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SEMI QUANTITATIVE FACIES ANALYSIS, DEPOSITIONAL ENVIRONMENT AND RENEWABLE ENERGY POTENTIAL OF EARLY JURASSIC DATTA FORMATION, PAKISTAN

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Abstract

The Datta Formation (Datta Nala, Surghar Range) in the Upper Indus Basin, Pakistan, characterizes the Triassic-Jurassic sequence. The formation is well-exposed and has been measured for its general features, but there is a notable gap in the detailed lithofacies analysis that integrates quantitative data. Extensive fieldwork was conducted to examine the semi-quantitative facies analysis and renewable energy potential of the early Jurassic Datta Formation in Pakistan. During fieldwork, four stratigraphic sections were measured: Nammal Gorge, Kasanwala, Paniala, and Gulla Khel section. The analysis of detailed measurements of sections and mineral composition suggested its economic importance, resource potential and special significance for the renewable energy sector in Pakistan and beyond. The basal part of the formation is rich in silica sand, vital for manufacturing solar photovoltaic panels and energy efficient glass. On the other hand, laterite is suitable for lithium-ion battery production, further highlighting the formation's strategic importance.

1. Introduction

The Triassic-Jurassic boundary is a globally recognized geological marker, preserved in various locations worldwide including Europe, the USA, Peru, British Columbia, southern Tibet, and northwest China. It is characterized by significant biotic changes such as the disappearance of numerous species and the emergence of Jurassic ammonites (Lai-shi *et al.*, 2007; Ali *et al.*, 2018). Triassic-Jurassic sequence in the Upper Indus Basin, Pakistan representing the Datta and Kingriali formations. The Datta Formation, as acknowledged by Danilchik (1961) and Danilchik and Shah (1967), substituted the term "Variegated stage" previously used by Gee (1945) and earlier researchers. In the Salt Range and the Trans Indus Range (Fig. 1), this formation is well-developed, characterized by its varied composition of red, maroon, grey, green, and white sandstone. siltstone, shale, and mudstone (Malkani *et al*., 2017; Yasin *et al.*, 2021; Wahid *et al.*, 2022). The Datta Formation also geographically defines a rough distribution of calcareous, carbonaceous, dolomitic, ferruginous glassy sand, and fireclay horizons, predominantly found along the continental margin during the Early Jurassic period. Characteristically, the lowest part of the formation contains fireclay, the top layer is recognized by a thick layer of maroon shale (4–7 m) that is found in the Trans Indus and Salt Ranges. The western share of the Salt Range, west of Jalar Lake, and the Trans Indus Ranges are where the formation is extensively developed, including Shinghar, Shaikh Budin Hill, Surghar, and the western Khisor Range. The thickness of the formation varies, measuring 212 meters at the type locality, increasing to 230 meters in Pannu Nala to the west, and exceeding 400 meters in Shaikh Budin Hill. However, the thickness decreases to 150 meters at the westernmost point of the Khisor Range and in Nammal Gorge (the Western Salt Range), with further reduction towards the east. In Hazara, the thickness ranges from 0 to 10 meters, while in Kala Chita (Chak Dalla area), it measures 6 meters. The general lithology of the Datta Formation includes sandstone, siltstone, limestone, dolomite, fossiliferous limestone, coal, conglomerate, sandy dolomite, fossiliferous dolomite, shale, and laterite/bauxite/paleosols. Within the formation, noteworthy sedimentary features include trough cross-bedding, wave cross-bedding, planar ripple marks, current ripple marks, bioturbation, mud cracks, and plant remains. Jurassic strata are present in the Baroch group in the Upper Indus Basin, encompassing sites like Datta Nala (Surghar Range) and Shinawari village (Samana Range, NWFP). Additionally, the Lower Indus Basin hosts Jurassic formations, evident in regions such as the Shirinab River (Chappar Mingochar and Shirinab Valley, Kalat) and the Chiltan Range (Quetta, Baluchistan). The Datta Formation, Shinawari Formation, and Samana Suk Formation are notable formations in the Upper Indus Basin., while the Lower Indus Basin features the Shirinab Formation, Chiltan Limestone, Sembar Formation, and Mazar Drik Formation (Malkani & Mahmood, 2016). One geologically significant feature of the Datta Formation is its disconformable lower contact, which overlies the Kingriali Formation, indicating an Early Jurassic age (Iqbal *et al*., 2015). Throughout its spread, the Datta

Formation possesses a disconformable lower contact. It lies unevenly on the Kingriali Formation in the Trans Indus, Eastern Kohat, Salt Range, and Kala Chitta ranges. Certain sections of Hazara lack development in terms of formation (such as the Kalapani Region) and unconformably sit above Precambrian Hazara Formation (?), Paleozoic, and Triassic rocks. This formation has an upper contact with the Shinawari Formation, which is gradational. Throughout its spread, the Datta Formation possesses disconformable lower contact. It rests unconformably on the Kingriali Formation in the Salt Range, Kala Chitta, Eastern Kohat, and Trans Indus Ranges. In Hazara, the formation is not developed in certain areas (such as the Kalapani Region) and unconformably sits above Precambrian Hazara Formation (?), Paleozoic, and Triassic rocks. This formation has upper contact with Shinawari Formation which is gradational. Although the formations of the early Jurassic Datta Formation are well exposed and have been considered for their general features, there is a notable gap in the detailed lithofacies analysis that integrates quantitative data. The research aims to address this gap by investigating the economic potential of the Datta Formation through an inclusive lithofacies analysis, which will include semi-quantifying the facies and examining their lateral variations across the formation.

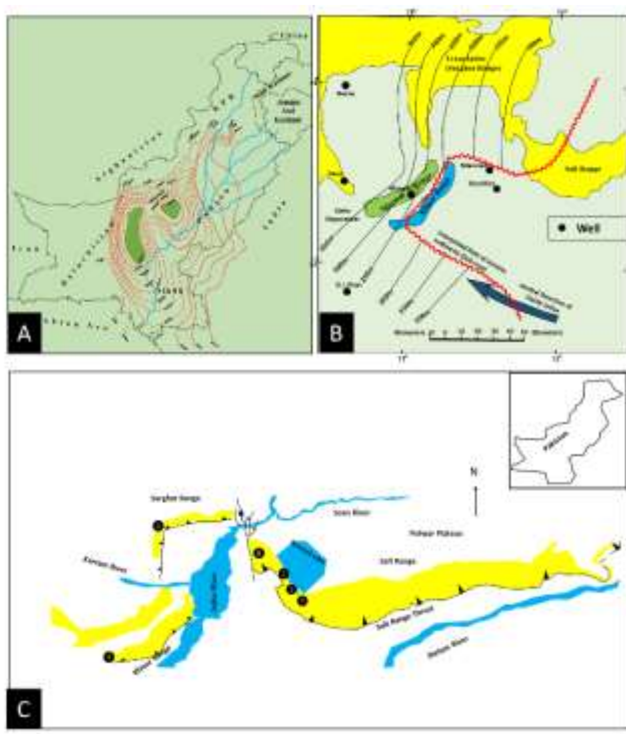


Figure 1: (a) Isopach Map of Jurassic strata (Mainly middle and lower), **(b)** Isopach map of Datta Formation in Upper Indus Basin, **(c)** The Salt Range and its adjoining areas. 1. Nammal Gorge, 2. Kasanwala section, 3. Paniala section, 4. Gulla Khel section.

2. Geological Framework

From a global tectonic perspective, the Indian Plate is one of three lithospheric plates that converge near Pakistan, along with the Eurasian Plate and the Arabian Plate (Ali & Aitchison, 2008). Westernmost on the Indian Plate the Indus Basin is located. The African Plate split from the Indian Plate during the Jurassic to Early Cretaceous eras, and the Indian Plate started to move northeast, eventually colliding with the Eurasian Plate during the Paleocene to early Eocene (Zhang *et al.*, 1984). This collision, characterized by intercontinental collisions, thrusts and abductions, is considered a prototype of the Himalayan Alps orogeny. Pakistan lies in a Tertiary convergence zone where the Arabian, Eurasian, and Indo-Pakistani plates interact**.** Pakistan's geological land features two sedimentary basins: the Indus Basin and the Baluchistan Basin, covering a combined area of approximately 828,000 squares. The Indus Basin, divided into the Upper and Lower Indus Basins, contains large tectonic structures and is more divided by sub-longitudinal basement highs and lateral uplifts (Brohi *et al*., 2012). Kohat and Potwar Basin, also referred to as Upper Indus, is situated in northern Pakistan between latitudes 32° and 34° north and longitudes 70° and 74° east (Qadri *et al.*, 2022; Rehman *et al.*, 2023; 2024). It is bounded to the west by the Sargodha High, which separates it from the Lower Indus Basin, while the Salt Range limits it on the south. The Main Boundary Thrust (MBT) lines up with both the northern and eastern boundaries (Raiverman, 2013). The Potwar sub-basin in the east and the Kohat sub-basin in the west make up the Upper Indus Basin, which is divided by the River Indus. The existence of the Datta Formation (Datta Nala, Surghar Range), the Shinawari Formation (Shinawari hamlet, Western Samana Range, NWFP), and the Samana Suk Formation (NE of Shinawari, Samana Range, NWFP) in the Upper Indus Basin indicates the Jurassic era (Ali, 2017). The Shirinab Formation (Shirinab River portion, Chappar Mingochar and Shirinab Valley, Kalat, Baluchistan), the Chiltan Limestone (Chiltan Range, SW of Quetta, Baluchistan), and the Sembar Formation (Sembar Pass, Marri Hills, Baluchistan) are the principal features of the Lower Indus Basin's Jurassic era.

3. Stratigraphy

The Salt Range, located in Pakistan, is the southernmost and youngest portion of the Western Himalayan Ranges. About 70 km south of the main Himalayan Ranges, the Salt series rises as a 180-km-long and 85-km-wide series of hills along the southern edge of Pakistan's Potwar Basin. The finest exposures of Paleozoic and Eocambrian strata are found in the center region, which is also the broadest located between Khewra and the Warchha (Ghazi *et al*., 2015). The Salt Range, bounded by the Salt Range Thrust, is composed of deposits ranging in age from Infra-Cambrian to Recent (Saw *et al.*, 2017; Sarwar *et al.,* 2024). One of the distinctive characteristics of the Salt Range is its thick salt sequence, whose distribution has affected thrust, normal, and reversal faults (Stewart & Coward, 1995). The tectonic growth stage of the Salt Range area is systematically varied, as evidenced by the structural alterations observed there (Jadoon *et al*., 2015). The existence of incompetent formations in the successions is related to these structural characteristics. The geological record of the Salt Range is replete with thick InfraCambrian calcareous to siliciclastic strata of the Indian Plate and relatively exceptionally thick Miocene-Pliocene molassic deposits of the Indus foredeep (Ullah, 2015). With the Recent Conglomerates being the newest exposed rock block and the Salt Range Formation being the oldest, the Salt Range displays an exposed sequence from Precambrian to Miocene. The Salt Range Formation is supported by subsurface evidence that shows a metamorphic rock sequence and Precambrian rocks underneath it. (Jabbara *et al*., 2023). The Salt Range's entire rock sequence is interrupted by several regional and local-scale unconformities (Gee & Gee, 1989). Here are a few notable gorges that cross the Salt Range, in addition to the readily accessible geology along the route. The Khewra, Warchha, Nilawahan, Nammal, and Chichali gorges are the most well-known of these gorges, having sites for studying the sedimentary successions (Fig. 2). Sedimentation in the Kohat-Potwar area started in the Precambrian and persevered until the Pleistocene. Three significant unconformities are observed: Ordovician to Carboniferous, Mesozoic to late Permian, and Eocene to Oligocene. The oldest sedimentary rock in the Kohat-Potwar Basin is the Salt Range Formation, covering metamorphic rocks (Mannan *et al*., 2024). Cambrian rocks consist of sandstone, siltstone, shale, and dolomite, represented by the Khewra, Kussak, Jutana, and Baghanwala formations. An unconformity shadows the Cambrian sequence, characterized as a disconformity, with a termination of deposition extending to the Permian (Malkani *et al*., 2017). The Permian sequence contains the Tobra Formation, Dandot Formation, Warcha Sandstone, Sardhai Formation, Amb Formation, Wargal Limestone, and Chhidru Formation. An unconformity follows the Permian sequence, foremost to the Triassic sequence, which includes the Mianwali Formation, Chak Jabbi Limestone, Tredian Formation, and Kingriali Formation. Another unconformity precedes the deposition of the Jurassic sequence, consisting of the Datta Formation. In the Surghar, Marwat, and Sheikh Budin Hills of the Trans Indus Ranges, as well as in the subsurface of the Kohat and western Potwar foreland-fold-thrust belts, the Datta Formation is well exposed (Parvez, 1992). The western Salt Range and Surghar Range (Trans Indus Ranges) include the clastic facies that make up the Datta Formation. These facies are typified by siltstone, fireclay, carbonaceous shale, oxidized hematitic sandstone, and varicolored sandstone, with the majority consisting of white silica sand. Only a few locations are home to the marly carbonate facies. Its thickness ranges from 150 to more than 350 m in the range front area and lowers to 15–30 m in the Hazara and Kalach Chitta areas (Abbasi *et al*., 2012). Numerous wells in the Kohat and Potwar fold-thrust-belt have shown the presence of the multistorey reservoir Datta Formation, which is mostly composed of clastic facies (Jabbara *et al*., 2023). The Jurassic rocks in the central Salt Ranges and the central and eastern Potwar fold-thrust-belt are sliding eastward due to pre-Tertiary uplift (Chen, 2009). The Datta Formation has an unconformable contact with the underlying dolomite series of the Kingriali Formation over most of northern Pakistan. It rests unconformably above Precambrian, Paleozoic, and Triassic rocks in the Hazara area. Meiospores from the formation have a rich flora, according to Masood and Bhutta (1985) (Abbasi *et al*., 2012). The most persistent Early Jurassic marker pollen in the lower Datta Formation is class opollis classoides (Murphy, 2023). The Toarcian Shinawari Formation, Samana Suk Formation, and Datta Formation are assumed to be Early Jurassic in age, respectively (Iqbal *et al*., 2021). Subsequently, a sequence of Cretaceous rocks is deposited, including the Chichali Formation, Lumshiwal Formation and Kawagarh Formation. Following another unconformity, the Paleocene sequence is deposited, comprising the Hangu Formation, Lockhart Limestone, and Patala Formation. An unconformity precedes the Eocene sequence, which encompasses the Margalla Hill Limestone, Chorgali Formation, Kuldana Formation, Nammal Formation, Sakesar Limestone, Panoba Shale, Bahadur Khel Salt, Chorgali Formation, Shekhan Formation, Kuldana Formation, and Kohat Formation (Fig. 3; Hashmi *et al*., 2018). The Oligocene period is not represented in the record. The Miocene sequence comprises the Rawalpindi Group, while the Late Miocene to Pliocene period is represented by the Siwalik Group.

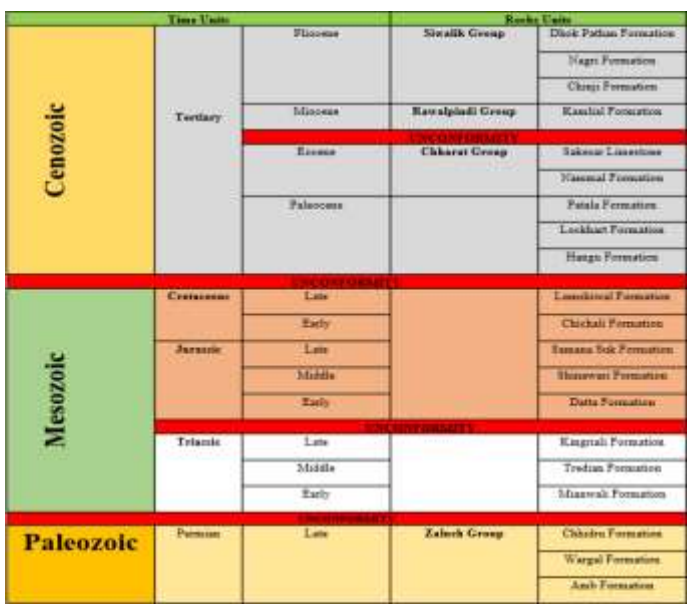


Figure 2: Generalized Stratigraphy of study area (Fatmi, 1977).

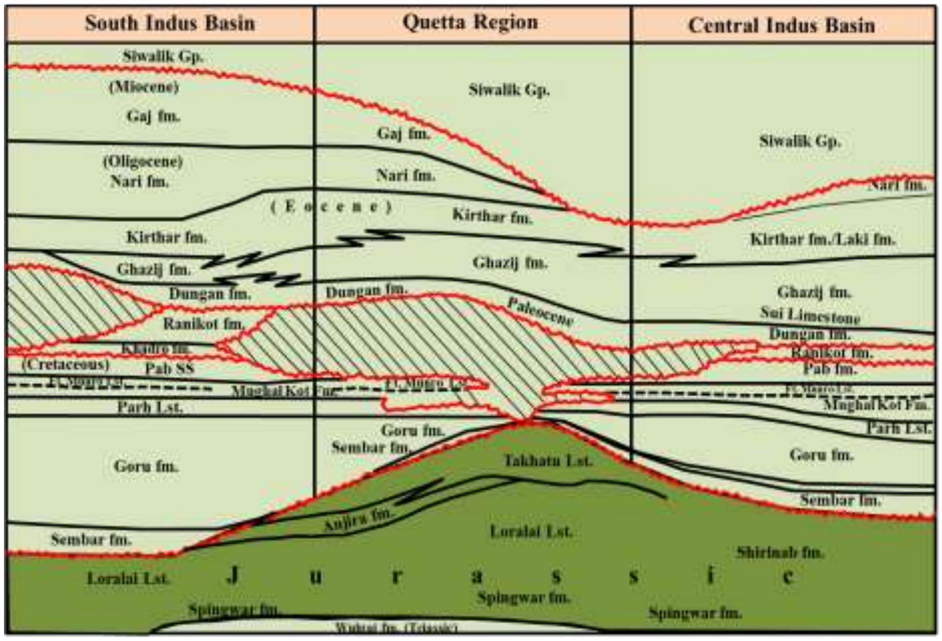


Figure 3: Stratigraphic Relationship, Lower Indus Basin

4. Methods and Dataset

In this research, extensive fieldwork was conducted to investigate the semi-quantitative facies analysis and renewable energy potential of the early Jurassic Datta Formation in Pakistan. The fieldwork covered seven days, from December 24 to 30, 2023, during which four stratigraphic sections were measured: Nammal Gorge, Kasanwala section, Paniala section, and Gulla Khel section. Detailed lithological descriptions were made, focusing on grain size, texture, facies types, facies associations, cyclicities, and trace fossils. Field description sheets were used to document these sedimentological studies, and field photographs captured sedimentary structures, bedding relationships, and any associated tectonic events. Key sedimentary structures such as trough cross-bedding, ripples, fossil beds, and high porous zones were carefully marked. Samples were collected at locations chosen based on lithological variations and sedimentary structures, with sample spacing ranging from meters to tens of meters, depending on formation heterogeneity. Field logs, which documents lithological and stratigraphic features, were digitized using Easy Core© software for detailed analysis and interpretation.

5. Results

The stratigraphic section that are subject of this study are Nammal Gorge (32°36'14.18"N, 71°47'48.24"E) in the Salt Range, Kasanwala (32°36'14.19"N, 71°49'45.64"E) in the Salt Range, Gulla Khel (32°58'28.82"N, 71°13'23.18"E) in the Surghar Range, and Paniala (32°14'25.20"N, 70°53'49.33"E) in the Khisor Range (Fig. 4). The lithologies in these sections are varied, with sandstone and siltstone predominating in Gulla Khel, Kasanwala, and Paniala, the latter having the most significant amount at 67%. Nammal Gorge, on the other hand, has a lithology that is 49%

composed of shale, which is a greater proportion. Dolomite, laterite, bauxite, palaeosols, and conglomerates are among the other prominent lithological elements found in these sections that revealing the complexity of the local geology.

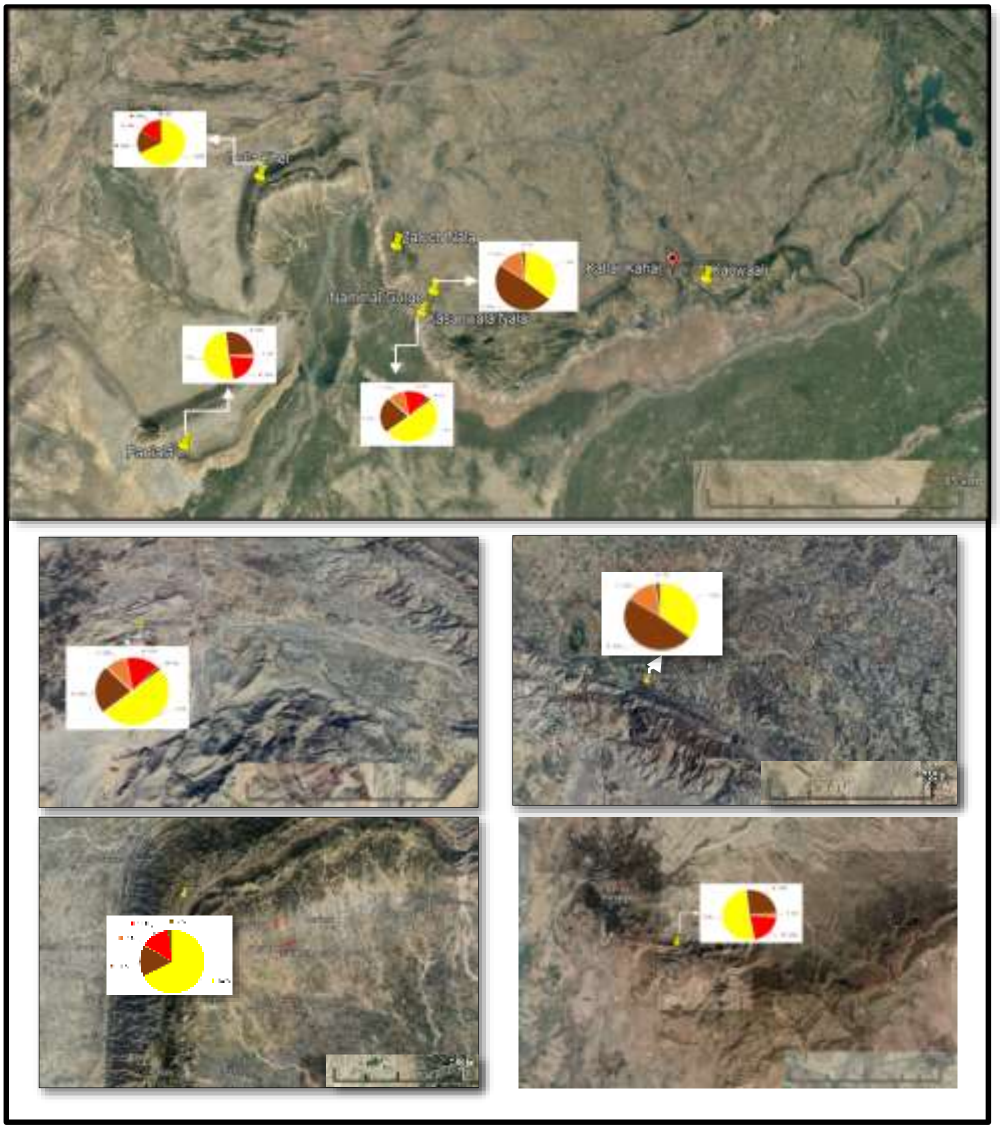


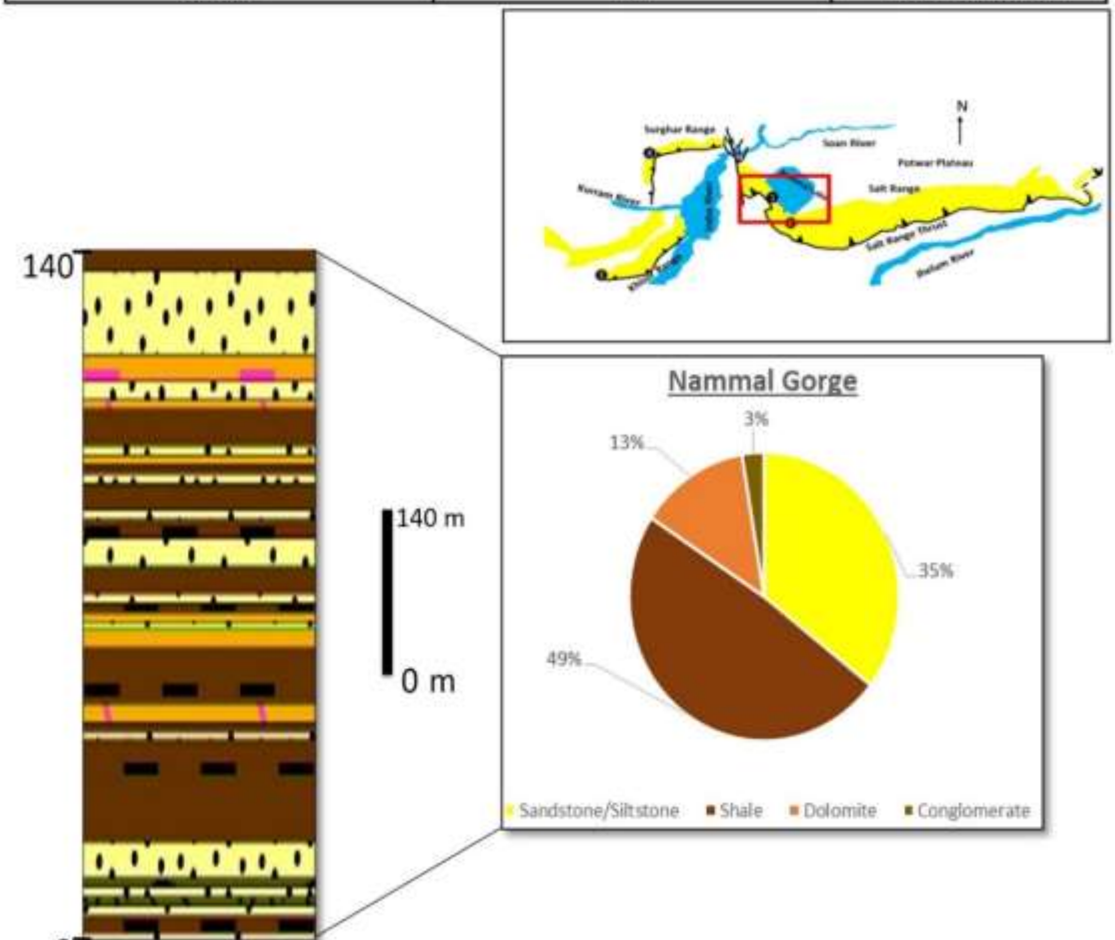
Figure 4: Satellite images of study area

5.1 Nammal Section

The Nammal Gorge in the Salt Range features a diverse lithology comprising various types of rocks. Sandstone and siltstone together make up 35% of the lithology, while shale is the most prevalent, comprising 49%. Dolomite accounts for 13% of the lithological composition, and conglomerate represents the remaining 3% (Table 1).

Table 1: Quantitative facies in Nammal Gorge Section.

Thickness (m)	%	Facies
50.22	35.53	Sandstone/Siltstone
68.82	48.68	Shale
18.6	13.16	Dolomite
3.72	2.63	Conglomerate
141.36	100	Total Thickness

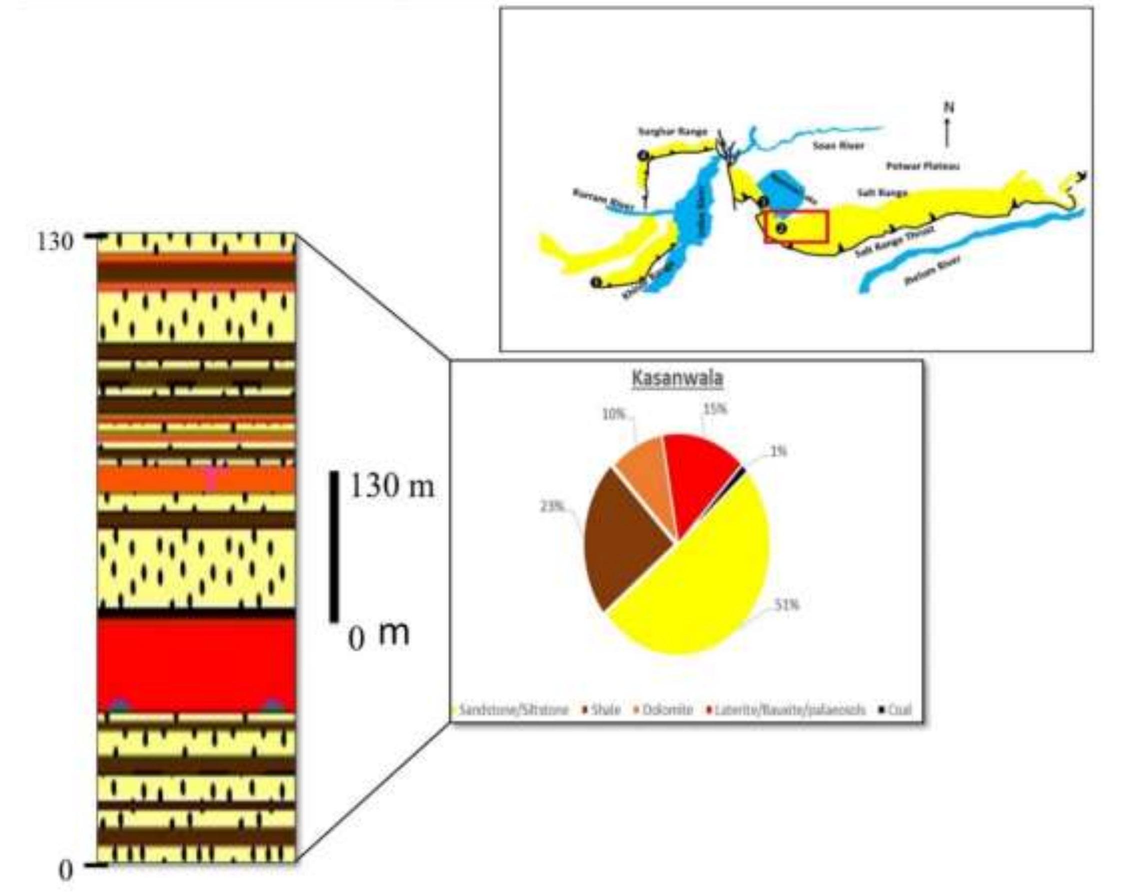


5.2 Kasanwala Section

The Kasanwala section has lithology of sandstone and siltstone, comprising 51% of the lithology. Shale is present 23%, while dolomite is present at 10% (Table 2). Laterite, bauxite, and palaeosols collectively account for 15% of the lithology, and coal constitutes 1%.

Table 2: Quantitative facies in Kasanwala Section.

Thickness (m)	%	Facies
66.6	50.68	Sandstone/Siltstone
30.6	23.29	Shale
12.6	9.59	Dolomite
19.8	15.07	Laterite/Bauxite/palaeosols
1.8	1.37	Coal
131.4	100	Total Thickness

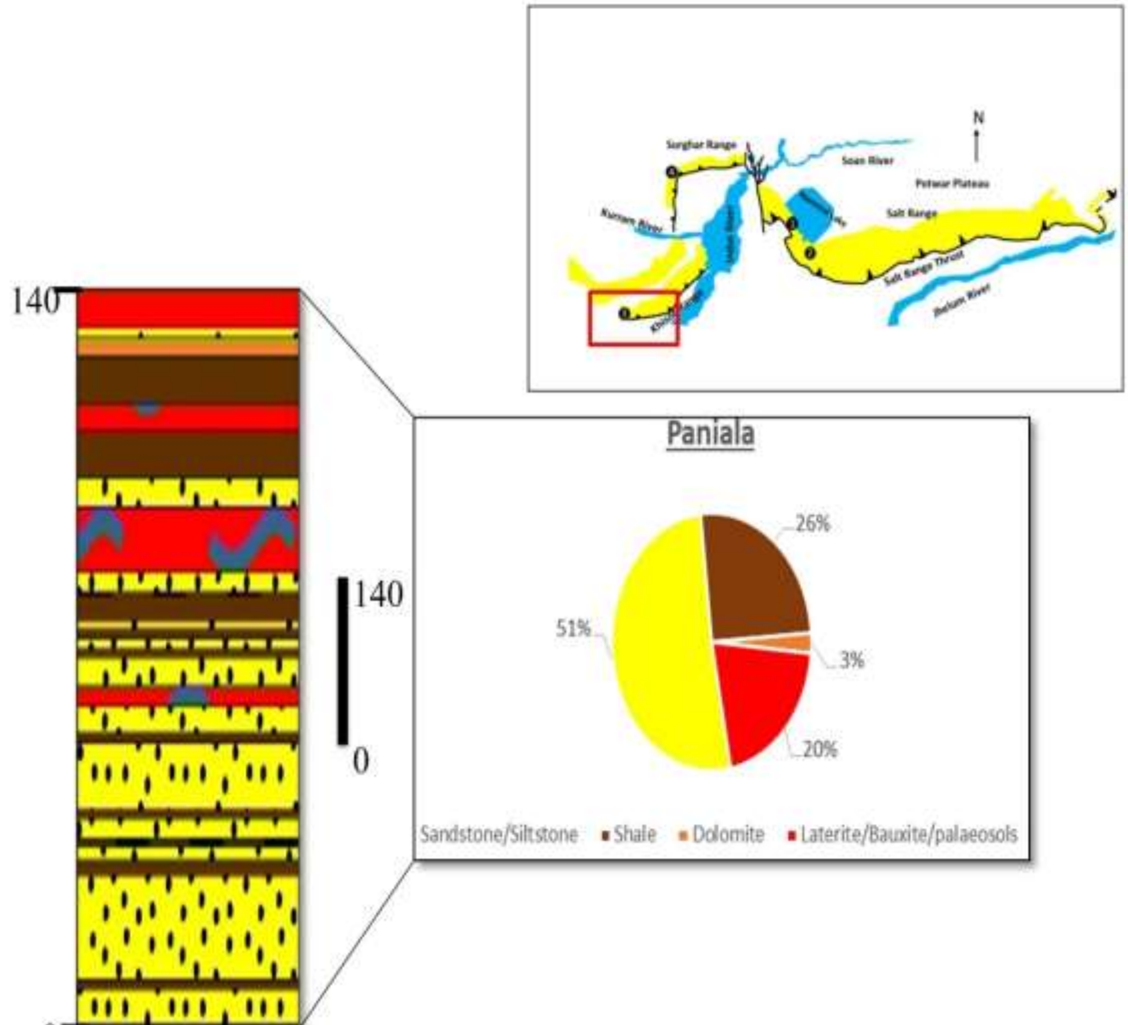


5.3 Paniala Section

In the Paniala section of the Khisor Range, the lithology is composed of sandstone and siltstone accounting for almost 51% of the lithology (Table 3). Shale is present 26%, while dolomite is present at 3%. Laterite, bauxite, and palaeosols collectively account for 20% of the lithology.

Table 3: Quantitative facies in Nammal Gorge Section.

Thickness (m)	%	Facies
71.63	51.28	Sandstone/Siltstone
35.87	25.64	Shale
3.58	2.56	Dolomite
28.64	20.51	Laterite/Bauxite/palaeosols
139.72	100	Total Thickness

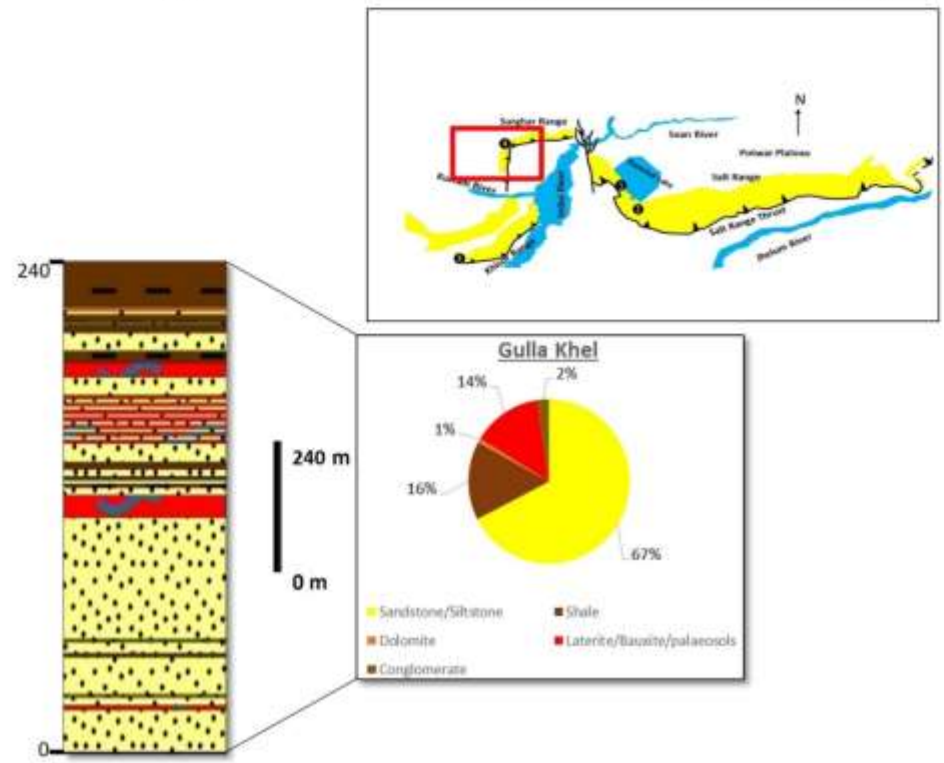


5.4 Gulla Khel Section

The Gulla Khel section, located in the Surghar Range, has lithology consisting of sandstone and siltstone, which together comprise 67% of the formation (Table 4). Shale is 16 % and dolomite is 1%. Laterite, bauxite, and palaeosols collectively make up 14% of the lithology, and conglomerate make up 2%.

Table 4: Quantitative facies in Gulla Khel Section.

Thickness (m)	%	Facies
156.6	67.44	Sandstone/Siltstone
36	15.5	Shale
1.8	0.78	Dolomite
32.4	13.95	Laterite/Bauxite/palaeosols
5.4	2.33	Conglomerate
232.2	100	Total Thickness



6. Discussion

6.1 Economic Aspect

The Datta Formation's mineral composition, which includes kaolinite, illite, tourmaline, zircon, rutile, laterite, bauxite, palaeosols, and coal, presents considerable economic potential. Notably, the formation's basal part is rich in silica sand, which is essential for the production of solar photovoltaic panels and energy-efficient glass. Additionally, the presence of laterite offers significant value, as it can be utilized in the production of lithium-ion batteries, further highlighting the economic importance of the Datta Formation's mineral resources.

Table 5: Economic Minerals

Economic Minerals	Facies	%
Kaolinite	Clay/Shale	69
Illite	Clay/Shale	31
Tourmaline	Sandstone	51.7
Zircon	Sandstone	29.4
Rutile	Sandstone	17.7
Laterite/Bauxite/Palaeosols	Laterite/Bauxite/Palaeosols	___________
Coal	Coal	___________
Silica Sand	Sandstone	___________

7. Conclusions

The Datta Formation is rich in various minerals crucial for several industries, making it vastly valued for various tenders. The prosperity of minerals such as kaolinite, illite, tourmaline, zircon, and rutile is demonstrated by their suitability for use in ceramics, pharmaceuticals, gemstones, nuclear technology, and energy production. The relevance of Datta Formation to the renewable energy sector, offering promising opportunities, sustainable resource exploitation and energy generation, is dependent on the presence of laterite, bauxite, paleosols, and coal. The analysis of detailed measurements of sections and mineral composition suggested its economic importance, resource potential, and special significance for the renewable energy sector in Pakistan and beyond. The basal part of the formation is conspicuously rich in silica sand, vital for manufacturing solar photovoltaic Panels and energy-efficient glass on the other hand, laterite is suitable for lithium-ion battery production, highlighting the formation's strategic importance.

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