Facies Analysis and Reservoir Characterization of Rohtas Limestone in Son Valley, Vindhyan Basin, MP

DISSERTATION REPORT

Submitted By

MEENAKSHI RAWAT (R770214013)

In partial fulfillment of the requirements for the award of the degree of

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UNDER THE MENTORSHIP OF

Amit Raina, AEE (Reservoir), ONGC

&

DR. S MAHANTI

GENERAL MANAGER (GEOLOGY), ONGC

Course coordinator
Dr. Mandira Agarwal
Associate Professor
UPES, Dehradun

Internal Mentor
Dr Pushpa Sharma
Professor
UPES, Dehradun

DEPARTMENT OF PETROLEUM ENGINEERING & EARTH SCIENCES
COLLEGE OF ENGINEERING STUDIES
UNIVERSITY OF PETROLEUM & ENERGY STUDIES
Bidholi Campus, Energy Acres, Dehradun-248007

April - 2016

DECLARATION

I hereby declare that this submission is my own and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other Degree or Diploma of the University or other Institute of Higher learning, except where due acknowledgement has been made in the text.

MEENAKSHI RAWAT
(R 770214013)

Oil and Natural Gas Corporation

Frontier Basin,K.D.M.I.P.E. Campus

9, Kaulagarh Road, Dehradun.

CERTIFICATE

This is to certify that Ms. Meenakshi Rawat, a student of M.Tech. Petroleum Exploration, Sem-IV, University of Petroleum & Energy Studies, Dehradun, has successfully completed his Dissertation work on topic **"Facies Analysis and Reservoir Characterization of Rohtas Limestone in Son Valley, Vindhyan Basin, MP "** from 7th January, 2016 to 30th April, 2016 at Vindhyan Block, Frontier Basin, Oil and Natural Gas Corporation (ONGC), Dehradun.
During the training she has maintained excellent discipline and normal code of conduct.

I wish all success for her.

Date: - 10 **May** 2016

Dr. S Mahanti
General Manager Geology,
ONGC, Dehradun

CERTIFICATE

This is to certify that the Project titled "**Facies Analysis and Reservoir Characterization of Rohtas Limestone in Son Valley, Vindhyan Basin, MP**" is carried out at ONGC, Dehradun, Uttarakhand from 7th Jan to 30thApril 2016 is submitted by **MEENAKSHI RAWAT**, **Roll No-13,** to University of Petroleum & Energy Studies, for the award of the degree of **MASTER OF TECHNOLOGY** in **Petroleum Exploration**. The project work carried is out by her under our supervision and guidance.

The content of the Project, in full or parts have not been submitted to any other Institute or University for the award of any other degree or diploma.

Internal Mentor
Dr. Pushpa Sharma
Professor
UPES, Dehradun

External Mentor
Dr. S Mahanti
General Manager Geology,
ONGC, Dehradun

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I also thank my parents and friends for their support throughout the project.

MEENAKSHI RAWAT

DECLARATION BY THE SCHOLAR

I hereby declare that this submission is my own and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other Degree or Diploma of the University or other Institute of Higher learning, except where due acknowledgement has been made in the text.

MEENAKSHI RAWAT

ABSTRACT

The project deals with Facies Analysis and Reservoir Characterization of Rohtas Limestone in Son Valley, Vindhyan Basin, MP**.** Presence of thermogenic gas has been established within Proterozoic Vindhyan sediments in the Son Valley part of Vindhyan Basin. The unconventional carbonate reservoirs of Rohtas Limestone have very low primary porosity and ultra-low permeability. The gas accumulation and the flow potential of hydrocarbons largely depend on the secondary porosity in the form of fractures.

Facies analysis of the Rohtas Limestone is attempted to understand the control of facies types for entrapment of gas. The study of Facies is made through analysis of lithological data, microfacies analysis along with the study of Gamma ray log, Density log and Caliper log of few selected wells.

The Rohtas Limestone has been divided in to three units, the upper, middle and lower. The Upper Rohtas Limestone comprises of thick limestone unit with very thin laminations of shale. The dominant facies consists of mudstone, dolomitic limestone and wackestone. The Middle Rohtas consists of predominant shale with thin limestone laminations. The Lower Rohtas consists of mainly limestone with interbedded shale. The main facies in the limestone comprises mudstone and dolomitic limestone.

The understanding of fracture geometry of Rohtas Limestone has been also attempted by integrating the high-resolution data from an electric borehole image log and its integration with the conventional wire line logs.

Xtended Range Micro Imager (XRMI) logs with improved signal to noise ratio with very high resolution borehole images, showing millimeter size features in the fabric of limestone reservoirs is useful to identify the closed fracture, open fractures, partially open fractures and the stress direction. It is also useful for identifying the Sedimentary Sequence, Reservoir Facies, Bedding Dips, which help to rationalize the choice for the next drilling location. Further it is used for identifying zones of testing and well stimulation. As a case study, XRMI and other log suites was studied for two selected wells to understand the distribution of fracture pattern in the Rohtas Limestone.

The project will be helpful in understanding the Geometry of Unconventional Reservoir of the Rohtas Limestone.

OBJECTIVES

- To understand the distribution of Facies within the Rohtas Limestone to identify suitable locale for hydrocarbon accumulation.
- To prepare correlation profiles of selected wells to understand the Facies distribution of Rohtas Limestone across the study area.
- Integrated study of conventional logs like Gamma ray, Density and Neutron Logs and lithological data are used to identify the lithofacies present in Rohtas Limestone.
- To use high resolution XRMI log to evaluate the fractures and also to know the maximum & minimum horizontal stress in Rohtas Limestone carbonate reservoir.
- To develop an understanding of well logging techniques to facilitate the present study.

MATERIAL AND METHODS

- Wells log data of seven well has been considered for the Facies analysis and two wells data are taken for Reservoir characterization of Rohtas Formation.
- Three profiles have been prepared two in dip direction and one in strike direction using Geologging software.
- Conventional logs like Gamma ray, Density and Resistivity logs are used to identify the distribution of broad lithology within the Rohtas Limestone.
- The data of cuttings, cores and petrography are integrated for identifying the main facies in Rohtas Limestone.
- Regional tectonics and the faults associated with fractures were analysed to understand the fracture distribution
- High resolution XRMI LOG is used to evaluate the fractures in carbonate reservoir to know the minimum and maximum stress direction

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PREFACE

Oil and Natural Gas Corporation Limited (**ONGC**) is an Indian state-owned Oil and Gas company headquartered at Dehradun, India and contributes 69% of India's crude oil production and 62% of India's natural gas production. It is one of the Asia's largest and most active companies involved in exploration and production of oil.

ONGC is the flagship company of India at present and in making this possible is a dedicated team of nearly 33,000 professionals with over 18,000 technically-competent experienced scientists and engineers which includes geologists, geophysicists, geochemists, drilling engineers, reservoir engineers, petroleum engineers, production engineers, engineering & technical service providers, financial and human resource experts and IT professionals.

ONGC has a unique distinction of being a company with in-house service capabilities in all the activity areas of exploration and production of oil & gas and related oil-field services. The company has adopted progressive policies in scientific planning, acquisition, utilization, training and motivation of the team.

Frontier Basin, Dehradun deals in Category III & IV sedimentary basins in India. These basins are generally poorly explored, logistically difficult, have diverse tectonic set-up and involve high risk & uncertain reward. Exploration in these basins is both- cost and technology intensive. Out of the seventeen onland frontiers in India, Frontier Basin is currently operating in three of them, viz. Himalayan Foothills, Rajasthan and Vindhyan, geographically spread over five states-Himachal Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh and Rajasthan.

The topic was selected keeping in view the ongoing activities at Vindhyan Basin, dealing largely with unconventional tight gas reservoirs. This is a little explored and challenging area of study. Real reservoir characteristics were studied to pave way for better future characterization.

CHAPTER 1

1.1 INTRODUCTION

Presence of thermogenic gas has been established within the Proterozoic sediments of Vindhyan Basin in the Son Valley sector. The accumulation of gas has been observed within ultra-low permeability and very low porosity unconventional reservoirs. Hydrocarbon accumulation and flow potential in carbonate reservoirs depends on fault-induced fractures. Therefore, borehole fracture studies are very important for calculating fracture porosity and permeability. The new borehole image interpretation technique was developed specifically to evaluate the porosity and permeability of carbonate reservoirs by integrating the high resolution data from an electrical borehole image log with the conventional wire line logs.

Presence of non-commercial gas has been observed in Son Valley sector within Rohtas Limestone, the topmost stratigraphic unit of the Lower Vindhyan sequence. The Rohtas Limestone is divided in to upper limestone middle shale and a lower limestone unit.

Xtended Range Micro Imager (XRMI) logs with improved signal to noise ratio with very high resolution borehole images, showing millimeter size features in the fabric of limestone reservoirs is useful to identify the closed Fracture, open Fractures, partially open Fractures and the stress direction. It is also useful for identifying the Sedimentary Sequence, Reservoir Facies, and Bedding Dips, which help to rationalize the choice for the next drilling location. Further it is used for identification for zones of testing and well stimulation. As a case study, XRMI and other log suites will be studied for two selected wells to understand the distribution of fracture pattern in the Rohtas Limestone.

1.2 LOCATION

The Vindhyan Basin is a Proterozoic basin in the Central part of India, situated between the Delhi - Aravalli Orogenic belt to the north-west and Son-Narmada Geo-fracture to the south.

The Bundelkhand Massif, located in the north-central part of the basin, divides it into two sectors: Chambal Valley to the west and Son Valley to the east.

The basins fill in Son Valley constitutes a considerable thickness (2-6Km) of unmetamorphosed, varyingly deformed sedimentary succession, which is divisible into carbonate dominated Lower Vindhyan (Semri Group) and Clastic dominated Upper Vindhyan (Kaimur, Rewa and Bhander Groups) sequences, separated by a large hiatus.

1.3 GEOLOGY OF THE BASIN

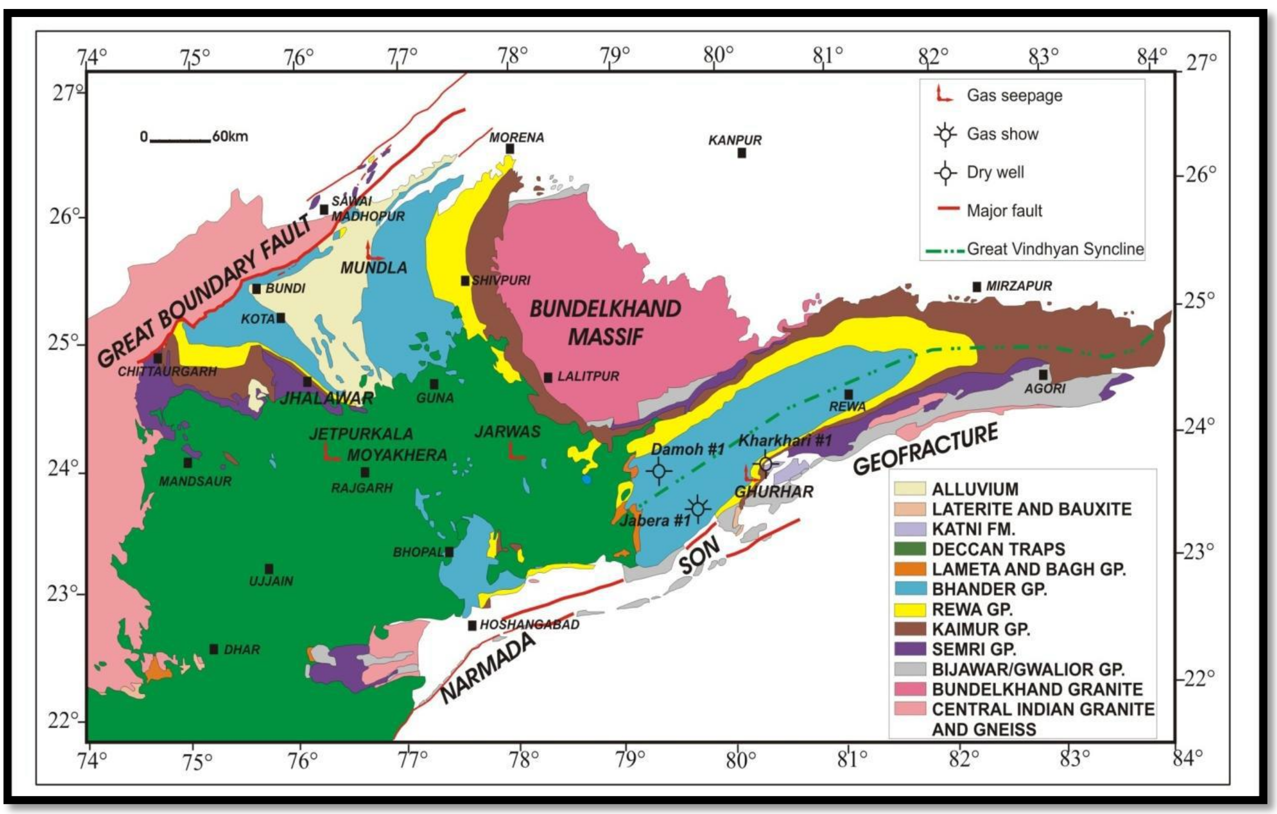


Fig .1 Geological map of Vindhyan Basin

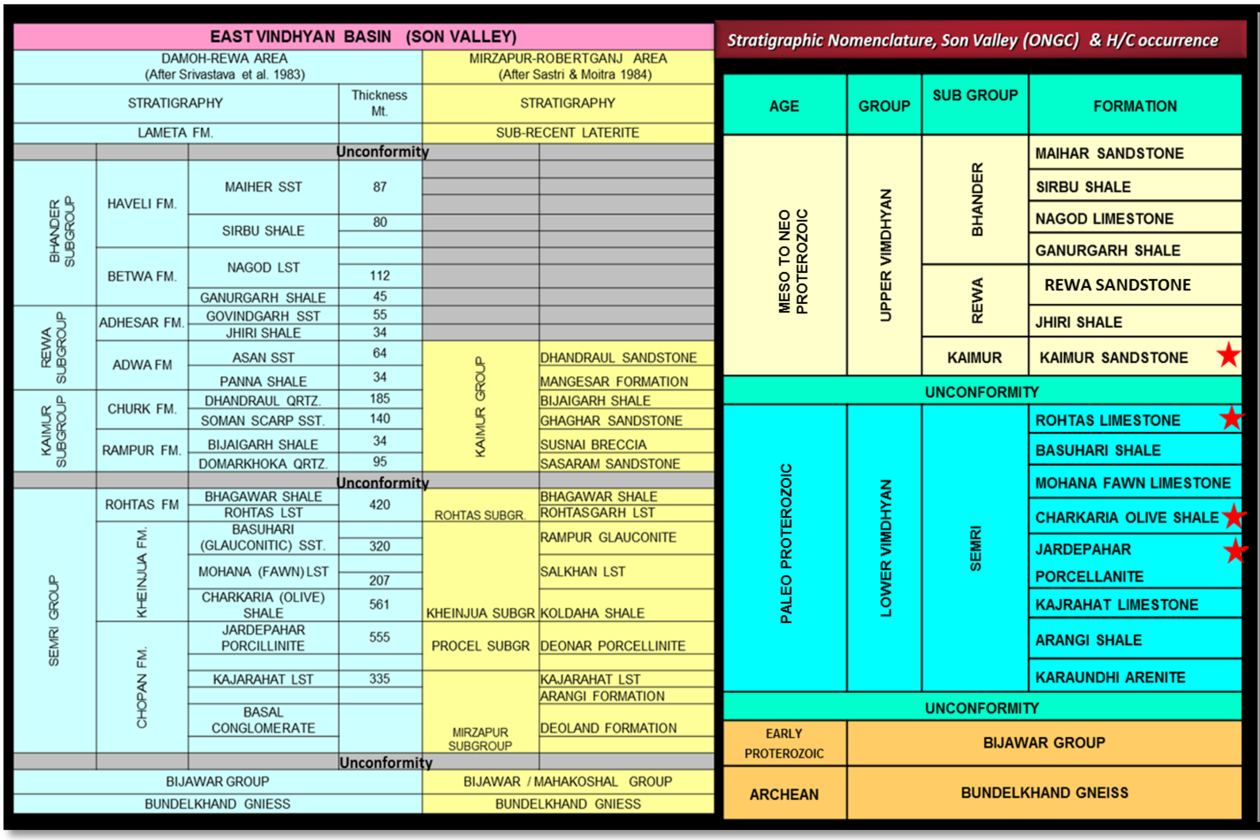


Fig.2: Generalized Stratigraphy of Son Valley, Vindhyan Basin

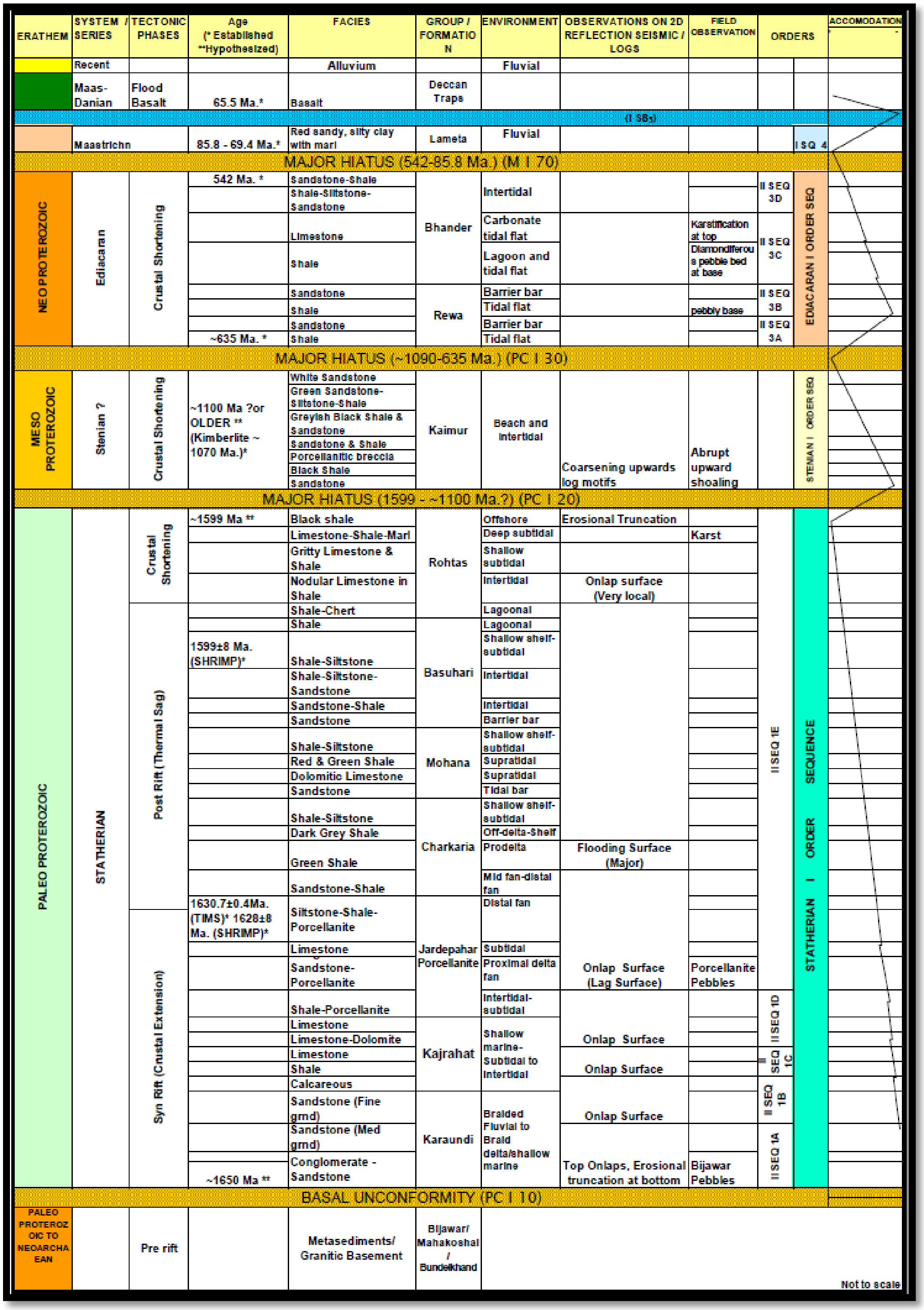


Fig.3: Sequence Stratigraphic Chart of Son Valley, Vindhyan basin

1.4 STRATIGRAPHY

The arcuate shaped Vindhyan basin of central India has developed over the Archaen-Paleoproterozoic basement consisting of highly deformed metamorphics and granitic rocks. As seen today Vindhyan rocks are present in two sectors, i.e. Son valley and Rajasthan-Chambal valley (Figure 1). The major tectonic elements in and around the Vindhyan basin are **Narmada-Son lineament to the south, Great Boundary Fault to the north-west and number of interbasinal faults cutting across the basin such as KotaDholpur, Ratlam-Sivpuri, Basoda-Barsingarh, Kannod- 2 Damoh-Bansipur-Rewa and Mukundra fault.**

Bundelkhand gneissic complex is situated in the north-central part and imparted a dominant control on the evolution of Vindhyan basin. Son-Narmada lineament is considered as the southern basin boundary fault (West, 1962 and Chaubey, 1969) which defines the Son valley Vindhyan basin. There are different tectonic models suggested for this basin such as Intracratonic basin (Biswas et al., 1993), foreland basin (Chakraborty, 1996), rift basin with well-defined syn-rift and post-rift phases (Ram et al., 1996; Bose et al., 2001). The current study demonstrate that Vindhyan basin initiation took place under an extensional regime with complex extensional fault system defining horsts and grabens with pronounced along-strike variation in morphology and style. Overall the Vindhyan succession is mildly deformed except in basin margin areas where the lower Vindhyans are moderate to strongly deformed and thrusted over by the older rocks.

Son valley Vindhyans has an ENE-WSW trending regional synclinal disposition with minor westerly plunge. Vindhyan succession represents a thick sedimentary pile, about 6000m belonging to Meso–Neoproterozoic age. The entire succession belongs to two distinct depositional cycles. The older one dominantly calcareous and argillaceous with Volcani-clastics, referred to as Semri or Lower Vindhyan. The younger cycle, is dominantly Siliciclastic with minor proportion of carbonates, commonly known as Upper Vindhyan comprising of Kaimur, Rewa and Bhander Subgroups. The upper Vindhyan succession unconformably overlies the lower Vindhyans.

1.5 Tectonic setting

The Vindhyan Basin is genetically associated with two mega tectonic elements: Great Boundary Fault (GBF) to the northwest and Son-Narmada Lineament (SNL) to the south. The Vindhyan strata of Son Valley define a broad ENE–WSW trending regional syncline in the central part. The axis of the syncline is slightly curved (convex towards north) and plunges gently towards west detailed account of tectonic framework including the fault systems, Paleo-structures, structural inversion and deformation history have been described by many workers from time to time (Jokhan Ram et al., 1996, Mahendra Pratap et al., 1999).

Son Narmada Lineament is a major crustal feature formed along the Archean structural trends and remained active throughout geologic history till the present day. It marks the tectonic sedimentation limit of Vindhyan Basin in south and south -east. The greater thickness of sediments in Son Valley area towards south implies an active southern margin along which relatively continuous subsidence was responsible for greater thickness of sediments. The northern and eastern margins of basin have gentle gradient. Intense structural deformation of the Lower Vindhyan Sequence in vicinity of SNL is evidenced by the presence of tight folds, normal and reverse faults, Thrusted contacts and Mylonitisation.

Initial tectonic evolution of Vindhyan Basin is controlled by basement related rift tectonics, which formed a number of horst and grabens along planes of weakness. Two main fault trends are evident, faults parallel to the SNL (E-W to ENE-WSW) as well as along NW-SE aligned oblique faults. The major half Grabens are located along the down thrown side of these rift related faults. Some of these faults show syn-sedimentary vertical movements. In later phase of evolution, compressional reactivation of pre-existing extensional faults under the influence of wrench related strike–slip movement along the Son-Narmada Lineament (SNL) resulted in the formation of inversion structures like Damoh, Jabera and Kharkhari.Major oblique faults divide Son Valley into a number of tectonic blocks (Fig.2.1), notable among them are the Udaipur-Tendukhera block, Jabera-Damoh block and Satna-Rewa-Kaimur block (Mahendra Pratap et al., 1999). Among these blocks, the Jabera-Damoh block is tectonically the most disturbed.

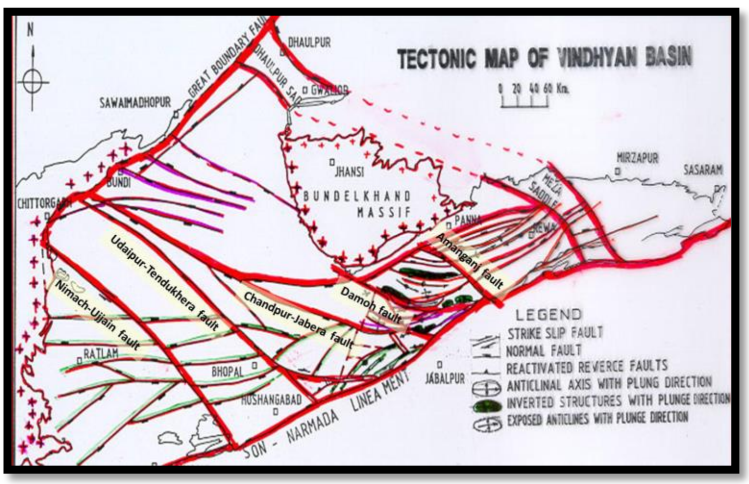


Fig.4 Tectonic Map of Vindhyan Basin

1.6 Basin Evolution

Several models have been proposed for the evolution of the Vindhyan Basin. Simple interior basin model was suggested by Biswas et al. (1993). Chakraborty et al. (1996) suggested that the basin initiated as a peripheral foreland basin in front of the coeval belts of Aravalli-Delhi-Satpura. Based on seismic data, Ram et al. (1996) postulated Vindhyan Basin as an intra/Pericratonic rift (half-graben) with well-defined pre-, syn- and post-rift phases of development in contrast to simple interior basin concept. They also pointed that the horst and graben structural style of syn-rift phase was replaced by a Carbonate-Clastic ramp basin setup during the post–rift stage. Raja and Casshyap (1996) considered that the 'U' shaped Vindhyan Basin developed as a post-Orogenic Pericratonic basin on Bundelkhand craton, following Middle Proterozoic collision with a southerly Protocontinent. They also opined the formation of this basin largely through rift - controlled subsidence under extensional regime.

With these observations, the basin is generally considered to be rifted (?) and evolved through multiphase geological history starting from 1400Ma (?) to 550Ma. The observed volcaniclastic units, faults and sedimentary deformation in the lower part of the Vindhyan section tend to support the rift origin. The initial rifting phase was followed by a phase of compressional reactivation under wrench related movement along Son-Narmada Lineament (SNL) and some oblique faults emanating from SNL forming major inversion structures. In Son Valley, the well-developed sub-basins that are seen today are the Bahuriband - Jabera - Damoh and Udaipur-Tendukhera depressions.

These depressions show half-graben morphology wherein three phases of evolution are evident (Fig.2.2).Crustal extension began at ~ 1.65 Ga, and continued For tens of millions of years. The basal Karaundi, Arangi Shale, Kajrahat and major part of Jardepahar formations were deposited during this time. Onlap surfaces and stratigraphic growth at several levels provide tangible evidence of crustal extension and tilting of fault blocks at the base of Lower Vindhyan. This tectonic evolution is supported by the sedimentological records of having a transition from Conglomerate/Arkosic sandstone at bottom to shallow marine carbonate and shale/siltstone at shallower level. The transition from syn rift to post-rift thermal subsidence (Phase 2) is marked in seismic records by the termination of local stratigraphic growth associated with tilting of extensional fault blocks (at the upper part of Jardepahar level, ~1.63 Ga). Compressional deformation began subsequent to the deposition of the uppermost part of the Lower Vindhyan (onlap surface within an inversion anticline). Basin inversion is thought to mark the end of the thermal subsidence phase and Lower Vindhyan sedimentation at ~1599 Ma. Upper Vindhyan subsidence is ascribed, tentatively, to continuing but likely episodic compression.

1.7 Age of Vindhyan sediments

Although the Vindhyan sediments have been broadly dated as Meso-NeoProterozoic age, determining the independent ages of different sequences has remained an area of considerable uncertainty. Exhaustive biostratigraphic dataset is available for Vindhyan sediments but comprises of only the organic-walled microfossils (Acritarchs, Coccoids and Filamentous Alga), whose age resolution is very coarse (50 Ma.). Neither terrestrial land plants nor marine DinoFlagellates existed during Vindhyan period therefore means of independent age assessment lack on account of absence of pollen, spores and forams. Best confidence lies in the Ediacaran acritarchs as they are constrained with robust age data elsewhere in the Australia and few other sites (Knoll 2006). Radiometric dates of the Vindhyan Basin are rudimentary. Only U-Pb (zircon) dates appear reliable on account of their low errors of 2σ.

The Vindhyan Basin is well known for its profusion of Stromatolites with remarkable morphological diversity. Kumar (1984) recognized two Stromatolite zones, viz. the Kussiella-Colonella zone and Conophyton-Colonella zone of Semri Group with Early to Middle Riphean age and the Baicalia-Tungussia Zone of Bhander Group, Late Riphean age. Sharma, Shukla and Venkatachala (1992) sorted out fifty records of Metaphytes and metazoan from different groups of Vindhyan Supergroup. On the basis of macro- fossils, they have assigned Vindhyan sediments an age of 1000 to 600 Ma. Based on investigations on surface and subsurface samples of Son Valley, Prasad et al., (2003, 2005) demarcated the Proterozoic sediments into various Meso-Neoproterozoic stages using Acritarch and microfossil data (1500-1450 Ma. to 544 Ma).

Prasad et.al (2005) analysed the stratigraphic distribution of selected Meso-Neo Proterozoic organic walled microfossils in Vindhyan sediments of well Damoh#1and dated the sediments as Meso-NeoProterozoic (Fig.2.3). Subsequently, KDMIPE has carried out studies on Palyno fossil assemblages encountered in other drilled wells of Son Valley. Based on the result of these studies, an attempt has been made to recognize biozones and to infer age and depositional environment based on the first appearance datum (FADs) and last appearance datum (LADs) of age significant taxa of Acritarch and associated organic walled microfossils.

CHAPTER 2

2.1 FACIES ANALYSIS AND RESERVOIR CHARACTERIZATION

The current study deals with study and interpretation of logs to interpret the lithology of sub-surface formation. The set of logs used comprises Calliper, gamma ray, SP, Sonic and resistivity Logs. Gamma ray log and SP log are lithology logs and their trend depicts the fining/ coarsening upward trends within a sequence. The set of logs have been further used to predict the lithology, zone of hydrocarbon saturation and various other reservoir and Petrophysical parameters.

In an unconventional reservoir set-up, with very low porosity and permeability values, the role of fracture induced secondary porosity becomes very important. The fractured zones in a well may be delineated using XRMI log which is based on contrast of resistivity. The log has very high resolution and thereby enables in identifying the highly fractured zones of interest. The orientation of the fracture data gives an insight into the Paleo-stress regime which prevailed in the area and resulted in generation of the fractures. The XRMI log of Lower Vindhyan Rohtas Formation has been studied in the following report.

2.12 FACIES ANALYSIS

The following logs of selected wells were analysed in the Rohtas Limestone section and were integrated with cuttings, SWC, conventional Core data and laboratory data to decipher the litho- facies and the micro facies present within the different units of Rohtas Limestone.

i. Caliper log: - A tool that measures the diameter of the borehole, using either 2 or 4 arms. It can be used to detect regions where the borehole walls are compromised and the well logs may be less reliable.

ii. Gamma Ray log: - A log of the natural radioactivity of the formation along the borehole, measured in API, particularly useful for distinguishing between sands and Shales in a Clastic environment. This is because sandstones are usually non-radioactive quartz, whereas Shales are naturally radioactive due to potassium isotopes in clays, and adsorbed uranium and thorium.

iii. Density:- The density log measures the Bulk Density of a formation by bombarding it with a radioactive source and measuring the resulting gamma ray count after the effects of Compton Scattering and Photoelectric absorption. This bulk density can then be used to determine porosity.

2.3 Carbonate Rocks

Since the Rohtas Formation comprises dominantly of carbonate it is prudent here to know the classification schemes of carbonate rocks as well as the depositional set up.

The carbonate rocks make up 10 to 15% of sedimentary rocks. They largely consist of two types of rocks.

I. limestones which are composed mostly of calcite ($CaCO_3$) or high Mg calcite [$(Ca,Mg)CO_3$], and

II. Dolostones which are composed mostly of dolomite [$CaMg(CO_3)_2$]

Because carbonate minerals in general are soluble in slightly acidic waters, they often have high porosity and permeability, making them ideal reservoirs for petroleum. limestone can be easily recognized in hand specimen or outcrop because of its high solubility in HCl. A drop of such acid placed on the rock will cause it to fizz due to the generation of CO_2 gas. A dolostone, on the other hand, will not fizz until a fine powder is made from the rock or mineral. Also, dolostones tend to weather to a brownish color rock, whereas limestones tend to weather to a white or gray colored rock. The brown color of dolostones is due to the fact that Fe occurs in small amounts replacing some of the Mg in dolomite.

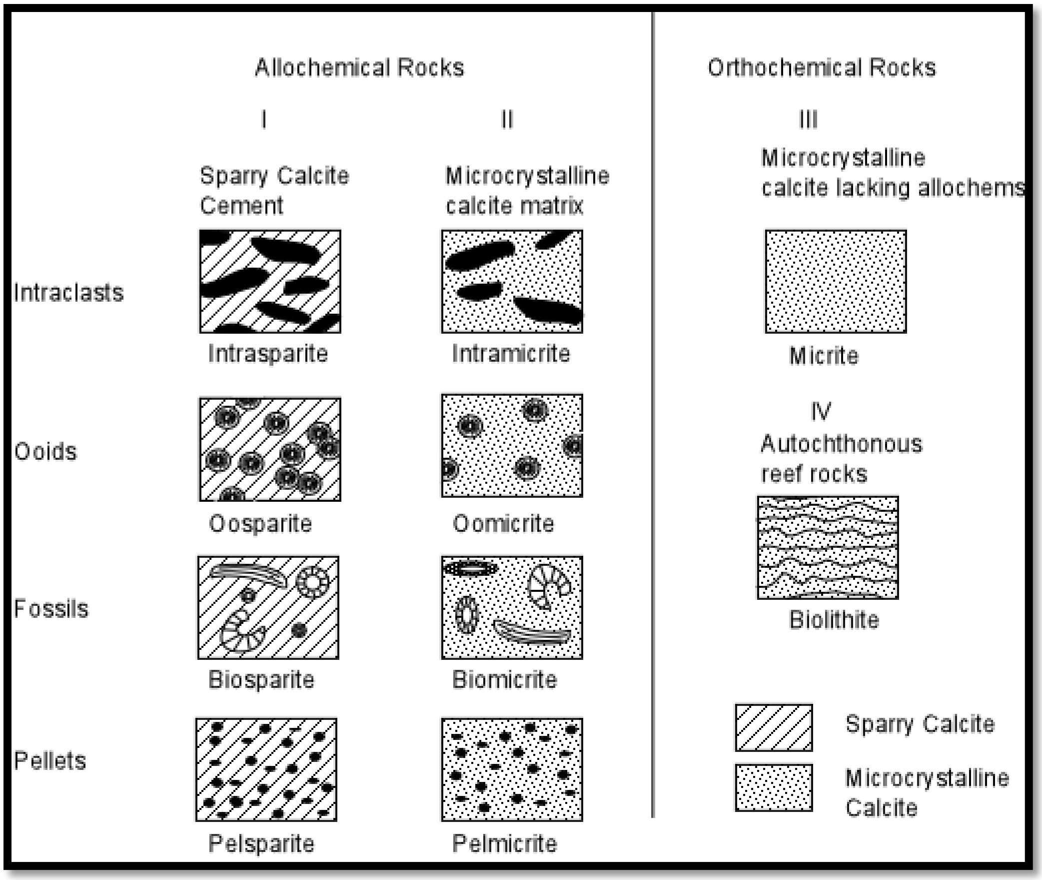


Fig.7 Folks Classification

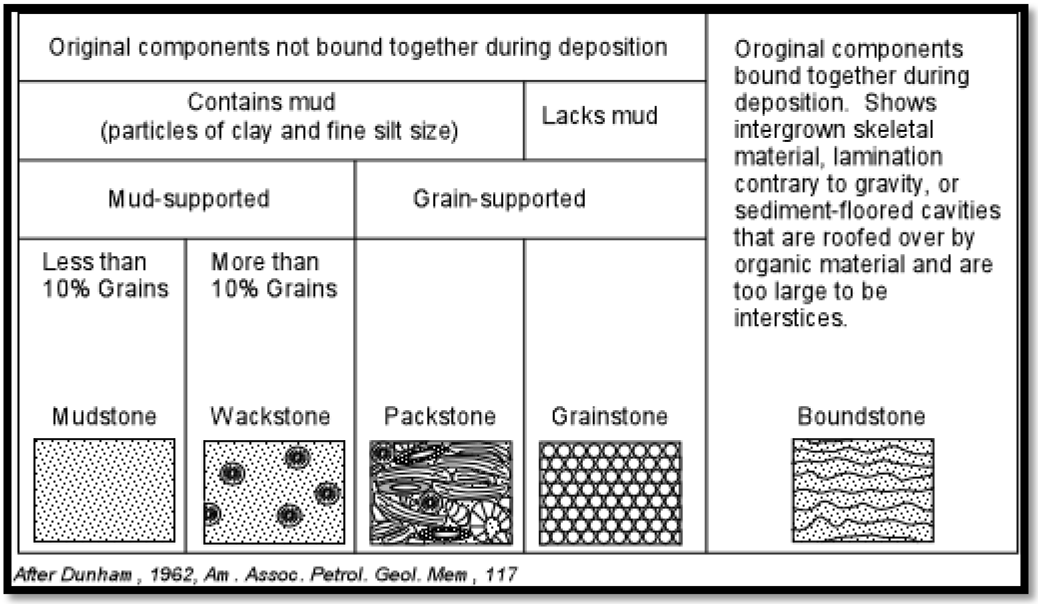


Fig.8 Dunham's Classification

2.4 Carbonate Depositional Environments

Most modern, and probably most ancient, carbonates are predominantly shallow water (depths <10-20 m) deposits. This is because the organisms that produce carbonate are either photosynthetic or require the presence of photosynthetic organisms. Since photosynthesis requires light from the Sun, and such light cannot penetrate to great depths in the oceans, the organisms thrive only at shallow depths. Furthermore, carbonate deposition in general only occurs in environments where there is a lack of siliciclastic input into the water. Siliclastic input increases the turbidity of the water and prevents light from penetrating, and silicate minerals have hardness much greater than carbonate minerals, and would tend to mechanically abrade the carbonates. Most carbonate deposition also requires relatively warm waters which also enhance the abundance of carbonate secreting organisms and decrease the solubility of calcium carbonate in seawater. Nevertheless, carbonate rocks form in the deep ocean basins and in colder environments if other conditions are right.

For this course, our discussion of carbonate depositional environments will be brief. See your text for more detailed discussion. The principal carbonate depositional environments are as follows:

- Carbonate Platforms and Shelves. Warm shallow seas attached the continents, or in the case of epiric seas, partially covering the continents, are ideal places for carbonate deposition. Other shelves occur surrounding oceanic islands after volcanism has ceased and the island has been eroded (these are called atolls). Carbonate platforms are buildups of carbonate rocks in the deeper parts of the oceans on top of continental blocks left behind during continent - continent separation. Reef building organisms from the framework of most of these carbonate buildups.

- Tidal Flats. Tidal flats are areas that flood during high tides and are exposed during low tides. Carbonate sands carried in by the tides are cemented together by carbonate secreting organisms, forming algal mats and stromatolites.

- Deep Ocean. Carbonate deposition can only occur in the shallower parts of the deep ocean unless organic productivity is so high that the remains of organisms are quickly buried. This is because at depths between 3,000 and 5,000 m (largely dependent on latitude - deeper near the equator and shallower nearer the poles) in the deep oceans the rate of dissolution of carbonate is so high and the water so under saturated with respect to calcium carbonate, that carbonates cannot accumulate. This depth is called the carbonate compensation depth (CCD). The main type of carbonate deposition in the deep oceans consists of the accumulation of the remains of planktonic foraminifera to form a carbonate ooze. Upon burial, this ooze undergoes diagenetic recrystallization to form micritic limestones. Since most oceanic ridges are at a depth shallower than the CCD, carbonate oozes can accumulate on the flanks of the ridges and can be buried as the oceanic crust moves away from the ridge to deeper levels in the ocean. Since most oceanic crust and overlying sediment are eventually subducted, the preservation of such deep sea carbonates in the geologic record is rare, although some have been identified in areas where sediment has been scraped off the top of the subducting oceanic crust and added to the continents, such as in the Franciscan Formation of Jurassic age in California.

- Non-marine Lakes. Carbonate deposition can occur in non-marine lakes as a result of evaporation, in which case the carbonates are associated with other evaporite deposits, and as a result of organisms that remove CO2 from the water causing it to become oversaturated with respect to calcite.

- Hot Springs. When hot water saturated with calcium carbonate reaches the surface of the Earth at hot springs, the water evaporates and cools resulting in the precipitation of calcite to form a type of limestone called travertine.

2.5 Correlation Profiles

In this report 3 profiles have been prepared; two profiles in dip direction while one in strike direction; Profile 1 – comprising wells A,B,C,D,E , Profile 2 – comprising wells D,H,I,J and Profile 3 - comprising wells A,F,D,G, 2 in dip direction and 1 in Strike direction.

The variation of thickness of each unit of the Rohtas Formation as well as variation in facies both vertically and laterally has been attempted with the study of these correlation profiles. Litho column in each well in the profile lines were prepared using the well data (cuttings, cores, petrography) and different kinds of logs. Gamma log is used for identification of lithology, shows more values in API if Shale and less values of Gamma log shows the presence of sandstone and further less value shows the presence of Limestone.

The Density value for Sandstone is 2.65 gm/cc, Limestone 2.71 gm/cc and for Dolomite it is 2.87 gm/cc.other logs like resistivity log, Neutron log and Caliper logs have been used.

These Rohtas Limestone is Further Divided into three parts according to the log readings into Upper Rohtas, Middle Rohtas and Lower Rohtas.

The upper Rohtas consists of Dolomitic Limestone in top part and limestone with thin beds of shale in the lower part. Middle Rohtas consists of Shale with laminations of Limestone and the Lower Rohtas consists of Limestone.

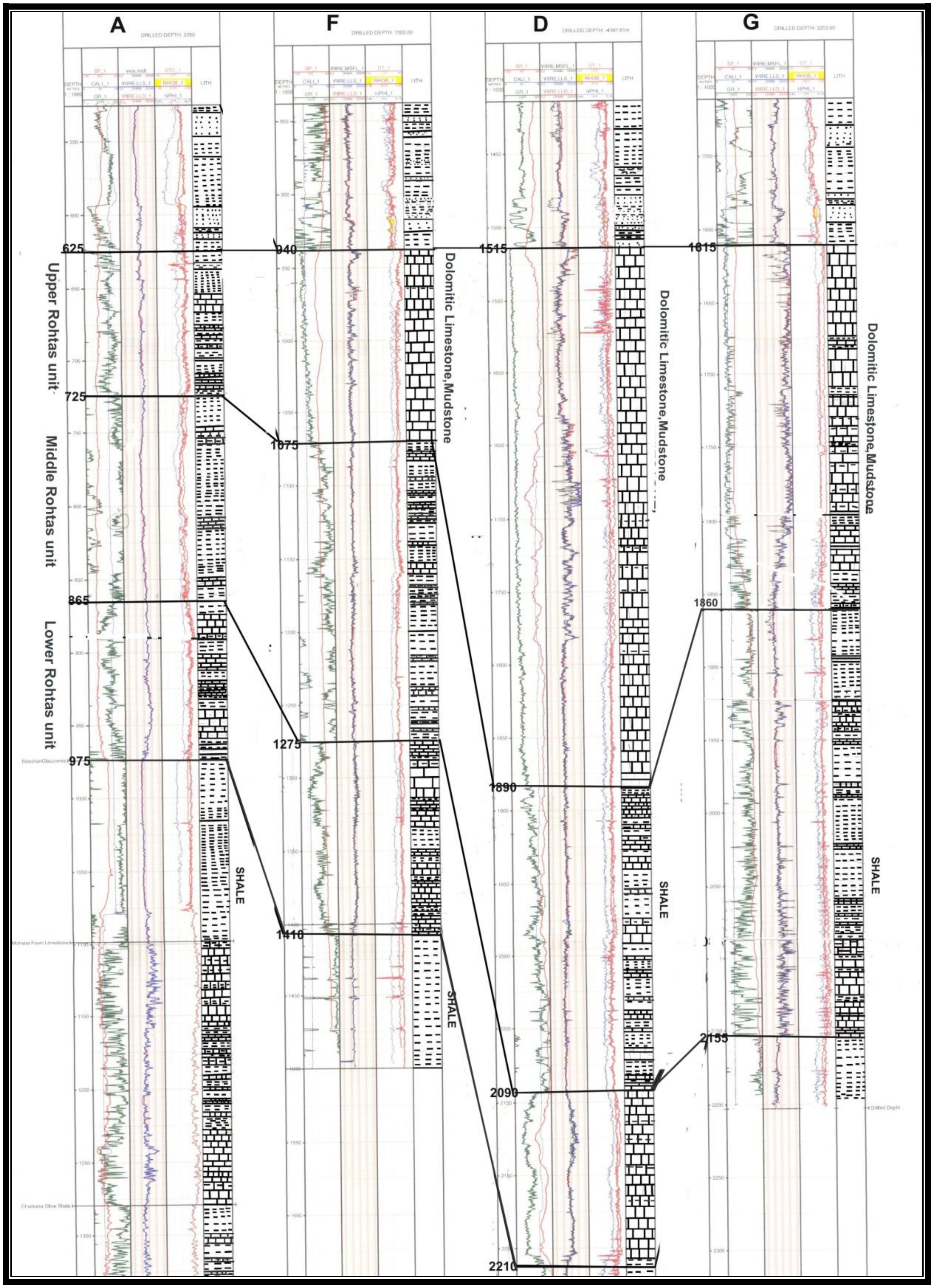
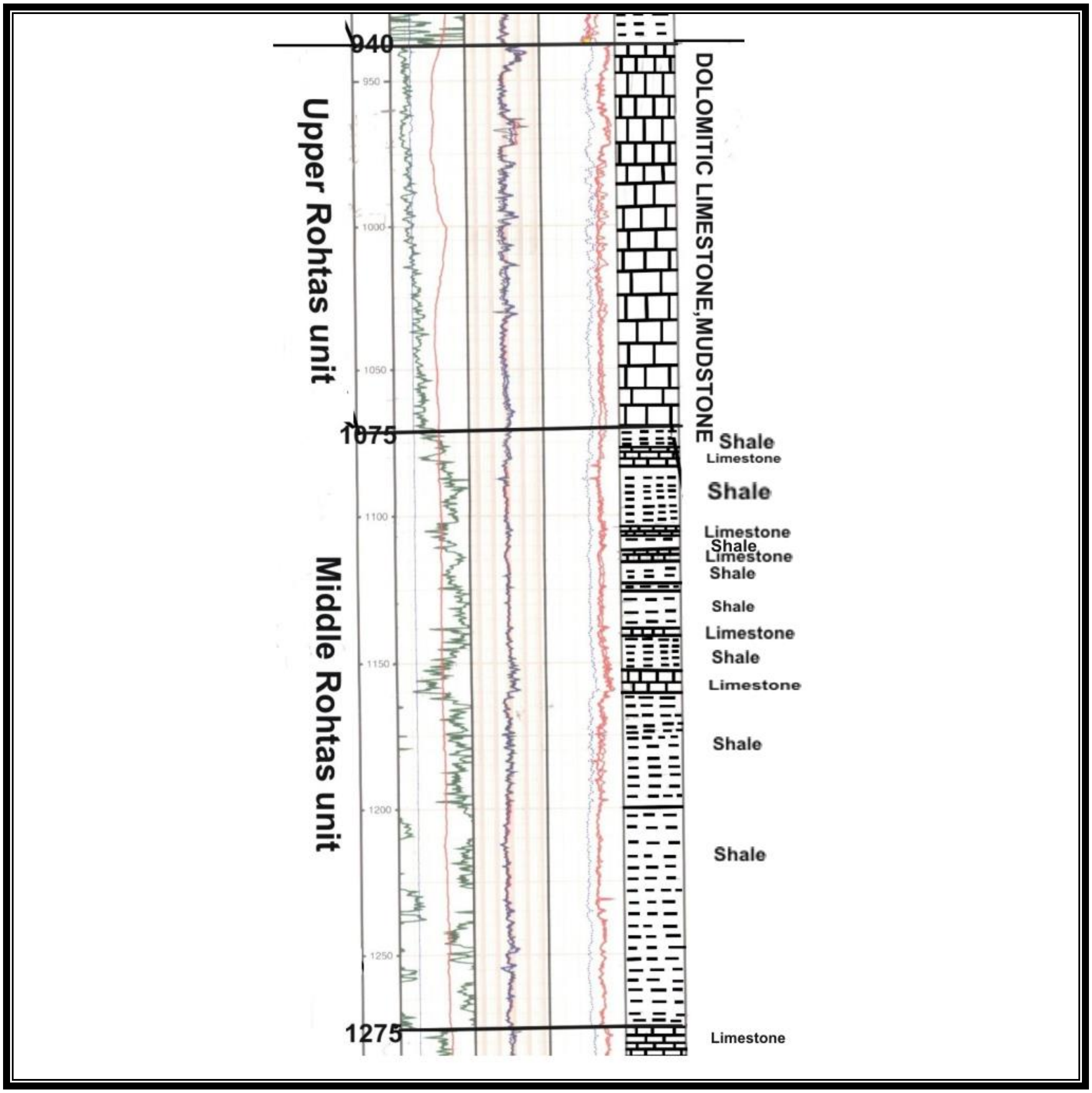
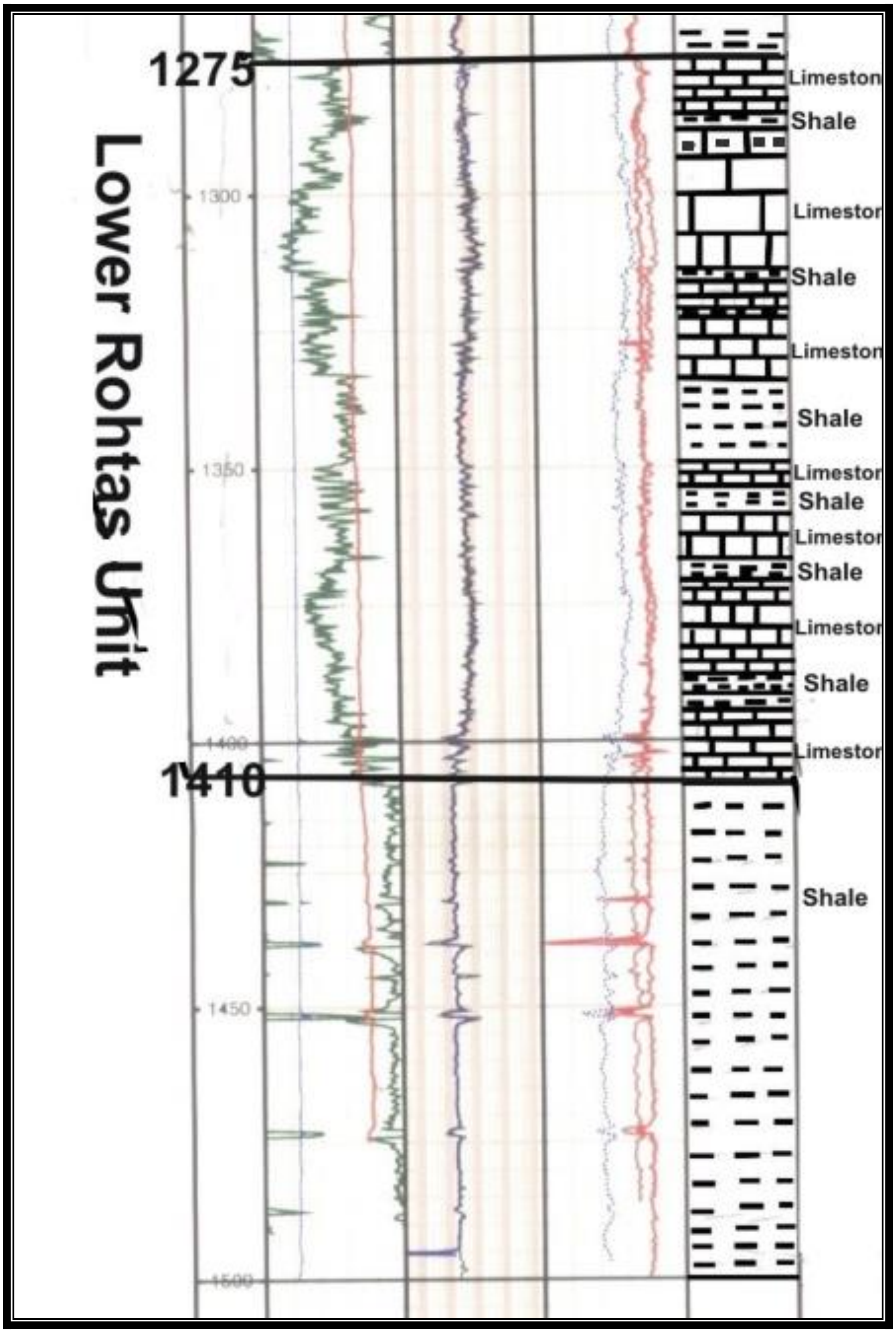

A
F
D
G
625
940
1515
1615
Upper Rohtas unit
725
1075
Middle Rohtas unit
865
Lower Rohtas unit
1275
975
1410
1890
1860
2090
2155
2210
Dolomitic Limestone,Mudstone
Dolomitic Limestone,Mudstone
Dolomitic Limestone,Mudstone
SHALE
SHALE
SHALE
SHALE

Fig.10 Correlation profile of wells A,F,D,G

Well F



Well F



1275
1410
Lower Rohtas Unit
1300
1350
1400
1450
1500
Limeston
Shale
Limestor
Shale
Limeston
Shale
Limestor
Shale
Limestor
Shale
Limestor
Shale
Limestor
Shale

Correlation profile of wells A, F, D, G –

Well Name	Upper Rohtas unit (Thickness, m)	Middle Rohtas unit (Thickness, m)	Lower Rohtas unit (Thickness, m)
Well D	375	200	110
Well F	135	200	135
Well A	100	140	110
Well G	175	255	-

Lithological Information from the Case study

- The Upper Rohtas Limestone comprises of thick limestone unit with very thin laminations of shale. The dominant facies consists of mudstone, dolomitic limestone and wackestone.
- The Middle Rohtas consists of predominant shale with thin limestone laminations.
- The Lower Rohtas consists of mainly limestone with interbedded shale.
- The main facies in the limestone comprises mudstone and dolomitic limestone**.**

Petro physical Characteristics of Rohtas Formation

1. **Upper Rohtas Formation-**

- The unit is penetrated by most of the wells and is represented mainly of limestone with frequent shale sequences.
- Limestone is dirty white , light gray,hard and compact , massive , recrystallized, at places pyritic interlaminated with Shale having occasional development of calcite crystals.
- At places limestone is yellowish with disseminated very fine grained quartz.
- Shale is dark gray, incipiently fissile, micaceous, silicified and occasionally feebly calcareous.
- Microfacies is dominantly mudstone composed of micrite, microsparite, minor detrital quartz grains and is partially dolomitized at some places.
- Development of rhombohedrel dolomitic crystal is observed within micritic mudstone.
- At times mudstones is found silicified, fractured and laminated.
- Presence of stylolaminations provides evidence of compaction.

- SEM studies show the presence of secondary porosity in the form of fractures and tensional cracks at places.

2. Middle Rohtas Unit

- The middle unit of Rohtas is dominantly argillaceous in nature and is represented by interlaminated calcareous shale/siltstone and Limestone.
- Shale is dark grey, poorly fissile , silicified , micaceous and feebly calcareous.
- The micro facies of middle Rohtas Limestone is predominantly mudstone with associated carbonaceous and argillaceous matter. Mudstone is re-crystallized /sparitized and partially dolomitized. Micro fractures are also observed in places.
- Presence of organic rich lagoonal shale within Middle Rohtas Limestone has been reported in drilled wells, which might have acted as effective source rocks for generation of hydrocarbon.

3. Lower Rohtas unit

- This unit mainly consists of grayish white, buff to reddish brown , sparitised limestone with thin laminations of argillaceous matter and a calcareous shale bed in between.
- The shale sequence is dark grey, thinly laminated mudstone with argillaceous lamina rich in organic matter and consists of scattered quartz in a groundmass of micrite and micro-sparite combine.
- Dolomitic mudstone with typical micro sucrose texture of dolomite, also contains scattered detrital quartz , spar filled fracture set in background micrite/microsparite combine.

Rohtas Depositional Environment

- The deposition of Rohtas Formation was initiated over the basin wide marine shale the Basuhari Formation.
- The deposition of this shale made a gently southerly sloping large inner shelf set up suitable for a widespread platform of carbonate environment leading to deposition of a thick carbonate sequence in a quiet water environment.
- Rohtas Formation is characterized by thin and rhythmic alterations of mudstone and shale, which appears to be deposited under carbonate tidal flat environment.

1. **Upper Rohtas formation**

- The upper Rohtas unit comprise of a thick sequence of carbonate punctuated by thin beds of shale. The study of conventional cores within the upper Rohtas unit shows presence of centimeter scale cyclothems represented by limestone and shale.
- The microfacies of the limestone comprises dominantly of mudstone, Dolomitic mudstone and rarely organic mudstone.
- Based on the Lithological assemblages and facies, it is inferred that the upper unit was deposited on a Limestone Shoal in an overall regressive phase.

2. **Middle Rohtas formation**
   - The middle unit predominantly represent argillaceous unit with infrequent thin to thick beds of limestone sandwiched within the thick shale.
   - The lithological assemblage suggests the deposition under a major transgressive event where almost the entire study area was sub tidal set up and mainly mudstone, dolomitic mudstone were found.
3. **Lower Rohtas formation**
   - The lower Rohtas unit comprises of almost uniform thickness excepting minor variations
   - The bottom and above members represent cyclothems comprising centimeter scale beds of Limestone and Shale.
   - The member comprises dominantly of shale.
   - The Limestone is represented dominantly by mudstone with occasional Dolomitisation. An intertidal to Subtidal environment is envisaged during the deposition of this unit.

2.6 Results and Conclusions

- Rohtas Formation represents a typical rhythmic section comprising repetitive shale limestone beds.

- Based on lithological data and log motifs, Rohtas Formation has been divided into three unit's upper, middle, lower units.

- The Upper Rohtas Limestone comprises of thick limestone unit with very thin laminations of shale. The dominant facies consists of mudstone, dolomitic limestone and wackestone.

- The Middle Rohtas consists of predominant shale with thin limestone laminations.

- The Lower Rohtas consists of mainly limestone with interbedded shale.

- Based on the Lithological assemblages and facies, it is inferred that the upper unit was deposited on a Limestone Shoal in an overall regressive phase.

- An intertidal to Sub tidal environment is envisaged during the deposition of this Middle Rohtas unit.

- The main facies in the limestone comprises mudstone and dolomitic limestone.

CHAPTER-3

3.1 WELL LOG INTERPRETATION

Well logging is the process of recording various petro-physical properties of rock/formations penetrated by drilling. Log responses are functions of lithology, porosity, fluid–content and textural variation of formation. This information coupled with characteristics of sedimentary structures derived from high resolution Dipmeter surveys provide detailed insight into the sedimentary environment and allows estimation of the reservoir geometry & orientations. As such logs are ideal tools not only for quantitative evaluation of fluid content of each potential reservoir but also for understanding the geometry of the reservoir.

3.1.1 WELL LOGGING – The Eye of Oil Industry

Well logging provides a cheaper, quicker method of obtaining accurate sub-surface petro-physical data. Well Logging measurements can:

•Ascertain hydrocarbon potential of the well.

•Determine hydrocarbon type and volume.

•Determine what types of fluid will flow and at what rate.

•Optimize well construction and hydrocarbon production.

Well Logging finally serves to:

i. Identify Hydrocarbon Reservoirs.

ii. Define Total and Recoverable Reserves

Definition: - Well Logging is the technique of making petro-physical measurements in the sub-surface earth formations through the drilled borehole in order to determine both the physical and chemical properties of rocks and the fluids they contain.

3.2 TOOLS OF WELL LOGGING

In well logging two types of tools are used.

A. Basic log

B. Advanced log

Basic log: - we have seven basic log and these are as follows:-

iv. Caliper log: - A tool that measures the diameter of the borehole, using either 2 or 4 arms. It can be used to detect regions where the borehole walls are compromised and the well logs may be less reliable.

v. Gamma Ray log: - A log of the natural radioactivity of the formation along the borehole, measured in API, particularly useful for distinguishing between sands and Shales in a Clastic environment. This is because sandstones are usually nonradioactive quartz, whereas Shales are naturally radioactive due to potassium isotopes in clays, and adsorbed uranium and thorium.

vi. Density:- The density log measures the Bulk Density of a formation by bombarding it with a radioactive source and measuring the resulting gamma ray count after the effects of Compton Scattering and Photoelectric absorption. This bulk density can then be used to determine porosity.

vii. Resistivity log: - Resistivity logging measures the subsurface electrical resistivity, which is the ability to impede the flow of electric current.

Advance log: - log which are come under this are as follows:-

i. NMR(Nuclear Magnetic Resonance):- Nuclear magnetic resonance (NMR) logging uses the NMR response of a formation to directly determine its porosity and permeability, providing a continuous record along the length of the borehole.

ii. Dipmeter: - It computes bed dips and azimuths by recording micro resistivity curves around the borehole wall.

iii. FMI (Formation micro imager):- it is a micro recording resistivity tool with high vertical resolution. This can then be used to identify the presence and direction of rock fractures, as well as understanding the dip direction of the stratigraphy.

3.3 XRMI LOG

The X-tended Range Micro Imager (XRMI™) tool, a wire line borehole imaging tool, is designed to obtain quality images even in environments with a high formation resistivity to mud resistivity (Rt:Rm) ratio.

The expanded operating range of the XRMI tool over conventional electrical imaging services is achieved through its state-of-the-art 32-bit digital signal acquisition architecture combined with a large increase in available power for the excitation current (EMEX). As a result, the signal-to-noise ratio of the raw measurements is improved by a factor of up to five, and the dynamic range is expanded by a factor of up to three.

The resulting images offer superior fidelity, even in highly resistive formations (Rt > 2,000 ohm-m) or relatively salty borehole fluids (Rm < 0.1 ohm-m). Tool Design and Superior Image Quality Besides the new electronics, the mandrel architecture derived from Halliburton's highly successful EMI™ imaging tool greatly helps the XRMI tool generate superior-quality borehole images. Pads mounted on six independently articulated arms help maintain pad contact in Rugose, washed-out, elliptical, or highly deviated boreholes. Further, a high sampling rate (120 samples per foot) and borehole coverage help obtain high-resolution pictures of the borehole walls.

3.4.1 Reduction in the E&P Risks

The XRMI tool reduces E&P risk by helping:

• Take the guess-work out of identifying the subsurface sedimentary sequence

• Describe the reservoir facies just like "cores," the ground truth

• Show bedding dips that help rationalize the choice for the next drilling location

• Choose the sidewall core zones, formation testing zones, and perforation intervals accurately by integrating images with other open-hole logs

• Compute accurate, high-resolution net-to-gross

3.4.2 Tool Description

The X-tended Range Micro Imager (XRMI™) tool, a wireline borehole imaging tool, is designed to obtain quality images even in environments with a high formation resistivity to mud resistivity (Rt:Rm) ratio. The expanded operating range of the XRMI tool over conventional electrical imaging services is achieved through its state-of-the-art 32-bit digital signal.

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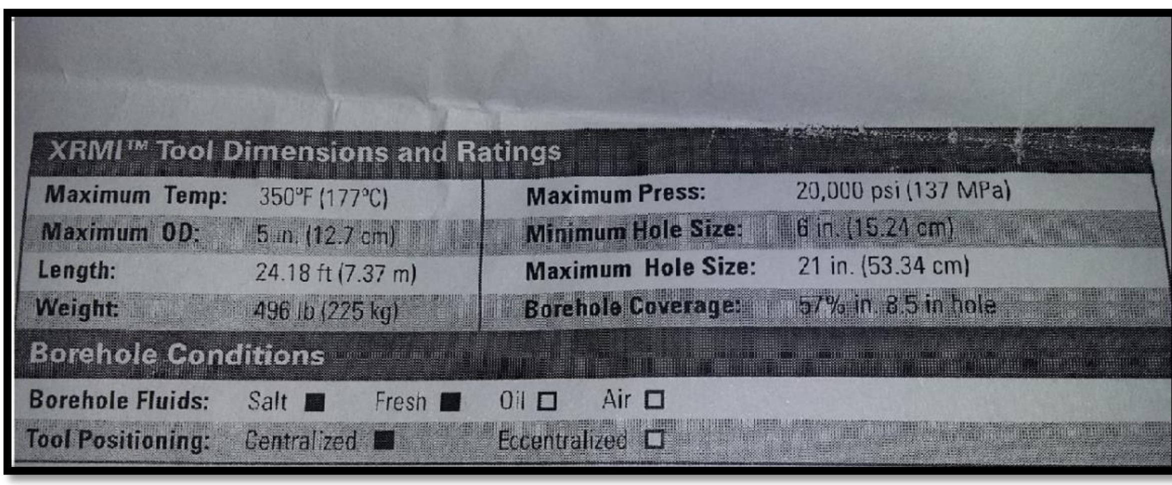

XRMI™ Tool Dimensions and Ratings			
Maximum Temp:	350°F (177°C)	Maximum Press:	20,000 psi (137 MPa)
Maximum OD:	5 in. (12.7 cm)	Minimum Hole Size:	6 in. (15.24 cm)
Length:	24.18 ft (7.37 m)	Maximum Hole Size:	21 in. (53.34 cm)
Weight:	496 lb (225 kg)	Borehole Coverage:	57% in. 8.5 in hole
Borehole Conditions			
Borehole Fluids:	Salt ■ Fresh ■	Oil □ Air □	
Tool Positioning:	Centralized ■	Eccentralized □	

Fig.12 XRMI tool Dimensions and specifications

3.4.3 Benefits

XRMI tool can:

• Optimize offset well placement by evaluating structural and stratigraphic features and bedding orientation

• Improve net-to-gross estimations in laminated Shaly sands and carbonates by delineating thin beds and laminations

• Rationalize the well stimulation and formation testing decisions by characterizing the secondary porosity (e.g., fractures and vugs) in reservoirs

• Optimize the drilling efficiency by evaluating and orienting borehole breakout

• Optimize the completion tactics and reservoir management by providing characterization of rock texture and electro facies

3.4.4 CASE STUDY: WELL A & WELL B, Son Valley, VINDHYAN BASIN

Steps followed:

- Study of XRMI log carefully.
- For each selected interval, note the following:
- Fracture Interval
- Fracture Intensity
- Nature of Fracture
- Percentage of occurrence of fractures
- Maximum and Minimum strike directions
- The intensity is classified as low, medium and high depending on the number of fractures.
- The nature of fracture is open, partially open and closed fracture. This is denoted on the log by color. Blue signifies open fracture; green partially open and red denotes closed fractures.
- List the strike direction for the log in ascending order and note the number of occurrences of each strike angle.
- Generate a Rose Diagram indicating the two major trends.
- Identify these trends and bisect it. This gives us the direction of Maximum Horizontal Stress.
- Perpendicular drawn to this indicated the Minimum Horizontal Stress direction

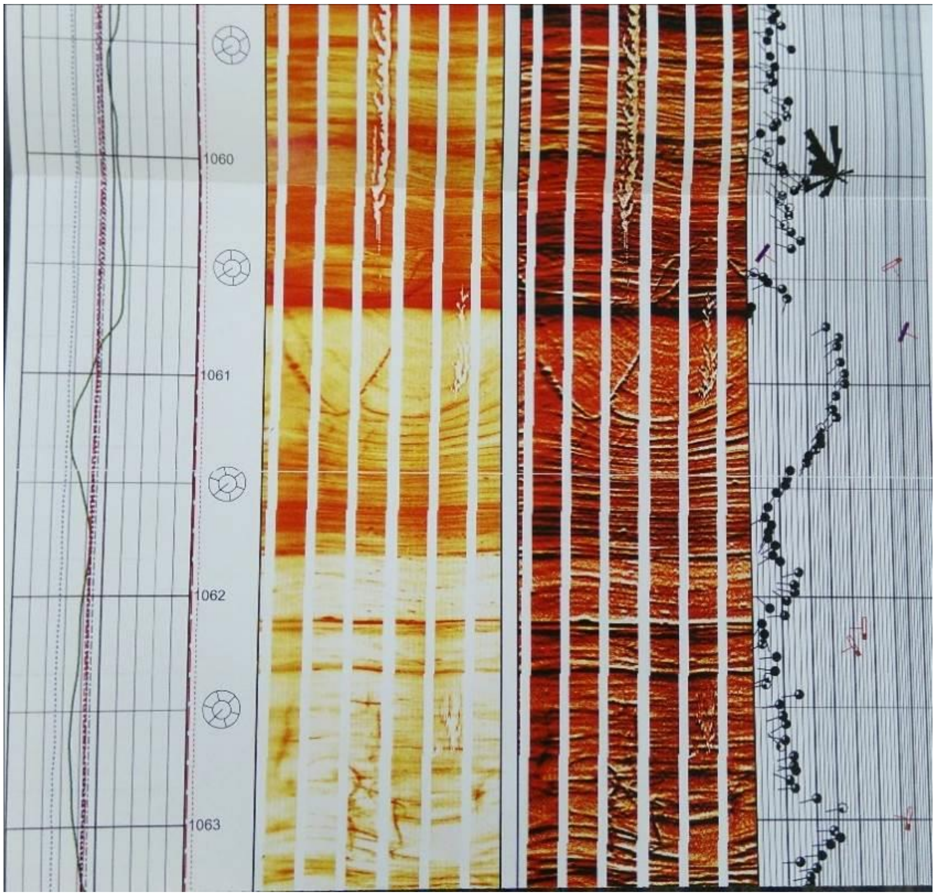

Fig.13 Sample of XRMI log (well I/K)

WELL K

Fracture Interval	Intensity	Nature	POF	OF	CF	S MAX	SMIN
1005-1006	low	partially open	1	0	0	95	
1008-1009	low	partially open	1	0	0	60	
1010-1011	low	partially open	1	0	0	20	
1011-1012	low	partially open	1	0	0	30	
1013-1014	low	partially open	1	0	0	170	
1014-1015	low	partially open	1	0	0	160	10
1017-1018	low	partially open	1	0	0	160	
1018-1019	medium	partially open	1	0	0	80	30
1023-1024	medium	partially open, open	0.33	0.66	0	160	90
1024-1025	low	partially open	1	0	0	40	
1025-1026	low	partially open	1	0	0	160	
1026-1027	low	partially open	0	1	0	80	
1027-1028	low	partially open	1	0	0	30	
1028-1029	low	partially open	1	0	0	20	

Fig.14 Sample of data compiled from XRMI log

Data required for Fracture Orientation through Rose Diagram

Angle	Frequency
0	18
5	14
10	37
15	1
20	16
25	1
30	26
35	1

40	7
45	11
50	2
55	0
60	24
65	0
70	18
75	10
80	17
85	9
90	15
95	1
100	26
105	0
110	9
115	0

WELL I

Fracture Interval	**Intensity**	**Nature**	**POF**	**OF**	**CF**	**S MAX**	**SMIN**
914-915	Low	open	0	1	0	45	
915-916	Low	open, partially open	0.5	0.5	0	45	40
916-917	Low	partially open	1	0	0	55	
917-918	Medium	open, partially open	0.66	0.33	0	180	50
918-919	Low	partially open	1	0	0	80	10
919-920	Low	open	0	1	0	25	
920-921	Low	partially open	1	0	0	110	100
921-922	Low	partially open	1	0	0	40	
922-923	Low	open	0	1	0	160	
927-928	medium	partially open, open	0.66	0.33	0	120	40
928-929	medium	open	0	1	0	90	80

929-930	medium	open	0	1	0	170	60
930-931	Low	open	0.5	0.5	0	70	10
941-942	Low	partially open	1	0	0	125	
943-944	Low	open	0	1	0	60	
947-948	Low	partially open	1	0	0	10	
948-949	Low	partially open	1	0	0	70	
950-951	Low	partially open	1	0	0	150	140
953-954	Low	partially open	1	0	0	130	120
954-955	Low	partially open	1	0	0	90	20
955-956	Low	partially open	1	0	0	40	
956-957	High	partially open	1	0	0	50	
957-958	medium	partially open	1	0	0	55	45
959-960	Low	partially open	1	0	0	80	40
960-961	Low	partially open	1	0	0	20	
962-963	Low	partially open	1	0	0	25	
965-966	Low	partially open	1	0	0	85	
968-969	Low	partially open	1	0	0	35	
972-973	Low	partially open	1	0	0	150	120
973-974	Low	partially open	1	0	0	30	20
976-977	Low	partially open	1	0	0	160	
977-978	Low	partially open	1	0	0	55	
986-987	Low	partially open	1	0	0	50	
988-989	Low	partially open	1	0	0	40	
990-991	Low	partially open	1	0	0	50	
991-992	Low	partially open	1	0	0	45	
992-993	Low	partially open, open	0.5	0.5	0	130	95
993-994	Low	partially open	1	0	0	50	30

Angle	Frequency
0	10
5	6
10	33

15	8

Strike Orientation Diagrams

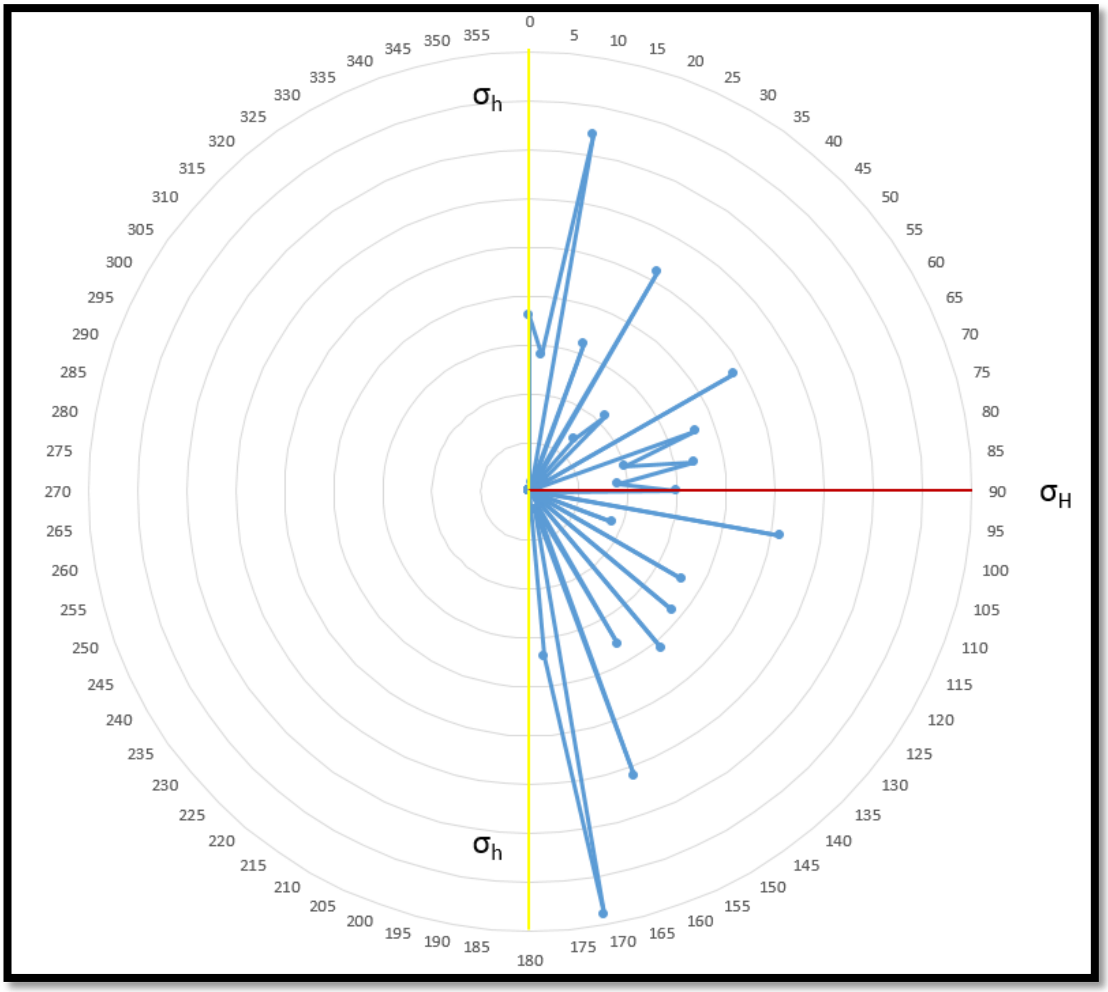

Figure 15: Strike orientation for Well 'K' showing direction of Minimum and Maximum horizontal stress

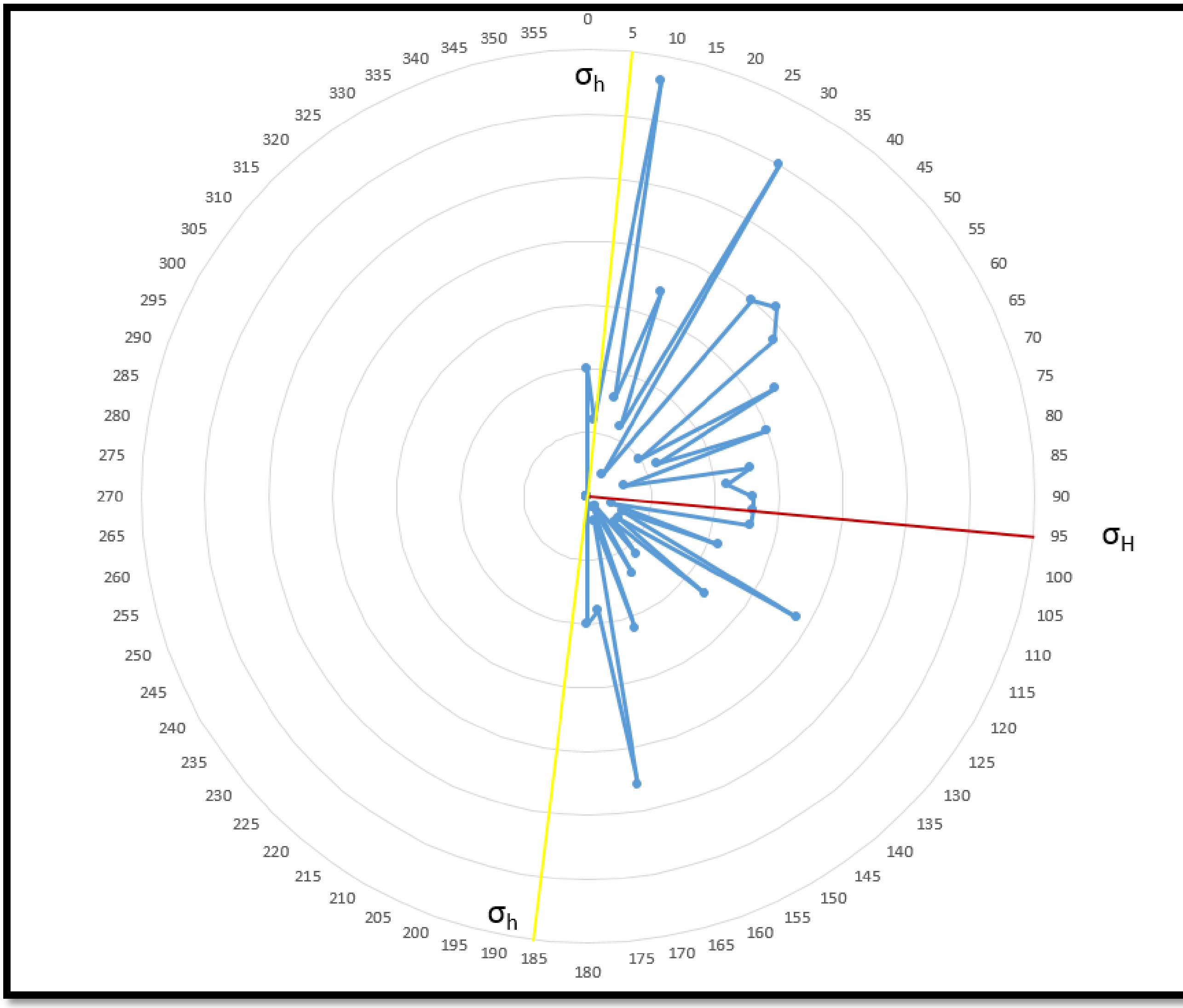

Figure 16: Strike orientation for Well 'I' showing direction of Minimum and Maximum horizontal stress

RESULTS

- The Rose Diagram obtained from the well data clearly indicates two major trends of strike directions of fracture.
- One is found to be parallel to a lineament near the basin while the other is found to be parallel to a major fault present in the basin.
- The direction of Maximum Horizontal stress is found to be 90º for Well "K" while it is found to be 95º for Well "I"
- The direction of Minimum Horizontal stress is perpendicular to the direction of Maximum Horizontal Stress.

Reservoir Characterization

Rohtas Limestone is an unconventional tight gas reservoir having very low porosities and ultra-low permeability's and low Reservoir pressure , leading to poor mobility of gas from the formation to the wellbore .Petrophysical analysis of conventional core has indicated absolute air permeability of 0.002 md , porosity 1.03% and grain density 2.69 gm/cc. Flow of gas is contributed by Matrix and Fracture Porosities. Upper Rohtas is found to have gas plays**.**

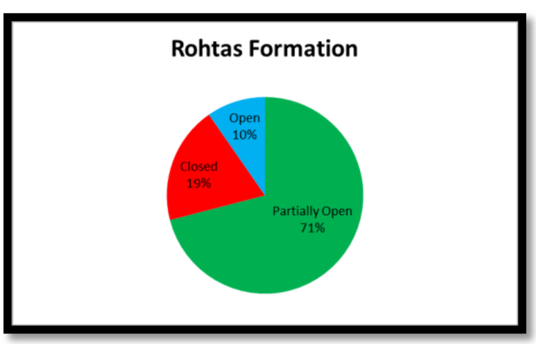

Fig17. Pie chart of the fractures in Rohtas formation in well I

RESULTS AND CONCLUSION

- Rohtas Formation is characterized by rhythmic beds of mudstone and shale which appears to be deposited under carbonate tidal flat environment.
- The Upper Rohtas Limestone comprises of thick limestone unit with very thin laminations of shale. The dominant facies consists of mudstone, dolomitic limestone and wackestone.
- The Middle Rohtas consists of predominant shale with thin limestone laminations.
- The Lower Rohtas consists of mainly limestone with interbedded shale.
- The main facies in the limestone comprises mudstone and dolomitic limestone.
- Presence of organic rich lagoonal shale within Middle Rohtas Limestone which might have acted as effective source rocks for generation of hydrocarbon
- The mudstone present in the upper Rohtas consists of fractures which results in secondary porosity that are essential for the existence of gas.
- XRMI log information indicates that direction of Maximum Horizontal stress is found to be 90º for Well "K" while it is found to be 95º for Well "I".

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