern flanks. These faults are younger than the major thrust fault. One of these faults separates Fimkassar from Turkwal structure on its northern flank.

The throw of this fault is about 200 meters. The trend of the major thrust and axis of the structure follow the regional tendency (Jadoon et al, 2003:46).

1.4 Problem Statement

On the basis of well log data, detailed studies have been conducted in the past on geophysical evaluation, Petrophysical analysis, and net pay estimations of the reservoir. An Integrated Structural, Geologic and Seismic Study were conducted to address the Fimkassar oilfield, but surface and sub-surface structural shift had to be made using structural and seismic data. Therefore, this study is entitled to find out the structural make up of Fimkassar oilfield, the movement involved in the sediments and the shift of surface and sub-surface structure.

1.5 Aims and Objectives

There are four main objectives of this research work;

1) Geological mapping of Fimkassar oil field.
2) Structural mapping of Fimkassar oil field.
3) Sub-surface seismic mapping to delineate the structures.
4) Find out the structural shift of Fimkassar anticline.

CHAPTER 2

REGIONAL TECTONICS AND STRATIGRAPHY

2.1 General Statement

The periphery of Pakistan lies in the circle of Arabian, Eurasian and Indo-Pakistan plates. From Permian to middle Jurassic the rifting of Indo-Pakistan plate from Gondwana land was followed by extensive sea-floor spreading and clattering in the end with Eurasian Plate. The collisions of these two plates caused massive uplifting which are today known as the “Himalayas Ranges” that lies between Eurasian and Indian Plate and also causing the emergence of foreland basin that conserved the accumulation for Rawalpindi and Siwalik group of Upper Indus Basin that is several kilometers thick Miocene to Recent fluviatile sequence (Aamir and Siddiqui, 2006:1-10). The Indian Plate is approaching the northward at rate of 40mm/year and subducting underneath of Eurasian Plate and this processes of subduction helped the emergence of quite a few thrust belts dipping in north-south direction (Shami and Baig, 2002:137).

2.2 Potwar Plateau

Potwar plateau has relatively constant elevation throughout from south to north and is present on the northern side of Salt Range. It also incorporates the most of drainage system of Soan River which has spreaded all over the basin. The Potwar Plateau is bounded by Jhelum strike slip fault from the east, which has effected the structure styles of the basin. The Kalabagh strike slip fault is present on the western side which is very prominent fault appearing on surface. Main boundary thrust (MBT) is present and is further bounded from south by Salt Range sedimentary basin. There is every possibility of folding structural style due to the movement of MBT. On the southern side there is Salt Range Thrust (SRT) which is also called Main Frontal thrust (MFT), which has uplifted the Potwar Sub Basin from the Punjab Plains (Fig 2.1).

The surface geology of Potwar Sub basin (Sis Indus Basin) consists of thick Pre-Cambrian evaporates, covered by the wide variety of Cambrian to Eocene age thin platform deposits, which are then further followed by the Molasses deposits of Miocene to Pliocene age. The entire succession is intensively deformed in Pliocene to Middle Pleistocene times by rigorous Himalayan Orogeny (Kazmi & Jan, 1997:67).

The Potwar Sub Basin regard as the oldest oil province in the Pakistan, as the first oil discovery in this basin dated back to 1914. In Sis Indus Basin a total of almost hundred and fifty (150) wells have been drilled upto date, many of them have experienced pre-mature abandonment because of the presence of high pressured water in the molasses deposits and results in drilling problems and operational complications. Potwar Sub Basin is relatively structurally complex with several folded structures and faults. Mostly the compressional deformation explains the difference between surface and sub-surface structures which are becoming complex with the straight movement of the plate creating duplexes. The main reasons for the difference are the presence of soft rocks which are helping in movement of the stratigraphic sequences at different levels mainly at salt Range Formation, Sardhai Shales, Chichali Formation, Patala Formation and Kuldana Formation. These levels having these formations are also confirming the movement through seismic which can be of great help in understanding the sub-surface structure. (Kazmi & Jan, 1997:67).

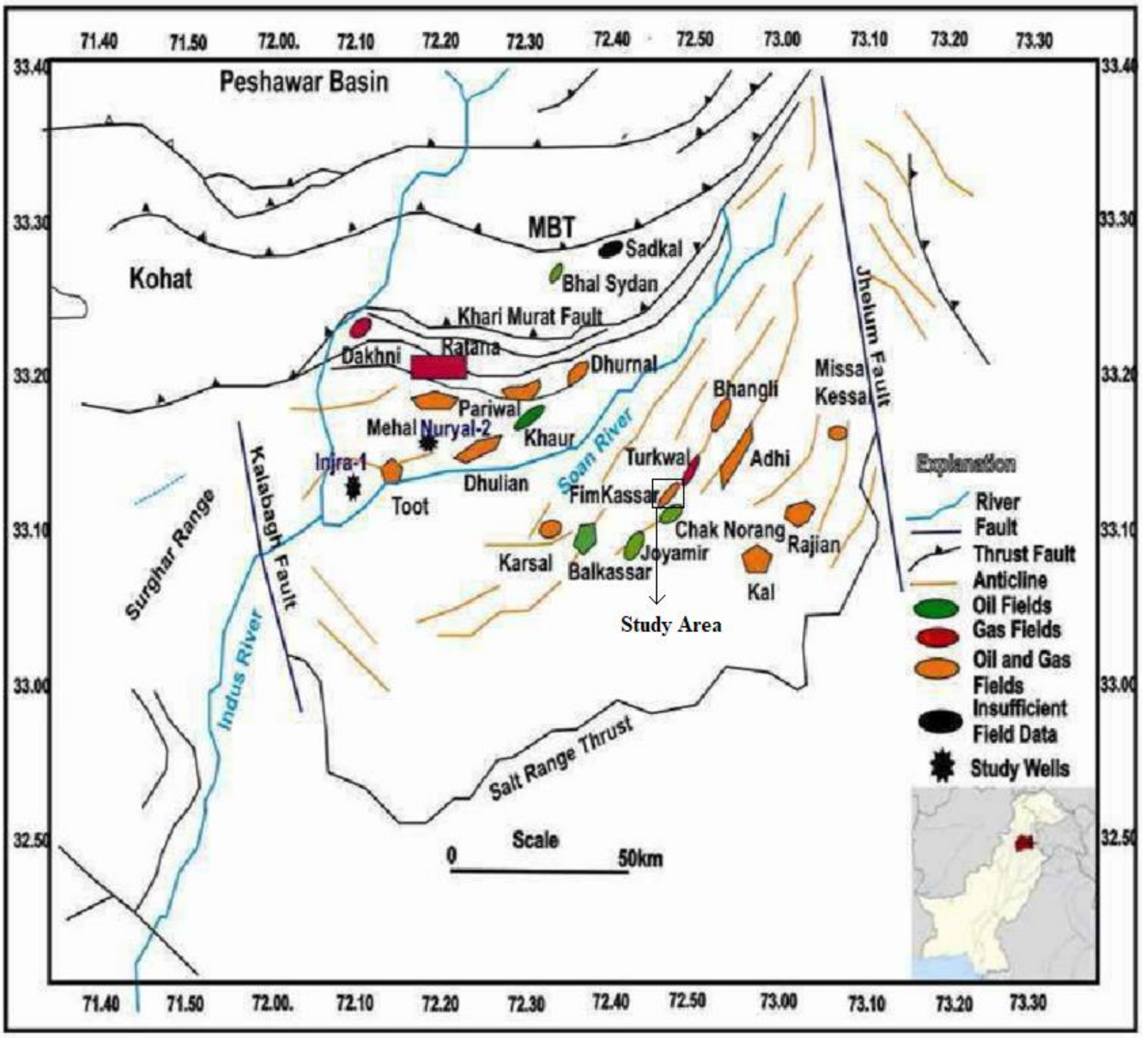


Figure 2.1 The Regional tectonic map of the Potwar Sub Basin, showing the study area (Raza, 1992).

2.3 Tectonic Framework of Potwar Sub Basin

The vast Soan Syncline divides the Potwar Sub Basin into two deformed zones; the Northern Potwar deformed Zone (NPDZ) and the Southern Potwar Deformed Zone (SPDZ). More intense deformation is seen in NPDZ than SPDZ. Extending south from MBT to the Soan Syncline is the belt of Neogene deformation. Generally east-north-east (ENE) trending formation outcrops and faults are present which are at right angle to the tectonic direction. Extensively dissected the NPDZ is a zone of broad synclines compressed into imbricate thrusts that are tightly spaced. The deformation style in NPDZ abruptly shifts from east to west. The NPDZ is followed in the south by asymmetrical wide syncline, which has a northward dipping south flank along the Salt Range and northern limb dipping following the NPDZ. A buried thrust fault in eastern NPDZ having foreland syncline behind Dhurnal Fault, and hinterland dipping imbricate stack further north and passive roof duplex. The western side of NPDZ is demarcated by compressed fault anticlines and the synclines, which indicate the emergent thrust, separate them (Kemal, 1991:121).

Southern Potwar Platform Zone eastern part is representing very strong deformation compared to western and central parts. Southern Potwar, central and eastern parts show minor deformation within the overthrusted Phanerozoic sedimentary section, which is resulted by effective decoupling within Eo-cambrian evaporates lying above basement (Yeats and Hussain, 1987:167). The contrast is related to fewer to several amount of salt thickness in the infra Cambrian especially thick in the eastern part and in comparison to the Potwar Plateau, the basement has a very complex low dip of 1° - 1.5°, with a 20 - 30° dip in the central part. Because of the thick salt in the eastern part where formations become more elastic and easily mobile over Jhelum fault is considered to be active fault which is providing a moving force to the structures and making them more complex (Moghal et al, 2003:07).

2.4 Tectonics of Eastern Potwar Basin

The deformation in Potwar area is the result of south verging thrusting, with some times anticlines separated by broad synclines. Thrust faults are normally linked with south dipping conjugate back thrusts which are dipping north and pop-up structures. Salt Range Formation is main fault detached on the regional plane of decollement apparently. (Aamir and Siddiqui, 2006:05).

The intense deform part of Potwar fold and thrust belt zone (PFTBZ) is represented by Eastern Potwar region having large low angle detachment. The overthrust tectonics dominates the area, and almost all formations are compressed into fault and fold dominated features. Most of folds in the Eastern Potwar are trending in NE-SW direction relative to the east - west trending folds in central region of Potwar area. Hydrocarbon traps which are fault bounded hold reserves in amount of billions of barrels that are produced by overthrusting. Eastern Potwar tectonic framework is largely limited by the Domeli forethrust systems, Salt Range and Dil Jabba. The extreme south boundary of the Potwar Basin is a regional thrust fault system bounded by the east - west trending arc and then finally merges into strike slip fault (Jhelum Fault) (Fig 2.2). Rocks of Paleocene to Eocene age are seen in hanging wall whereas Molasse of Neogene age has been intensely underthrusted in footwall of large Overthrust structure.

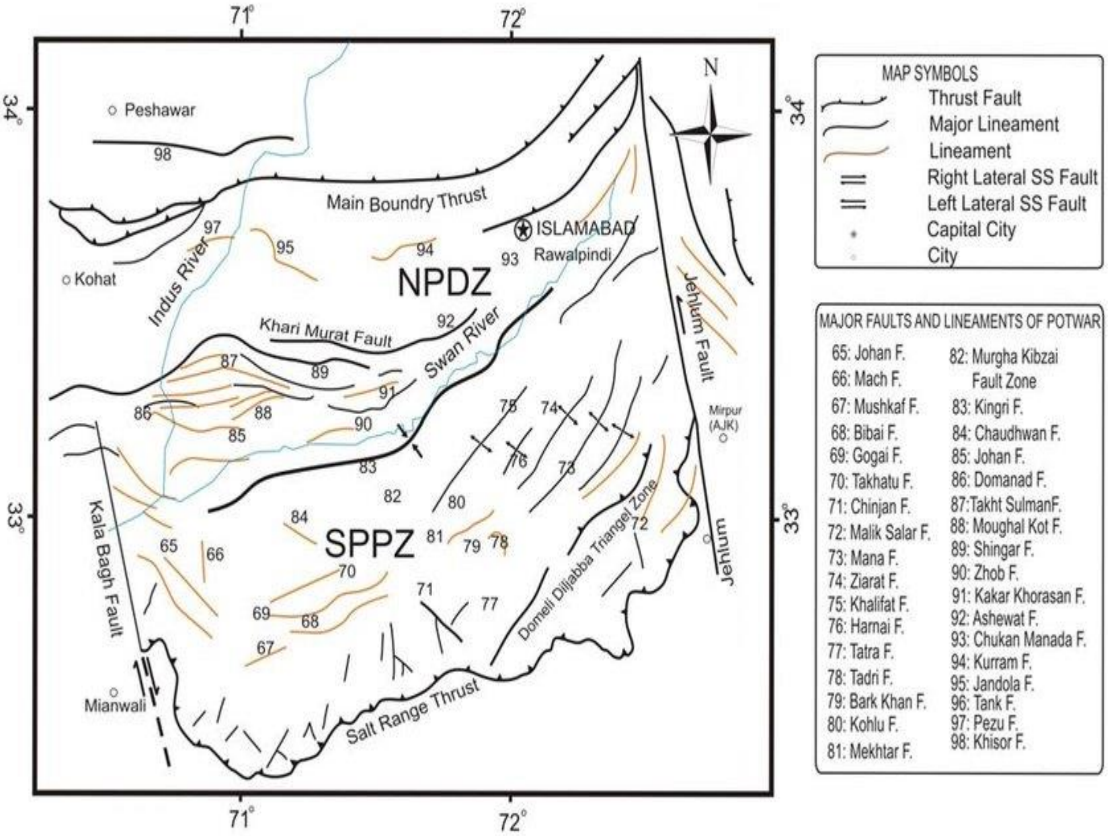


Figure 2.2 The major tectonic framework of eastern Potwar Sub Basin with clearly Marked, Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ) (Aamir and Siddiqui., 2006).

2.5 Major Structures of Study Area

2.5.1 Soan Syncline

This is a broad, wide and asymmetrical syncline having younger rocks (Siwalik and Lei Conglomerate) in the core and older rocks (Cambrian- Eocene) on its limbs. Its axis is represented by the Soan River (Shami and Baig, 2002:126). At the northern limb of Soan syncline, Dhok-Pathan Formation is overlay on the Nagri Formation which truncates in the south of Dhurnal area. In the north of Soan Syncline there is imbricate thrust faulting and horizontal shortening (Jaswal et al., 1997:317).

2.5.2 Turkwal and Fimkassar Anticlines

These structures are located in the southwestern Potwar Sub Basin. These have Pindori Anticline in the north, Joyamair anticline in the south, Adhi anticline in the east and Soan Syncline in the west.

Turkwal structure is northeast-southwest trending asymmetrical anticline steeply dipping to the north. It is separated from Fimkassar structure in south by a left lateral strike slip fault. The structure present in Potwar Sub Basin involves mostly Eocene rocks. In Eocene a complete petroleum system has been identified where Sakesar Limestones and Chorgali Formation are well known reservoirs. Because of decollement Miocene rocks from Chinji Formation are exposed on flanks and the decollement repeating from Murree Formation. Fimkassar structure also has northeast-southwest trending. It has a 23 by 13 km northeast-southwest trending surface expression with vertical closure 1, 800 - 1, 900 m. At Eocene level areal extent is 45 sq km and vertical closure is 58 m. The crestal areal closure is calculated as 7.5 sq km and fault related closure is 37.5 sq km (Shami and Baig, 2002:128).

2.5.3 Chak Naurang Anticline

It is characterized as a fault propagation fold. The southward verging anticline has two limbs which are steeply and moderately dipping southern and northern limbs. Northward-strong dipping strong basement reflector/horizon is seen in reflection data which is overlain by evaporites section. In Rawalpindi Group and Siwaliks molasses deposits, the extremely reflecting platform over the evaporite section sequence is offset, and the faults appears to be losing displacement (Pennock et al, 1989:845).

2.5.4 Tanwin Banis Anticline

A salt-thickened core is present in this anticline, highly strong reflectors having same seismic character as of the continental deposits appears and is cut-off by thrust faults from both southeast and northwest directions. Interpretation of geometry shows an emerging triangle zone and that zone have been mapped a minimum of 9 km towards southwest. The fold is interpreted towards 9 km northeast of the Tanwin-Banis and is covered by a southwest trending thrust which resulted in development of popup back thrust (Pennock et al, 1989:849).

2.5.5 Adhi Gungril Anticline

Adhi Gungril anticlines are mainly symmetric in structure. The crustal region dips more gently as compared to moderately dipping flanks. This structure is pop-up structure and bounded by number of reverse faults is represented by reflection data in the direction of northwest and southeast. They have Pindori Anticline in the northwest and Rajian Anticline in the southeast. These structures are flanked by Murree/Kamlial Formation and have Cambrian-Eocene rocks in the core (Pennock et al, 1989:849).

2.5.6 Joya Mair Anticline

This is a double-plunging anticline that dips 100°southeast (SE) and 4° northeast (NE). The anticline has Cambrian-Eocene rocks in the core and Murree/Siwalik Formations on its limbs. The anticline is separated by Chak Naurang-Wari fault from Chak Naurang anticline. The fold axis of anticline trends from northeast-southwest. The geological structure, borehole and seismic data show the Joyamair structure is a combination of two opposite faults making a triangle zone in sub-surface. These faults moving opposite to each other and making the structure more complex for hydrocarbons recovery. The Joyamair triangle zone is segmented along left lateral Vairo and Dhab Kalan faults and lies in Southern Potwar Deformed Zone (SPDZ) (Shami and Baig, 2002:138) (Fig 2.3).

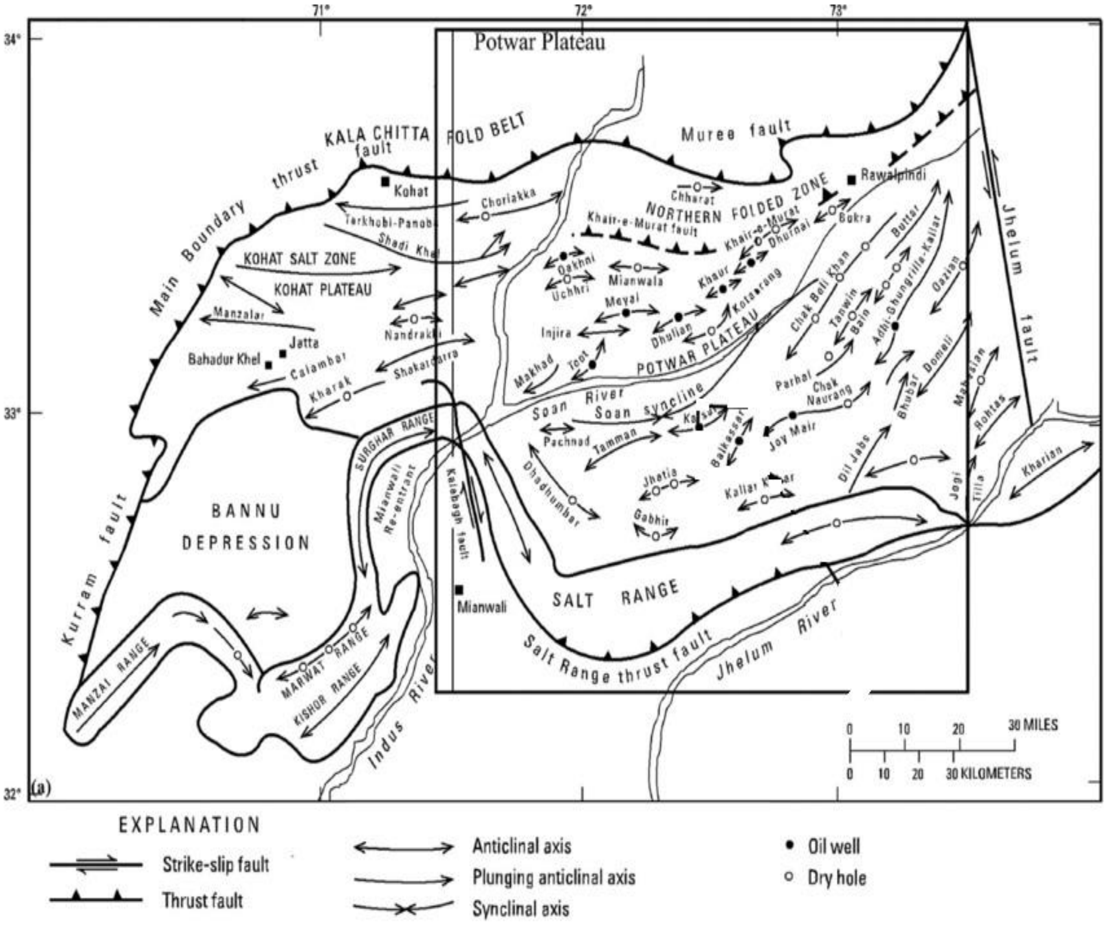


Figure 2.3 The map showing Potwar Basin different major tectonic structures (Shami & Baig., 2002).

2.6 General Stratigraphy

The stratigraphic sequence of Potwar Sub-Basin is from Pre-Cambrian to Quaternary age. The regional thrusting of decollement is because of the presence of ductile evaporates. The vaporization is either interlaid locally or the intrusion is caused by igneous rocks of Khewra traps. The major unconformities are outlined by the missing age of Ordovician through Carboniferous and Upper Cretaceous rocks (Shah, 1977:34).

The whole stratigraphic succession of Potwar Sub-Basin has been severely deformed by intense tectonic activity in Pliocene to middle Pleistocene time during the Himalayan Orogeny.

In the Eastern Salt range, the Salt Range Formation is well developed and exposed and has unconformable contact with underlying basement sequence. The continental sedimentary succession overlay on Salt Range Formation comprises shallow water sediments of Cambrian to Eocene age and have a significant unconformities at the base of Permian and Paleocene (Farah et al., 1984:105).

Potwar Sub Basin was uplifted during Ordovician – Carboniferous period. As a result, no sediments were deposited during this extensive time period. Because of disconformity, the basin’s second immediate stratigraphic sequence change is due to complete absence of Miocene sedimentary succession stretching from Late Permian to Cretaceous throughout the area. In Mesozoic times, the depocenter was present in the central section of Potwar Sub Basin, where a thick Mesozoic sedimentary succession with developed Paleocene and Eocene rocks exists (Aamir and Siddiqui, 2006:06).

2.7 Stratigraphy of Eastern Potwar Basin

In Potwar region rocks of Pre-Cambrian to Quaternary age are found. Their thickness exceeds more than 7925 m and was developed in different environments in this area. Very intense periods of uplift and erosion are seen in numerous major unconformities. In Fimkassar field oldest penetrated rock, is the Salt Range Formation which is encountered at 3633 m in the well Turkwal Depp – 01 (Aamir and Siddiqui, 2006:07).

Stratigraphy can be divided into three bounded sequences, (Mesozoic to Late Permian), (Ordovician to Carboniferous) and (Oligocene) age unconformities are present in this area shown in (Table 2.1). Due to complex thrusting identification of three unconformities is not easy. In Potwar Sub basin, thick infra Cambrian evaporite deposits are mostly overlain by Cambrian to Eocene age thin platform deposits, which are then followed by thick Miocene – Pliocene period molasse deposits. Severe deformation in this region is caused by strong tectonic activity which occurred during the Himalayan uplift. Salt Range Formation in this area is oldest penetrated formation, and is composed of halite with some marl, dolomite and shales. In eastern salt range the Salt Range Formation can be seen best developed. The salt is resting unconformably above the Pre Cambrian basement. Cambrian to Eocene shallow water sediments are found in overlying platform sequence along with major unconformities (Aamir and Siddiqui, 2006:07).

Table 2.1 The Generalized Stratigraphic column of Salt Range, with possible Source, Reservoir and Seal (Modified after Fatmi, 1973).

QUAT	PLEIS		Lithology	Source	Reservoir	Seal
TERTIARY	PLIO-CENE	Siwalik Group				●
	MIOCENE	Rawalpindi Group				
	EOCENE	Chorgali Fm			●	●
		Sakesar Lst			●	
		Nammal Fm				
	PALEOCENE	Patala Fm		●		
		Lockhart Fm				
		Hangu Fm				
CRETACEOUS	E	Lumshiwal Fm				
		Chichali Fm		●		
JURASSIC	L					
	M	Samana Suk Fm				
		Shinawri Fm				
	E	Datta Fm			●	●
TRIASSIC	L	Kingriali Fm				
	M	Tredian Fm				
	E	Mianwali Fm				
PERMIAN	LATE	Chhidru Fm				
		Wargal Fm				
		Amb Fm				
	EARLY	Sardhai Fm		●		
		Warccha Fm			●	
		Dandot Fm				
		Tobra Fm			●	
CAMBRIAN		Baghanwala Fm				
		Jutana Fm				
		Kussak Fm				
		Khewra Sandstone			●	
PRE-CAMBRIAN		Salt Range Fm		●		

There is also a major unconformity between the platform sequence and the underlying molasses deposits, where the whole Oligocene sedimentary record is missing. The Murree Formation, Kamlial Formation, Chinji Formation, Nagri Formation and Dhok Pathan Formation make up the molasses deposits (Aamir and Siddiqui, 2006:08). The lithological units encountered in the study area are as follows:

1) Nagri Formation
2) Murree Formation
3) Chorgali Formation
4) Sakesar Limestone
5) Patala Formation

2.7.1 Nagri Formation

It was named by Lewis (1937). This formation primarily contains medium to coarse grained sandstone that is bluish grey to dull red in color having salt and pepper pattern, with subordinate clays having reddish grey and pale orange color and conglomerates consists of pebbles limestone and igneous rocks. The formation is widely deposited in Indus basin and its thickness is variable in different locations. Its thickness ranges from 300m to 1500m. The formation has vertebrate's remains recorded by Pilgrims (1913), Anderson (1928) and Pascoe (1963). The fauna indicates an Early Paleocene age of the formation.

2.7.2 Murree Formation

Murree Formation was named by Stratigraphic Committee of Pakistan. Its type section is present in the north of Dhok Miaki, Attock District. The formation comprised of greenish grey sandstone, red and purple clay with minor intraformational conglomerate. The Murree Formation is well exposed in Kohat-Potwar province of Upper Indus Basin. It ranges in thickness between 180 m and 600 m. Murree Formation is devoid of fossil. Only few plants remain silicified wood, fish remains and mammals' bones have been reported. Based on the fauna the formation is of Early Miocene age.

2.7.3 Chorgali Formation

The term "Chorgali beds" was codified as Chorgali Formation by the Stratigraphic Committee of Pakistan in 1920. The type section of this formation is well exposed near Chorgali pass in Khair e Murat ranges. This formation is pre-dominantly consists of shales and limestones (Cheema et al, 1977:67). The formation is divided into two units. The lower unit comprises of dolomitic limestone and shale, and the upper unit is composed of predominantly of shale with subordinate limestone.

The limestone of this formation is medium bedded and color is ranging from light grey to yellowish grey. While the shales of Chorgali is calcareous in nature and of green to greenish grey color. The formation has fossils content of foraminifera, mollusks and ostracodes as reported by Davies and Pinfold (1937). The fauna present in the formation indicates Early Eocene age of the formation.

2.7.4 Sakesar Limestone

Gee used the term Sakesar Formation or Sakesar Limestone to describe an Eocene Limestone formation exposed in Salt Range, Potwar Sub Basin. This formation is predominantly composed of Limestone with minor amount of marl and some chert in upper part. Sakesar Limestone is nodular, and typically massive bedded and ranges from cream to light grey in color. The formation is widely distributed in Salt Range and Surghar Range. The formation thickness varying considerably from 70m to 150m. The formation has foraminifera, mollusks and echinoids. Based on the fauna, its age is Early Eocene.

2.7.5 Patala Formation

Patala Formation was named after "Patala Shale" of Davies and Pinfold (1937) by Stratigraphic Committee of Pakistan. Its type locality is marked near Patala Nala in the salt Range. It is primarily comprised of shales and marl with minor amount of sandstone and limestone (Cheema at al, 1977:71). The shale is greenish grey, calcareous and carbonaceous. The limestone is light grey and nodular. It has coal seams of the economic value.

The formation is widely exposed in Kohat- Potwar and Hazara area. Its thickness varies between 30 and 180 m. The formation is fossiliferous and contains abundant foraminifera, mollusks and ostracodes (Smout and Haque, 1956:57). Based on the fauna, the formation is of Late Paleocene age.

2.8 Petroleum Play of Potwar Sub-Basin

Potwar marine facies has great potential of hydrocarbon. Previous drilling was restricted up to Eocene carbonate. Recent discoveries in Potwar resulted in delineation of deep subsurface crest. The average Geo-thermal gradient of the order of 2° C per 100 m is recorded in Potwar region and the oil window lies between 2750-5200 m (Kadri, 1995:275).

Non-commercial oil has been encountered in the shale of Precambrian Salt Range Formation (well drill in Dhariala, Kallar Kahar). The Cambrian marine shale of Kussak, Jutana and Khisor formations has source potential for hydrocarbon. Oil is produced from Khewra Sandstone in Adhi field. In Permian, shale of Dandot and Sardhai Limestone and Black shale of Zaluch group has source potential of oil. Triassic unit of Potwar having versatility in the environment of deposition has reason that cannot act as a good source rock. Only the Khatkiara member of Tredian Formation have good reservoir characteristic. The Jurassic black clay and organic content of Datta and some parts of Shinawari Formation are believed to be good source rocks while Datta is acting as reservoir at Meyal, Toot and Dhulian oil fields. Similarly, Samanasuk Formation has also good reservoir characteristic. The Cretaceous Chichali Formation has good source potential due to abundant of organic material while Lumshiwal Formation is good reservoir having gas discovered in some area of Punjab Platform (Shami and Baig, 2002:133).

2.8.1 Source Rocks

Potential source rock in study area is of Paleocene age known as Patala Formation (Khan et al, 1986). The total organic content (TOC) found in isolated pockets of oil shales of Salt Range Formation is ranging from 27 – 36%, and is considered as the possible source in this region (Shami and Baig, 2003:134). Highly fossiliferous Lockhart Limestone values of TOC in the northern Potwar region are calculated to be 1.4 % and also considered as a source rock.

2.8.2 Reservoir Rocks

Oil producing reservoirs of Cambrian to Eocene are present in Salt Range Potwar Foreland Basin (SRPFB). Sakesar and Chorgali formations carbonates which are highly fractured are categorized as major producing reservoirs in Fimkassar oil field. The primary porosity is less than 1% as shown in core analysis of the field in the Chorgali Formation and Sakesar Limestone. The wells of northwestern Potwar, fracture porosity is relatively higher because the rocks were deformed several times (Shami and Baig, 2002:134).

2.8.3 Cap Rocks

Good sealing potential for reservoir of Infra-Cambrian age is observed in evaporates and thick shale layers. Mudstone, inter bedded shale and siltstone provide seal for Limestone of Eocene age. Intra formational shale also acts as seals for Cenozoic and Mesozoic age reservoirs.

Chorgali and Sakesar limestone is sealed by the Kohat Formation and Kuldana clays along with Rawalpindi group of Miocene age. Because of variable movement and erosional rate various Formations show different thickness in the basin. Therefore, placing of cap rock is not always with one formation. Kuldana Formation is ideal cap rock however, where due to erosional movement Kuldana Formation thinned and clays and shales of Murree Formation substitute the cap rock (Shami and Baig, 2003:135).

2.8.4 Traps

The thinned skin tectonics has developed the traps, which further produced pop-up structure, faulted anticline and positive flower structure especially above the pre-cambrian salt. Moreover, clays and shales of Murree Formation also provides significant horizontal and vertical seals to Eocene reservoirs wherever it is in contact (Shah, 1977:39).

2.9 Entrapment of Hydrocarbons in Potwar Sub Basin

In Potwar Sub Basin generally the play types are salt cored faulted anticlines, and sometimes highly asymmetrical to overturn anticlines. As, in contrast to the western part of Potwar Sub Basin, the eastern part has experienced much more intense fracturing. So, due to the salt pop-up structures, hydrocarbon discoveries in the eastern section (south of Soan Syncline) are largely from extended anticlines extending from NE – SW with steeply dipping flanks.

In contrast to the conventional plays, there may also exist certain unconventional plays including:

- The presence of sub-thrust (autochthonous) plays in the central, western Potwar and Northern Potwar Deformed Zone (NPDZ).
- Eocene carbonates having diagenetic play (matrix porosity) that lies in between Balkassar and Fimkassar oil field
- The structural and stratigraphic (truncation) play in western part of the basin, and Salt diapir play in the domain of the Kalabagh strike-slip fault (Shah, 1977:43).

Table 2.2 The Generalized Stratigraphy of Fimkassar Oil Field (M. Ishfaque et al., 2017).

Reservoir
source

Age	Thickness m	Formations	Lithology	
Pliocene	400 -1500	Siwaliks		
Miocene	900-3000	Kamlial Murree		Cap Rock
Oligocene				
Eocene	50-150	Chorgali Sakesar Nammal		Reservoir rock
Paleocene	20-60	Patala Lockhart Hangu		Source Rock
Mesozoic & late Permian				
EarlyPermian	10-20	Amb Sardhai Warcha Danbot Tobra		
Carboniferous to Ordovician				
Cambrian	110-200	Baghanwala Jutana Kussak Khewra		
Infra Cambrian	0-2000	Salt Range		
Pre Cambrian		Basement		

CHAPTER 3

METHODOLOGY

3.1 Available Data

The Toposheet no 43-C/16 provided by the Geological Survey of Pakistan (GSP), seven 2D seismic lines and well data of Finkassar-01, Fimkassar-02 and Fimkassar-04 provided by the Directorate General of Petroleum Concession (DGPC), Government of Pakistan at the request of Head of the Department, Earth and Environmental Sciences (E &ES), Bahria University Islamabad.

3.1.1 Seismic lines

Following are the seismic lines issued from DGPC;

Table 3.1 The table shows the seismic lines issued by Directorate General of Petroleum Concessions (DGPC).

Serial No	Seismic Lines	Type
1	G884 – FMK – 101	Strike
2	G884 – FMK – 103	Dip
3	G884 – FMK – 104	Strike
4	G884 – FMK – 105	Dip
5	G884 – FMK – 106	Strike
6	G884 – FMK – 107	Dip
7	G884 – FMK – 108	Dip

3.1.2 Well Data

Following well data have been issued from DGPC;

Table 3.2 The table shows well log data issued by Directorate General of Petroleum Concessions (DGPC).

S. No	Well Name	Log Suites
1	Fimkassar – 01	Temperature log, GR, SP, MSL,DLL
2	Fimkassar – 02	BHC, GR, SP, DLL, MSFL,CNL, LDL
3	Fimkassar – 04	BHC, GR, SP, LDL

3.2 Research Methodology

3.2.1 Field Work

A field work was conducted on the Fimkassar structure based on identification of the structural features on the surface, measuring the outcrop sections, measuring the attitudes structural features in order to identify the anticlines and synclines, and the plotting of the data on the area toposheet. The precise geographic location of the strata and structures was marked while using Global Positioning System (GPS). Lithological changes and other main megascopic features for example colour, texture, contact associations and grain size development was carefully observed in the field study.

3.2.2 Laboratory Work

1) The structural map was prepared and digitized by using ARC GIS Map.
2) The geological cross-sections were developed on the basis of field data.
3) Sub-surface structural identification on the basis of 2D seismic data and well log data and correlation of surface and sub-surface structure (Fig 3.1)

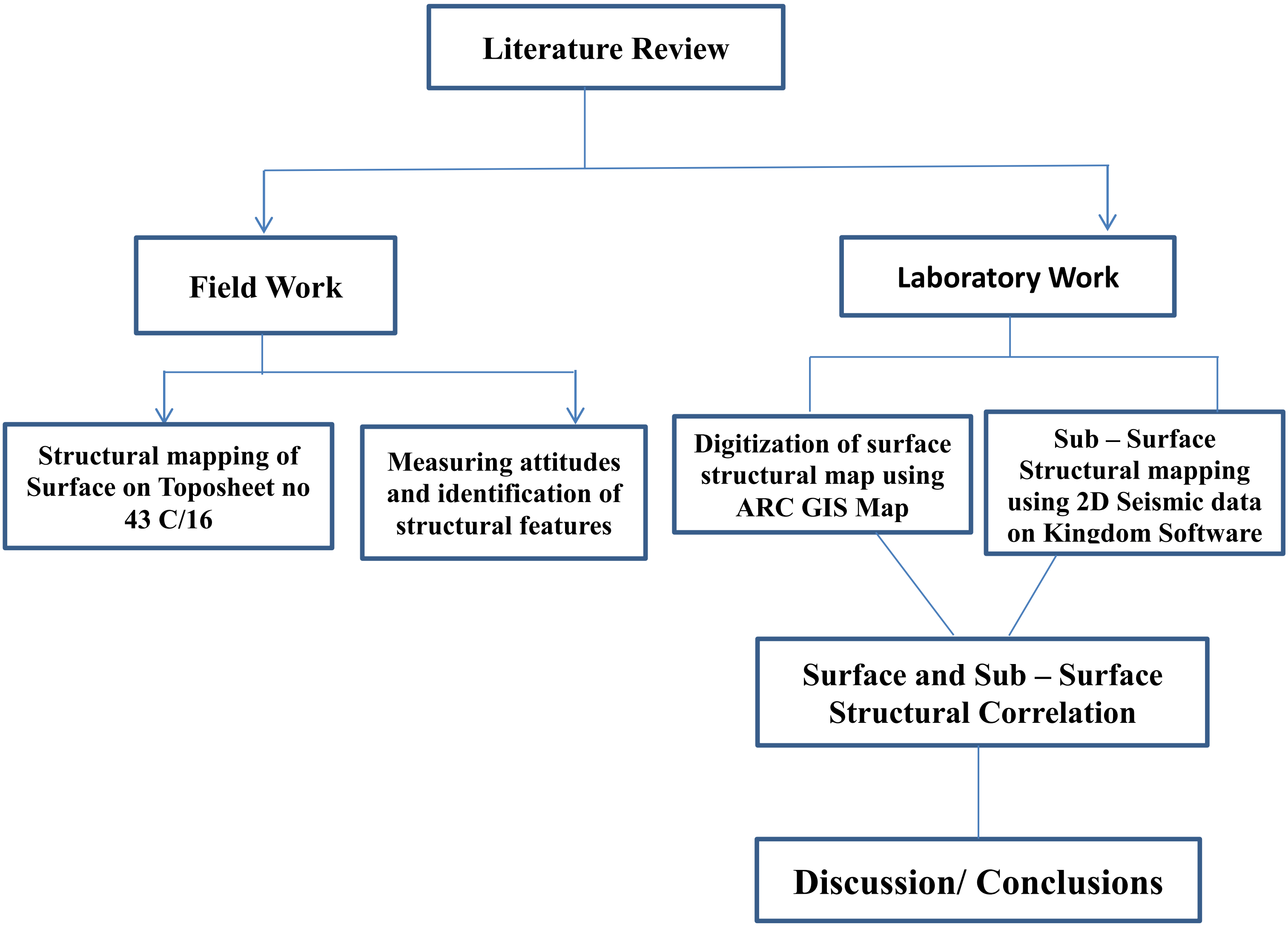


Figure 3.1 The Flow chart of the methodology followed during the proposed research.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In seismic interpretation, we interpret the section which brings information from subsurface and evaluates structures and the lithologies with the help of seismic sections and well data. A line of geophone that records seismic reflections of the coming seismic energy is known as seismic lines. Seismic lines display the subsurface image and geology of the area. Seismic sections had different orientations which are found in base map (Fig 4.1).

The 2-D seismic data was collected and interpretation was made. This transformed the seismic reflection into structural picture by processing. The contour map for sub-surface horizons (Chorgali and Sakesar) was made and an attempt was made to convert the further depth by suitable velocities. An attempt was also made to identify the basement. The seismic interpretation especially reflection interpretation typically encompasses calculating the location and recognizing concealed interface or sharp transition formations from processed seismic pulses go back to the ground surface. The methodology followed for the seismic Interpretation includes the points listed below:

1. Making of identifiable reflector
2. The velocities determinations of selected reflector
3. The conversion of time to depth
4. The restoration of depth section
5. The time contour mapping of targeted reservoirs

The Interpretation of seismic section is carried out primarily by two main approaches;

1. Structure Analysis
2. Stratigraphic Analysis

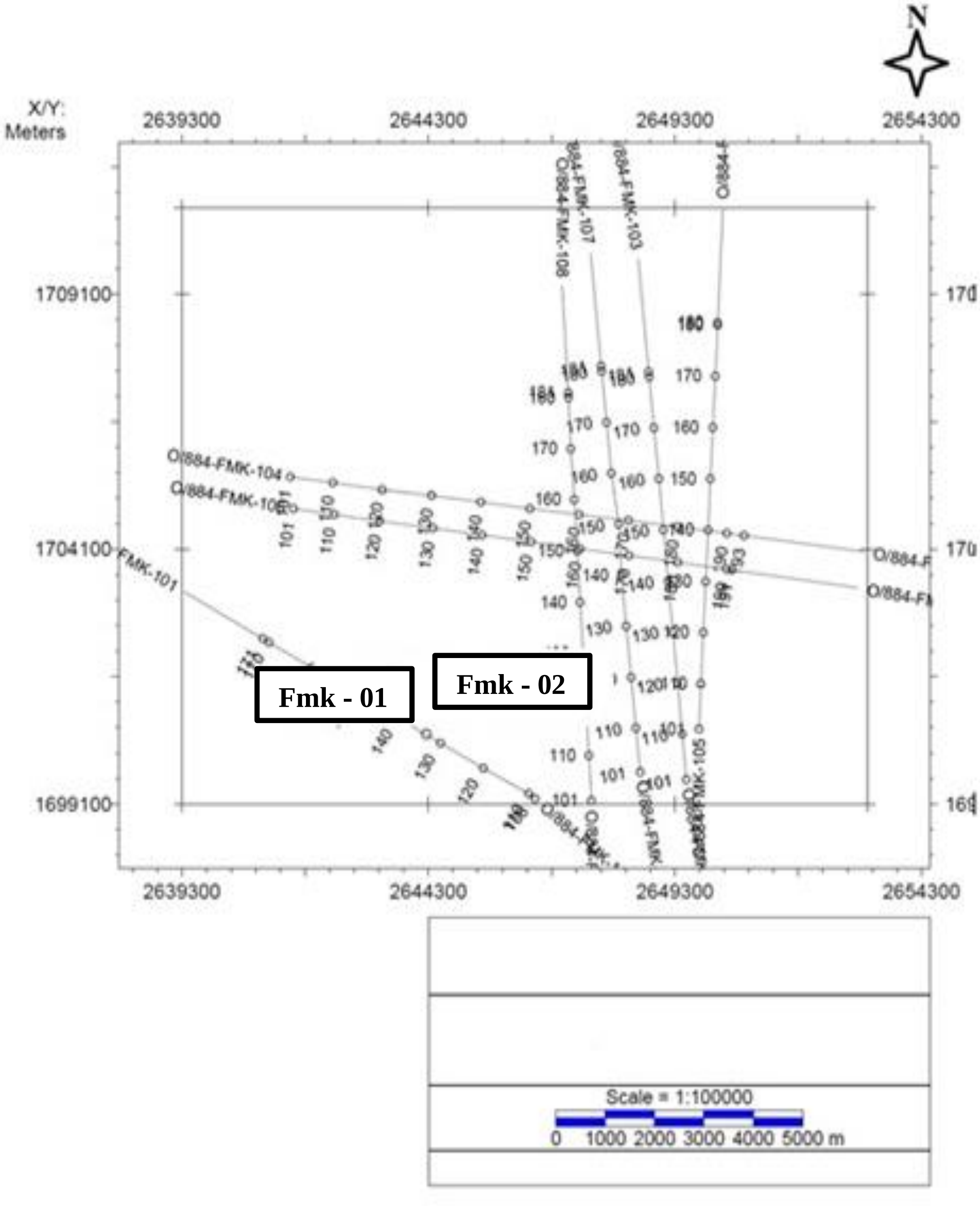


Figure 4.1 The seismic base map showing all the seismic lines for Fimkassar oilfield.

4.2 Structural Analysis

It is essentially the study of reflector geometry based on seismic reflection time. The foremost purpose of structural analysis from seismic section is to discover the structural traps that incorporate hydrocarbons. The geometry of targeted reflection events was mostly shown using two-way reflection times rather than the development of time and depth contour maps in structural interpretation. By converting times into depth and utilizing an acceptable velocity, structural maps can be created from time structure maps.

4.3 Stratigraphic Analysis

The seismic stratigraphic analysis plays an important role in determining the environmental conditions and depositional processes, because genetically related sedimentary sequences present in sub-surface and surface area normally consists of concordant strata which shows mismatch with sequence above and below especially for the correlation of oil well and reservoir planning.

According to Dobrin & Savit (1988), in entire history, the practice of locating hydrocarbons in stratigraphic traps by seismic reflection approach is not much more reliable as it is in case of structural traps. As a thumb rule, reefs, pinch outs, erosion related features, truncation of strata, facies transition and sand lenses either associated with lakes or buried channels results in the formation of stratigraphic traps.

4.4 Interpretation of Given Seismic Sections

The following lines have been analyzed and interpreted:

i. G884 – FMK – 101, (Strike Line)
ii. G884 – FMK – 103, (Dip line)
iii. G884 – FMK – 104, (Strike Line)
iv. G884 – FMK – 105, (Dip Line)
v. G884 – FMK – 106, (Strike Line)
vi. G884 – FMK – 107, (Dip Line)
vii. G884 – FMK – 108, (Dip Line)

The strike lines orientation is in direction from east to west and dip lines orientation is from north to south.

4.5 Identification of Horizons

The first step in the interpretation of a processed seismic section is to choose the high quality seismic reflections from the section. The reflectors on the seismic section are marked on the basis of distinct coherence of visible reflections, which appeal us most from the above subsurface interface. In this study two reflectors are marked in the seismic sections, which are named as Chorgali Formation and Sakesar Formation.

4.6 Identification of Fault

The next step in the seismic interpretation is the identification of faults. Faults are considered as broken reflectors in the seismic section, which continues after slight distortion in the portion of the horizon. This study is the part of the compression regime. Therefore major thrust faults are marked.

4.7 Interpretation of Seismic Sections

4.8 Interpretation of Strike Lines

Lines G884 – FMK – 101, G884 – FMK – 104, and G884 – FMK – 106 are the strike lines which were interpreted below.

4.8.1 Interpretation of Seismic Line G884 – FMK – 101

The seismic section of the line G884 – FMK – 101 shows an anticlinal shape structure in the sub-surface. In interpreted seismic section, the direction of shooting is from SE – NW and the time values gradually increases along the y-axis from top to bottom. The two prominent reflectors for Sakesar and Chorgali Formation were marked clearly showing the intact strata. In my interpretation no faults trend were seen as it was clear in the dip line. However, the basement separation is quite clear (Fig 4.2).

The lines 104 and 106 shows similar trend of reflectors showing fair continuity of reflector without showing any fault system. It is recommended here that with the help of latest filters, we might be able to identify the fault continuity which we have been identifying in dip lines.

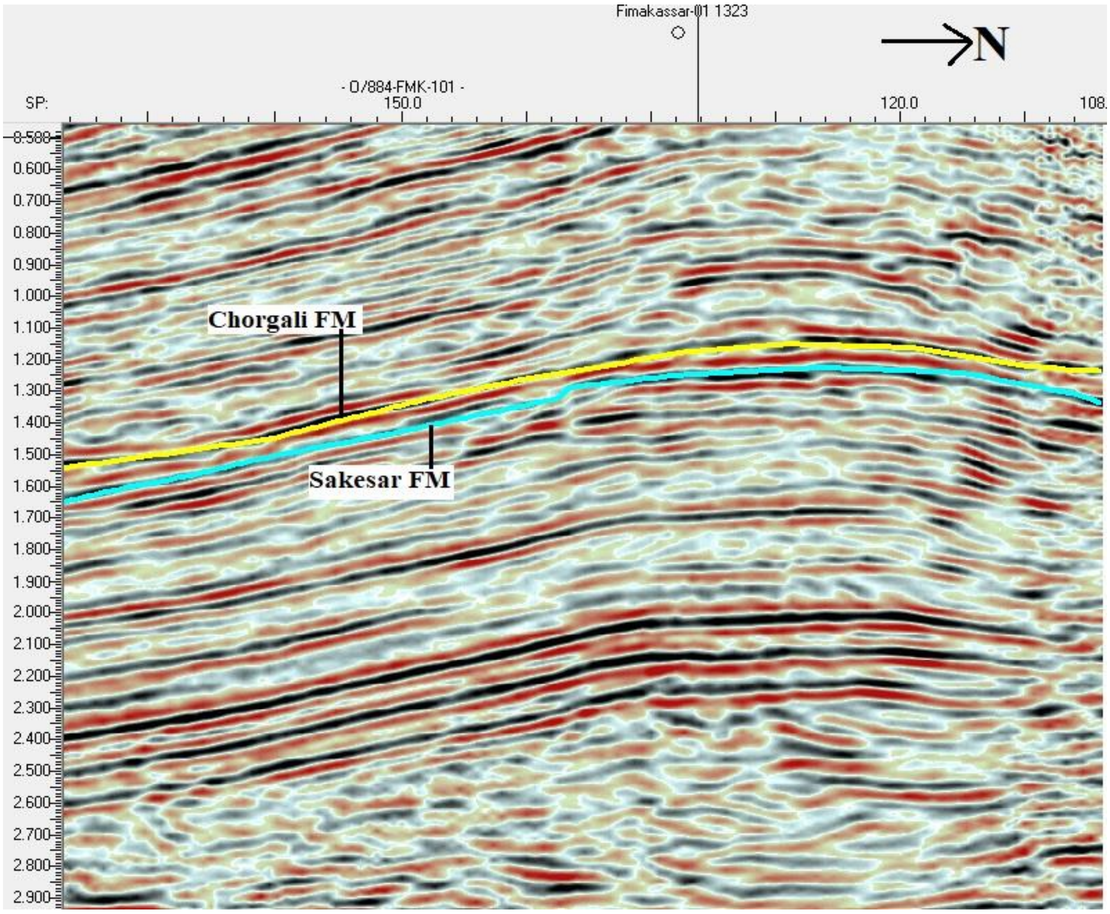


Figure 4.2 The interpreted seismic section of seismic line G884-FMK-101.

4.9 Interpretation of Dip Lines

Lines G884 – FMK – 103, G884 – FMK – 105, G884 – FMK – 107, and G884 – FMK – 108 are the strike lines which are interpreted and shown in figure below.

4.9.1 Interpretation of Seismic Line G884 – FMK – 103

The interpreted seismic section of the line G884 – FMK – 103 shows an anticlinal shape structure in the sub-surface. In interpreted seismic section, the direction of shooting is from NW – SE and the time values gradually increases along the y-axis from top to bottom. The two prominent reflectors for Sakesar and Chorgali Formation were marked clearly whereas two faults were identified on seismic section. The main pop-up structure is in between F2 and F3 showing discontinuity in depth. However, basement separation is very clear (Fig 4.3).

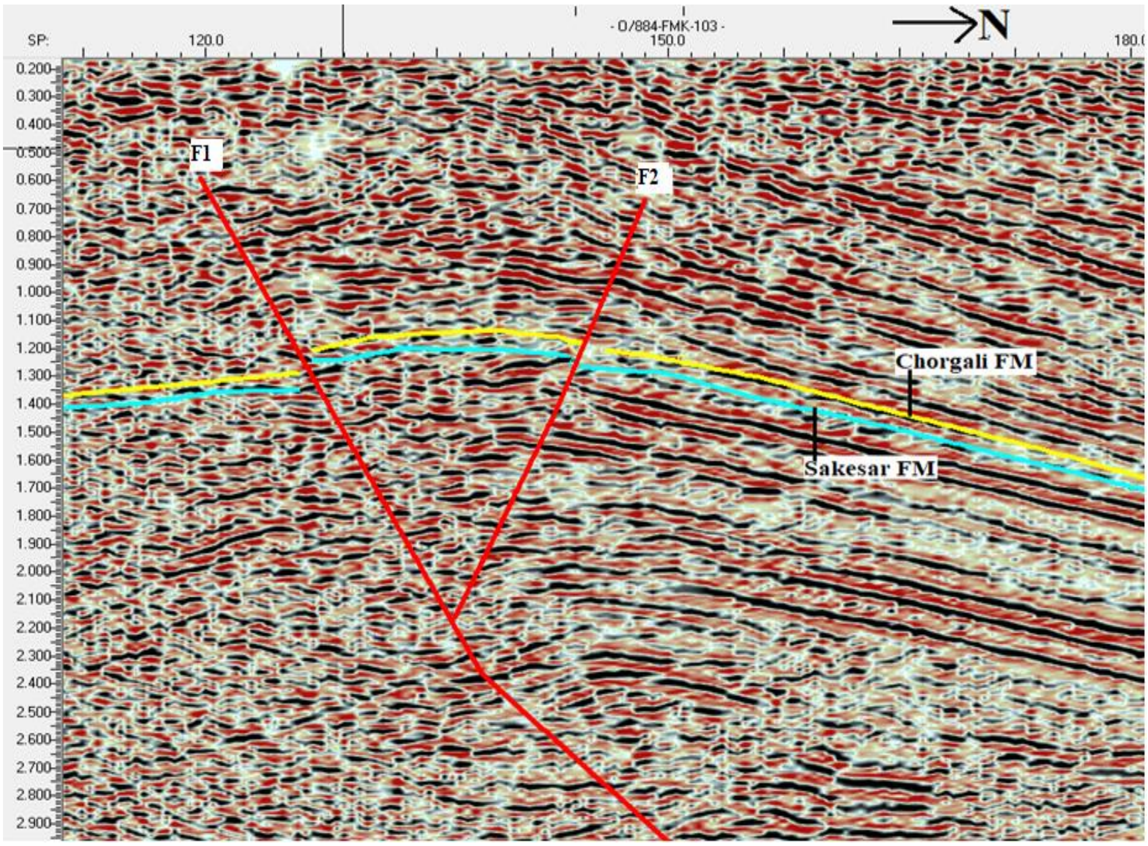


Figure 4.3 The interpreted seismic section of seismic line G884-FMK-103.

4.9.2 Interpretation of Seismic Line G884 – FMK – 105

The interpreted seismic section of the line G884 – FMK – 105 shows an anticlinal shape structure in the sub-surface. In interpreted seismic section, the direction of shooting is from NW – SE and the time values gradually increases along the y-axis from top to bottom. The two prominent reflectors for Sakesar and Chorgali Formation were marked clearly whereas two faults were identified on the seismic section. The main pop-up structure is in between F2 and F3 showing discontinuity in depth. In this section the structure is showing little broadening with better reflection in the northern side. Reflectors are missing on the southern side, showing discontinuity of formation layer. The basement line is quite clear separating the marine sequence (Fig 4.4).

Figure 4.4 The interpreted seismic section of seismic line G884-FMK-105.

4.9.3 Interpretation of Seismic Line G884 – FMK – 107

The interpreted seismic section of the line G884 – FMK – 107 shows an anticlinal shape structure in the sub-surface. In interpreted seismic section, the direction of shooting is from NW – SE and the time values gradually increases along the y-axis from top to bottom. The two prominent reflectors for Sakesar and Chorgali

Formation were marked clearly whereas two faults F2 and F3 were identified. The main pop-up structure is between F2 and F3. This Line indicates structure broadening as compared to the western line G884 – FMK – 108 (Fig 4.5).

Figure 4.5 The interpreted seismic section of seismic line G884-FMK-107

4.9.4 Interpretation of Seismic Line G884 – FMK – 108

The interpreted seismic section of the line G884 – FMK – 108 shows an anticlinal shape structure in the sub-surface. In interpreted seismic section, the direction of shooting is from NW – SE and the time values gradually increases along the y-axis from top to bottom. The two prominent reflectors for Sakesar and Chorgali Formation were marked clearly whereas three faults F1, F2, and F3 were visible on the seismic section. The main pop-up structure is in between F2 and F3. The F2 and F3 are joining with the main F1 fault in the lower part. However, the marine sequence is separating from the basement line clearly. The seismic line shows the sub-surface pop-up have no continuity with the surface anticlinal appearance (Fig 4.6).

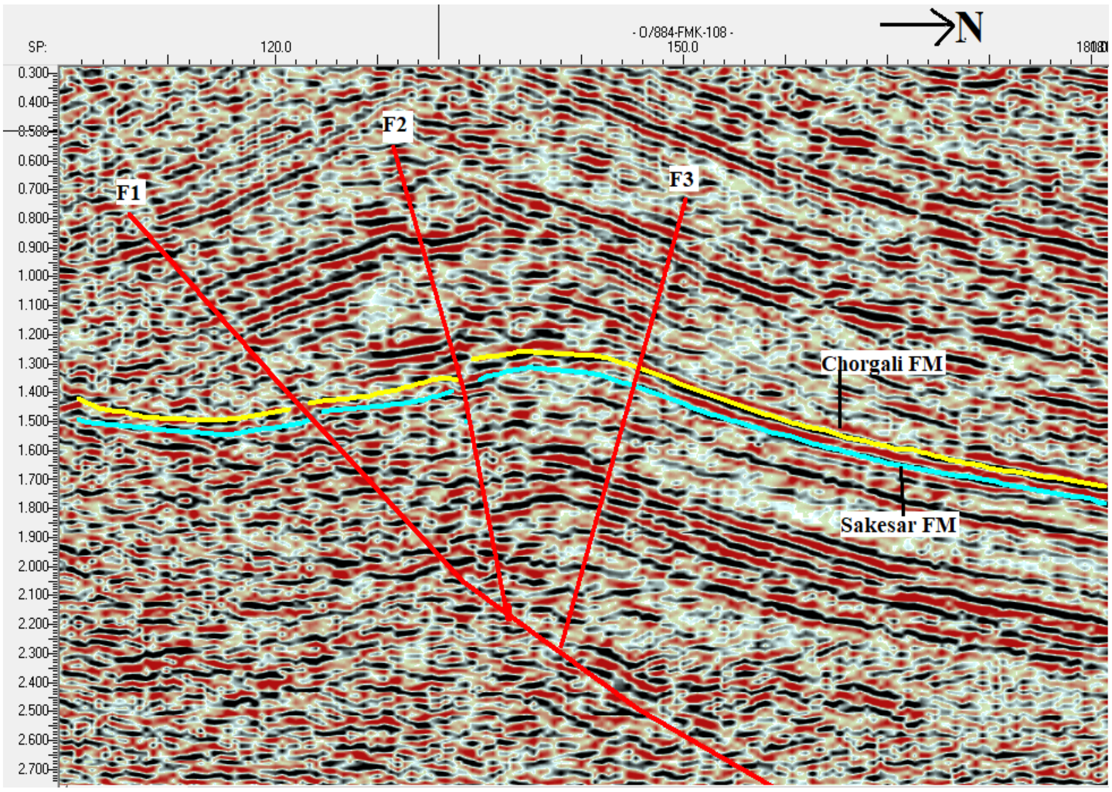


Figure 4.6 The interpreted seismic section of seismic line G884-FMK-108.

4.10 Generation of Time Contour Maps

For the construction of time contour maps there should be more than one seismic sections of the similar area to be interpreted. There are seven seismic lines of the study area (G884 – FMK – 101, G884 – FMK – 103, G884 – FMK – 104, G884 – FMK – 105, G884 – FMK – 106, G884 – FMK – 107, AND G884 – FMK - 108) that are interpreted and time contour maps are made. The time contour maps are made by the following procedures:

i. From the seismic section the time reading have been transferred to particular seismic lines on the base map after specific interval.
ii. To construct iso-contour lines, join the points of equal values on the seismic lines.

4.10.1 Chorgali Formation Time Contour Map

The time contour map of Chorgali showing shallow time ranging from 1.14ms to 1.16 ms in the center of contour map surrounded by two thrust faults. So the structure is confirmed from the contour map which is an anticlinal structure. Shallow value of time is 1.14 ms and greater value of time is 1.6 ms with 0.02 s contour interval. The interpreted time map of Chorgali indicates synform anticlinal structure with little high in the north-eastern part. A smaller fault is also running in between F2 and F3 in the northeast to southwest (NE-SW) directions which would be a source of communication within the reservoir. Southwestern part of the map is also showing high rise of the anticline (Fig 4.7).

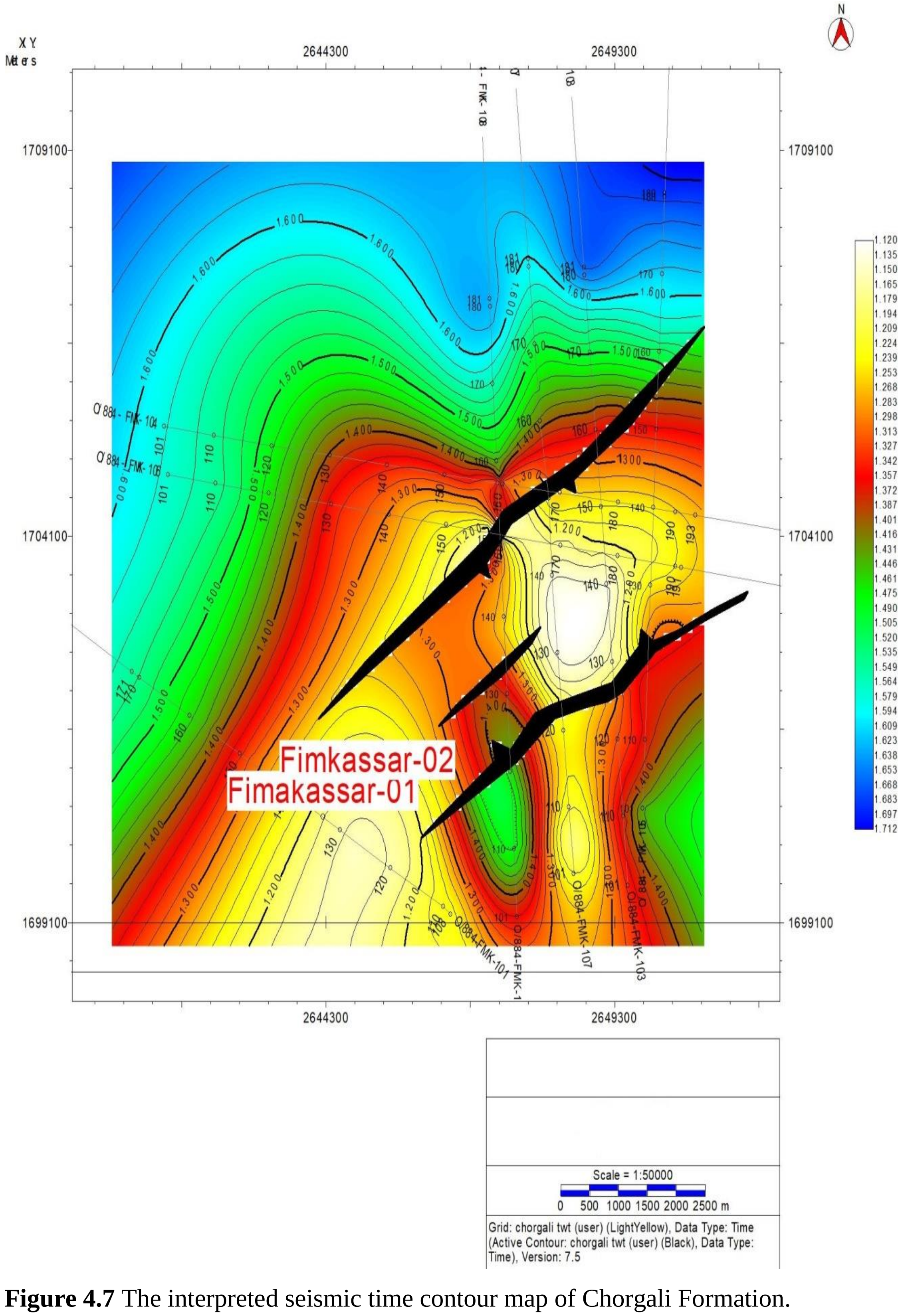


Figure 4.7 The interpreted seismic time contour map of Chorgali Formation.

4.10.2 Sakesar Formation Time Contour Map

The interpreted time map indicates overall structure is in the northeast to southwest (NE-SW) in direction. The time contour map of Sakesar showing shallow time ranging from 1.24 ms to 1.28 ms in the center of contour map surrounded by two thrust faults. Here the structure is confirmed from the contour map which is an anticlinal structure. Shallow value of time is 1.24 ms and greater value of time is 1.9 ms with 0.02s contour interval. The interpreted time map of Sakesar Formation which is a reservoir in same structure at Eocene level duplicating two major faults F2 and F3 and duplicating the upper trend. It is also equipped with the smaller fault running northeast to southwest (NE-SW) which would be the source of communication within the structure. This synform anticline is showing a high on north eastern part and southwestern part at same level (Fig 4.8).

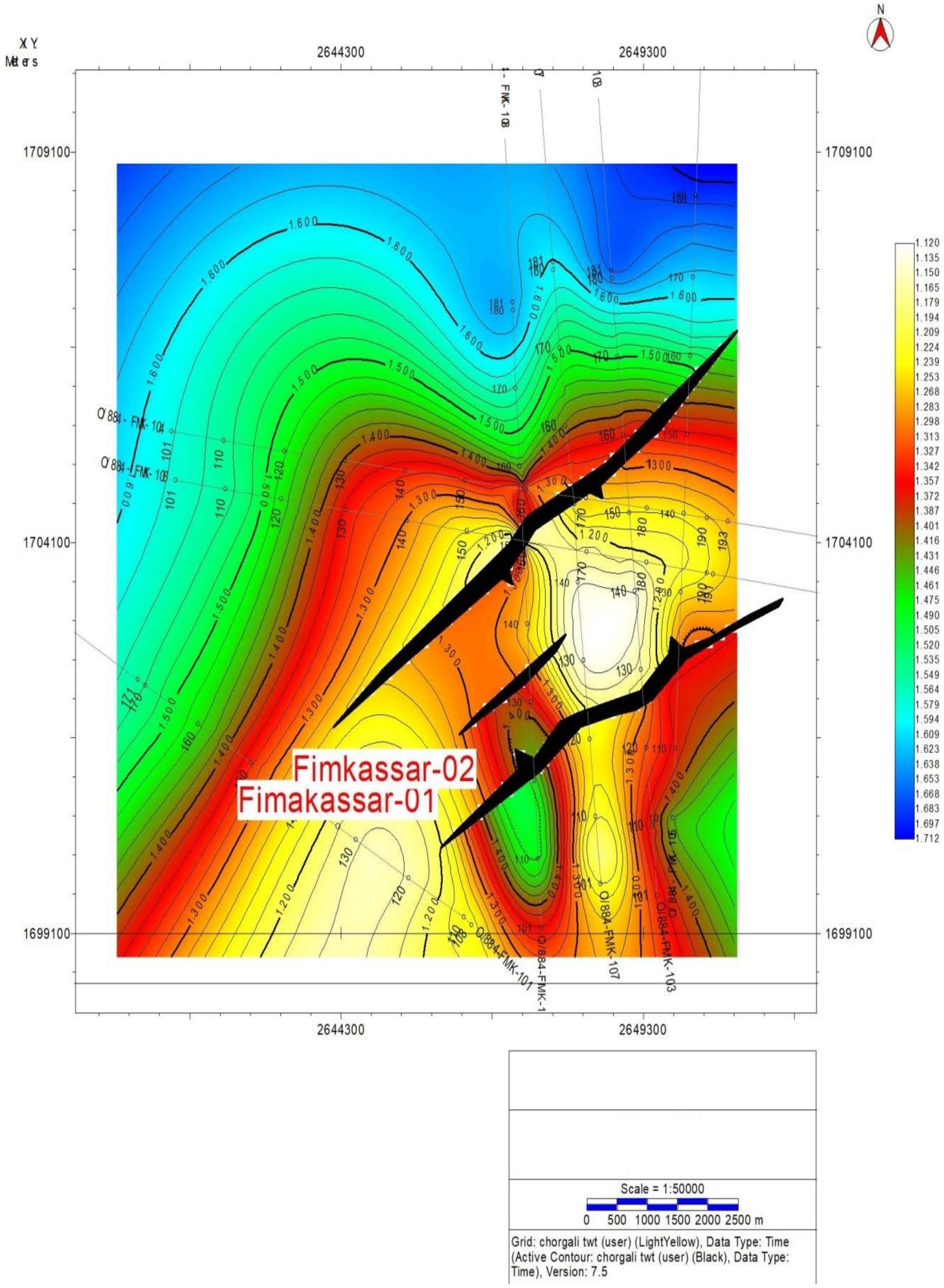


Figure 4.8 The interpreted seismic time contour map of Sakesar Formation.

4.11 Generation of Depth Contour Maps

To make a depth contour map it is necessary that more than one seismic sections of the same area must be interpreted. There are seven seismic lines which are interpreted and depth contour maps are made. The depth contour maps are made by the following procedure:

i. Depth contour maps are generated after solving the velocity window on an excel sheet. Depth contour maps represent the variation in structure in terms of depth
ii. By constructing a depth contour map, more precise position of horizons in the subsurface are known
iii. As compared to time the unit in depth is in meter instead of seconds, instead of time now the depth is shown

4.11.1 Chorgali formation Depth Contour Map

The depth contour map of Chorgali showing shallow depth ranging from 2600m to 2800 m in the center of contour map surrounded by two thrust faults. Here the structure is confirmed from the contour map which is an anticlinal structure. Shallow value of depth is 2550 m and greater value of time is 3550 m with 50 m contour interval. The interpreted time map of Chorgali indicates synform anticlinal structure with little high in the north-eastern part. A smaller fault is also running in between F2 and F3 in the northeast to southwest (NE-SW) directions which would be a source of communication within the reservoir. Southwestern part of the map is also showing high rise of the anticline (Fig 4.9).

4.11.2 Sakesar Formation Depth Contour Map

The depth contour map of Sakesar showing shallow time ranging from 2900 m to 3000 m in the center of contour map surrounded by two thrust faults. Here the structure is confirmed from the contour map which is an anticlinal structure. Shallow value of time is 2800 m and greater value of time is 4500 m with 50 m contour interval. The interpreted time map of Sakesar Formation which is a reservoir in same structure at Eocene level duplicating two major faults F2 and F3 and duplicating the upper trend. It is also equipped with the smaller fault running northeast to southwest (NE-SW) which would be the source of communication within the structure. This synform anticline is showing a high on north eastern part and southwestern part at same level (Fig 4.10).

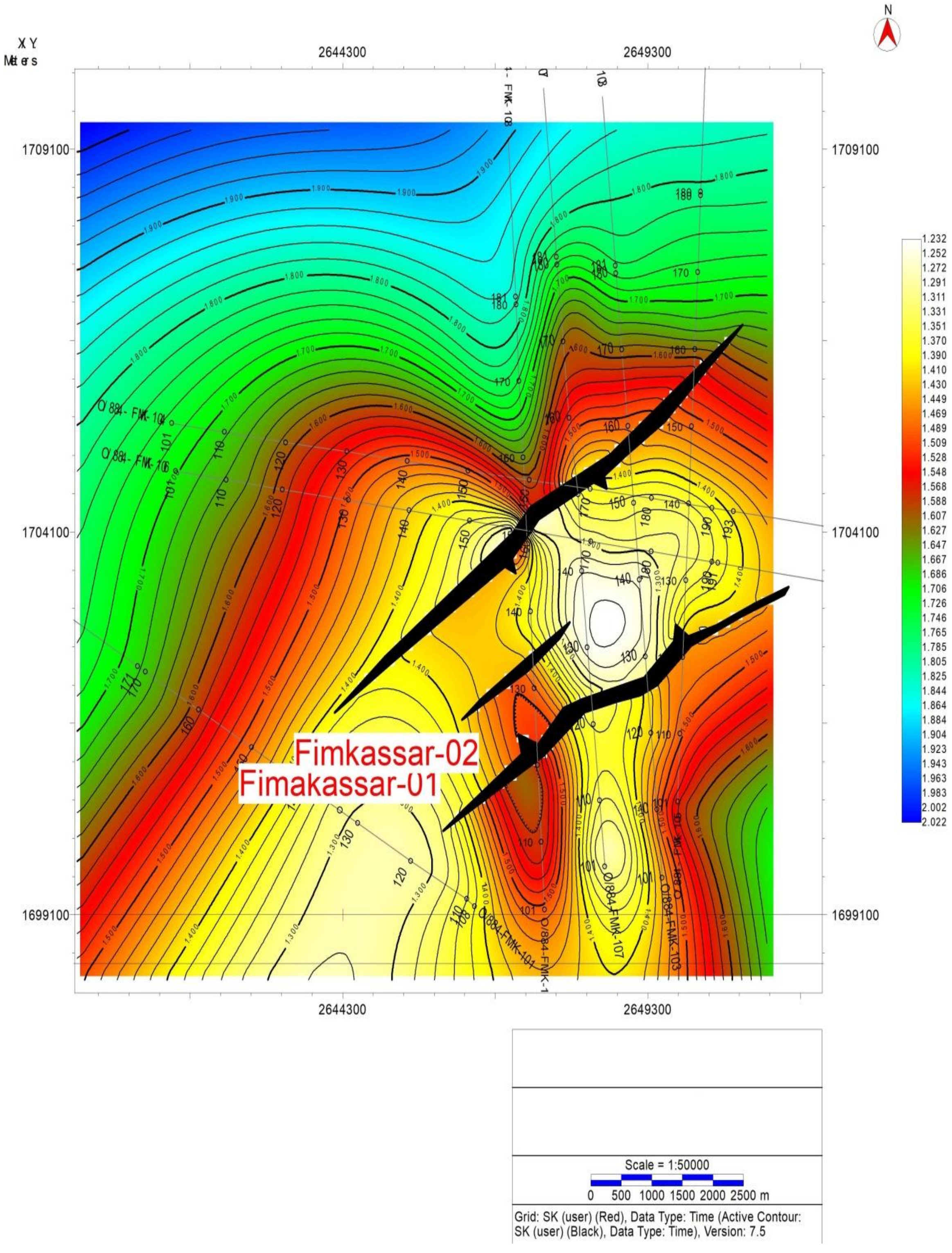


Figure 4.9 The interpreted seismic depth contour map of Chorgali Formation

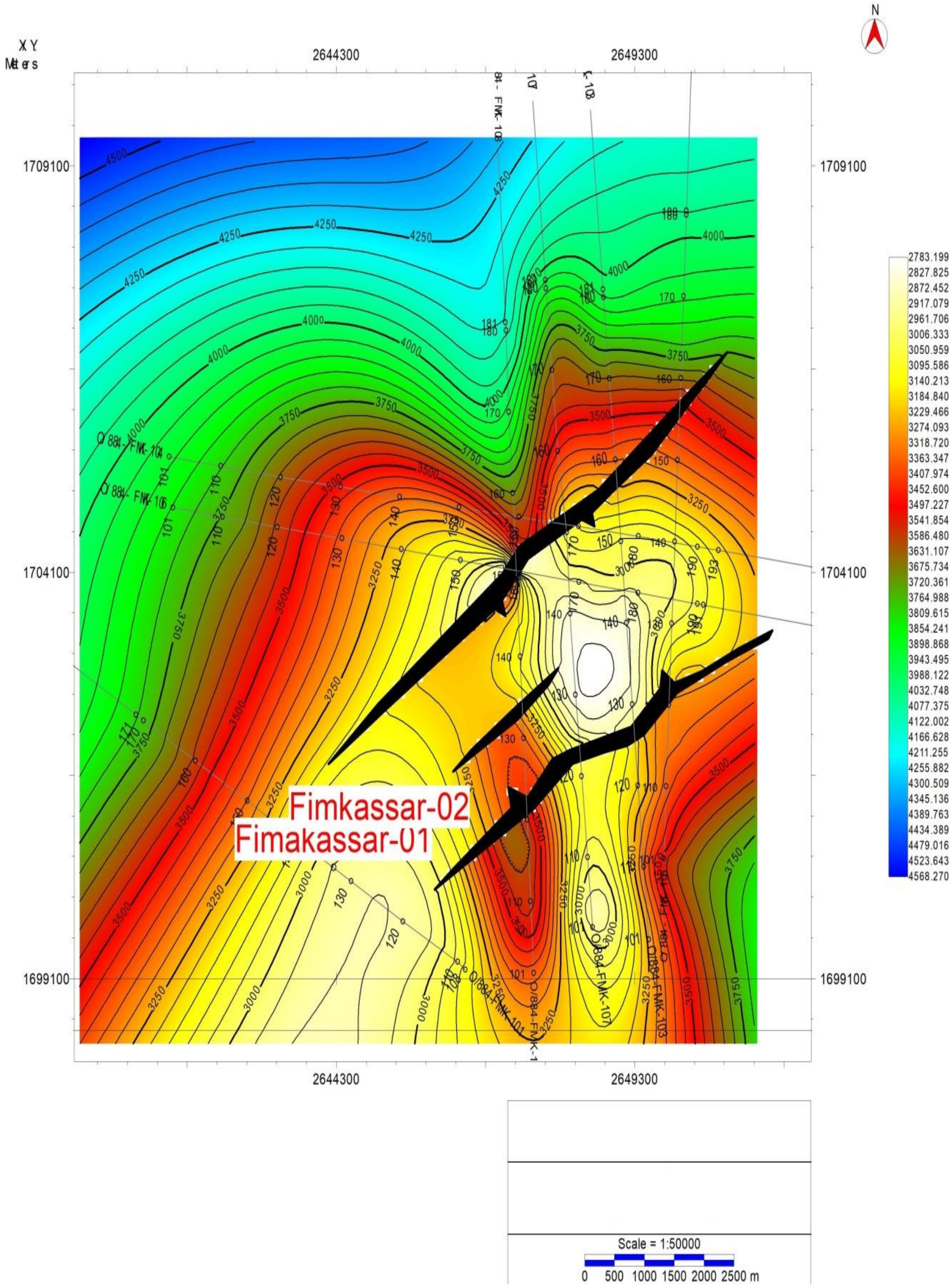
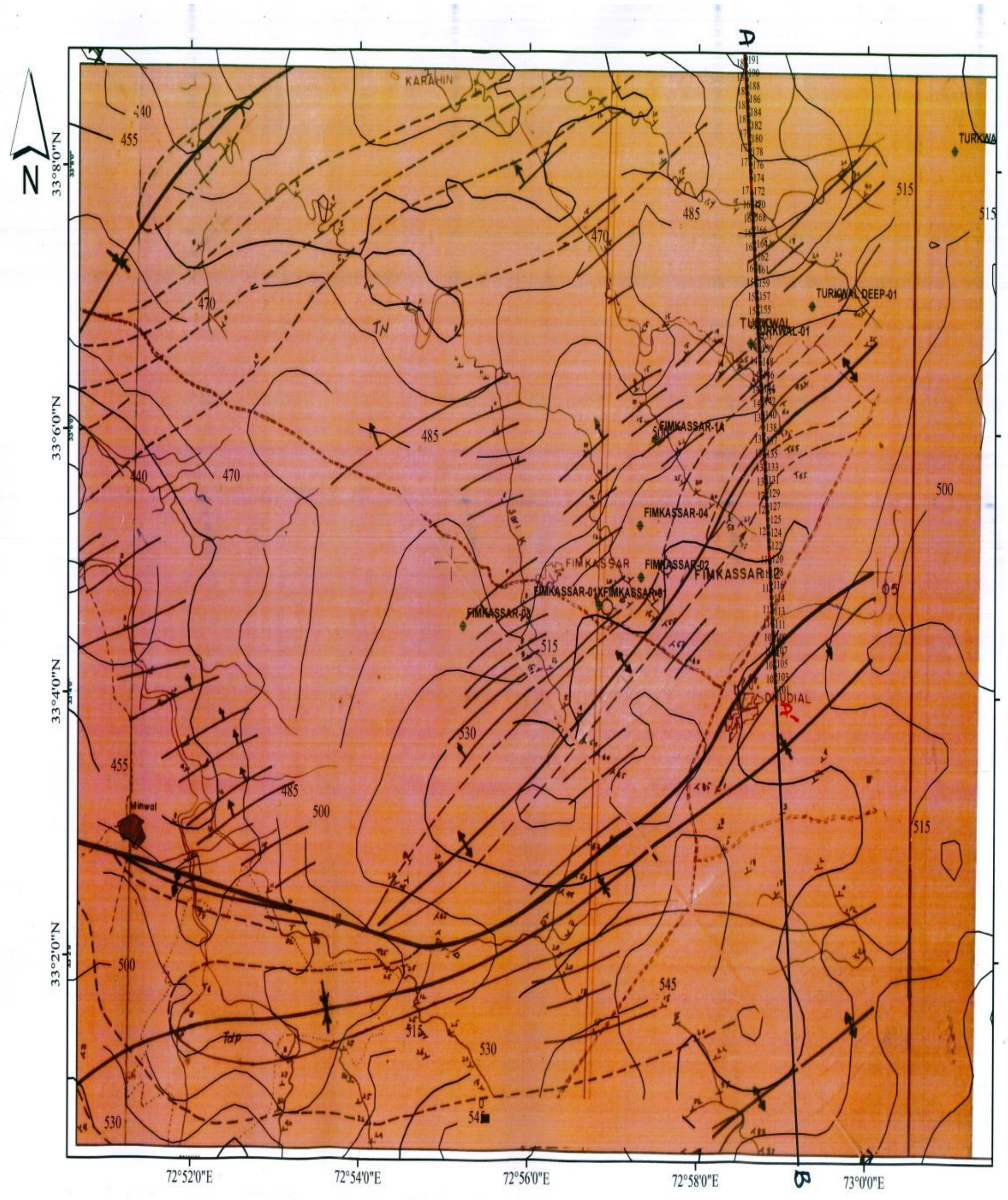


Figure 4.10 The interpreted seismic time contour map of Sakesar Formation

4.12 Correlation

The Surface Geologic mapping was carried out identifying Nagri Formation on the surface with a faulted NE-SW trending faulted anticline on Fimkassar field, where structure data along with the fractures were studied. The structural map was prepared with the help of structural data over a large area covering Fimkassar Field with neighboring area indicating folding trend making anticline and syncline on the surface (Figure 5.1). Traverses were made in order to confirm the structure. Several attempts were made to collect the data almost in all Nala cuts appearing in the area. The structural shortening of 4750 m was calculated with the help of structural data, specifically for the project area (Fig 5.2A).

The 2-D seismic lines were collected and interpreted keeping in view the base map and producing horizons (Chorgali and Sakesar) were marked along with the major faults occurring in the area covered by seismic lines. A structural shift was calculated with reference to surface of almost 10 shot points (1500 m) towards the north (Fig 5.2B). Previously, well locations were followed looking at the permanent marker of the seismic lines which were affecting the structural shift understanding. This is enlightening the development of the structure and easier marker for well location. This will also add for the reservoir for injection and for maintaining its pressure.



Scale 1 : 50,000

Figure 4.11 The manual structural map of the study area, Fimkassar oilfield.

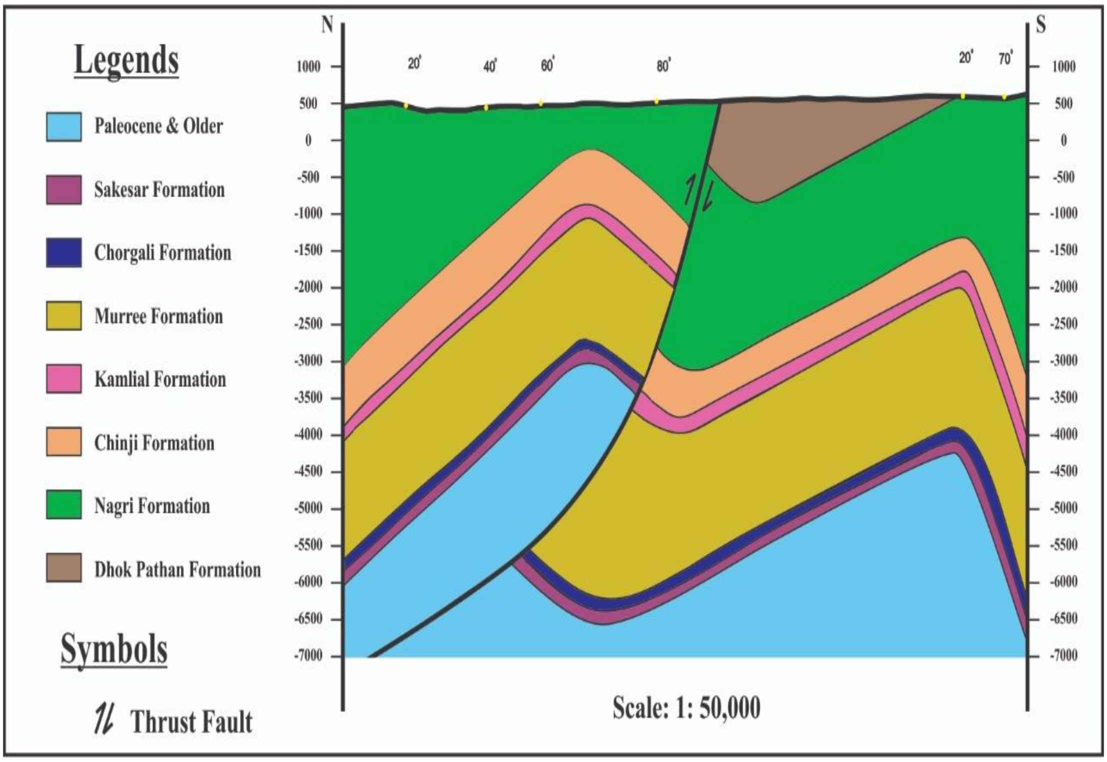


Figure 4.12 The cross-section shows the surface anticlinal structure of Fimkassar oilfield

CONCLUSION

The Surface geologic mapping was carried out for Fimkassar oil field. But couldn’t trace complete anticline on surface because of limited exposure due to cultivation, vegetation and human activities. No faults were traced on surface. Following are the conclusions drawn from this study.

1. The seismic lines revealed reverse faults making it suitable for drilling wells forming a triangular zone in the south.
2. A structural sift of 3.182 Km was observed in the sub-surface anticlinal structure over surface anticline.

FUTURE WORK & RECCOMENDATION

The following recommendation could be drawn;

i. Geologic mapping should be extended on a larger area including surrounding oilfield
ii. A lead from the Choa Saidan Shah should be traced to Joyamair, Fimkassar and Turkwal Field
iii. Detailed study of Chorgali and Sakesar should be added from the type locality
iv. 2 D Seismic lines across the basin would help for better understanding of structural style in the basin
v. It is recommended here that with the help of latest filters, we might be able to identify the fault continuity which we have been identifying in dip lines

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