In the name of Allah the most Merciful and The
Mighty and is always with us. He who created
this planet earth and the beautiful mountains
on its surface to provide stability and balance
to the earth. He created every thing from water
and man is created weak.

Dedicated to my beloved parents and sisters

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ABSTRACT

Chichali Formation, exposed in the Southern Hazara, was evaluated from hydrocarbon source rock point of view. Surface samples were collected from outcrop and geochemical analyses were carried out through Rock–Eval pyrolysis. Maturity of the source rock and kerogen types was determined by Vitrinite reflectance microscopy.

Organic carbon content, of most of the samples of Chichali shales, represents very well to excellent source potential. However, pyrolysis has given extraordinarily very low values of S_1,S_2,GP and HI, indicating Chichali shales of the study area as spent source rock at present .Tmax and Vitrinite reflectance values demonstrate that Chichali shales falls within gas window. Organic matter is fine grained and occurs in layers. Bituminite and micrinite are the major macerals, indicating that the main organic matter was originally Kerogen type II.

Oil and gas generated, during the course of thermal maturation of Chichali shales, might have migrated and accumulated within the potential traps of the overlying and adjacent areas.

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 General Introduction

The study area lies between latitudes 33°.50′ N to 34°.50′ N and Longitudes 72°.50′ E to 73°.50′ E and mainly cover the Southern Hazara. It is bounded by Panjal fault in the north and Murree fault in the south (Fig. 1.1).

The area is covered by the Survey of Pakistan topo-sheets nos; 43 G/1, 43 G/2, 43 G/5, 43F/3,43 F/4, 43F/8. Thandiani (8748 ft) is the highest peak in the study area. Winters are extremely cold and the summers are moderate, while slopes exceed 35°. There was plenty of vegetation in the area that limits the detailed study of the area.

Despite of extremely mountainous terrain, the area contains a good network of roads, which provides access to most of the area. Many jeep-able tracks are also available. Most of the areas, large and rugged tracks between the roads, are only accessible by foot.

Hazara hills and mountains form the southern part of the "Lesser Himalayas" with high relief, which ranges from 610 meters above sea level near Islamabad to 2,982 meters at Miranjani near Nathiagali. The Galis lying between Murree and Abbottabad form highest mountainous areas in Hazara and serve as water division between the Indus and Jehlum River systems. The area is very complex structurally and consists of a number of deformational features.

Chichali Formation is widely distributed in the Trans Indus ranges, Western Salt range, Northern Kohat ranges, Nizampur, Kala-Chitta and Southern Hazara (Fatmi, 1966). In Southern Hazara, which is the main focus of this study, the Chichali Formation is well exposed in Jabri, Thandiani, Kalapani, Baghnotar (Domail), Changla Gali and Kohala etc (Fig.1.2). The Chichali Formation, in the study area generally consists of sandstone and shale. The sandstone is dark-green and greenish-grey in colour. It weathers to rusty brown colour and is generally glauconitic. Shale occurs in lower part and is dark-grey, bluish-grey and greenish-grey in colour. It is mostly sandy, silty and glauconitic (Fatmi, 1973). In Southern Hazara, the Formation is 33m thick and is varying in age from Late Jurassic to Early Cretaceous (Shah, 1977).

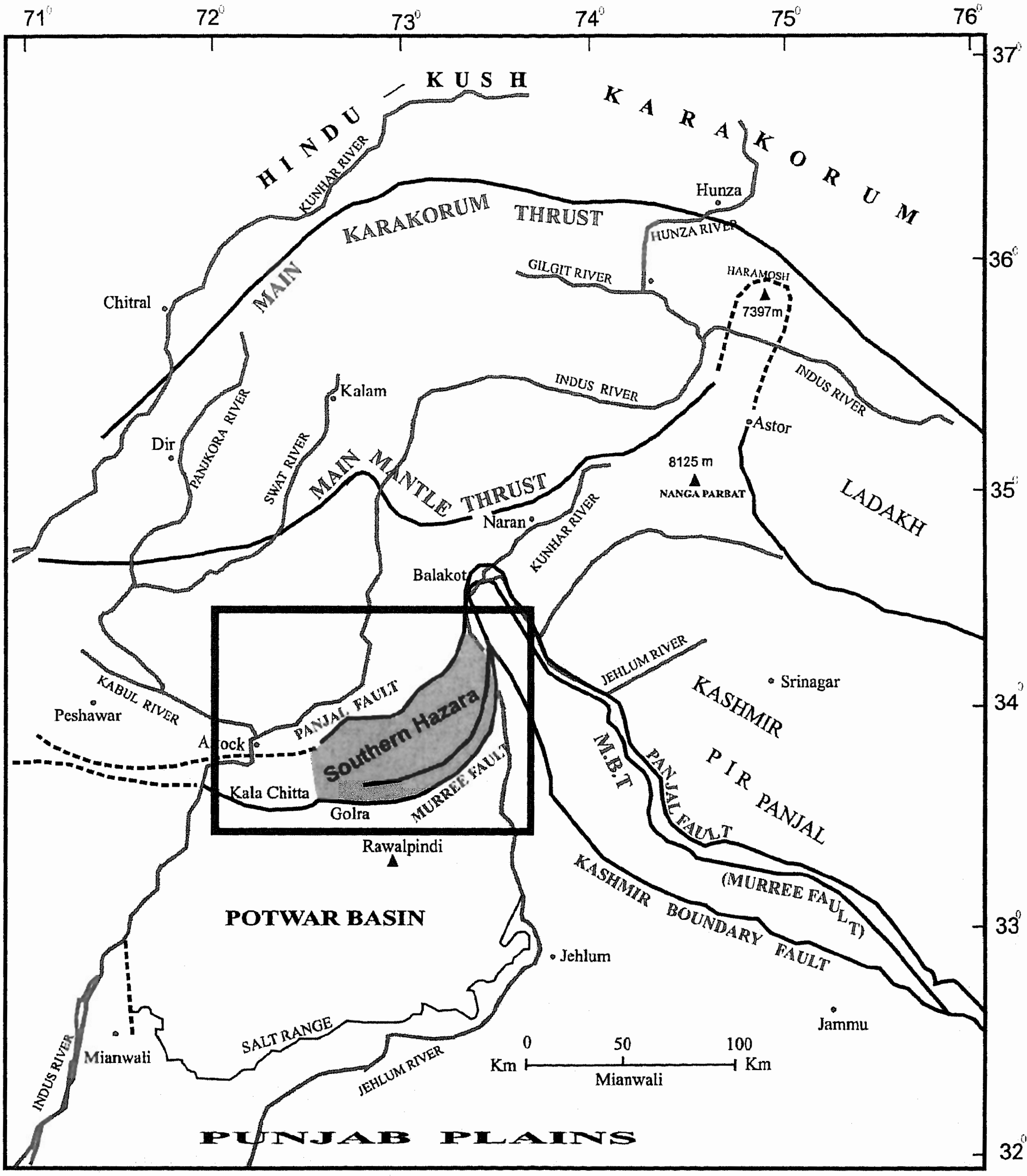


Figure 1.1: Regional tectonic setting of northern Pakistan showing the study area of Southern Hazara fold and thrust belt (modified after Latif 1970 and Shah 1977).

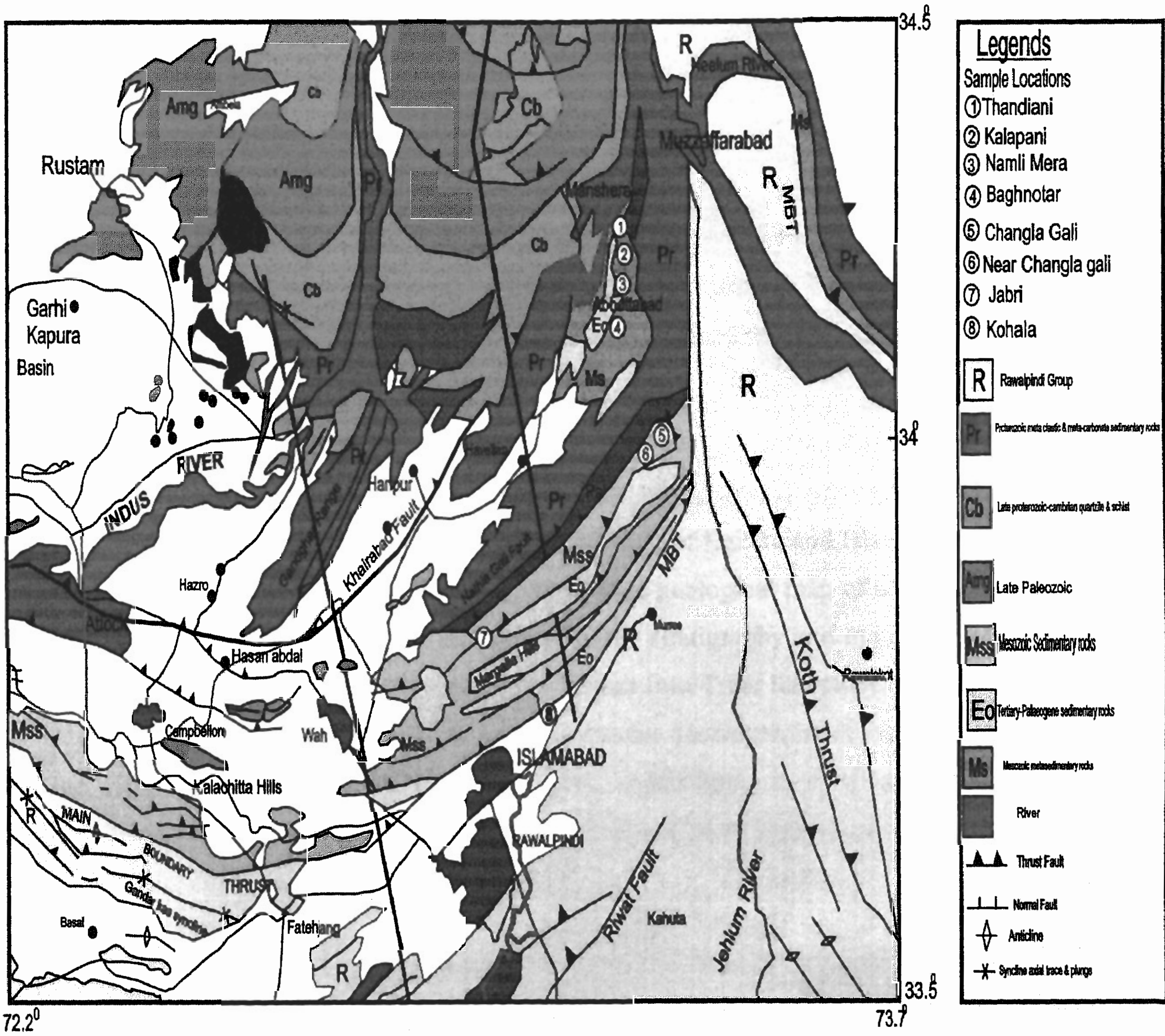


Figure 1.2 : Location map of the study area showing prominent structural features and sample locations modified after Khan and Searle 1996.

1.2 AIMS AND OBJECTIVES

- To evaluate the Chichali Formation as a Source rock for oil and gas generation on the basis of geochemical parameters.
- To investigate the presence of possible multiple source units within the Chichali Formation.
- To determine the type of hydrocarbon (oil, gas, condensate) formed.
- To infer the depositional environment of the Chichali Formation in the study area.
- To determine the thermal maturity of the source rock exposed within the study area.

1.3 PREVIOUS GEOLOGICAL WORK

Middlemiss (1869) in his detailed work on the geology of Hazara and Black Mountains for the first time presented a preliminary and reconnaissance geological map of a large part of Hazara, described the rock units and gave an account of the stratigraphy and major structures. He broadly classified the rocks units present in this section into Trias limestone, Spiti shales, Grey limestone, Giumal sandstone and Nummulitic limestone. However, he did not attempt to separate the different limestone, shale and marls units, as we know them today within the Nummulitic series. He found the area structurally much disturbed to make these subdivisions possible.

Wadia (1931) applied the name "Syntaxis" to the sharply curving mountain structure in the eastern half of the area. From 1948 to 1951, Khan et al. of the Geological Survey of Pakistan mapped the rock types in parts of several quadrangles in the Hazara District, but this work is unpublished. Geologic reports relating to this area have been published by the Punjab University (Shams, 1961., Marks and Ali., 1961 Ali, 1962).

Gardezi and Ghazanfar (1965) published a paper on the geology of the area near Nathia Gali in which they have done extensive work on the Hazara Formation. Latif (1970) gave a brief account of the stratigraphy of southern eastern Hazara, supported by a geologic map at a scale of one inch to a mile. He classified the litho-stratigraphic units into seven groups separated by unconformities and further subdivided them into twenty-one formations correlating them with the adjoining areas. He distinguished different formations within the loose and broad grouping of Tertiary "Nummulitic Series" of Middlemiss (1869). He renamed most of the units in accordance with the stratigraphic code. The Stratigraphic Committee of Pakistan later accepted some of these nomenclatures.

Calkins and Offield (1975) gave an account and a map of the geology of Hazara-Kashmir Syntaxis and the adjacent regions including those occurring to the north of presently mapped area. Structurally, they called the mapped area of Southern Hazara as the Garhi Habibullah syncline. According to them, southwards of Garhi Habibullah syncline the rocks have been deformed into a series of doubly plunging northeast trending asymmetrical folds with one limb generally faulted. They described the ruptures as a system of anastomosing faults that run parallel to the strike of the beds for a considerable distance. Coward et al (1978) explained the steep dipping thrust sheets in the Galiat. Schnellmann and Gnehm (1999) published a report on NW Himalayan Fold Thrust Belt in Hazara, Pakistan in which they presented a geologic map and cross section at a scale of 1:21,120 along with a kinematic and dynamic model to evaluate the deformation present in the area.

The Chichali Formation is a marine argillaceous and aranaceous facies rich in glauconite and is formed in marginal shallow transgressive seas in reducing environment (Fatmi, 1966). In the Central Indus Basin, the rocks of different ages such as Chichali/Sember Formation are the main potential source rocks for hydrocarbon generation (Sheikh, 1999). Potential hydrocarbon reservoirs may occur in the Chichali Formation (Ghazanfar et al, 1990). In upper Indus basin Chichali Formation, that is equivalent to Sember Formation, also bears source rock characteristics, with the presence of coal beds and richness in the organic matter. In Kala-Chitta Range, Chichali Formation lies within the oil window (Kadri, 1995).

As far as the hydrocarbon potentials of the study area are concerned, no detailed geochemical work has been carried out in this regard in the area. However, preliminary studies regarding geology, stratigraphy and structure of the Southern Hazara area have been conducted by HDIP-BGR Technical Corporation (1987), Ghazanfar et al. (1990), Kadri (1995) and Mujtaba (2004). The present study deals with the geochemical characteristics of the Chichali Formation of the Southern Hazara area in order to find out potential source rock for hydrocarbons.

1.4 HYDROCARBON POTENTIAL OF CHICHALI FORMATION

According to the combined study of HDIP/BGR (Porth & Hilal, 1990), the predominant organic matter of the analyzed samples of the Chichali Formation, vitrinite and inertinite prevail in the analyzed samples. Some samples of the Sembar formation is collected from the Mughal Kot, Lorlai and Mazar Drik areas, however contains a significant Percentage of Pre-bitumen and solid bitumen. Probably, major parts of the formation were originally slightly bituminous. The TOC of the Chichali Formation is comparatively high (0.52 % to 1.86 % in Mughal Kot areas, upto 2.14 % in Lorlai areas, and 1.08 to1.79 % in Mazar Drik area), despite the partly very high degree of thermal maturity. It is assumed that a considerable percentage of organic matter has escaped during the coalification process and that the original TOC was distinctly higher than the measured ones. Results derived from the analysis of the surface samples are supported by the core samples from wells. All samples collected from Chichali Formation in Giandari-1 well, contains a major percentage of bitumen (pre-bitumen and solid bitumen). TOC reaches 4.33 % despite the very high coalification, i.e., more than 3 % of vitrinite reflectance. The Chichali facies, encountered in Giandari-1 well, is considered as holding very good oil prospects if present in neighboring areas too where they fall under moderate maturity (i.e., within oil window), (Mujtaba, 1999).

From the available few geochemical parameters it has been inferred by HDIP/BGR scientists (Porth & Hilal, 1990) that there is a possibility that the gas which is accumulated in the gas fields of southern Suliman Fold belt area (i.e., Sui and Pirkoh area), Zindapir Anticlinorium (Dhodak and Rhodo area), and Punjab platform (i.e., Nandpur and Panjpir gas fields areas) has its source in the Early Cretaceous Sembar Formation (Chichali Formation). As mentioned earlier, Chichali Formation is marine with organic-petrographic and geochemical characteristics indicative of a good to excellent oil and gas sourcing potential at adequate thermal maturity levels. The results of the Carbon and Deuterium-isotope measurements carried on gas samples from Sui, Pirkoh and Nandpur fields, indicate predominantly marine organic source material (Porth & Hilal, 1990).

CHAPTER 2

STRATIGRAPHY OF THE STUDY AREA

2.1 STRATIGRAPHY OF THE STUDY AREA

The stratigraphic succession of Hazara fold-thrust belt ranges in age from Eo-cambrian to Pleistocene/Recent, interrupted by seven unconformities, with major absence of middle and upper Paleozoic sequence (Calkins et al., 1975). Latif (1970) has divided the litho-stratigraphic units into seven groups; each separated by an unconformity. He has further subdivided theses groups into twenty-one formations. The stratigraphic nomenclature, used in this study, is adopted after Shah (1977). A comparison of the nomenclature of rock units, exposed in southern Hazara, adopted by Latif (1970) and Shah (1977) given in the Table1.1.

Table 2.1. Comparison of nomenclature of rock units exposed in southeast Hazara adopted by Latif (1970) and Shah (1977).

Name of Rock Units in Hazara Adopted By Shah (1977)		Names of Rock Units in Hazara Adopted By Latif (1970)	
Murree Formation (Rawalpindi Group)		Murree Formation (Rawalpindi Group)	
------------Unconformity---------	Oligocene	------------Unconformity---------	
Kuldana Formation Chorgali Formation Margala Hill Limestone Patala Formation	Eocene	Kuldana Formation Lora Formation Margala Hill Limestone Kuza gali Shale	Galis group
Lockhart Limestone Hangu Formation	Paleocene	Mari Limestone Not mentioned	
------------Unconformity---------	Paleocene	------------Conformity---------	
Kawagrah Formation Lumshiwal Sandstone Chichali Formation	Cretaceous	Chanali Limestone Giumal Sandstone Spiti Shale	Hothla group
------------Unconformity---------		------------Unconformity---------	
Samana Suk Formation Shinawari Formation Datta Formation	Jurassic	Sikhar Limestone Maira Limestone	Upper part Thandiani group
------------Unconformity---------		------------Unconformity---------	
Hazira Formation Abboatabad Formation	Cambrian	Hazira Formation Galdanian Formation Sirban Formation Kakul Formation	Abboatabad group
------------Unconformity---------		------------Unconformity---------	
Tanawal Formation Hazara Formation	Precambrian	Tanol Formation Hazara Group	

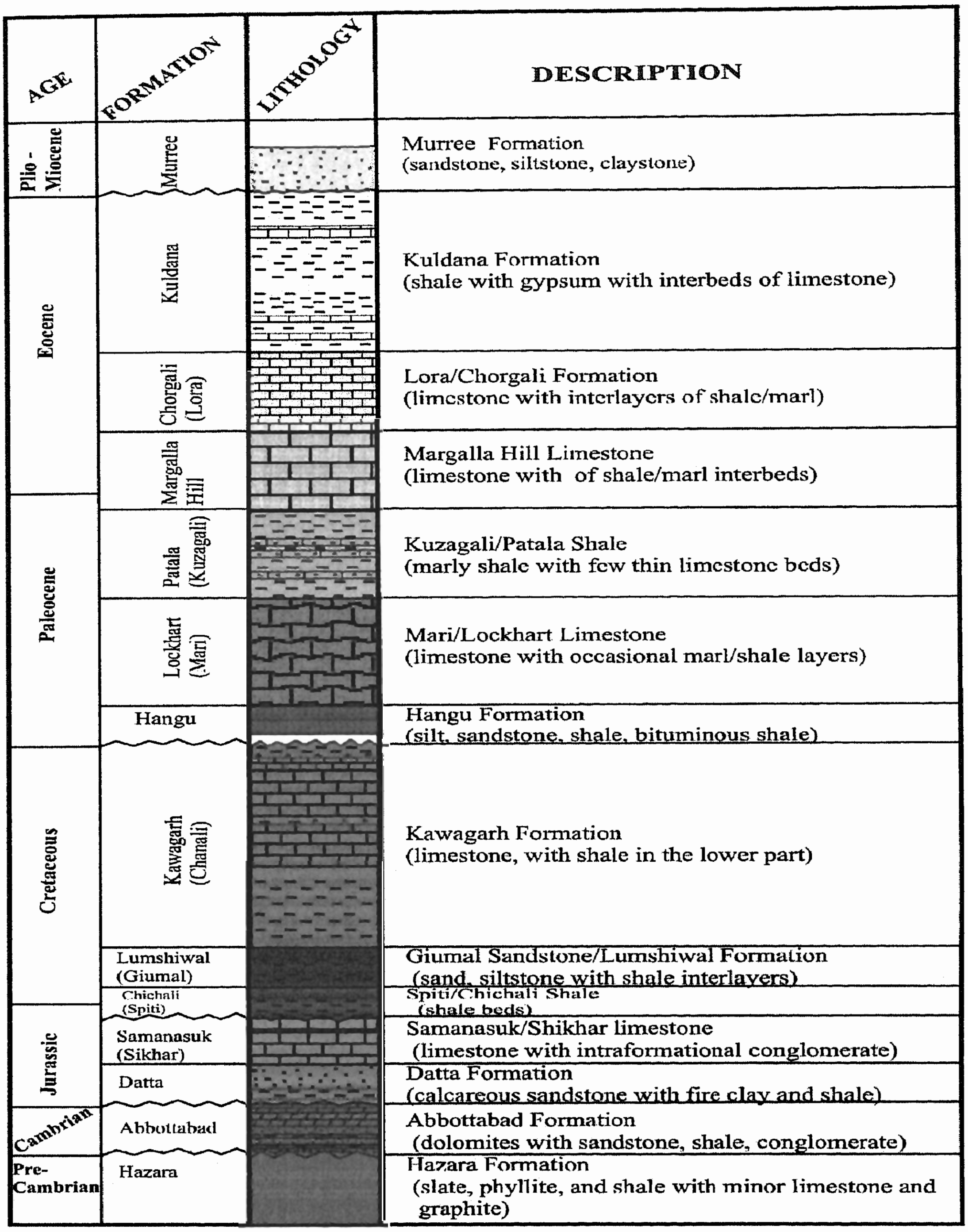


Figure 2.1: Generalized Stratigraphic Column of Hazara (modified after Latif 1970 and Shah 1977).

1. Hazara Formation

The name "Slates series of Hazara" has been given by Middlemiss (1896) and "Hazara Slates Formation" by Marks and Ali (1961). Calkins et al. (1969) named it "Hazara Formation".

The Hazara Formation consists of slate, phyllite and shale with minor occurrences of limestone and graphite layers. Slates and phyllite are green to dark green and black, but are rusty brown and dark green on weathered surface. Some thick bedded, fine to medium-grained sandstone is also present. Limestone beds with maximum thickness of 150 m and a sequence of calcareous Phyllite and gypsum ranging from 30 to 120 m are found in Southern Hazara and Kashmir.

Marks and Ali (1961) regarded the Formation as a deep-water turbidity current deposit. Calkins et al. (1969) disagreed with that concept, contended that the beds of limestone, graphite and gypsum are unlikely to occur in a turbidite sequence, and regarded most of the formation as probably a shallow water argillaceous sequence. The Hazara Formation is equivalent to "Dogra Slates", which are overlain by fossiliferous Cambrian rocks. On this basis Calkins et al. (1969) assigned a late Pre-Cambrian age to the Hazara Formation.

Latif (1970) has reported fossils similar to Protobollela in the Hazara Formation showing that it may be lower Paleozoic in age. Latif (1973) correlated the Salt Range Formation with the Hazara Formation because of evaporite facies found in both the Formation. A major unconformity exists between the Pre-Cambrian Hazara Formation and the Jurassic succession. An intervening Abboatabad Group is missing in the Galiat area, which is present in other parts of the Hazara District. The Hazara Formation has an unconformable contact with the Jurassic succession.

2. Tanawal Formation

Wynne (1875) described the rocks of this formation as "Tanol Group". Middlemiss (1869) named these as "Tanol Quartzite". Calkins et al (1969) made a detailed study and used the name Tanawal Formation for this rock unit. Marks and Ali (1962) and Latif (1970) named them as "Tanol Formation".

The Tanawal Formation consists of mainly quartzose-schist, quartzite and schistose conglomerate. The unit is well exposed in the south and southeastern margin of the "Manshera Granite". To the south of "Manshera Granite", the Tanawal Formation mainly consists of medium-grained quartzite and fine-grained mica-schist. The Tanawal Formation underlies the Abboatabad Formation and overlies the Hazara Formation in the area near Abboatabad and the Indus River.

Ali (1962) estimated the thickness as 1666 m. At quite few places, the Tanawal Formation is missing and the Hazara Formation underlies the Abboatabad Formation. In northeastern part of the southern Hazara, the Tanawal Formation directly overlies the Precambrian Salkhala Formation with an unconformity. Calkins (1969) correlated the Tanawal Formation with the Muth Quartzite of Silurian Devonian age exposed near Shimla, India. The Tanawal Formation is younger than Hazara Formation of the Late Precambrian age and older than the Abboatabad Formation. The Tanawal Formation is Cambrian in age.

3. Abboatabad Formation

Waagen and Wynne (1875) studied the sequence of dolomite and quartzite rocks overlying the Hazara formation in the Sirban Hill near Abboatabad. Middlemiss (1896) renamed it "Infra-Trias". Calkins et al. (1969) described the Abboatabad Formation as consisting mainly of dolomite, quartzite and phyllite with many lithologic changes and inter-fingering facies from place to place.

Marks and Ali (1962) suggested the name Abboatabad Formation. Latif (1970) named this unit of rocks as "Abboatabad Group". The type section of the Formation is designated near Abboatabad town. The Formation consistently extends to Garhi Habibullah, Sherwan and the Indus River.

In the Sherwan, area the Abboatabad Formation has an unconformable contact with Tanawal formation. In the eastern part of southern Hazara, across the Panjal fault, the underlying Tanawal Formation is missing and the Abboatabad Formation rests unconformably over the Hazara Formation. The thickness of the Formation in the type section is about 660 m. Marks and Ali (1962) estimated the thickness as 900 m in the Tanol area, 833m northeast of Muzaffarabad and only 100 to 300m on the east flank of Garhi Habibullah syncline (Calkins et al., 1969). It is more characteristics of Lower Cambrian rocks on a worldwide basis (Shah, 1977).

4. Hazira Formation

The name Hazira Formation was introduced by Gardezi and Ghazanfer (1965) for a predominantly shale-siltstone unit exposed near the village of Hazira. The type section has been chosen near the said village in Hazara area. The Formation is composed mainly of dirty grey and yellowish brown calcareous, shaly siltstone containing earthy concretions. Latif (1970) separates the "Galdanian Formation" from the Hazira Formation and correlated the "Galdanian Formation" with the "Panjal Series" of Kashmir.

The Hazira Formation attains a maximum thickness of 300 m (Latif, 1970). It over-lies super-positionally the Abboatabad Formation and is overlain by the basal Jurassic arenite. The fauna present in the Formation is Proifera, Calyptoptamatids and annelida. This fauna according to Fuchs and Mostler indicates not only Cambrian but also very clearly shows that the fossiliferous part of the Hazira Formation is most probably Early Cambrian.

5. Datta Formation

The name "Datta Formation" was introduced by Danilchik (1961), Danilchik, and Shah (1967) to replace the name "Variegated Stage" of Gee (1945).

The type section is located in Datta Nala (Lat. 33° 00′ N: Long. 71° 19′ E) in the Surghar Range. The Formation is mainly of continental origin and consists of variegated (red, maroon, grey, green and white) sandstone, shale, siltstone and mudstone with irregularly distributed calcareous, dolomitic, carbonaceous, ferruginous glass, sand and fireclay horizons. The Formation extends as a tongue in Kala-Chitta, Hazara and parts of Kohat area. In Hazara, the basal beds are brownish calcareous grits. The thickness in the type locality is 212 m but increases to 213 m in Sheikh Badin Hills. In Kala-Chitta, the thickness is 6 m. In Hazara, the thickness ranges from 0-10 m.

The Formation has disconformable contact throughout its distribution. It rests unconformably on the Kingarili Formation in the Salt Range, Trans–Indus Ranges, Kala-Chitta and eastern Kohat. In Hazara the Formation unconformably overlies doubtful Precambrian (Hazara Formation), Paleozoic and Triassic rocks. The upper contact with the Shinawari Formation is gradational.

No diagnostic fossils have been reported from the formation except some carbonaceous remains. As the formation underlies the Shinawari Formation, which in it lower parts, has yielded lower Toarcian ammonites, the previous workers have assigned an early Jurassic age to it.

6. Shinawari Formation

The term "Shinawari Formation" was introduced by Fatmi (1964, verbal communication: Fatmi and Khan, 1966) after the village of this name in the western part of Samana Range, Kohat district.

The Formation, in its type locality, consists of thin to well bedded limestone with nodular marl calcareous and non-calcareous shale and quartzose, ferruginous and calcareous sandstone. The limestone is grey, brownish grey, fine to coarse texture and includes sandy oolitic and ferruginous beds. The Shale is grey, dark-grey, brownish-grey, splintery calcareous and non-calcareous. The sandstones are both quartzose and ferruginous and calcareous. The presence of sedimentary structures such as current bedding and ripple marks, have also been reported.

From the lower part of the Formation in Hazara (Bagnotar) and Kala Chitta (Chak Dalla) *Bouleiceras* is reported. From Hazara in addition to *Bouleiceras,* Latif (1970) recorded *Terebrautla, Zeilleria and Eotrapezium.* From the Marwat ranges bivalves and brachiopods have been reported (Fatmi, 1972) from the lower part. The fauna from the lower part indicates an Early Jurassic age, but the upper part may extend to Middle Jurassic.

The Formation is widely developed in Kohat, Kala-Chitta, Hazara, Trans Indus ranges and Salt Range. The formation is 12 m thick in Chak Dalla section of Kala-Chitta Range and 25 m thick in Baghnotar section of Hazara. The Formation has a transitional contact with the under lying Datta Formation and overlying Samana Suk Formation.

7. Samana Suk Formation

Davies (1930) introduced the name "Samana Suk" for the Jurassic limestone in Samana Range. The name is extended to include similar limestone sequence in the Salt Range and Trans Indus ranges ("Baroch limestone" of Gee, 1945) Kala-Chitta and Hazara. The name Samana Suk is derived from the peak in the Samana Range (Lat. 33° 33′ 50″ N: Long. 70° 50′ 13 ″ E).

In the type locality, the formation consists of grey to dark grey, medium to thick-bedded limestone with subordinate marl and calcareous shale intercalations. The limestone is oolitic and has some shelly beds. In the Salt Range, and Trans-Indus ranges (Surghar Range, Sheikh Badin Hills) the limestone is lighter in colour; medium to thin bed and is marly and shaly in the lower part. In the type locality, the thickness is 186 m. It is 170 m further southeast in the Darsamand section but thickness eastward in eastern Kohat, Nizampur, Kala-Chitta and Hazara where the thickness varies from 190 m to 366 m Baghnotar, Hazara (Shah, 1977).

The Sikhar Limestone was observed along the Gora Gali/Karakki road repeatedly between Ruppar Bridge and Karakki at seven different locations. It occurs near Uchhlar, Khanpur Lake and Bhallar. It was observed to the north of Islamabad along the road to Daman-e-Koh well as in the Saidpur area. The upper part of the Formation contains ammonites, belemnites, brachiopods, pelecypodes and gastropods, representing unrestricted open shelf environment. The lower contact is transitional with Shinawari Formation and is placed at the top of the last sandstone unit of the Shinawari Formation. The upper contact with the Chichali Formation is disconformable.

The Formation is Middle Jurassic in age. The Formation is correlated with the Chiltan limestone and Mazar Drik Formation of the Lower Indus Basin.

8. Chichali Formation

The name "Chichali Formation" was established by Danilchik (1961), Danilchik, and Shah (1967) for rocks previously described as "Belemnite beds" from the Salt Range and Trans-Indus ranges (Spath, 1938; Gee, 1945). Latif (1970) used the name "Spiti Shale" for the

Chichali Formation. The Chichali Formation overlies the Samana Suk Formation disconformably.

In the type locality, the Formation consists of dark green, greenish grey weathering rusty brown, glauconitic sandstone, with dark grey, bluish grey, greenish grey, sandy, silty, glauconitic shale in the lower part (Shah, 1977). In the Western Salt Range, Trans Indus ranges and Samana Range, the lower part of the Formation generally consists of dark bluish grey to black, sandy, glauconitic shales grading upward into greenish black or bluish black brown weathering, glauconitic, calcareous, fossiliferous sandstone with common phosphate nodules. The upper part is generally formed by an unfossiliferous, glauconitic and chamositic sandstone, which locally has the quality of a low grade, iron ore.

In southern Hazara, the formation, in the lower part, consists of glauconitic sandstone with a nodular silty, calcareous, Phosphatic base, followed by glauconitic sandy shale or dark pyritic unfossiliferous shale in the upper part.

In southern Hazara, (north of Jabrian Rest House on the Haro River) the thickness of the Formation is 33 m while further north the thickness is 34 m near Jhamiri to 64 m north-west of Kalapani. In Hazara, dark-grey to black shales and siltstone prevails.

The Chichali Formation is Late Jurassic (late Oxfordian - Tithonian) in age. The Formation contains abundant belemnites, ammonites and pelecepods, besides gastropods, brachiopods, vertebrate remains as well as foraminifera. Ammonites indicate a late Oxfordian to Neocomian age. The Formation is correlated with the Sembar formation and parts of the Goru Formation of the axial belt and the Sulaiman and Kirthar provinces.

9. Lumshiwal Formation

Gee (1945) proposed the name "Lumshiwal Sandstone" for usage in the Salt Range, but due to variations in lithology and areas other than type locality, the name has been amended by the Stratigraphy Committee of Pakistan (1977). The name is extended to Hazara, Kalachitta and Kohat. It replaces the older name "Giumal Sandstone" and "Main Sandstone series" in Hazara, Kalachitta and Kohat. In the type locality and other sections of the Trans-Indus ranges, the lithology consists of thick-bedded to massive, light grey, current- bedded sandstone with silty, sandy, glauconitic shale towards the base.

The sandstone is feldspathic, ferruginous and contains carbonaceous material in the upper part. Except from the lower most part, this contains glauconite and some poorly preserved specimens of Gryphaea sp. and Hibolithes sp., the formation in the Trans-Indus ranges is unfossiliferous and mostly of continental origin. Away from the Trans–Indus ranges, to the north, northeast and northwest, the Formation is mostly marine and consists of sandstone and siltstone with argillaceous and shelly limestone in the upper part.

In southern Hazara section near Jabrian Forest Rest House, north bank of the Haro River, the thickness is 50 m while further north in northern Hazara; the thickness varies from 20 m near Jhamiri village roadside section to 10 m near Kathwal. In northern Hazara (Jhämiri, Jabrian, Kathwal-Kalapani sections), the formation is a quartzose, ferruginous sandstone, weathering yellowish-brown, rusty brown to light grey with locally calcareous sandstone or sandy limestone with abundant fossil casts.

The lower contact with the Chichali Formation appears transitional. In the Kohat and Hazara area, the upper contact with the upper Cretaceous Kawagarh Formation is disconformable. The age of the beds in the Kathwal Kalapani section is Tithonian to middle Albian. The Formation is correlated with the Goru Formation of the Lower Indus Basin.

10. Kawagarh Formation

The name Kawagarh Formation was approved by the Stratigraphy Committee of Pakistan, (1977) to incorporates Day's "Kawagrah Marls" (1962) and its facies changes in Kohat and Hazara area. Latif (1970) used the name "Chanali Formation" for the Kawagarh Formation.

Kawagarh Formation is named after the Kawagarh Hills, north of main Kalachitta Range in Cambellpur District (Lat.33° 45′′30″: Long. 70° 28′ 30″ E). The Kawagarh Formation is its type locality consists of dark marl and cleaved calcareous shale, which weathers light grey, brownish grey, and nodular argillaceous limestone in its westerly extension in the Kohat area. In parts of southern Hazara the Formation is typically a thin to thick-bedded, sublithologic limestone similar to western Kohat. The Kawagarh Formation in Hazara consists of grey, olive grey, light grey sublithologic limestone with subordinate marl and calcareous shale.

In Hazara, the thickness varies from 45 m in the south (Changla Gali) to over 200 m in the middle of the area (Changla section). It is 70 m thick in Kathwal section. The Formation has a disconformable contacts with the overlying Hangu Formation of Paleocene age and the under lying Lumshiwal Formation of mainly Early Cretaceous age. Latif (1970) has reported the foraminifera from southern Hazara. The age of the Formation is thus Late Cretaceous.

11. Hangu Formation

The "Hangu Shale" and "Hangu Sandstone" of Davies (1930a) from the Kohat area have been formalized by the Stratigraphy Committee of Pakistan (1973) as Hangu Formation and the name extended to include the "Dhak pass beds" of Davies and Pinfold (1937), the Langrial iron ore is part of this Formation.

The lithology in the Kohat area consists of sandstone with grey shale intercalations in the upper part. The sandstone is white, light grey and reddish brown, weathers dark rusty brown, fine to coarse grained and medium to thick bedded. In the Trans-Indus ranges and salt range, the formation consists of dark grey, rarely variegated sandstone and argillaceous limestone (Shah, 1970). The formation is widely exposed and present in the subsurface in the Kohat-Potwar and Hazara areas. It is 90 m thick in Lockhart section, 50 m at Hangu, 75 m at Darsamand 150 m in the Kohat pass area. It is less than 15 m thick in the Nizampur-Kalachitta area and 35 m at Mandeha Banni in Hazara.

In Samana Range, Surghar Range and Salt Range, the Formation contains a rich fauna including gastropods, Pelecypodes, nautilids, corals and foraminifera. The Formation disconformably overlies the Kawagarh Formation in the Kohat, Kalachitta and Hazara areas and unconformably overlies various Paleozoic and Mesozoic Formations of Cretaceous age in the Salt and Surghar range. It is conformably overlain by the Lockhart Limestone.

The rocks are distributed almost all over Southern Hazara where contact between Hothla and Galis groups is exposed.

The Formation shows considerable variation in a south east- northwesterly direction in the Nummulitic Zone. The laterite near Changla-gali and Sohaba in the southeast is replaced by limonite near Kundla and Bandi, and by oolitic haematite near Nathia-gali and Dubran in the northwest. The overlying coal bands near Malkot in the southeast are replaced by carbonaceous shales near Changla-gali and by shales near Kuzagali in the North West. The Formation is Early Paleocene in age.

12. Lockhart Limestone

Davies (1930) introduced the term "Lockhart Limestone" for a Paleocene limestone unit in Kohat area and this usage has been extended by Stratigraphy Committee of Pakistan (1977) to similar units in other parts of the Kohat Potwar and Hazara. Latif (1970) in his work used the term "Mari Limestone" for the Lockhart Limestone.

A section exposed near Fort Lockhart (Lat. 33° 26′ N: Long. 70° 30′ E) in the Samana Range has been designated as the type locality. In the Hazara and Kala-Chitta areas, the limestone is dark grey and black in colour and contains intercalations of marl and shale. The limestone is generally bituminous and gives off fetid odour on a fresh surface. The Formation conformably and transitionally overlies and underlies the Hangu Formation and the Patala Formation respectively. The Formation is Paleocene in age.

The main limestone part of the formation is seen to contain more argillaceous bands in the southeast than in the northwest. The Formation is 260 m thick in Kala-Chitta and 90 m to 242 m in Hazara. The minor one of these occupies the centre of the slate Zone, distributed in approximately a six miles radius around Harnow and occupying the regions of Kakul, Bagnotar and Sirban and missing from the regions of Tarnwai, Thandiani, Abboatabad and Havelian.

13. Patala Formation

Latif (1970) used the name "Kuzagali Shale" for the Patala Formation was formalized by the Stratigraphy Committee of Pakistan (1977) for the Patala shales of Davies and Pinfold (1937) and its usage was extended to other parts of the Kohat-Potwar and Hazara. The section exposed in Patala Nala (Lat. 32° 40′ N: Long. 71° 49′ E) in the Salt range has been designated as type locality.

In Hazara, the shale is green and brown to buff in colour with inter beds of nodular limestone. The Formation has been assigned a late Paleocene age throughout its extent, except for the Hazara area where it extends into early Eocene.

The Patala Formation conformably overlies the Lockhart Limestone. The Nammal Formation in the Salt Range, the Panoba Shale in the Kohat and the Margala Hill Limestone in the Hazara area conformably overlie the Patala Formation. Latif (1970) reported smaller foraminifers from Hazara. The Formation is richly fossiliferous and contains foraminifers, mollusks and ostracodes.

The Formation shows a thickening from 60.96 m in the Margalla region to over 182.88 m in the Kuza-gali region .The limestone bands are frequent in the upper parts near Kuzagali.

14. Margala Hill Limestone

The term Margala Hill Limestone of Latif (1970) has been formally accepted by Stratigraphy Committee of Pakistan for the "Nummulitic Formation" of Waagen and Wynne (1872), the upper part of the Hill Limestone of Wynne (1875) and Cotter (1933) and part of the "Nummulitic Series" of Middlemiss (1896). The name is derived from the Margala Hills in Hazara. The Shahdara Section (Lat. 33° 48′ N: Long. 73° 10′ E) of southeast Hazara is considered the type section of the Formation.

The Formation consists of limestone with subordinate marl and shale. The limestone is grey, weathering pale grey, fine to medium grained, nodular, medium to thick bedded and rarely massive. The marl is grey to brownish grey while the shale is greenish brown to brown in colour. The unit is well developed in Hazara, Kalachitta, eastern Kohat and Potwar. The lower and upper contacts with the Patala Formation and the Chorgali Formation, respectively, are conformable. The age of the formation is Early Eocene.

The exposures of the Formation have been traced as north as Nawanshahr and as far south as Ratta Hotar. Most of the exposures are found in the southern part of the Nummulitic Zone, occupying more than one third of the zone area. Foraminifers, molluscs and echinoids are common in the formation. Raza (1967), Cheema (1968) and Latif (1970) recorded a number of foraminifers from the formation.

15. Chorgali Formation

The term "Chorgali Beds" of Pascoe (1920) has been formalized as Chorgali Formation by the Stratigraphy Committee of Pakistan. Shah (1977) used the term Chorgali Formation as a general term, which includes the Bhadrar beds in the Salt range and the Lora formation in Hazara. Latif (1970) used the term "Lora Formation" for the rocks exposed in Hazara. The section exposed in Chorgali pass (Lat. 33° 26′ N: Long. 72° 41′ E) in the Khair-e-Murat range has been chosen the type section.

The Formation is composed of shale and limestone. The shale is greenish grey, red, occasionally variegated and calcareous. Some grits beds are also intercalated. In the Hazara area, the Formation is composed of thinly intercalated limestone and marl, which are light to pale yellow to cream. It is 150 m thick at Chorgali Pass and about 45 m in southern Hazara.The age of the Formation is Eocene.

The Formation is represented as far north as Nathiagali near the Government House, and as far south as Nurpur. It is well developed in the Lora valley, on the Ghora Gali-Maksud road between Kotli and Phallgali, other exposures of the Lora Formation are found near Bansragali, Daryagali and Mangial. It is generally found in the Nummulitic zone in the southern regions but is absent from the Slate Zone. The main fossils present are foraminifers, mollusks and ostracodes has been reported by Davies and Pinfold (1937), Gill (1952) and Latif (1970).

16. Kuldana Formation

The term Kuldana Formation has been formally accepted by the Stratigraphy Committee of Pakistan, for the "Kuldana Beds" of Wynne (1874 p.68) after its occurrence near Kuldana. It was latter described by Middlemiss (1896, p, 42-43) as "Kuldana Series". The Kuldana bed of Wynne (1874) was formalized as Kuldana Formation by Latif (1964). The type section is located near village of Kuldana (Lat.33° 56′ N: Long. 73° 27′E), north of Murree Hill station. The Formation is composed of shale and marl with occasional beds of sandstone, limestone, conglomerate and bleached dolomite. In Hazara area, the unit predominantly comprises of various coloured shale and marl. The shale is crimson purple, brown, buff, pale grey and red in colour.

The Formation is widely distributed in southern Hazara, Kala-Chitta, northern Potwar and Kohat. It is about 150 m thick in Hazara, Kala-Chitta and northern Potwar areas where it ranges from about 120 m (at Mami Khel) to 150 m (at Panoba) in the Kohat area. The Formation is represented in Hazara as far north as Kalabagh Cantt and as far south as Islamabad. It has not been reported outside the Nummulitic Zone. In the Nummulitic Zone, itself, it is generally found in the southern half with a tendency to appear associated with the upper formations of the Galis Group. Some Foraminifers, gastropods, bivalves and some vertebrates have been reported from different parts of the Formation.

The Formation is of Early to early Middle Eocene in age. In the Hazara, Kala-Chitta and Potwar, the Formation has a conformable contact with the underlying Chorgali Formation, where as in the Kohat area, it conformably overlies the Jatta Gypsum. The upper contact with the Kohat Formation is conformable everywhere except in southern Hazara and parts of Kala-Chitta where the Murree Formation overlies it disconformably.

17. Rawalpindi Group

The Stratigraphy Committee of Pakistan has approved the term Rawalpindi Group after the Rawalpindi District, as proposed by Pinfold (1964) for the rocks comprising "Murree Formation" and Kamlial Formation" in the Kohat-Potwar Province. The group consists of alternations of sandstone and shale of fresh water origin. The sandstone is light to dark red, purple and grey in colour, while the shale is purple and red.

The rocks of the group are widely distributed in the Kohat-Potwar Province. The thickness increases from southwest to northwest and reaches at least 3,330 m in the north. The lower contact of the group with various Formations is disconformable, while the upper contact with the Siwalik Group is conformable. Vertebrate and plant remains including silicified wood, indicating Miocene, age have been reported from the group.

18. Murree Formation

The "Mari Group" of Wynne (1874), "Murree Beds" of Lydekker (1876) and "Murree Series" of Pilgrim (1910) have been formally named Murree Formation by the Stratigraphy Committee of Pakistan (1977). The name is derived from the Murree hills in the Rawalpindi

District. A section exposed to the north of the Dhok Maiki (Lat. 33° 25′ N: Long .72° 35′ E) in the Cambellpur district has been designated as the type section. The Formation is composed of a monotonous sequence of dark red and purple clay and purple grey and greenish sandstone with subordinate intra-formational conglomerate. The basal strata of the formation consist of light greenish grey calcareous sandstone. The Formation is widely developed in the Kohat-Potwar Province. It has also been recognized in Kashmir. It is 3030 m thick in northern Potwar, 9 m in Banda Daud Shah in Western Kohat and the thickness range is 180-600 m in the northern Salt range. The Formation unconformably overlies various Formations of Eocene age. Its upper contact is broadly transitional with the Kamlial Formation. The Murree Formation is poorly fossiliferous and contains only few plant remains, silicified wood, fish remains, Frog and mammalian bones have also been recorded. The fauna indicates an Early Miocene age for the Formation.

2.2 TECTONIC SETTING AND DEFORMATIONAL STYLE

The Hazara area, in northern Pakistan, is part of northwestern Himalayan Fold and Thrust belt (Lillie et al., 1987). This area remained a sedimentary basin intermittently from Cambrian to Tertiary and contains many superimposed basinal sedimentary megacycles (Shah, 1977; Kemal et al., 1992). The Southern Hazara area i.e. the Hazara fold-thrust belt is bounded by Panjal fault in the north and Murree fault in the south (Fig. 1.1).

The mountain ranges of the Himalaya along with the Karakorum and Hindu-kush constitute one of world's most prominent topographic features. It is a 2500 km long and partly 300 km broad area running from Pakistan into India, Nepal, Bhutan and China. The Himalaya was created by the collision of the Indian plate with Eurasian plate (Tahihkheli et al., 1979; Coward et al., 1985) during the Eocene time, along the Indus Suture or the Main Mantle Thrust (MMT). Smaller fragments broke away from the huge Gondwana plate and drifted northwards with respect to the Asian plate. These terrains were accreted to the Asian plate before the Indian plate followed .The Neo-Thetys, the ocean between India and Asia was closed and subducted to the north. This subduction gave rise to an Andean type margin in then Eastern Himalaya, while two oceanic island arcs developed in the west, Ladakh and Kohistan. Convergence continued, with result of the Indian plate colliding with the margin of the Asian Plate.

This relative movement is well documented with magnetic anomalies in the Indian Ocean, the Indian Subcontinent, the Himalaya, Tibet and Asia (Windley, 1995).
Himalayas is one of the world's most rapidly uplifting regions on earth, with areas like Nanga-Parbat uplifting with a rate of 1cm/Year (Zeitler, 1985). The deformation progressively migrated southward away from the early Eocene collision zone at the MMT and reached the Main Boundary Thrust (MBT) by the Miocene time. It finally migrated to the Salt range area as the Main Frontal Thrust (MFT) approximately by 1m.a. (Fraser, 1998)

Gansser (1964) divided the Himalayas into Higher, Lesser and Sub-Himalayas. The Higher and Lesser Himalayas represents the internal zone or the hinterland of the Himalayas and are bounded to the north by the Indus Suture Zone or the MMT and to the South by the MBT. The part of the Himalayas to the south of the MBT is included in the external zone or the foreland thrust belt.

There is a sharp loop in the geologic structures in the area i.e. known as Hazara Kashmir Syntaxis. All the rock units and major faults follow around this loop. The MBT is amongst the most important lineament associated with the Syntaxis. The syntaxis mostly entraps rocks belonging to the Rawalpindi and Siwalik Groups of Miocene and younger ages.

The study area lies in the Lesser Himalaya of the western limb of the Hazara-Kashmir Syntaxis. The Lesser Himalaya is subdividing into three tectonic units separated by thrust faults (Greco and Spencer, 1993). The structurally uppermost unit is Proterozoic to Cambrian Tanawal unit (Bossart et al., 1984). Its northern Boundary, the Oghi shear, has been correlated with the Main Central Thrust (MCT) in the Central Himalaya (Greco et al., 1993). To the south, crossing the Panjal (also called Manshera) Thrust (Coward et al., 1985), the Hazara Unit (Bossart et al., 1984) follows the Pre-Cambrian Hazara Slates, which are overlain tectonically by the Cambrian Abbottabad Group in the north and unconformably by Jurassic formation in the south.

The southern end of the Hazara unit is marked by the Nathia Gali Thrust (Latif, 1970). Both the Nathia Gali Thrust and the Panjal Thrust are branching with the MBT towards the East. The MBT marks the lower, southern boundary of the Lesser Himalaya.

All the geologic structures present in the study area are northeast/south west oriented and shows a southeast tectonic transport direction. Amongst these structures is the Nathia Gali Thrust, which is responsible for most of the deformational elements present in the area.

Structurally, Hazara fold-thrust belt represents a mega synclinorium, which is, along the Murree-Abbottabad road, and is divisible into at least two synclinoria, i.e., the Nawan-shahr synclinorial complex towards Abbottabad and the much larger Kuza Gali synclinorial complex towards Murree. The two-synclinorial complexes comprise a large number of NE-SW trending smaller structures. On the Murree-Abbottabad road, the Kuza Gali synclinorial complex is bounded in the northwest by the Nathia Gali fault against the Hazara slates near the locality of Kalabagh. Rocks older than Mesozoic, however, are not exposed in the southeast, suggesting that the depositional axis of the basin was systematically shifting towards the southeast and south (Ghazanfar et al., 1990).

Stratigraphically, the area of the southeastern Hazara forms a part of the much larger so-called Kohat-Potwar sedimentary basin. It shows a complete stratigraphic succession from Precambrian to Miocene with the notable absence of Middle and Upper Paleozoic sequence in addition to a number of others smaller disconformities.

The Hazara fold and thrust belt, of which the Kuza Gali-Dunga Gali-Ayubia area stratigraphically as well as tectonically forms the northeastern part, runs in the form of an E-W elongated linear belt that turns northwards in the east to merge into the Hazara-Kashmir Syntaxis.

2.3 CHICHALI FORMATION

As described earlier, this Formation was established by Danilchik (1961) and Danilchik and Shah (1967) for rocks previously described as "Belemnite beds" from the Salt Range and Trans-Indus ranges (Spath, 1938; Gee, 1945). Latif (1970) used the name "Spiti Shale" for the Chichali Formation.

In the type locality, the formation consists of dark green, greenish grey weathering rusty brown, glauconitic sandstone, with dark grey, bluish grey, greenish grey, sandy, silty, glauconitic shale in the lower part (Shah, 1977).

In the study area, the formation in the lower part consists of glauconitic sandstone with a nodular silty, calcareous, Phosphatic base, followed by glauconitic sandy shale or dark pyretic unfossiliferous shale in the upper part.

In section of northern Hazara (near Sabrina, Jhamiri, Kathwal and Kalapani i.e., north of Haro river) the formation shows a facies change described by dark silty shale with nodules and are similar to the "Spiti Shale" of the Himalayas (Kashmir).

North of Jabrian Rest House on the Haro River, the thickness of the formation is 33 m while further north the thickness is 35 m near Jhamiri to 64 m north-west of Kalapani, where dark–grey to black shales and siltstone prevails. The Formation is correlated with the Sembar formation and parts of the Goru Formation of the axial belt and the Sulaiman and Kirthar provinces.

The Chichali Formation rests disconformably upon different Jurassic rocks units (Mazar Drik, Chiltan and Loralai) .The type locality is in Chichali pass in the Surghar Range. The Formation is widely distributed throughout the Suliman fold belt and consists of dark-grey to black, silty and calcareous shales. In Khum-tangi, the base of the Formation is sandy and glauconitic. In Mara Rud, reddish and greenish shales with some prevailing laterite bands represent the Formation. In, Tangi, several ophiolite layers upto 2 m thick were noticed which are intercalated with the shales and have overcooked the overlying and under lying sediments (Porth and Hilal, 1990). The thickness of the Formation varies drastically from place to place e.g., it is 260 m in Mughal-kot, 133 m at the type locality, about 65 m in Dilkuna, about 55 m in Mazar Drik and 10 to15 m in Khum Tangi. The thicknesses of the Formation encountered in wells are as: 624 m in Zindapir-1, 1,437 m in Jandran –1 and 334 m in Tadri Main –1.

The rifting of Indo-Pakistan Plate, from Africa and Madagascar, initiated regressive deposition of Early Cretaceous deltaic and associated deep sea fan lobes which prograded across southeast and central Pakistan. The Potential source rock of the study area i.e. Chichali

Formation and also some of the famous reservoir rocks i.e. (Lumshiwal Formation of the Punjab Platform area) were deposited during this time period.

The Late Jurassic to Early Cretaceous Chichali Formation is missing in the wells of Eastern Punjab Platform area i.e., (Marot-1, Bahawalpur East–1 and Karampur-1) In rest of the platform Chichali Formation is represented by alternation of yellowish–grey to dark-grey, partly black shales and siltstones with subordinate white to light grey limestone. The whole sequence is glauconitic. Local occurrence of coal stringers has been reported. The contact with the underlying Samana-Suk Formation is disconformable. Environment of deposition has been inferred as Shallow marine to littoral. Maximum-drilled thickness of the Chichali Formation was encountered in Panjpir-2 well as 60 m (Mujtaba, 1999).

Based on very wide lateral distribution, considerable thickness and favorable geochemical parameters, Chichali Formation (and the time equivalent to Sember Formation) has been rated as an important oil and gas source rock unit in the middle as well as in the adjoining Lower Indus Basin. As far as areal distribution is concerned Chichali Formation is present not only in the whole Sulaiman Fold belt and Sulaiman depression areas, but also encountered in some of the wells drilled in the southwestern potion of the Punjab platform (e.g., Ahmedpur-1 well). Chichali Formation is however, not encountered in any of the well drilled in northern, central and eastern portion of the Punjab platform. The formation on the outcrop reaches a thickness of more than 200 m (i.e. Mughal Kot area) In the sub surface area Chichali Formation has encountered as 624 m thick in Zindapir-1 well in the Sulaiman Fold belt area, and not only 20 m thick in Ahmedpur-1 well of southern Punjab Platform. In the southern Sulaiman Fold belt area the Chichali Formation has been reported as 827 m thick, which is the maximum thickness reported till now. Similarly, gas has also been reported from Early Cretaceous Chichali Formation in Nandpur-1 well (39% C1, 57 % N2) (Mujtaba, 1999).

CHAPTER 3

MATERIALS AND METHODS

3.1 Sample Collection

The quality of any geochemical interpretation as well as its significance is determined directly by the quality of the samples and the initial design of the sampling program. Geochemical data may be obtained on numerous types of samples, including outcrop, cuttings, cores seeps, produced oil and gases.

No single sample can effectively represent all of the geochemical attributes associated with a hydrocarbon source rock system. Significant differences have been observed in the level of organic enrichment, hydrocarbon generation potential and organic matter type, as indicated by Hydrogen index (HI), between individual samples. Such organic geochemical variations are consistent with the variability in the litho-facies itself. Because of both the stratigraphic and lateral variability, observed in source rocks, sampling programs need to incorporate both random sampling and channel (composite) sampling. Channel sampling provides a more representative overview of the source potential of a formation or intervals that may be effectively diluted.

The channel sampling approach is most appropriate when one is attempting to correlate oil to a specific source because oils represent an integrated product. From subsurface samples, source rock potential cannot be adequately assessed if the well has been drilled using an oil-based mud. The situation results in anomalously high generation potentials because of hydrocarbon contamination. Caving can also result in problems. Specially caving may results in the dilution of source rock intervals and at the same time an over-estimation of possible source rock thicknesses if the caved material represents coaly intervals and an under estimation of the absolute level of thermal maturity.

Unlike subsurface samples, outcrop sample quality may be highly variable due to weathering. Surface weathering tends to results in oxidation, which reduces a samples level of organic enrichment, total generation and apparent oil-proneness. It may also influence the observed level of thermal maturity. It is, therefore, important that the freshest samples be obtained for analysis.

Thirty two (32) samples were collected from the outcrops of the Chichali Formation of the study area for source rock analysis and organic matter maturity. The samples were collected from nine (9) localities namely **Kalapani, Thandiani, Namli Mera, Baghnotar (Domail), Mohar, Changla Gali, Near Changla Gali, Jabri, and Kohala** (Fig.1.1).

The Geochemical techniques applied are: -

1. Total Organic Carbon
2. Rock Eval Pyrolysis
3. Vitrinite Reflectance

3.1.1 Sample Preparation

The samples collected were washed, crushed and grinded to make powder of 200 mesh for analysis.

3.1.2 Analytical Methods

Standard methods to determine total organic carbon and pyrolysis were used. The detail is as under;

3.1.2.1 Total Organic Carbon (TOC %)

The total organic carbon content is a direct measure of its organic richness. Sufficient quantity of organic matter must be present in a sedimentary rock before it is qualified as a potential source rock for subsequent hydrocarbon generation. Kerogen (insoluble organic material) and Bitumen (soluble organic material) constitute the Total Organic Carbon (TOC) of the sedimentary rock. In general, higher the concentrations of marine organic matter, the better the source potential.

Shales containing less than 0.5% TOC and carbonate with less than 0.2% TOC are generally considered as a non source rock and no further analysis is performed on these samples.

TOC is easy to measure. The dried rock samples are crushed and treated with HCl to remove carbonates. After acid treatment, the sample is subjected to oxidation, so that non-carbonate carbon is converted to CO_2 or CO. This is usually done in a Leco furnace, which measure evolved CO_2 by Infra Red cell. Before analysis, the instrument (LECO Carbon and Sulphur Analyzer CS-244) was calibrated with standard rock rings. After Calibration, the real samples were placed in Carbon Determinator and the % age of the Total Organic Carbon (TOC) was determined (Wasim and Shahnaz, 2004). The schematics diagram showing various steps for the determination of TOC is shown in figure 3.1.

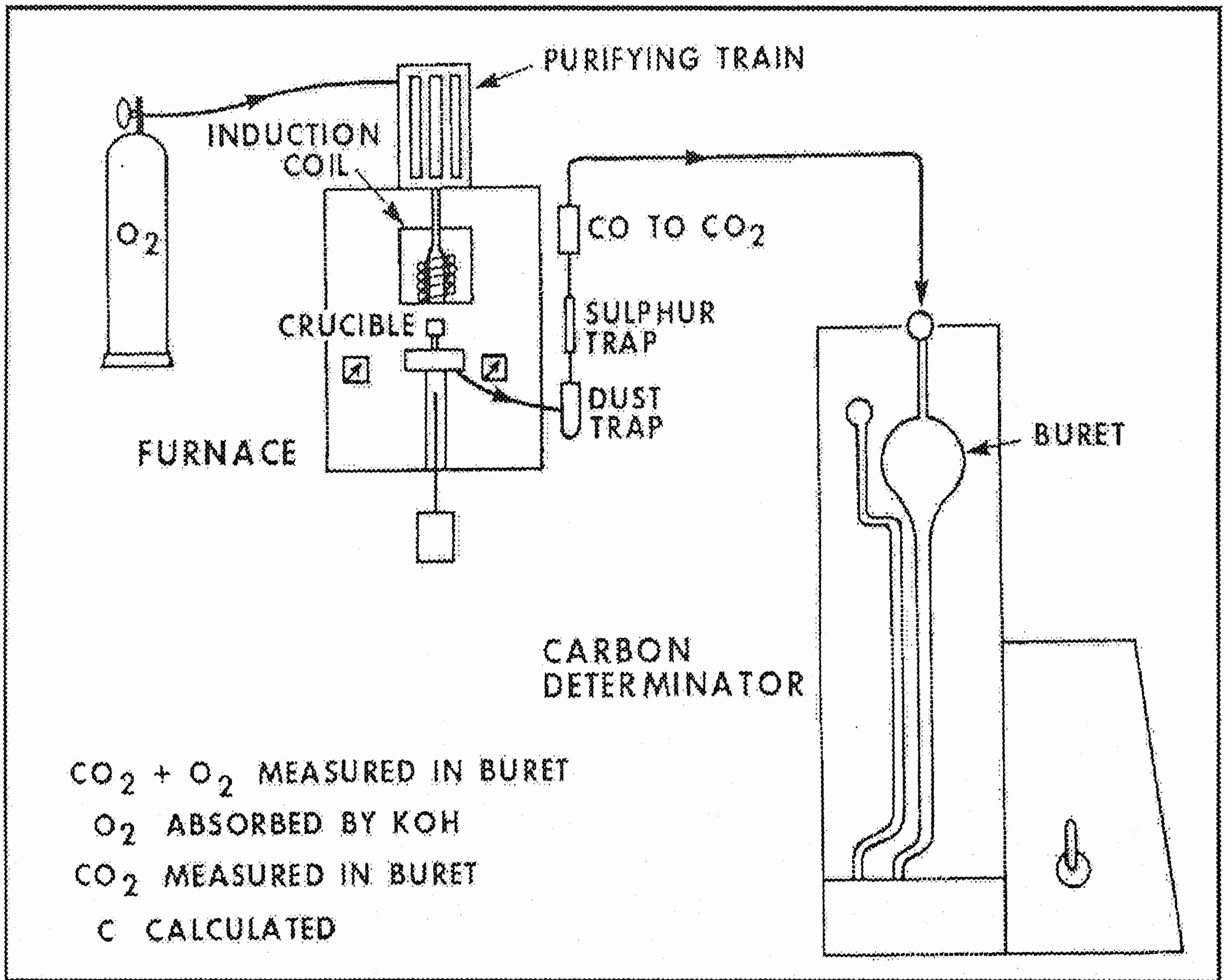


Figure 3.1: Schematic diagram of LECO carbon analyzer for TOC estimation.

3.1.2.2 Rock Eval Pyrolysis

Pyrolysis is the process whereby a sample of rock is heated under controlled temperature condition for a certain time interval. Organic compounds are released in two stages. In the 1st stage free hydrocarbons present in the rock (S_1) are released. In the 2nd stage, volatile hydrocarbons formed by thermal cracking are released (S_2). Pyrolysis is the best screening technique to identify possible source and reservoir intervals, which can be used for details.

The analysis is carried out by an instrument designed to heat the sample in a programmed manner. Flame Ionization Detector (FID) and Thermal Conductivity detector (TCD) are used to measure the evolved hydrocarbons (S_1) and (S_2) and (S_3) for non-hydrocarbons like CO_2 and water. The most widely used equipment is Delsi-Nermang Rock-Eval II plus TOC module. It is used to estimate three geochemical parameters.

- The S_1 peak, which represents the amount of free hydrocarbons at 300°C.
- The S_2 represents the hydrocarbons generated by thermal cracking of kerogen at temperature range of 400-550°C.
- The S_3 peak represents the amount of CO_2 produced from kerogen. It is collected at a temperature range 70-250°C.

The thermal maturation is indicated by the values of Tmax. The value of Tmax below 435°C indicates immaturity, the value of 435-470°C indicate main phase of oil generation, while value greater than 470°C reflects over mature zone. For the determination of genetic potential (GP= S_1+S_2), Tmax, S_1, S_2, S_3, Hydrogen Index and other Rock Eval parameters, the samples were analyzed using Rock Eval II (Wasim and Shahnaz, 2004).

3.1.2.3 Vitrinite Reflectance

Vitrinite reflectance technique is also one of various techniques used for determining the maturation of rocks. The maturation of rocks is indicated by mean of reflectivity (Ro %). The Vitrinite reflectance scale has been calibrated by other maturity parameters and by field studies in oil and gas provinces, so that Ro % may be correlated with the main zones and thresholds of petroleum generation as follow.

REFLECTANCE	MATURITY
Ro< 0.55	Immature
0.55- 080	Oil and gas generation
0.80-1.0	Cracking of oil to gas condensate zone
2.5 and Above	Dry gas generation

Vitrinite reflectance is a very good maturity indicator, the maximum oil generation occurs around 0.8-1.0% Ro, and the end of oil generation is around 1.3%. The higher values observed for gas generation range from 1.3-3.0% Ro.

Visual (optical) descriptions of kerogen may also give a useful guide to petroleum potential and petroleum type. From microscopic examination in reflected light, kerogen may be classified into the exitinite, vitrinite and inertinite groups. The exinite group comprises macerals with significant oil potential, while the vitrinite groups are gas prone. Inertinite have no petroleum generating potential .Measurements of the reflectance of vitrinite is used as an index of thermal maturity (Wasim and Shahnaz, 2004).

Other frequently used kerogen maturation parameters are Fluorescence, Thermal alteration index (TAI), Spore color index (SCI), Conodont alteration index (CAI), Methyl-phenanthrene index, Gas chromatography patterns and Biomarkers (Hunt, 1996).

Table 3.1. Showing properties of Coal macerals and their classification (Carpenter, 1988; American society for testing and materials, 1979)

CLASSIFICATION OF COAL MACERALS (PHYTOCLASTS)					
Maceral Group	Kerogen type	Reflectivity	Maceral subgroup	Maceral	Description
LIPTINITE (EXINITE) Waxy, lipid-rich and resinous parts of plants such as spores, cuticles and resins.	II	Low		Sporinite	Plants spores and pollen
	I			Alginite	Marine and freshwater algae.
	II			Cutinite	Waxy cuticles from plant leaves.
	II			Resinite	Resins, fats and oils from plant bark, stems and leaves.
	II			Liptodetrinite	Detrital fragments of other liptinites.
	II			Bituminite	Secondary liptinite possibly derived from algae or bacterial breakdown.
VITRINITE Cell walls, cell contents and precipitated gels of plant material.	III	Intermediate	Telovitrinite	Telocolinite	Woody tissue of stems, branches, leaves and roots. Primary cell walls. Homogenous and banded.
	III			Telinite	Structured cell wall material of land plants.
	III		Vitrodetrinite	Desmocollinite	Precipitated humic gels. Slightly darker and slightly lower in reflectivity compared to telocollinite.
INERTINITE Plant material which has been strongly oxidized during the peat stage of coalification.	IV	High	Teloinertinite	Fusinite	Woody tissue aromatized during early coalification (charring, oxidation etc).
	IV			Semifusinite	Woody tissue partly aromatized during coalification.
	IV			Sclerotinite	Fungal mycelia (spores). Possible product of oxidation of liptinite macerals.
	IV		Detroinertinite	Inertodetrinite	Detrital fragments of other inertinites.
	IV		Geloinertinite	Macerinite	Possible product of oxidation of gels.

CHAPTER 4

REVIEW OF GEOCHEMICAL AND PETROGRAPHICAL ANALYSIS

4.1 Potential Source Rocks

Source rock is defined as a unit of rock that has generated oil or gas in sufficient quantities to form commercial accumulations. The organic origin of oil and gas is now largely undisputed.

Limited source rock is defined as a unit of rock that contains all the prerequisites of a source rock except volume.

Potential source rock is a unit of rock that has the capacity to generate oil or gas in commercial quantities but has not yet done so because of insufficient catagenesis (thermal maturation). The distinction between source rocks and potential (immature) source rocks are essential in petroleum systems studies and when correlating oils to their source rocks.

Active source rock is in the process of generating oil or gas. The distribution of active source rock is essential in petroleum system studies. Active source rocks cannot occur at the surface, as they required adequate burial depth to generate oil or gas. Rocks capable of generating and expelling commercial quantities of hydrocarbons must contain elevated levels of organic matter. The requirement for an elevated level of organic enrichment is due to the need to saturate the source rock pore network with hydrocarbons for expulsion to occur. A statistical study of fine-grained sedimentary rocks suggests that in order for a rock to be considered organically enriched and a possible hydrocarbon source, it must contain at least 1.0 by weight % organic carbon; although this value is greater than that has commonly suggested in the literature. The richness or petroleum-generation potential of source rock can be determined by measurements of total organic carbon (TOC) and the pyrolysis yield. Before describing the results of TOC and pyrolysis analysis, let us first look into the organic matter.

4.2 Organic Matter

There is now a wealth of geochemical evidence that petroleum is sourced from biologically derived organic matter buried in sedimentary rocks. Organic-rich rocks, capable of expelling petroleum compounds, are known as source rocks. Source beds form when a very small proportion of the organic carbon, circulating in the Earth's carbon cycle, is buried in sedimentary environments where oxidation is inhibited. From petroleum point of view, the small proportion of carbon, which escapes from the cycle as a result of deposition in such sedimentary environments where oxidation to organic matter is limited, is important. Such environments are generally depleted in oxygen, such as, some restricted marine basins, deep lakes and swamps environments that are toxic for bacteria. Petroleum is, therefore, sourced from organic carbon that has dropped out of the carbon cycles at least for some time. It, however, rejoins the cycle when extracted by man and combusted.

Much of the world's oil has been sourced from marine source rocks. Source beds may develop in enclosed basins with restricted water circulating (reducing oxygen supply) or on open shelves and slopes as a result of upwelling or impingement of the oceanic mid water oxygen-minimum layer. In the world oceans, simple photosynthesizing algae (phytoplankton) are the main primary organic carbon producers. All the organic mater is made up of varying proportions of four main groups of chemical compounds. These are carbohydrates, proteins, lipids and lignin. Only lipids and lignin are normally resistant enough to be successfully incorporated into sediment and buried.

Lipids are present in both marine organisms and certain parts of land plants and are chemically and volumetrically capable of sourcing the bulk of the world's oil. Lignin is found only in land plants and cannot source significant amounts of oil, but is an important source of gas. Anoxic conditions are required for the preservation of organic matter in depositional environments, because they limit the activities of anaerobic bacteria and scavenging organisms which otherwise result in the destruction of organic matter.

Anoxic conditions develop where oxygen demand exceeds oxygen supply. Oxygen is consumed primarily by the degradation of dead organic matter; hence oxygen demand is high in areas of high organic productivity. In aquatic environments, oxygen supply is controlled mainly by the circulation of oxygenated water, and is diminished where stagnant bottom waters exist. Other factors are; the transit time of organic matter in the water column from euphotic zone to sea floor, sediment grain size, and sedimentation rate which effects source bed deposition

4.3 Depositional Settings

The three main depositional settings for the formation, of source beds are lakes, deltas and marine basins. Lakes are the most important settings for source bed deposition in continental sequences. Favorable conditions may exits in deep lakes, where bottom water are not disturbed by surface wind stress, and at low latitudes, where there is little seasonal overturn of the water column and temperature-density stratification may develop. Source bed thickness and quality is improved in geologically long-lasting lakes with mineral clastic input.

Deltas may be important settings for source bed deposition. Organic matter may be derived from freshwater algae and bacteria in swamps and lakes on the delta-top, marine phytoplankton and bacteria in the delta-front and marine pro-delta shales most probably, from terrigenous land plants growing on the delta plain.

There are several primary factors, which control the aerial distribution of source rocks, their geochemical type and their effectiveness i.e., the amounts of discovered original conventially recoverable reserves of oil and gas generated by these rocks. These factors are geological age, paleo-altitudes of the depositional areas, structural forms in which the deposition of source rocks occurred and the evolution of biota.

4.4 Kerogen

The term Kerogen originally referred to the organic matter in oil shales that yielded oil upon heating. Kerogen in rocks has four principal sources: marine, lacustrine, terrestrial and recycled. Most of the world's oil has formed from the marine and lacustrine kerogens, where as most of coal is from terrestrial plants and the recycled kerogen is largely inert (Hunt, 1996).

Kerogen is the most important form of organic carbon on earth. It is 1000 times more abundant than coal plus petroleum in reservoirs and is 50 times more abundant than bitumen and other dispersed petroleum in non-reservoir rocks (Hunt, 1972). Soluble disseminated bitumen (extractable organic matter) together with petroleum and natural gas are present in relatively small amounts. Kerogens are chemical compounds that comprise segment of organic matter in sedimentary rocks, insoluble in the normal organic solvents because of their huge molecular weight (more than 1,000). The soluble portion is known as bitumen. Each kerogen molecule is unique because, it is formed by the random combination of numerous monomers. Kerogen is the precursor to hydrocarbon (Fossil Fuels) and the material that forms oil shale.

4.5 Maturity

In petroleum geology, the maturity of a source rock is a measure of its state in terms of hydrocarbon generation. Maturity is established using a combination of geochemical and basin modeling techniques. Organic rich rocks termed as source rocks will alter under increasing temperature such that the organic molecules slowly mature into hydrocarbons. Source rocks are broadly categorized as immature (no hydrocarbon generation), sub-mature (limited hydrocarbon generation), mature (extensive hydrocarbon generation) and over-mature (most hydrocarbon have been generated).

The maturity of a source rock can also be used as an indicator of its hydrocarbon potential. Aquatic and terrestrial organic matter, i.e. preserved in sediments, is converted to kerogen by biological and very low temperature processes termed diagenesis. As sediments are more deeply buried, kerogen is converted into oil and gas by thermal processes, known as catagenesis. Under extreme thermal stress, organic matter is metamorphosed into methane and graphite by a process, called as metagenesis.

4.6 Parameters for the evaluation of source rock characteristics (Welte, 1984; Hunt, 1979, 1997; Peter and Moldowan, 1993; Magoon and Wallace, 1994)

4.6.1 Organic Richness (TOC %)

The ability of a potential source rock to generate and release hydrocarbons is dependent upon its contents of organic matter, which is evaluated by Total Organic Carbon (TOC) expressed as weight percent organic carbon (Hunt, 1979) and determined by LECO Carbon and Sulphur determinator CS-244. In the interpretation of TOC data, the following guidelines are used:

TOC (weight %)	Quality of source rock
0.0 - 0.5	Low/ Non Source
0.5 - 1.0	Marginal
1.0 - 2.0	Moderate
2.0 - 4.0	Very Good
4.0-Upward	Excellent

Table 4.1: Parameters for the evaluation of source rock characteristics (After Welte, 1984; Hunt, 1979, 1997; Peter and Moldowan, 1993; Magoon and Wallace, 1994)

4.6.2 Rock Eval Pyrolysis

The pyrolysis of rock samples and the determination of the resulting hydrocarbon products are used to derive at absolute values of the genetic potential for generating hydrocarbons under optimal thermal conditions, and to classify the type of organic matter and the maturation stage (Horsfield and Welte, 1984).

To determine these parameters Rock Eval Pyrolysis was carried out by heating the sample at 300°C for 3 min to release hydrocarbons already present in rock. The instrument is calibrated with rock standard IFP 55000. The following classifications of the source rock are used:

4.6.2a. S_1 =Amount of hydrocarbons present in the rock in the free or adsorbed state.

4.6.2b. S_2 = Amount of hydrocarbons and hydrocarbon like compounds generated during pyrolysis of kerogen.

<2.5 mg/g of rock	Non Source
2.5 - 5 mg/g of rock	Marginal Source Potential
> 5 mg/g of rock	Good Source Potential.

4.6.2 c. S_3 = Oxygen containing compounds like CO_2 and H_2O produced during pyrolysis.

4.6.2 d. Tmax (°C)

Tmax is the temperature, which is recorded for the maximum of S_2, and varies as a function of the thermal maturity of the organic matter. Tmax is a good maturation index for type II and type III organic matter. In most cases, the oil window is attached for value around 435°C. Except for type II-S for which it begins around 420°C

<435	Immature for oil
435 – 470	Mature for oil
>470	Over mature for oil

4.6.2 e. Hydrogen Index (HI, mg Hydrocarbons /g TOC)

The hydrogen index corresponds to the quantity of hydrocarbon generated relative to the total organic carbon (TOC). The hydrogen index is an important calculated parameter that helps to define whether a sample is prone towards oil, mixed oil and gas. The hydrogen index is not computed if total organic carbon (TOC) is <0.5 % wt. In the interpretation of hydrogen index data, the following guidelines are used.

$$HI = (S_2/TOC) * 100$$

0 - 200	Gas
200 – 300	Mixed oil and gas
> 300	Oil

4.6.2 f. Oxygen Index (OI) (To characterize type of Kerogen)

Oxygen index is defined as the ratio between S_3 (expressed in mg CO_2/g rock) and TOC (expressed as weight percent).

$$OI = (S_3/TOC) * 100$$

<50	Oil
50 – 100	Oil and Gas
>100	Gas

4.6.2 g. Genetic Potential (GP)

GP = S 1 + S 2

<2 kg/t of rock	No oil potential, limited potential for gas.
2 - 5 kg/t of rock	Fair source potential
5 – 10 kg/t of rock	Good source potential

4.6.2 h. Production Index (PI)

PI = S 1 / (S 1 + S 2)

0 - 0.4	No significant accumulation or generation of hydrocarbons.
0.4 – 1	Possible accumulation of generated or migrated hydrocarbons

4.6.3. Source rock maturity summary

Immature Source Rocks:	Tmax<435°C Ro<0.65%
Over-mature Source Rocks:	Tmax<450°C Type I
	Tmax<465°C Type II
	Tmax<540°C Type III

Oil Window **Ro % = 0.65 to 1.3%**

Tmax 440 to 450 °C for Type I organic matter

Tmax 435 to 460 °C for Type II organic matter

Tmax 420 to 460°C for Type IIS organic matter

Tmax 435 to 470°C for Type III organic matter

Gas and Condensate:	**470°C to 540°C Type III**
Dry Gas	**Ro% = >1.6% Tmax>540°C Type III**

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1. Organic Richness

The sample collected from nine different locations of Chichali Formations exposed in southern Hazara area, with some field observations and photographs as given below:

Locations	Figure No.
Kalapani	(Figure 4.1)
Thandiani	(Figure 4.2)
Namli Meera	(Figure 4.3)
Baghnotar (Domail)	(Figure 4.4)
Mohar	(Figure 4.5)
Changla Gali	(Figure 4.6)
Near Changla gali	(Figure 4.7)
Jabri	(Figure 4.8)
Jabri	(Figure 4.9)
Kohala	(Figure 4.10)

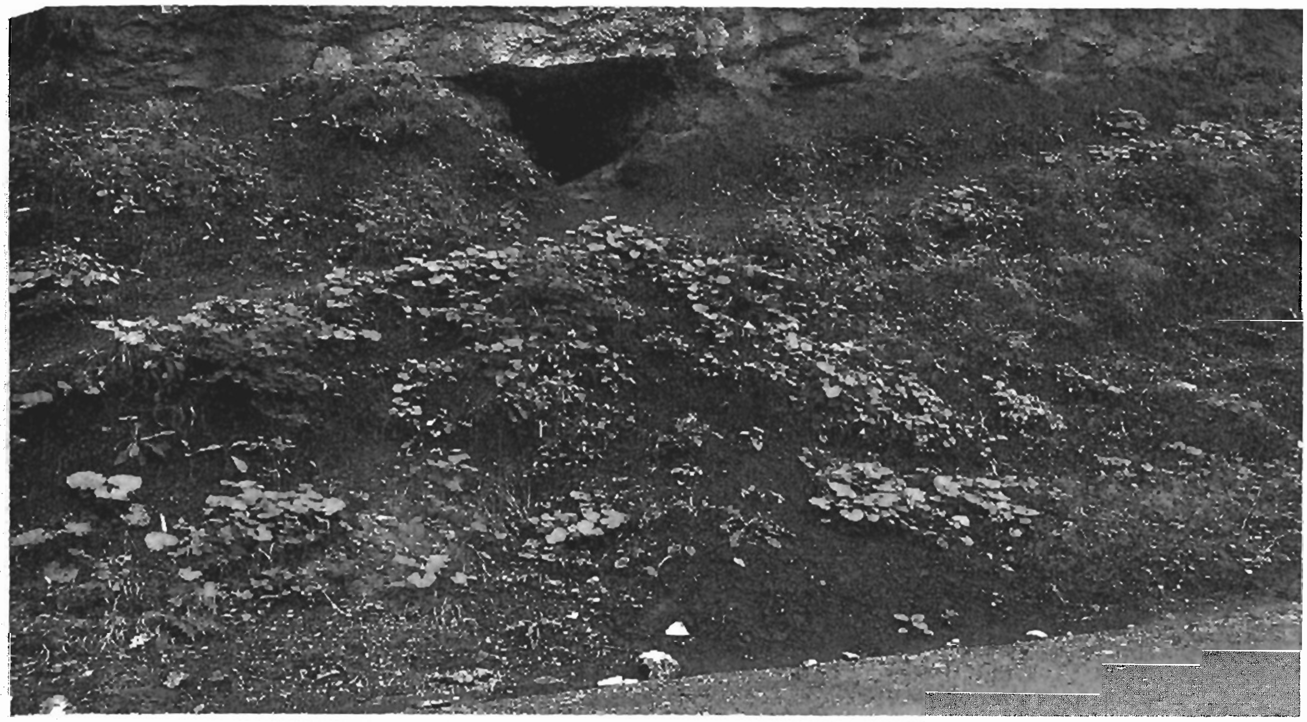


Figure 5.1: Picture showing the Chichali Formation exposed in Kalapani location.

5.1.1: Kalapani Oil Shale: -

The Chichali Formation at Kalapani location is dark black in colour and is exposed along the road side from Kalapani to Thandiani (Fig. 5.1).At this location maximum thickness of the Chichali formation is 15 to 20m.The base of the Formation is not exposed ,while the upper contact is with some limestone probably Lockhart. It looks due to some fault that the Chichali formation is exposed here. The latitudes and longitude data of the Kalapani village is (35°44′91″N, 74°36′ 89″E). Elevation from the sea level is 6176ft.

Three samples collected from the location were subjected to geochemical analysis and shows very good results of TOC (1.81, 2.95, 3.43) .While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and shows that it is spent source rock at present.

Figure 5.2: Picture showing the Chichali Formation exposed in Thandiani location.

5.1.2: Thandiani Oil Shale: -

The Chichali Formation is exposed in small a path just on the other slope of main Thandiani height. It is dark grey to black and splintery in nature. Due to high vegetation the top and bottom are not exposed (Fig. 5.2). At this location maximum thickness of the Chichali formation is 10 to 15 m. The latitudes and longitude data of the Thandiani village is (34° 13′ 78″ N, 21° 10′ 89″E). Elevation from the sea level is 8748 ft.

Two samples collected from the location were subjected to geochemical analysis and shows very good results of TOC (2.75, 2.75) .While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and shows that it is spent source rock at present.

Figure 5.3: Picture showing the Chichali Formation exposed in Namli Mera location.

5.1.3: Short of Namli mera Oil Shale: -

A small patch of Chichali Formation is present along the road side, where a small water spring is also present within the Chichali formation. The Chichali formation is dark grey to black in colour with yellow phosphate and rusty brown patches. On one side Samana Suk Limestone is in contact with Chichali, while the remaining side is covered with loose gravel (Fig 5.3).At this location maximum thickness of the Chichali formation is 20 by 10 m. Two shale samples have been taken from the Location i.e. from the top and middles (Table 4.3).The latitudes and longitude data of Namli mera is (34° 07′ 43″ N, 73° 22′00″E). Elevation from the sea level is 8773 ft.

Three samples collected from the location were subjected to geochemical analysis and shows very good results of TOC (3.72, 4.15, 5.12 .While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and shows that it is spent source rock at present.

Figure 5.4: Picture showing the Chichali Formation exposed in Baghnotar location.

5.1.4: Baghnotar Oil Shale: -

The Chichali Formation is exposed, at three spots along the roadside. It is dark grey to black in colour (Fig. 4.4).At this location maximum thickness of the Chichali formation is 10 m. Six shale samples have been taken from the location (Table 4.3).The latitudes and longitude data of the Baghnotar village is (34° 08′ 31″ N, 73° 20′ 94″ E).
Elevation from the sea level is 4472 ft.

Ten samples collected from the location were subjected to geochemical analysis and the samples showed very good results of TOC (4.62, 3.75, 3.91, 2.65, 2.47, 1.74, 2.44, 1.94 3.63, 2.77).While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

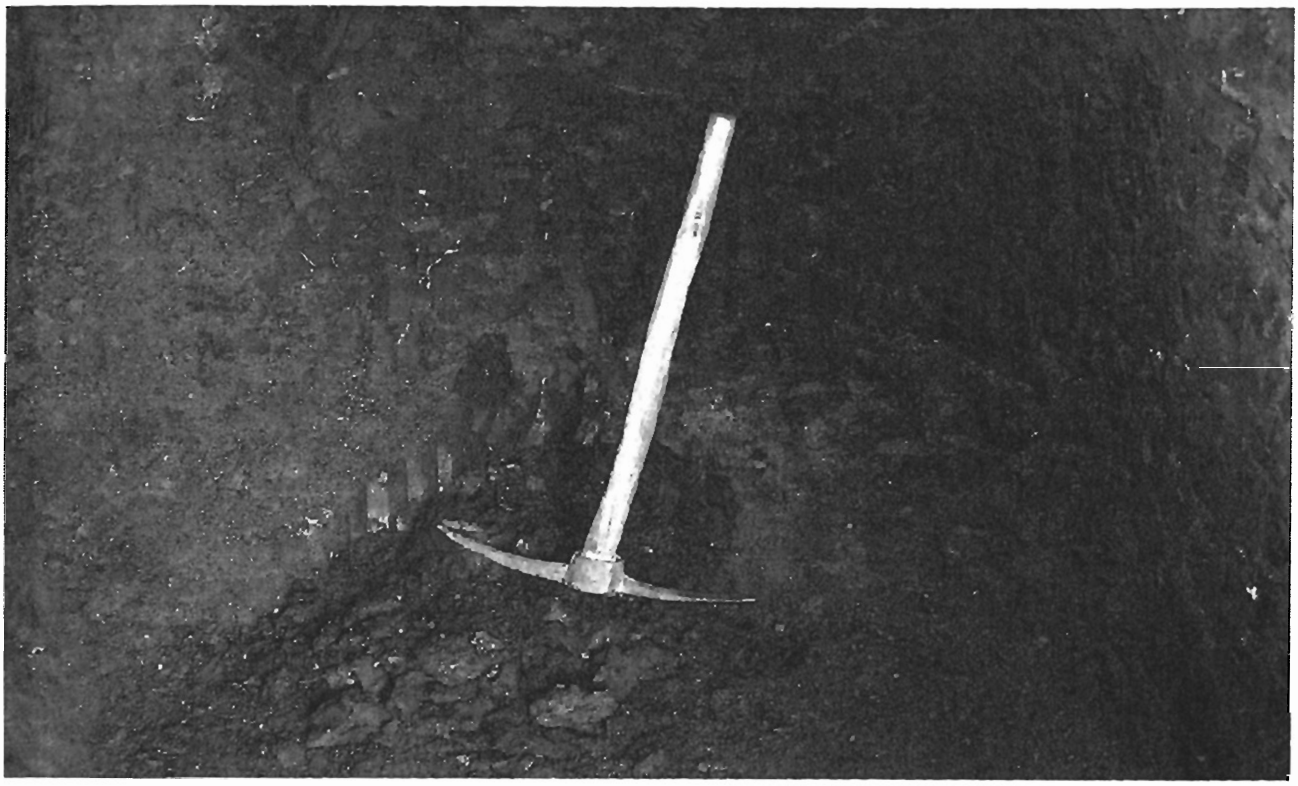


Figure 5.5: Picture showing the Chichali Formation exposed in Mohar location.

5.1.5: Mohar Oil Shale: -

A fresh sample of the Chichali formation was collected from a new mine, which is excavate within Chichali formation in search of coal. The sample is black in colour with some white minute substances. Within the mine Chichali, formation is 4ft thick and mine was excavated upto 5 ft in length (Fig. 5.5). Chichali formation was in contact with some limestone probably Samana Suk on one side and debris on other side. A full exposure of Chichali formation was also noticed in the vicinity. The latitudes and longitude data of the Baghnotar village is (34° 08′ 31″ N, 73° 20′ 94″ E). Elevation from the sea level is 4470 ft.

The sample collected from the location was subjected to geochemical analysis and the sample showed very good results of TOC (3.20). While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

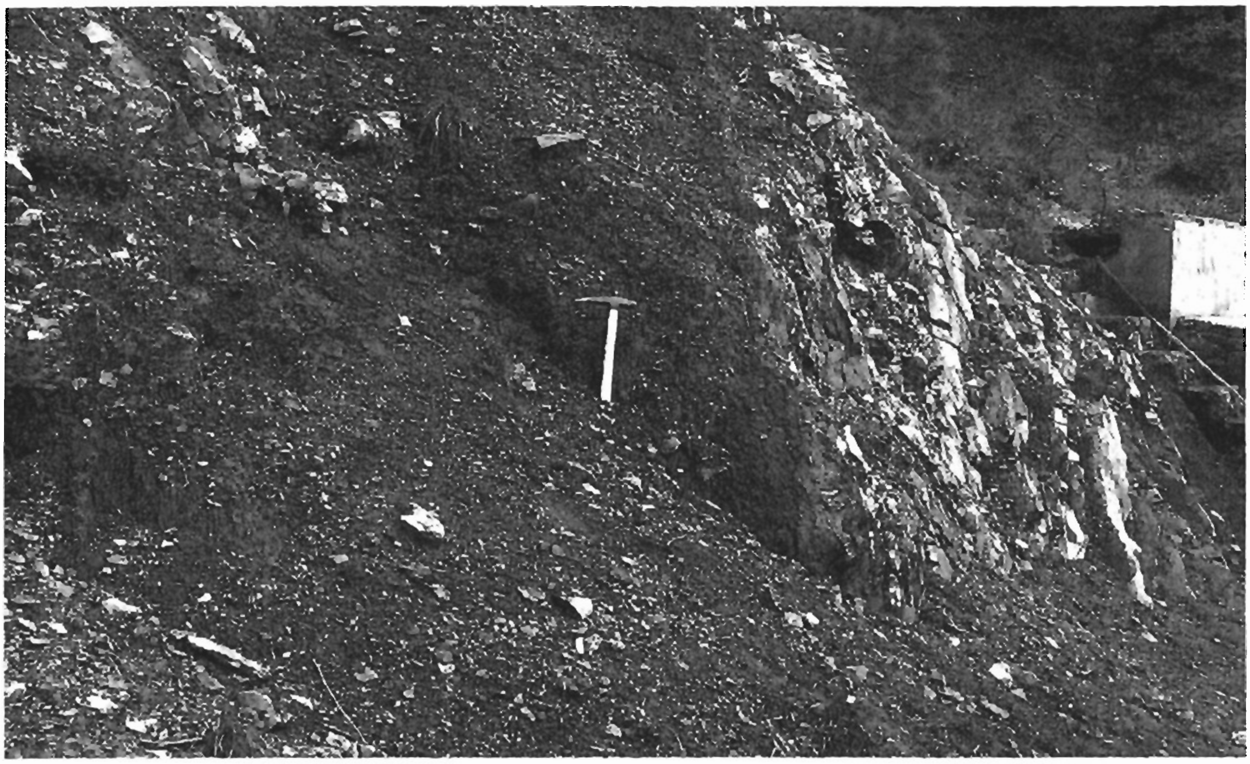


Figure 5.6: Picture showing the Chichali Formation exposed in Changla Gali location.

5.1.6: Changla Gali Oil Shale: -

The Chichali Formation is exposed, in two patches with thinly bedded limestone in between. The Formation is dark grey to black in colour and some, what splintery in nature with no belemnites (Fig. 5.6). The latitudes and longitude data of the Baghnotar village is (33° 59′ 73″ N, 73° 23′ 45″ E). Elevation from the sea level is 8318 ft.

Four samples collected from the location were subjected to geochemical analysis and the sample showed very good to excellent results of TOC (10.96, 1.93, 5.54 & 27.87). While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

Figure 5.7: Picture showing the Chichali Formation exposed in Near Changla Gali location.

5.1.7: Near Changla Gali Oil Shale: -

The Chichali Formation is exposed, in patches with thinly bedded limestone in between. The Formation is dark grey to black in colour (Fig. 5.7). The latitudes and longitude data of the Baghnotar village is (33° 59′ 73″ N, 73° 23′ 45″ E). Elevation from the sea level is 8318 ft.

Four samples collected from the location were subjected to geochemical analysis and the sample showed very good to excellent results of TOC (10.96, 1.93, 5.54 & 27.87). While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

Figure 5.8: Picture showing the Chichali Formation exposed in Jabri location.

Figure 5.9: Picture showing the Chichali Formation exposed in Jabri location.

5.1.8:1 Km west of Jabri Oil Shale: -

About 30 m of exposure of the Chichali formation is present along the road with debris on one side and limestone on other side. The Shale is dark grey to black in colour and is highly splintery in nature (Fig. 5.8 & 5.9). No belemnites or sandstone bands were found within the Chichali Shale. The latitudes and longitude data of the Jabri village is (33° 59′ 74″ N, 73° 23′ 45″ E). Elevation from the sea level is 3918 ft.

Five samples have been collected from the location were subjected to geochemical analysis and the sample showed very good to excellent results of TOC (2.12, 1.99, 2.96, 3.86 & 3.07). While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

Figure 5.10: Picture showing the Chichali Formation exposed in Kohala location.

5.1.9: Just short of Kohala Oil Shale: -

About 10 m thick Chichali Formation is present along the road. The Shale is light grey to dark grey with intercalations of Khaki and black band, splintery in nature with no belemnites (Fig. 5.10). The latitudes and longitude data of the Kohala village is (33° 52′ 82″ N, 73° 11′15″ E). Elevation from the sea level is 3379 ft.

Two samples have been collected from the location were subjected to geochemical analysis and the sample showed very good to excellent results of TOC (0.42 & 0.52). While the values given by Rock Eval Pyrolysis are too much low (Table 4.2) and the result shows that it is spent source rock at present.

The organic carbon data (TOC) of the samples of Chichali Formation collected from the nine different localities, of the study area is given in the Table 5.1. and is graphically presented in Fig. 5.11.

Table 5.1. TOC (%) of rock samples collected from Chichali formation of Southern Hazara.

o.	Sample No.	Lab. No	Locality	TOC	Remarks
1.	1.5.9.2005	Pr.10676	Kalapani	1.81	Moderate
2.	2.5.9.2005	Pr.10677	Kalapani	2.95	Very Good
3.	3.5.9.2005	Pr.10678	Kalapani	3.43	Very Good
4.	4.5.9.2005	Pr.10679	Thandiani	2.75	Very Good
5.	5.5.9.2005	Pr.10680	Thandiani	2.75	Very Good
6.	6.6.92005	Pr.10681	Short of Namli Mera	3.72	Very Good
7.	7.6.9.2005	Pr.10682	Short of Namli Mera	4.15	Excellent
8.	8.6.9.2005	Pr.10683	Short of Namli Mera	5.12	Excellent
9.	9.6.9.2005	Pr.10684	Baghnotar (Domail)	4.62	Excellent
10.	9A.6.9.2005	Pr.10685	Baghnotar (Domail)	3.75	Very Good
11.	9B.6.9.2005	Pr.10686	Baghnotar (Domail)	3.91	Very Good
12.	9C.6.9.2005	Pr.10687	Baghnotar (Domail)	2.65	Very Good
13.	10.6.9.2005	Pr.10688	Baghnotar (Domail)	2.47	Very Good
14.	11.6.9.2005	Pr.10689	Baghnotar (Domail)	1.74	Moderate
15.	12.6.9.2005	Pr.10690	Baghnotar (Domail)	2.44	Very Good
16.	13.6.9.2005	Pr.10691	Baghnotar (Domail)	1.94	Moderate
17.	14.6.9.2005	Pr.10692	Baghnotar (Domail)	3.63	Very Good
18.	15.6.9.2005	Pr.10693	Baghnotar (Domail)	2.77	Very Good
19.	16.6.9.2005	Pr.10694	Mohar	3.20	Very Good
20.	17.6.9.2005	Pr.10695	Changla Gali	10.96	Excellent
21.	18.6.9.2005	Pr.10696	Changla Gali	1.93	Moderate
22.	19.6.9.2005	Pr.10697	Changla Gali	5.54	Excellent
23.	20.6.9.2005	Pr.10698	Changla Gali	27.87	Excellent
24.	21.6.9.2005	Pr.10699	Near Changla Gali	3.63	Very Good
25.	22.6.9.2005	Pr.10700	Near Changla Gali	4.58	Excellent
26.	23.6.9.2005	Pr.10701	1km West of Jabri	2.12	Very Good
27.	24.6.9.2005	Pr.10702	1km West of Jabri	1.99	Moderate
28.	25.6.9.2005	Pr.10703	1km West of Jabri	2.96	Very Good
29.	26.6.9.2005	Pr.10704	1km West of Jabri	3.86	Very Good
30.	27.6.9.2005	Pr.10705	1km West of Jabri	3.07	Very Good
31.	28.6.9.2005	Pr.10706	Just short of Kohala	0.52	Low
32.	29.6.9.2005	Pr.10707	Just short of Kohala	0.46	Low

The organic carbon content of thirty out of the total thirty-two samples, range between 1.74 to 27.87 % TOC, generally indicating very good to excellent source potential. Two samples, with TOC 0.46 to 0.52 % can be rated as non-source, whereas one sample shows TOC as high as 27 .87 %, which is highest reported so far for Chichali Formation.

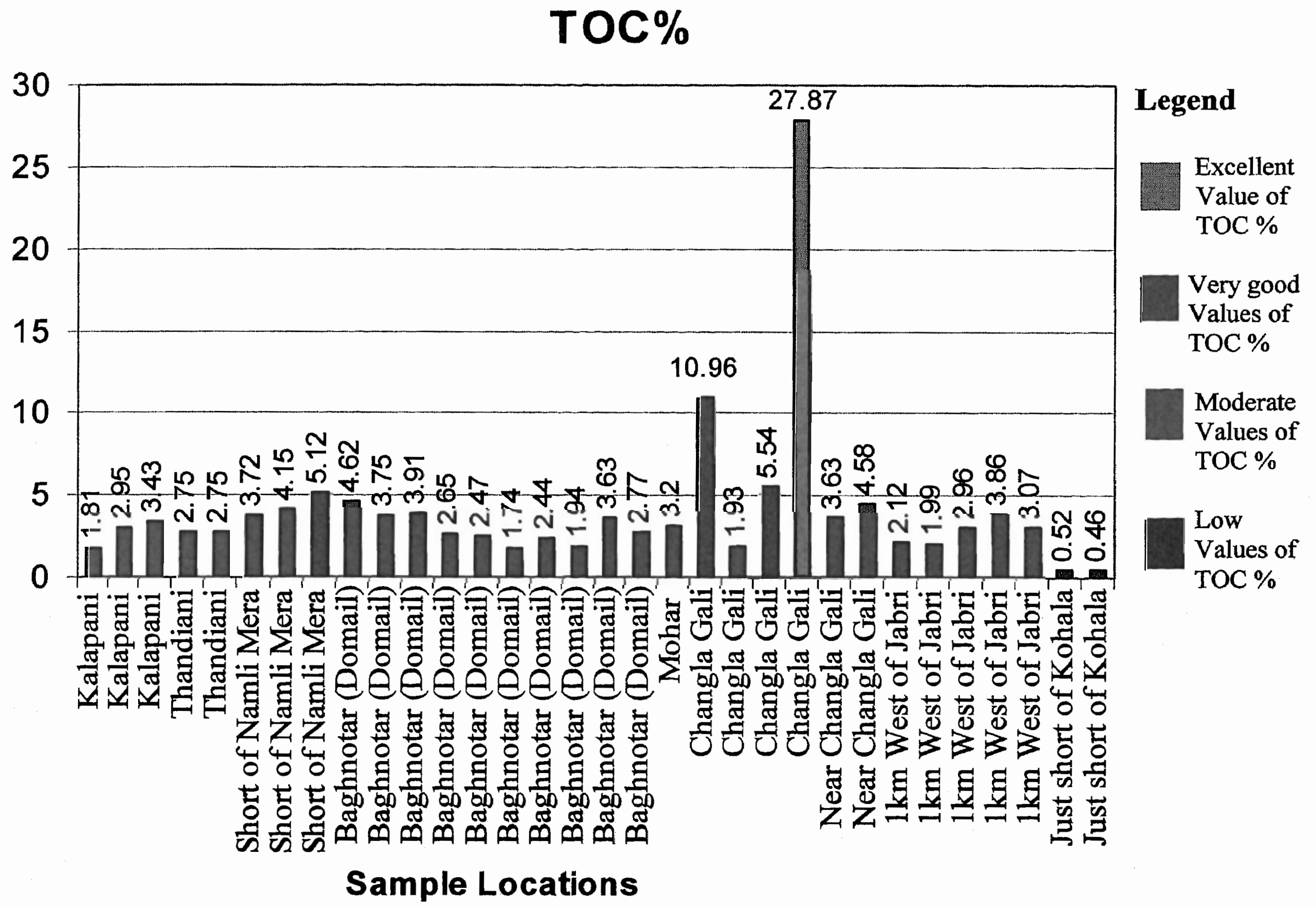


Fig.5.11: Graph showing the TOC results of Chichali shale samples of the studied area

5.2. Rock Eval Pyrolysis

The Tmax values of (446^0C to 535^0C) are indicating over-mature stage for oil as well as gas generation.

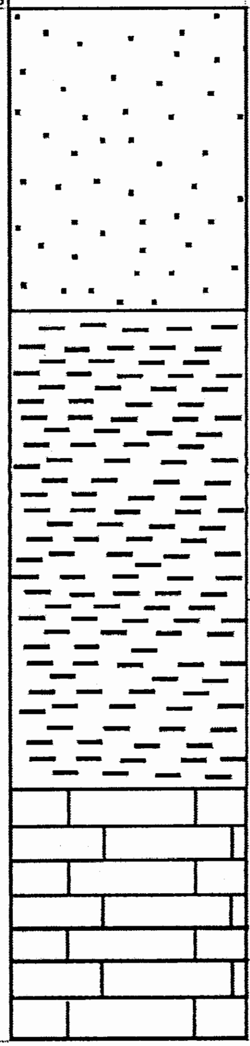
Table 5.2 represents extraordinarily very low values for S_1, S_2, and S_3, Genetic Potential (GP), Hydrogen Index (HI), and Oxygen Index (OI), as compared to significant high to very high organic carbon content. This extraordinary analysis result clearly indicates that Chichali Shales, in the study area of Hazara, are spent source rock, and the current organic carbon most probably falls in the category of S_4 residual graphitic carbon.

Table 5.2.TOC and Rock-Eval Pyrolysis data of rock samples of Chichali Formation from southern Hazara

S.No.	Sample Location	TOC (%)	Tmax (^{0}C)	S_1	S_2	S_3	S_2/S_3	GP	HI	OI	PI	PC
1.	Kalapani	1.81	523	0.05	0.05	1.24	0.00	0.00	0	68	0.50	0.00
2.	Kalapani	2.95	535	0.01	0.03	0.82	0.03	0.04	1	27	0.25	0.00
3.	Kalapani	3.43	472	0.02	0.02	1.14	0.01	0.04	0	33	0.50	0.00
4.	Thandiani	2.75	425	0.03	0.00	0.72	0.00	0.03	0	26	1.00	0.00
5.	Thandiani	2.75										
6.	Short of Namli Mera	3.72										
7.	Short of Namli Mera	4.15	446	0.00	0.03	0.28	0.10	0.03	0	6	0.00	0.00
8.	Short of Namli Mera	5.12	432	0.01	0.08	0.20	0.40	0.09	1	3	0.12	0.00
9.	Baghnotar (Domail)	4.62	479	0.02	0.03	0.06	0.50	0.05	0	1	0.05	0.00
10.	Baghnotar (Domail)	3.75										
11.	Baghnotar (Domail)	3.91		0.01	0.06	0.12	0.15	0.07	1	3	0.17	0.00
12.	Baghnotar (Domail)	2.65										
13.	Baghnotar (Domail)	2.47										

S.No.	Sample Location	TOC (%)	Tmax (^0C)	S_1	S_2	S_3	S_2/S_3	GP	HI	OI	PI	PC
14.	Baghnotar (Domail)	1.74										
15.	Baghnotar (Domail)	2.44										
16.	Baghnotar (Domail)	1.94	522	0.07	0.06	0.04	0.13	0.54	1	2		
17.	Baghnotar (Domail)	3.63										
18.	Baghnotar (Domail)	2.77										
19.	Mohar	3.20										
20.	Changla Gali	10.96	506	0.01	0.07	0.23	0.30	0.08	0	2	0.12	0.00
21.	Changla Gali	1.93										
22.	Changla Gali	5.54	466	0.02	0.01	0.71	0.01	0.03	0	12	1.00	0.00
23.	Changla Gali	27.78		0.04	0.32	0.67	0.47	0.36	1	2	0.11	0.03
24.	Near Changla Gali	3.63										
25.	Near Changla Gali	4.58										
26.	1km west of Jabri	2.12										
27.	1km west of Jabri	1.99	460	0.09	0.03	0.44	0.12	0.75	14	1		
28.	1km west of Jabri	2.96										
29.	1km west of Jabri	3.86	534	0.00	0.04	1.34	0.02	0.04	1		0.00	0.00
30.	1km west of Jabri	3.07										
31.	Just short of Kohala	0.52										
32.	Just short of Kohala	0.46										

Table 5.3. TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Kalapani,southern Hazara.

Formation	Unit Thickness	Lithological Column	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI	VR
Lumshiwal												
Chichali	20 m		3	6176 Ft	3.43	472	0.02	0.02	1.14	0	33	2.64
			2		2.95	535	0.01	0.03	0.82	1	27	
			1		1.81	523	0.05	0.05	1.24	0	68	
Samana Suk												

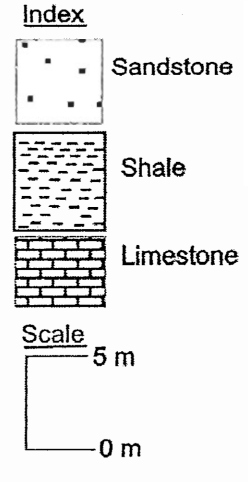
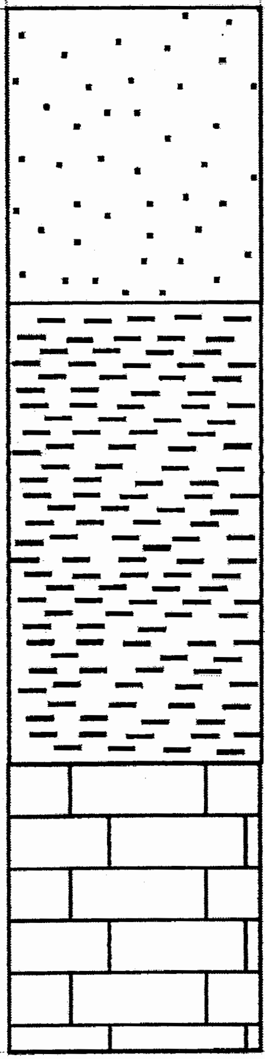


Table 5.4.TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Thandiani ,southern Hazara.

Formation	Unit Thickness	Lithological Column	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI
Lumshiwal											
Chichali	15 m		5	8748 Ft	2.75						
			4		2.75	472	0.06	0.05	0.25	17	26
Samana Suk											

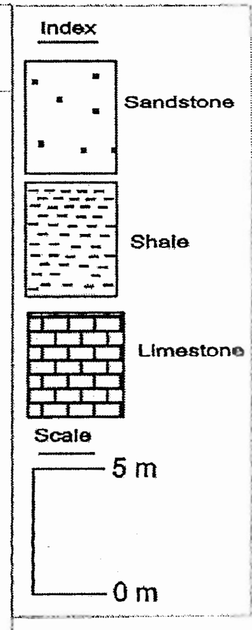
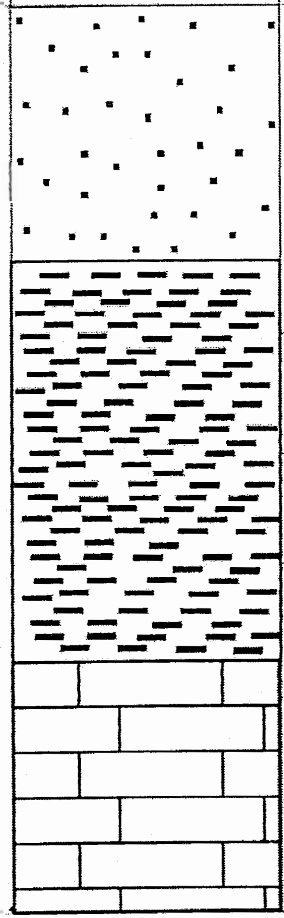


Table 5.5.TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Namli mera ,southern Hazara.

Formation	Unit Thickness	Lithological Column	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI	VR
Lumshiwal												
Chichali	20 m		8	8773Ft	5.12	432	0.01	0.08	0.20	1	3	
			7		4.15	446	0.00	0.03	0.28	0	6	2.58
			6		3.72							
Samana Suk												

Index

Sandstone

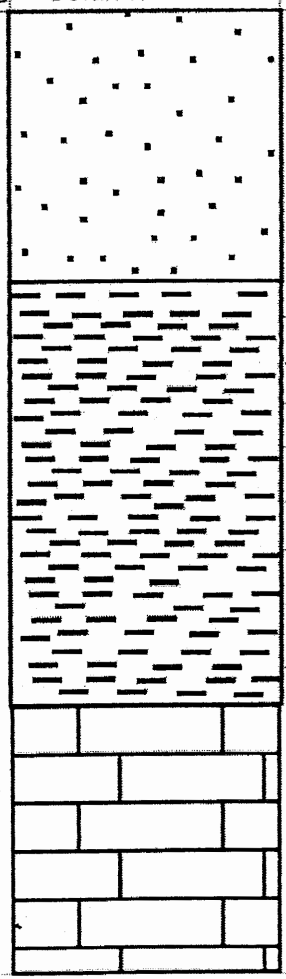
Shale

Limestone

Scale 5 m – 0 m

Table 5.6.TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Baghnotar,southern Hazara.

Formation	Unit Thickness	Lithological Column	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI	VR
Lumshiwal												
Chichali	25 m		16	4472 Ft	1.94	522	0.07	0.06	0.04	1	2	2.52
			15		2.44							
			14		1.74							
			13		2.47							
			12		2.65							
			11		3.91		0.01	0.06	0.12	1	3	
			10		3.75							
			9		4.62	479	0.02	0.03	0.06	0	1	
Samana Suk												



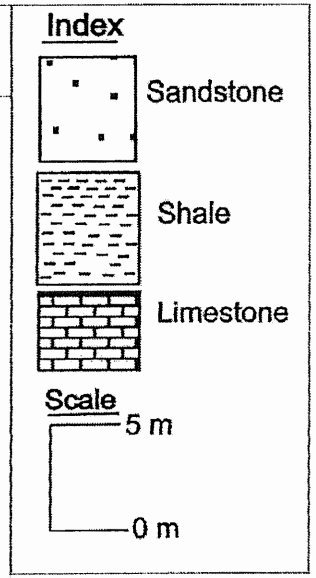
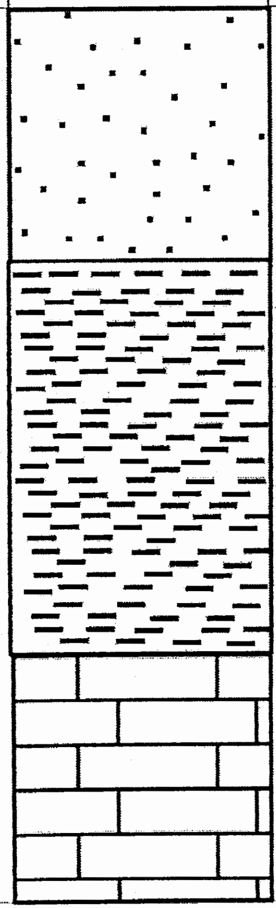


Table 5.7.TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Changla Gali,southern Hazara.

Formation	Unit Thickness	Lithological Column	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI	VR
Lumshiwal												
Chichali	20 m		20	8318 Ft	10.96	506	0.01	0.07	0.23	0	2	1.73
			21									
			22		5.54	466	0.02	0.01	0.71	0	12	
			23		27.78		0.04	0.32	0.67	1	2	
Samana Suk												

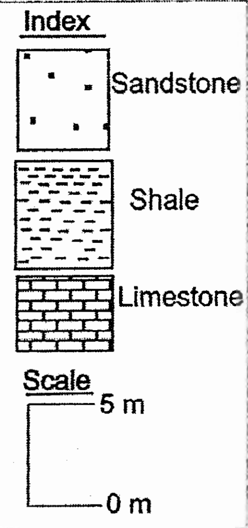
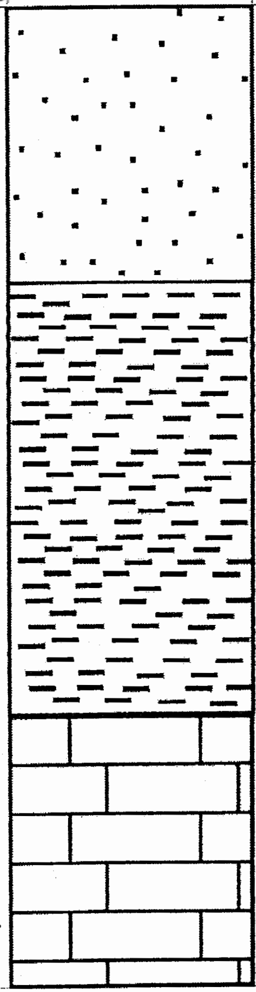


Table 5.8.TOC,Rock-Eval pyrolysis and Vitrinite reflectance data of Chichali Formation from Jabri ,southern Hazara.



Formation	Unit Thickness	Sample No.	Elevation (GPS)	TOC	Tmax	S_1	S_2	S_3	HI	OI	VR
Lumshiwal											
Chichali	30 m	26	4318 Ft								
		27		1.99	460	0.09	0.03	0.44	14	1	
		28									
		29		3.86	534	0.00	0.04	1.34	1	0	2.47
		30									
Samana Suk											

Index: Sandstone, Shale, Limestone

Scale: 5 m – 0 m

5.3. Maturity (Vitrinite Reflectance (R_o %) and Maceral analysis)

Five outcrop samples of Chichali Formation were taken for Vitrinite reflectance measurements and maceral analysis. The samples about 1mm size were embedded in araldite and polish sections were prepared. Samples were study under blue and white light using MP3 Zeiss-microscope. The saphir standards of 0.576% and 1.674% reflectance were used for Calibration. Organic matter in five samples is common to abundant and in one sample it is little. Organic matter is mostly bituminite in nature. Random vitrinite reflectance measurements of all the samples vary from 1.73 to 2.64%. Random vitrinite reflectance measurements of selected samples are given in Appendix-1.

Table 5.10 shows the vitrinite reflectance studies of six samples. This test has been were carried out to evaluate the maturity of Chichali shales in the study area. Average random vitrinite reflectance is 2.30 %, with the minimum value of 1.73%, and maximum value of 2.64 %. Based on vitrinite reflectance study, the Chichali Formation, at present, falls within the dry gas window. A brief description of the type of organic matter and random vitrinite reflectance are given below.

TableNo.5.10.Organic Petrographic results of Chichali shale samples of southern Hazara.

		ORGANIC MATTER					Maturity Vitrinite Reflectance	
	Sample Locations	**Abundance**	**Vit**	**Ine**	**Bit**	**Alg**	**% Rr**	**No. of Measurements**
1	Kalapani	3-4	/	O	X		2.64	2
2	Namli Mera	3-4	/	O	X	/	2.58	7
3	Baghnotar	3-4	/	●	X	/	2.52	13
4	Changla Gali	2	X	/		/	1.73	15
5	Jabri	3-4	/	O	X		2.47	15
6	Mohar	3-4	/	O	X		1.88	8

5.3.1 Sample No: 1 Chichali Formation from Kalapani Area

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is common to abundant and mostly fine to very fine grained. Bituminite is the dominant maceral. Inertinite is the second major maceral, present in the form of inertodetrinite and micrinite. Vitrinite is the third maceral present in the form of vitrodetrinite. Some pyrite particles are also present (Fig. 5.11).

Maturity: Average random Vitrinite reflectance is 2.64 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.3.2 Sample No: 2, Chichali Formation from Namli Mera Area

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is common to abundant and mostly fine-grained. Bituminite is the dominant maceral. Some relics of alginite are also present. Inertinite is the second major maceral, present in the form of inertodetrinite and micrinite. Vitrinite is also present in the form of vitrodetrinite. Some graphitized particles of inertinite are also there. Some pyrite particles are also present (Fig. 5.12).

Maturity: Average random Vitrinite reflectance is 2.58 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.3.3 Sample No: 3, Chichali Formation from Baghnotar Area.

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is common to abundant and mostly fine to medium grained. Bituminite is the major maceral. Relics of alginites are observed, however, the percentage of micrinite increases. Inertinite is the second major maceral, and consists mostly of inertodetrinite and micrinite. Vitrinite is the third maceral consists of vitrodetrinite (Fig. 5.13).

Maturity: Average random Vitrinite reflectance is 2.52 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.3.4 Sample No: 4, Chichali Formation from Changla Gali Area.

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is little and medium grained in size. Vitrinite is the dominant maceral present in the form of telinite and vitrodetrinite. Inertinite is the second major maceral, present in the form of inertodetrinite. Some relics of alginite are also observed and micrinite (Fig. 5.14).

Maturity: Average random Vitrinite reflectance is 2.52 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.3.5 Sample No: 5, Chichali Formation from Jabri Area.

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is common to abundant and some what coarser in nature. Bituminite is the major maceral. Some solid bitumen particles are also observed. Inertinite is the second major maceral, present in the form of inertodetrinite and semi-fusinite. Vitrinite is the third maceral present in the form of vitrodetrinite. Some graphitized particles of inertinite are also there (Fig.5.15).

Maturity: Average random Vitrinite reflectance is 2.47 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.3.6 Sample No: 5, Chichali Formation from Mohar Area.

Rock Type: Black splintery carbonaceous shale

Organic Matter Type

Organic matter is common to abundant and some what coarser in nature. Bituminite is the major maceral. Inertinite is the second major maceral, present in the form of inertodetrinite. Vitrinite is the third maceral present in the form of vitrodetrinite (Figure 4.17).

Maturity: Average random Vitrinite reflectance is 2.47 %. It shows that this sample is marginally over-matured which is also in agreement with Rock-Eval maturity parameters.

5.4. Composition of organic matter

Organic petrographic study has revealed that Chichali shales have abundant organic matter in the samples studied. Organic matter is fine-grained and occurs in layers. Mostly bituminite and micrinite are the major macerals, where as, inertodetrinite is the third main maceral. However, in the sample collected from Changla Gali area (sample no. 23) vitrinite was found in the samples containing dominant organic matter (Figure 4.13). It is also to mention here that the same sample of Changla Gali has yielded the maximum (i.e., 27% TOC). Some vitroditrinite, pyrite and graphite are also present. The macerals composition indicates that the main organic matter is Kerogen type II. It is interesting to note that the highest value of TOC, i.e: 27.87% (Table 4.1), constitute of Vitrinite and shows the lowest Vitrinite reflectance value, i.e: 1.73% (Table 4.10).

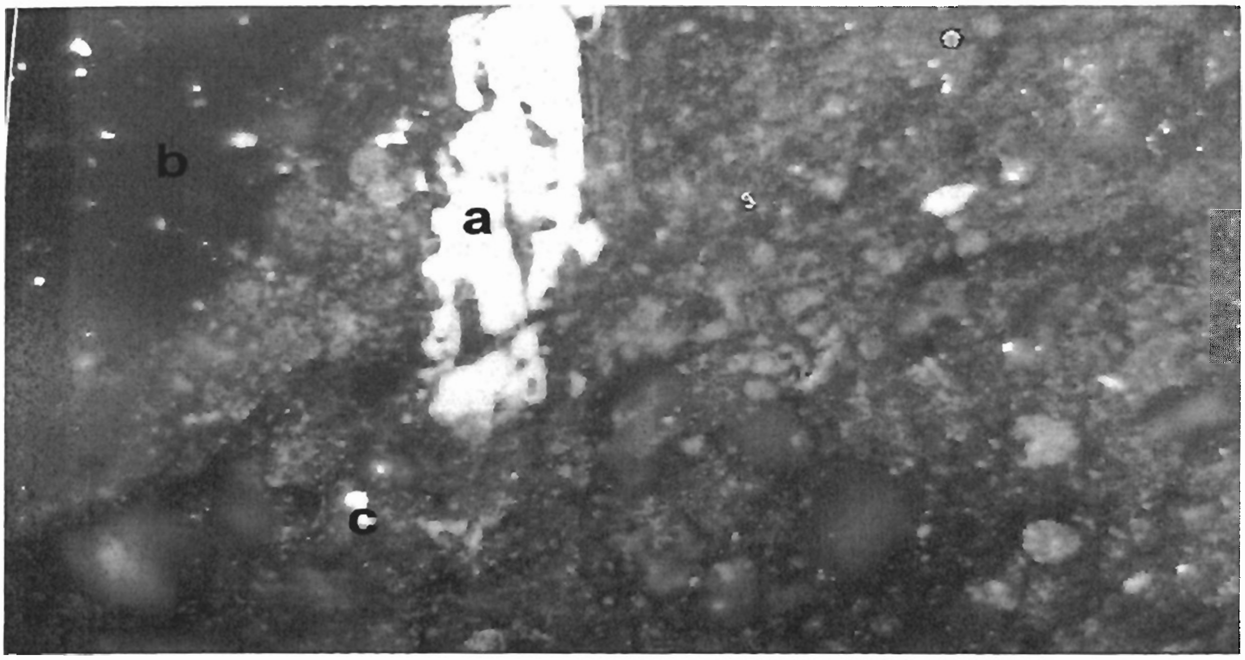


Figure 5.11. Photomicrograph showing the inertinite (a), with black spots of bituminite (b) and white spots showing the pyrite (c) of the Kalapani location of sample no. 3. Study under white light, oil imm.600x.

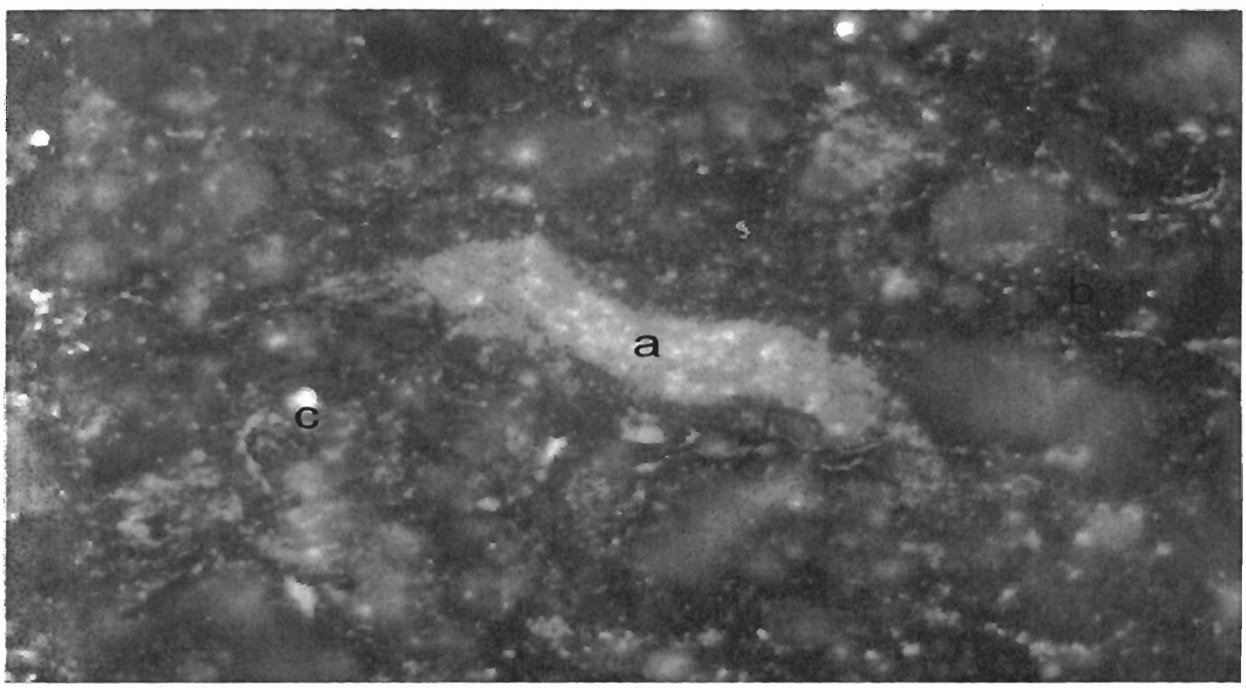


Figure 5.12. Photomicrograph showing the micrinite (a), with black spots of bituminite (b) and white spots showing the pyrite (c) of the Namli Mera location of sample no. 8. Study under white light, oil imm.600x.

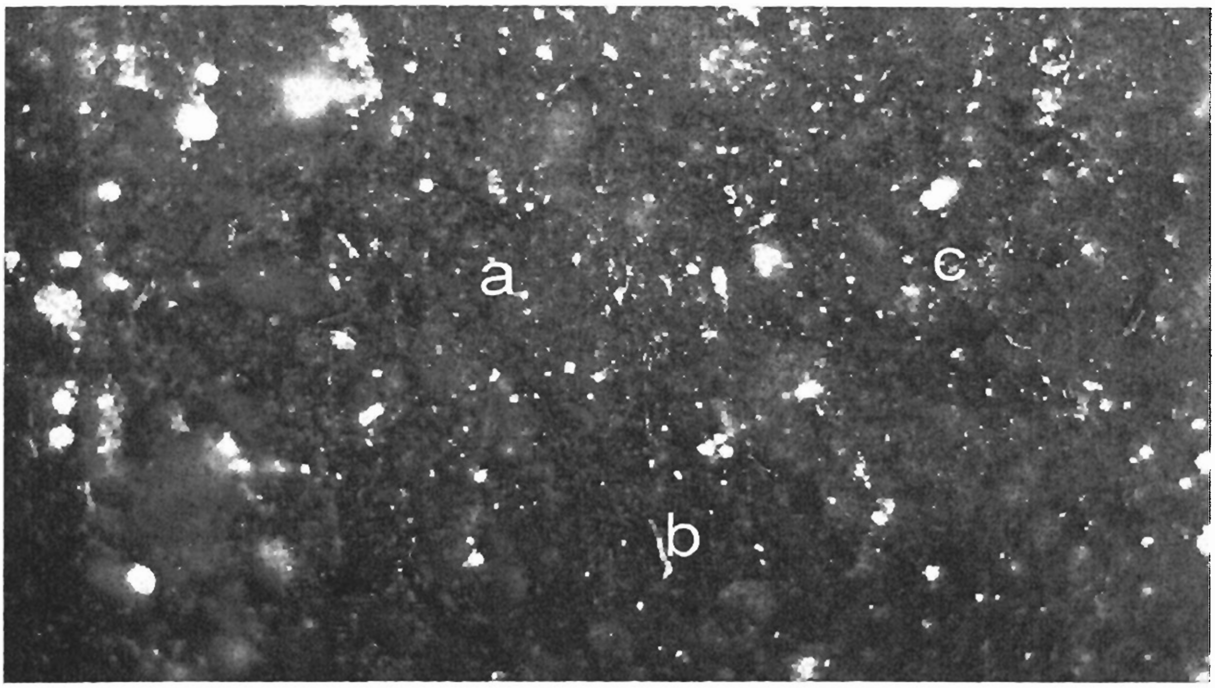


Figure 5.13. Photomicrograph showing the bituminite (a), relics of alginite (b), and white of pyrite (c) of the Baghnotar (Domail) location of sample no. 11.Study under white light, oil imm.600x.

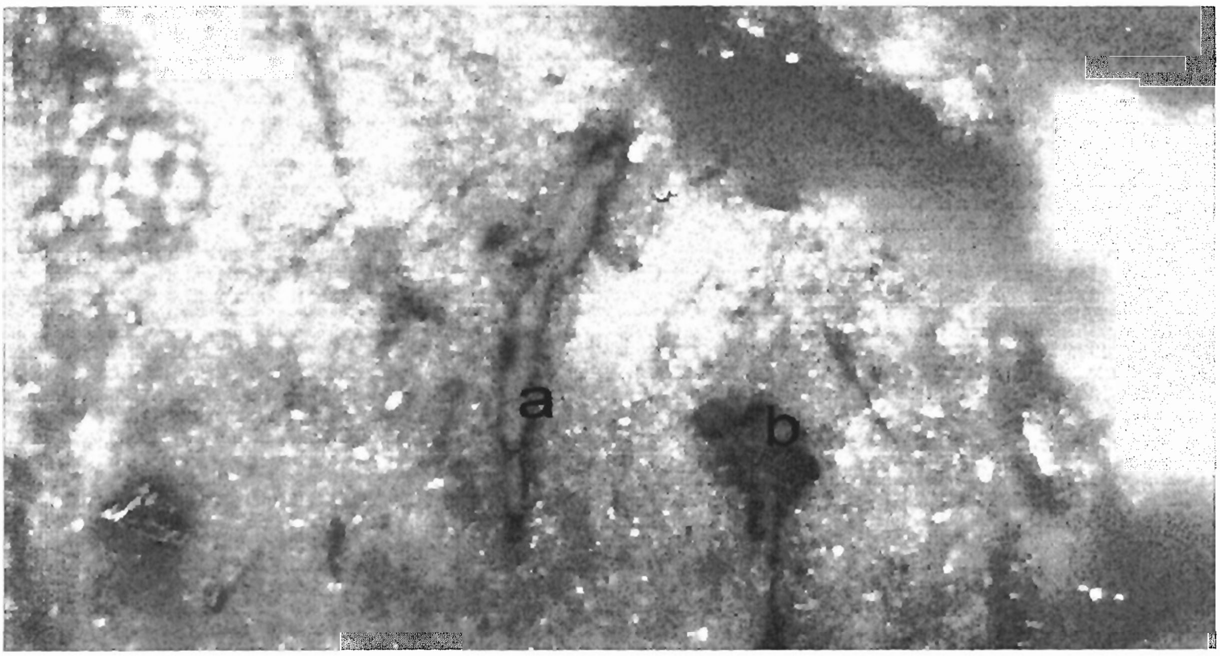


Figure 5.14. Photomicrograph showing the telinite (a), and black spots showing the bituminite (b), of the Changla Gali location of sample no. 23. Study under white light, oil imm.600x.