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Field Investigations and Organic Content Measurement of Cretaceous Chichali Shale, Chichali Gorge, Trans Indus Ranges, Pakistan

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Conflicts of Interest
There are no conflicts to declare.

ABSTRACT

The Cretaceous Chichali Formation in Chichali Gorge section, Trans Indus Ranges, is 60m thick. The Chichali Formation is divided into different members based on lithological variations, i.e., lower, middle, and upper members. The lower member ~25m comprises carbonaceous sandy shale inter-bedded with fine-grained glauconitic sandstone. The shales of this member are complete with Belemnites fossils. The middle member is ~20m thick, composed of thick fine bedded grained glauconitic sandstones with shale having few Belemnites. The upper ~25m thick member is comprised of dark green glauconitic sandstone, which lacks Belemnites. The results of the geochemical analysis of investigated shales samples show slight variations in TOC results, with the highest value of 0.41 wt% (CPC-1) and the lowest value of 0.12 wt% (CPC-10). The highest TOC value is reported in the dark black carbonaceous shales, full of Belemnites (lower member) of the Chichali Formation. In contrast, the lowest value of TOC is reported in the upper greenish shales, which lacks Belemnites (upper member) of the Chichali Formation. It has been observed that all the samples have less than 0.5 TOC wt%, which indicates that the Chichali Shale is below the minimum limit required for a rock to act as a potential source rock.

Keywords: CHICHALI SHALE, FIELD INVESTIGATIONS, TOC, TRANS INDUS RANGES, PAKISTAN

1. Introduction

Shale rock has been conventionally declared as the key source of hydrocarbons in sedimentary basins (Ju et al., 2014). Shales have been deposited over a broad range of geological time (from Precambrian through

Cenozoic) and are common throughout the world's sedimentary basins. However, not all shales are organic-rich; hence not all shales are deemed prospective as shale gas reservoirs. Paleoenvironmental and geological factors (tectonism, sedimentation rates) affecting the development of self-sourced, organic-rich shales have been discussed by Eoff (2013). Organic-rich shales are mostly formed in anoxic deep marine environments; however, anoxic environments, which stimulate organic-rich deposits, can also occur in shallow marine settings (Rine and Ginsburg, 1985; Loucks and Ruppel, 2007). Worldwide petroleum exploration has revealed that most of the world's petroleum source rocks originated during the Cretaceous, the source rocks from the Albian–Coniacian era accounting for around 60% of the world's oil and gas fields (Irving et al., 1974). Many petroliferous basins, like Zagros Basin in the Middle East, the Maracaibo Basin in Venezuela, and the Songliao Basin in China, are associated with Cretaceous source rocks. Furthermore, hydrocarbon resources in some basins, like Russia's Western Siberia Basin, the Gulf of Mexico Basin, Rocky Mountain foreland basins, and North America's North Slope Basin, are derived from Cretaceous sources rocks. The Lower Cretaceous Eagle Ford shale in the Texas basin is a well-known shale gas source rock in America (Bruner and Smosna, 2011). Similarly, in India, a thick sequence of organic-rich Cretaceous shale occur in numerous sedimentary basins such as Krishna Godavari Basin (Early Cretaceous Raghavapuram Shale) Cauvery Basin (Andimadam and Sattapadi shales, Early Cretaceous) (Padhy et al., 2013).

In Pakistan, the Cretaceous rocks are (up to 3000 m thick) distributed around 300,000 km^2 and extends throughout the Indus Basins. The Cretaceous source rock average TOC (up to 2.84 percent) and source rock thickness are contributed to the daily production of more than 30,000 barrels of oil and around 1200 million ft^3 of gas (Kadri, 1995). The pyrolysis findings reveal that the Cretaceous age source beds in the Middle Indus Basin are thermally mature for gaseous hydrocarbons. However, in the Southern Indus Basin, the Cretaceous source rocks are within the oil window in some areas (Kadri, 1995). In the Upper Indus Basin (Kohat basin), Cretaceous sediments are restricted to the western region, whereas they are mainly eroded in the Potwar basin. This erosion occurred during the Early Cretaceous period due to the Indian Plate movement (Wandrey et al., 2004b). Many researchers have declared that the Lower Cretaceous shale (Sembar Shale) in the Lower Indus Basin of Pakistan holds good source rock potential for shale gas (Ahmed et al., 2013; Haider et al., 2012; Shiekh and Giao., 2017; Sohail, 2020) which is age equivalent of Chichali Formation in Upper Indus Basin having same fossils (Belemnites). However, Chichali Formation in the Upper Indus Basin is yet to be declared the source rock for shale gas potential, requiring a detailed geochemical investigation. The key objective of this study is to evaluate the organic richness of Cretaceous Chichali Shale for shale gas. Therefore, a detailed field trip was conducted to study physical properties, lithofacies changes, and thickness of Chichali Shale at its type locality (Fig. 1). A number of fresh outcrop samples of shale were systematically collected for laboratory analyses.

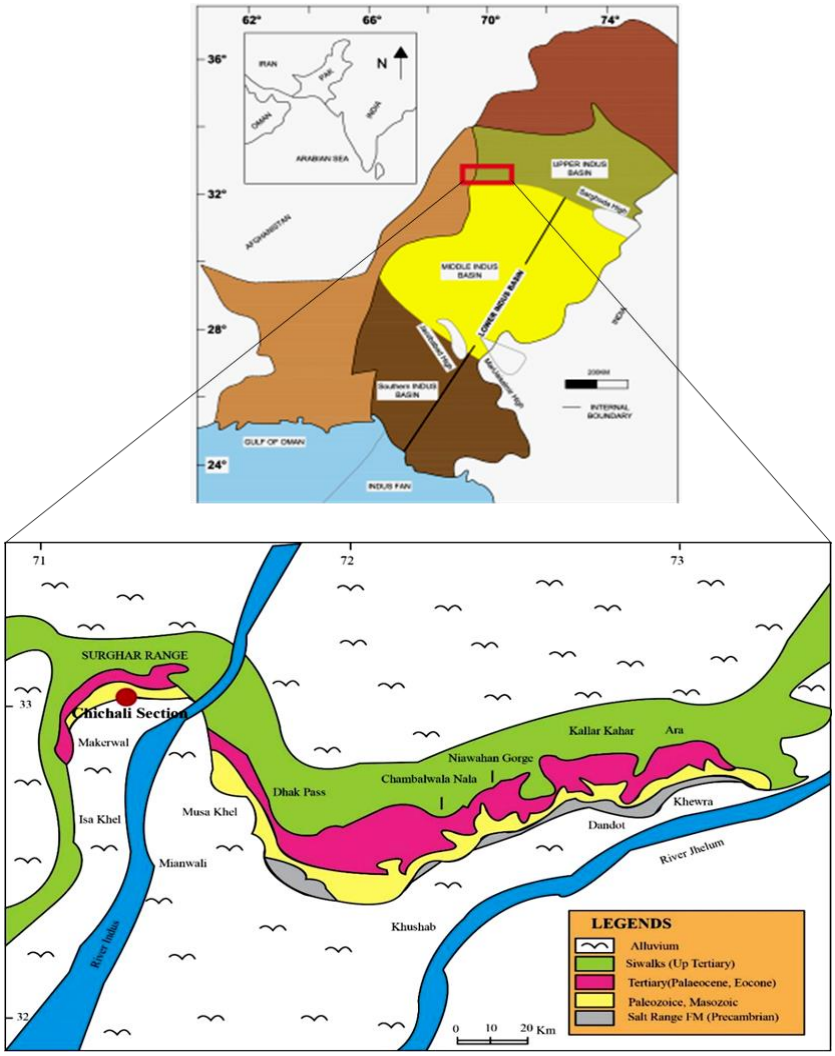


Fig. 1: The geological map of the Trans Indus and Salt ranges. Red dot shows the Chichali Gorge Section (after Khan, 2013).

2. Geological settings of Chichali Gorge

The Chichali Gorge (Fig. 1) is located in the Surghar Ranges, Mianwali District, Pakistan. The EW inclination of the Surghar Range marks the eastern boundary of the Trans Indus Ranges (TIR). The TIR is located on the western side of the River Indus; however, the Salt Ranges is on the eastern side. The Trans Indus and Salt ranges are a major deformational front of the Kohat Fold and Thrust zone in northern Pakistan (Ahmed et al., 2005). Various researchers have thoroughly investigated the structural and stratigraphic configuration of the Trans Indus and Salt ranges (Gee, 1989; Abbasi and McElroy, 1991; Danilchik, 1961). The geology of the Surghar Ranges has been extensively researched by Danilchik and Shah, 1987. While mapping of Chichali Gorge was done by Meissner et al., 1974. The Mesozoic rocks exposed in the Chichali Gorge Section are older, whereas the Eocene rocks create the skyline at the end of the section (Ahmad et al., 1999; Fig. 2). The Chichali and Lumshiwal formations are Cretaceous rocks found in Chichali gorge (Shah, 2009). This study focuses on the Chichali Formation in the Surghar Ranges represents the dominant lithologic unit well exposed in Chichali Gorge.

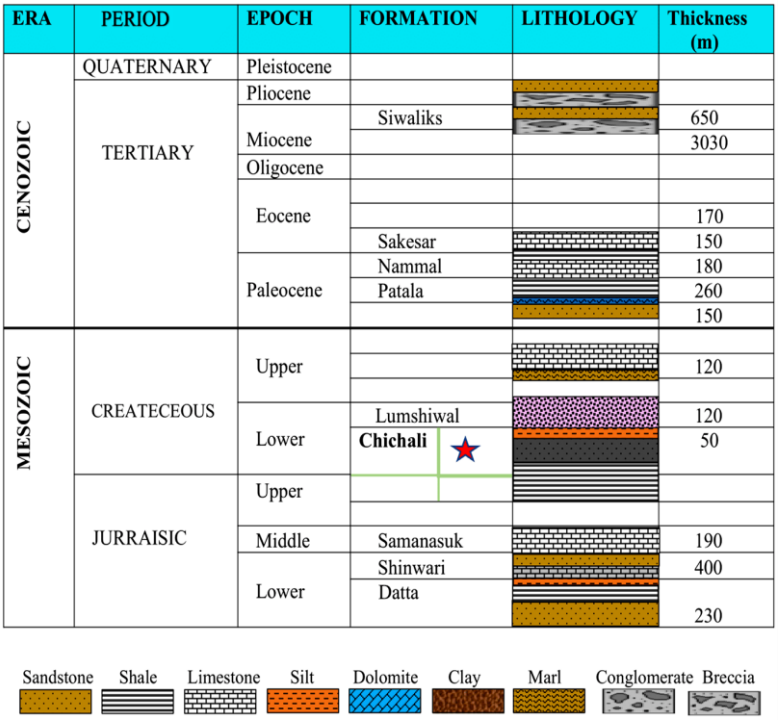


Fig. 2: Generalized stratigraphic column of the Chichali Gorge (Ahmad et al., 1999).

3. Materials and methods

The present research was accomplished in two stages; fieldwork and laboratory analysis.

3.1 Fieldwork

Different methods have been applied during fieldwork to recognize the lithology, dipping direction, strike, position, etc using brunton compass, magnifying lens, geological hammer. Google maps and GPS were used to track the locations of the samples site. Samples were collected based on thickness, change in lithology, and different stratigraphic horizons. Structural features (fold, fault and bedding plane, etc.) and sedimentary features (cross bedding, ripple marks, mud cracks, and nodules, etc.) were observed to understand tectonic and environmental conditions.

3.2 Laboratory analysis

The geochemical analysis is a direct approach for determining source rock properties and assessment of hydrocarbon-producing zone. The source rock is an organic-rich sedimentary rock that can generate hydrocarbons due to thermal maturation (Rezaee, 2002). To assess the organic richness, utilizing the TOC analyzer as a fundamental geochemical screener (Bozcu, 2017; Peters, 1986; Newport et al., 2016; Peters et al., 2016; Yandoka et al., 2016). Estimating total organic carbon (TOC) as a geochemical parameter for identifying source rock in shale gas reservoirs is the main task (Yandoka et al., 2016). Total organic carbon content describes the quantity of organic matter present in a rock in percent (%) and directly measures its organic richness (Hakimi et al., 2010; Passey et al., 2010).

Table. 1: Standard TOC values for source rock evaluation (Tissot and Welte, 1984; Ahmad et al., 2019).

Generation potential	TOC Wt% (for Shales)	TOC Wt% (for Carbonates)
Poor	0.0 -0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

After samples collection and preparation, initially, six selective samples were chosen for TOC analysis. Leco CS-300 analyzer (Fig. 3) was used to measure TOC at Hydrocarbon Development Institute of Pakistan (HDIP) Islamabad. All the samples were washed with water, dried, crushed, and then decarbonized by acid treatment to remove the inorganic carbon before TOC measurement.

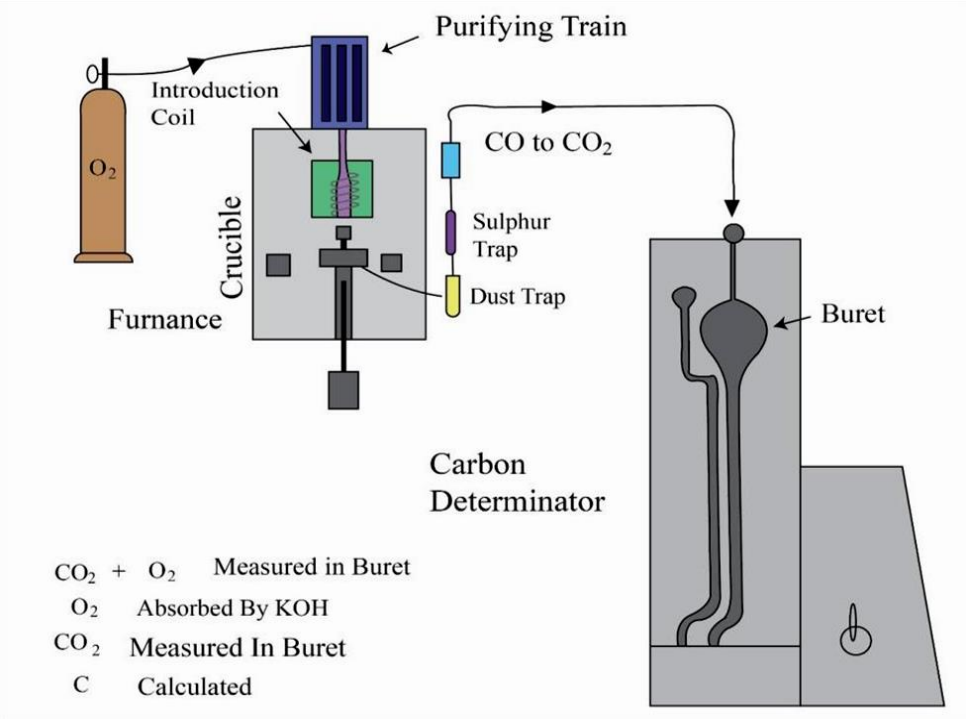


Fig. 3: Schematic diagram of LECO carbon analyzer for TOC estimation housed at HDIP Islamabad.

4. Results and discussion

4.1 Field observation

The M2 Motorway is the fastest route to travel the Chichali Gorge section from Islamabad (capital). The main city in the study area is Mianwali, one of the big districts of Punjab, Province, Pakistan. The accessibility map of this area is shown below in (Fig. 4). The entrance of the Chichali Nala Section (Fig. 5) started at 32° 59" 36' N Latitude and 71° 24" 14' E Longitude (noted by GPS). It may be reached by traveling from Mianwali to Kalabagh on the paved road, then continuing on the partly metalled route from Kalabagh to Chapri (12 km west of Kalabagh). The Chichali Gorge is located 3 kilometers east of Chapri village and is accessible through an unpaved road. The Chichali Gorge is also a pass that connects the Punjab and Khyber Pakhtunkhwa provinces (Khan, 2013).

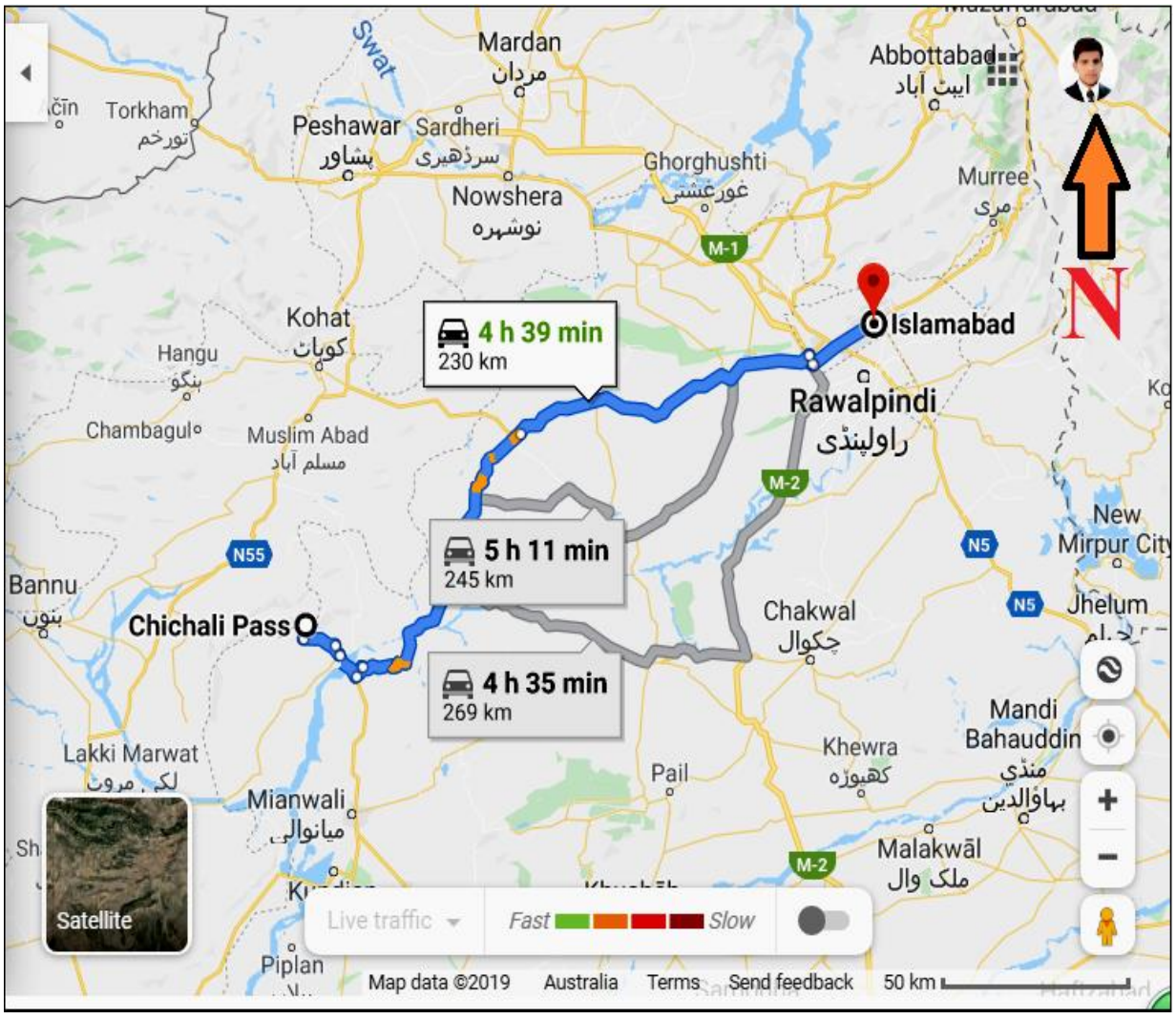


Fig. 4: Accessibility map generated from Google maps showing the route of the Chichali section from Islamabad (Capital).

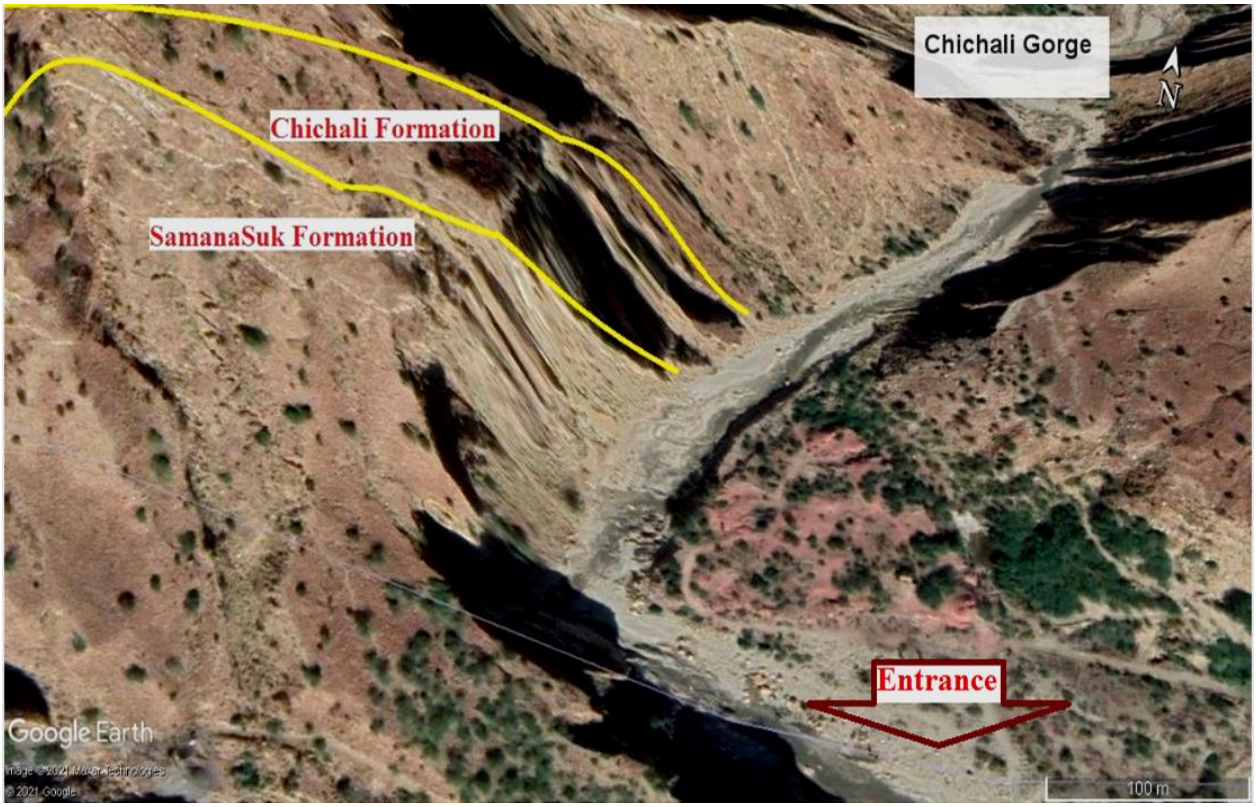


Fig. 5: Panoramic view of interior of Chichali Gorge showing entrance, including Chichali Formation.

In Chichali Gorge Section, Chichali Formation overlain by Lumshiwal Formation (33° 00" 11' N, 71° 24" 15' E) and underlain by Samana Suk Formation (33° 00" 09' N, 71° 24" 17' E) as shown in (Fig. 6).

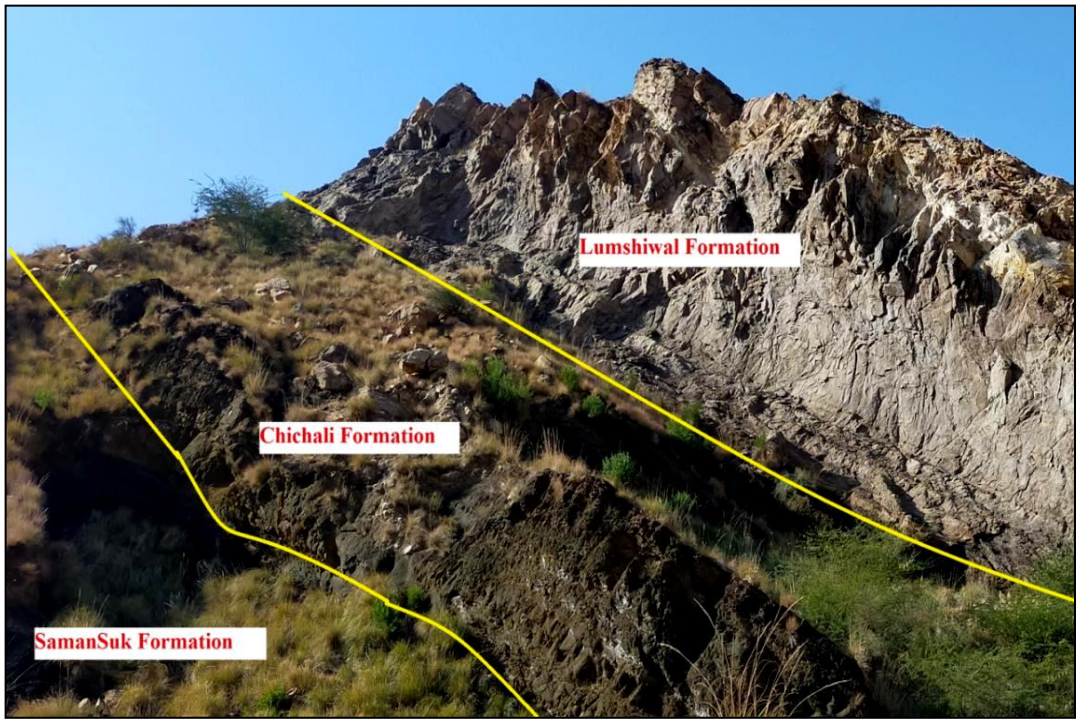


Fig. 6: Field Photograph of Chichali Formation showing its upper and lower contact in Chichali Gorge section.

Chichali Gorge Section is also the type locality of the Chichali Formation. Chichali Formation found 60m thick in this section (Fig. 7a). The lower member ~25 m comprises carbonaceous sandy shale inter-bedded with fine-grained sandstone. The weathered surface of the rocks has a greenish color due to the high glauconite content, while on fresh surfaces, it is dark grey to black. The sediments of this member are full with Belemnites fossils (Fig. 7b). The middle member is ~20 m thick. It is composed of thick-bedded fine-grained glauconitic sandstones inter-bedded with shale. The fresh color of the rock surfaces is bright green, while the weathered color is greenish (Fig. 7c). The upper member is ~25 m thick. This member is ascendant comprised of dark green glauconitic sandstone, which lacks Belemnites. The sandstone has mud cracks (Fig. 7d) filled with selenite in the lower half of the member.

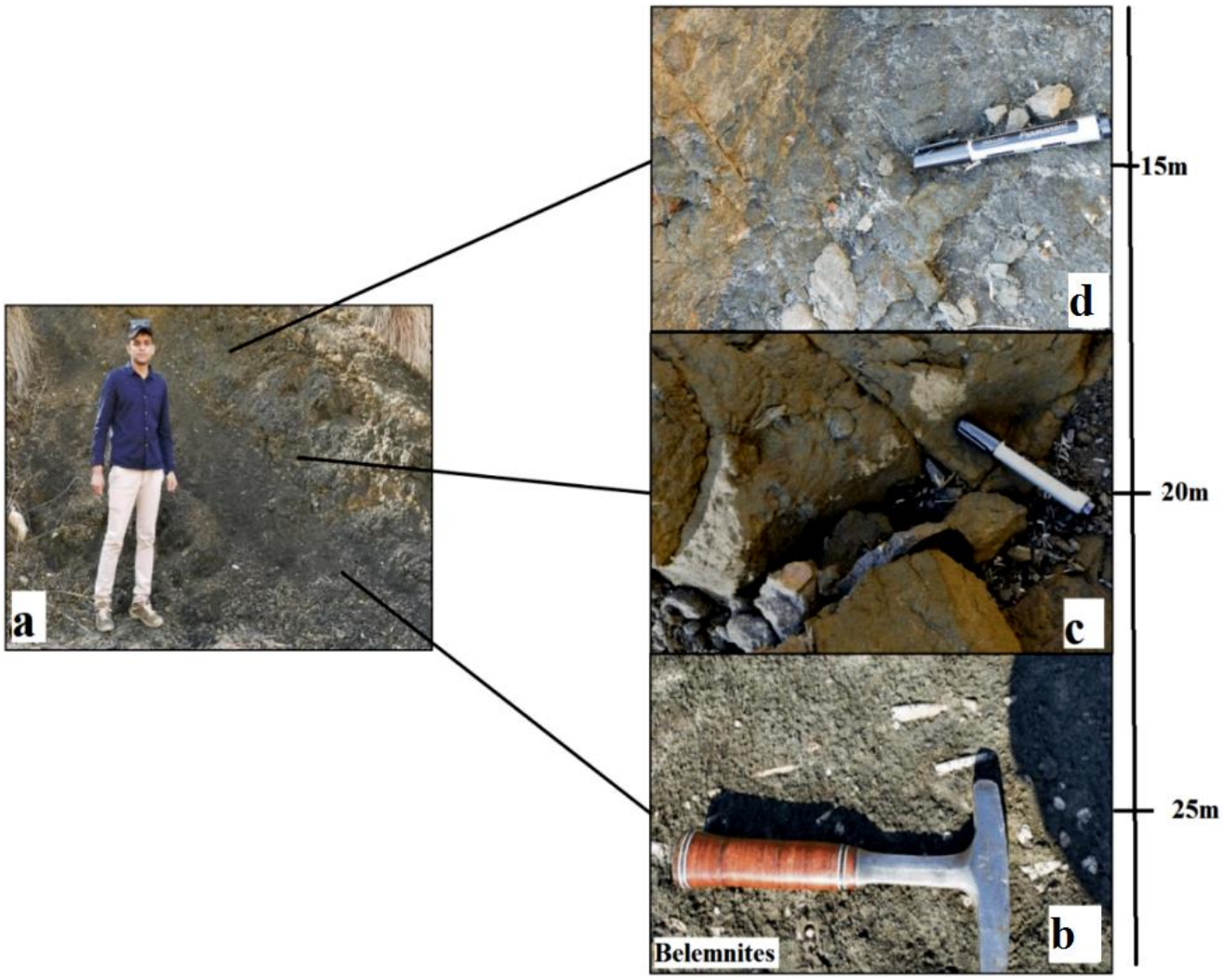
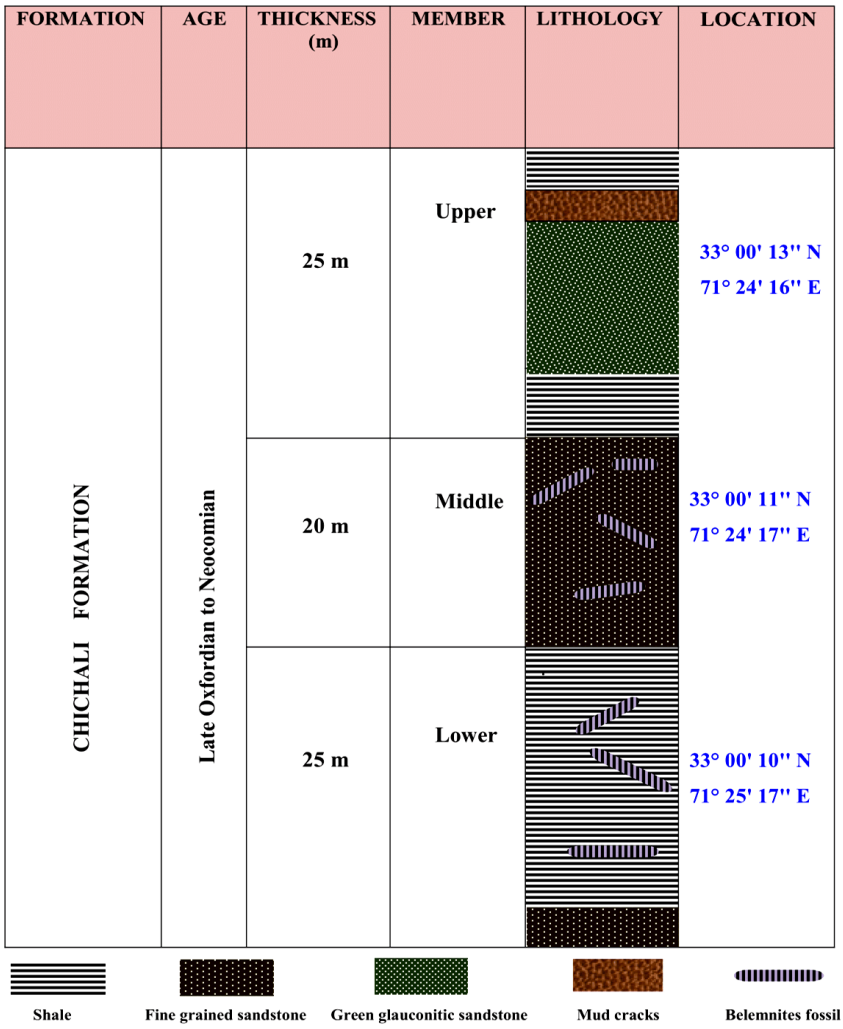


Fig.7: (a) Exposure of Chichali shale at Chichali Gorge, **(b)** the lower member, dark grey to black sandy shale containing Belemnites fossil **(c)** middle member of the Chichali Formation, thick-bedded fine-grained glauconitic sandstones inter-bedded with greenish shale, **(d)** upper member of the Chichali Formation consist of soft dark green glauconitic sandstone having mud cracks.

Table 2: Lithological log of the Chichali Formation in Chichali Gorge section



4.2 Organic richness

The results of the TOC analysis of investigated shales samples are given in Table 3. There are slight variations in TOC results, with the highest value of 0.41 wt% (CPC-1) and the lowest value of 0.12 wt% (CPC-10) of the sample among them. The highest TOC value is reported in the dark black carbonaceous shales (lower member) of the Chichali Formation (Fig. 8). In contrast, the lowest value of TOC is reported in the upper greenish shales (upper member) of the Chichali Formation exposed in the Chichali Gorge section. It has been observed that all the samples have less than 0.5 TOC wt%, which indicate that the Chichali shale is below the minimum limit required for a rock to act as a potential source rock (Tissot and Welte, 1984; Hunt 1996; Makky et al. 2014) therefore, further analyses had not carried out on these samples. However, Chichali Formation has fair to good source rock potential in other areas, including the Kalachitta Range, Mela-05 wells, Chonai-1 and Pezu-1 wells, southern Hazara (Zeb et al., 2020; Shahzad, 2007; Khan, 2007; Iqbal et al., 2007; Quad Consulting Limited, 1996).

Table.3: TOC Results of Chichali Shale at the Chichali Gorge section.

Sample ID	Area	Age	Description	TOC wt%
CPC 1	Chapri	Cretaceous	Dark grey shale	**0.41**
CPC 5	Chapri	Cretaceous	Grey sandy shale	**0.20**
CPC 6	Chapri	Cretaceous	Black shale	**0.34**
CPC 9	Chapri	Cretaceous	Black spiti shale	**0.15**
CPC 10	Chapri	Cretaceous	Fossilferous shale	**0.12**
CPC 17	Chapri	Cretaceous	Sandstone	**0.33**

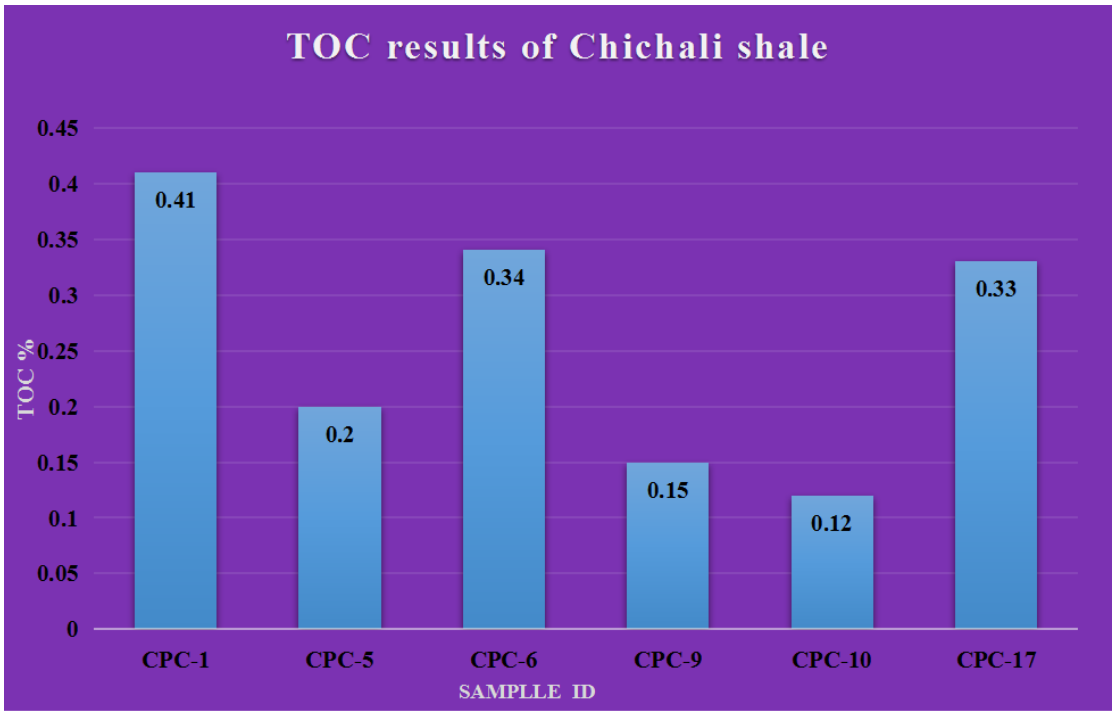


Fig. 8: Graph showing TOC results of Chichali Shale at the Chichali Gorge section.

5. Conclusion

The following conclusions have been deduced as a result of this study;

1) In Chichali Gorge Section, Chichali Formation overlain by Lumshiwal Formation and underlain by Samana Suk Formation. The Chichali Formation is 60m thick in Chichali Gorge Section.
2) The lower member ~25 m thick comprises carbonaceous sandy shale inter-bedded with fine-grained sandstone. The weathered surface of the rocks has a greenish color due to the high glauconite content, while on fresh surfaces, it is dark grey to black. The sediments of this member are full of Belemnites fossils. The middle member is ~20 m thick. It is composed of thick-bedded fine-grained glauconitic sandstones inter-bedded with shale. The fresh color of the rock surfaces is bright green, while the weathered color is greenish.The upper member is ~25 m thick. This member is comprised of dark green glauconitic sandstone, which lacks Belemnites. The sandstone has mud cracks filled with selenite in the lower half of the member.
3) The TOC analysis of investigated shales samples shows slight variations in results, with the highest value of 0.41 wt% (CPC-1) and the lowest value of 0.12 wt% (CPC-10). The highest TOC value is reported in the dark black carbonaceous shales (lower member) of the Chichali Formation. In contrast, the lowest value of TOC is reported in the upper greenish shales (upper member) of the Chichali Formation.
4) It has been observed that all the samples have less than 0.5 TOC wt%, which indicates that the Chichali Shale is below the minimum limit required for a rock to act as a potential source rock.

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