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LITHO-STRUCTURAL MAPPING USING REMOTE SENSING AND FIELD WORK TECHNIQUES: A CASE STUDY FROM CENTRAL SALT RANGE ARA, RAWAL AND SIDHANDI VILLAGE, PUNJAB PAKISTAN

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ABSTRACT

In the Central Salt Range lithological structural mapping has been a great challenge and of great interest to geologists as it is in rugged and inaccessible mountain terrain. In this paper a comprehensive lithological mapping conducted in the villages of Ara, Rawal and Sidhandi which are located in Central Salt Range region of Punjab, Pakistan. This study uses a combination of remote sensing techniques and field work to elucidate the geological and structural characteristics of the study area. Due to complex tectonic history and mineral resources Central Salt Range is of great geological interest.

In this research we combined data from geological field observations and satellite images to produce detailed lithological and structural maps. Remote sensing data help to identify surface features and geological structures. These ground truth observations are complemented by extensive field work including geological mapping and structural analysis.

Our work represent a diverse rock composition in the study area, including sedimentary rocks and various fault systems. We classify fault zones on basis of their characteristics, and our structural analysis provides insight into the fault history of the region. Moreover, the study discusses the implications of these geological features for understanding regional tectonics, potential mineral deposits, and land resources in the area.

This work demonstrates the synergy between remote sensing techniques and fieldwork in understanding the geological complexities of the Central Salt Range. This work provides valuable information for geological mapping and risk assessment in the area. Additionally, this research demonstrates the importance of a multidisciplinary approach in geological investigations, emphasizing the importance of integrating remote sensing and field data to enhance our understanding of complex geological environments.

Keywords: Litho-structural mapping, Remote sensing, Fieldwork techniques, Central Salt Range, Ara, Rawal, and Sidhandi villages, Punjab, Pakistan, Geological analysis, Satellite imagery, Structural mapping, Fault systems, Geological features, Tectonic history, Mineral resources, Sedimentary rocks, Deformation history

INTRODUCTION

Rock mapping constitutes a fundamental pillar of geological investigations, providing a comprehensive understanding of the distribution and characteristics of diverse rock types across Earth's surface. The genesis of lithostructural maps can be traced back to the late 18th and 19th centuries, and since their emergence, they have played a pivotal role in unraveling Earth's geological history and addressing land-use issues pertaining to natural hazards. Historically, lithostructural mapping relied extensively on field geologists traversing rugged terrains to meticulously document the textures, details, and composition of rock formations. These detailed rock maps serve as invaluable repositories of geological information. The color patterns employed in lithological maps effectively convey the spatial distribution of various geological features across Earth's surface.

Technological advancements have revolutionized the field of rock mapping, introducing a plethora of methodologies that encompass aerial photography interpretation and satellite remote sensing. The continuous development of remote sensing and geographic information systems (GIS) has empowered researchers to achieve remarkable breakthroughs in various Earth science disciplines, establishing these technologies as indispensable tools for rock mapping. Researchers frequently employ data derived from satellite and remote sensing techniques to conduct lithology-based studies. Previous research has yielded a suite of methods for distinguishing and mapping different rock types using multispectral data, including principal component analysis (PCA) data, band ratio data, and classification based on multispectral data [1,2].

Lithostructural mapping of Ara, Rawal and Sidhandi Village (lang. 73^0 7’ 30’’to 73^0 15’ 00’’, lat. 32^0 42’ 00’’ to 32^0 45’ 00’’) was carried out at 1:12500. On the basis of structural cross section, detailed tectonic and structural interpretation was done. The structural synopsis of areas Siki, Basharat, Chail Abdal area are better understood, all these areas are fall with in Eastern Salt Range. Existence of normal faults in area suggest the involvement of salt tectonics there. Long narrow series of ridges are the important geomorphological feature in the area. A wide variety of sedimentary structures like salt pseudomorph, cross bedding, lamination, mud cracks, ripple marks, bioturbation and other features such as vuggy porosity, fractures, Stromatolites and Stromatolitic heads was observed. The Formations ranging from Cambrian to Miocene were studied, Lockhart Formation of Paleocene age is missing in the area and two major unconformities are present one at the base of Permian and other at base of tertiary [3]. Due to presence of much limestone, laterite and coal the economic potential of the area is very good.

GEOGRAPHIC SETTING AND ACCESSIBILITY OF THE STUDY AREA

Our study areas are easily accessible as several metaled and un-metaled roads connect each other’s. As the study area is located in district Chakwal, the M-2 motorway is best option to access the study areas. M -2 motorway will lead till Kalar Kahar then Choa Sedan Shah road will end up to Ara, then Chak Mujahid Gharewal Road will lead towards Rawal and Baghanwala.

The Rawal and Sidhandi Valley and Ara are 132 km, 141 km and 143 km away from Sargodha respectively. And Rawal and Sidhandi Valley and Ara are 159 km, 163 km and 176 km away from capital city respectively.

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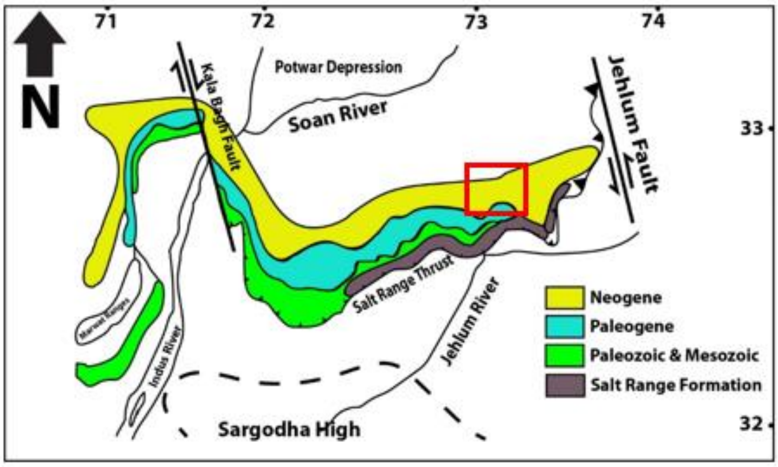

Figure 1: Map showing the location of study area with red rectangular.

TECTONICS OF SALT RANGE

The Salt Range, situated in the northwest of Pakistan, rightfully earns its moniker as the "Field Museum of Geology" due to its remarkable geological riches. It stands as an open book of Earth's history, adorned with abundantly fossiliferous stratified rocks that provide a vivid chronicle of geological epochs. The Permian carbonate succession, renowned for its brachiopod fauna, is a particularly captivating feature [4]. Recently documented foraminifer biostratigraphy further enhances the Salt Range's allure [5]. The Salt Range's geological significance extends to its Permo-Triassic marine sections, particularly well-studied and valuable for stratigraphic frameworks. Ammonites, with their intricate shell structures, stand out as key players in unraveling the Salt Range's geological evolution.

Geographically, the Salt Range is bounded by the Jhelum River to the east and the Indus River to the west, spanning the coordinates of 32°15' to 33°0' N and 71°34' to 73°45' E [6]. Beyond the Indus River, a distinct north-south trend emerges. The Salt Range constitutes the north-south section, while the Trans Indus Salt Range extends eastwards. The overall orientation is east-west, with an arcuate shape that curves towards the south, turning northwestward at its western end and northeastward towards its eastern extremity [7]. The Salt Range's elevation averages 800 meters, with Mount Sakesar, the highest peak, reaching an impressive height of 1,570 meters [8]. The top half of the scarp exposes Permian or Eocene limestone, while Tertiary sandstones are visible in the lower half [9].

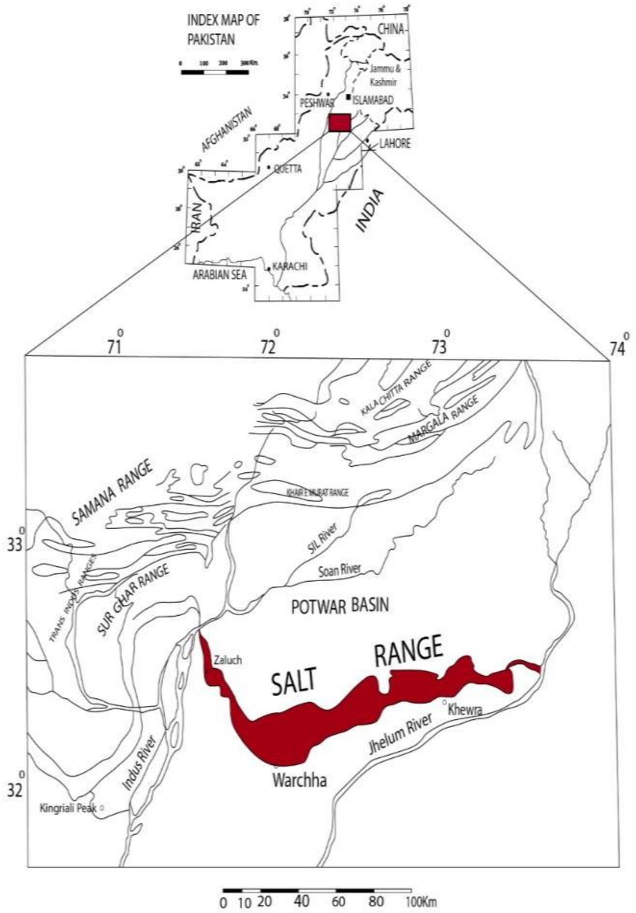

Figure 2: Salt Range location Map in the northern Pakistan (Ghazi et al. 2014).

The Potwar Basin, situated in the vicinity of Rawalpindi with an average elevation of 500 meters, is bordered by the Salt Range to the south and the Kala Chitta Hills (33°37′ N, 73°8′ E) to the north [10]. Previous investigations have suggested the possibility of the Punjab Foreland Basin's thrust sheets being uplifted due to their southward push across the basin. As a result of the ongoing collision between the Indian and Eurasian plates, the Salt Range represents the Himalayas' youngest and southernmost east-west trending frontal fold and thrust belt [11].

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The Salt Range is distinguished by two key regional differentiators: the presence of substantial salt deposits and the occurrence of numerous regional and local-scale non-depositional events spanning from the Eocambrian to the Pleistocene [12]. Along the active Salt Range Thrust, the Salt Range extends beyond its fan material to the north. Simple, broad, shallow folds and a gently descending monocline characterize the range's northern flank. The folding intensifies towards the south, resulting in the formation of east-west-trending faults and over folds along the southern scarp [13].

According to tectonic theory, the Himalayas represent a recent collisional mountain belt formed approximately 67+2 Ma when the northward-migrating Indian Plate collided with the Asian Plate [14]. This collision was accommodated solely by the closure of the Tethyan Ocean and the lateral displacement of rigid blocks out of the path of the Indian subcontinent without significant crustal thickening, leading to the absence of Substantial Mountain building [15].

This study aims to provide a comprehensive overview of the Salt Range's regional geology, encompassing primary tectonics and their interrelationships, stratigraphy and sedimentation, and structural patterns. The structural features derived from Landsat data are employed to highlight the tectonic processes and topography within the Salt Range region. These images also aid in elucidating the lateral dispersion of the thrust front.

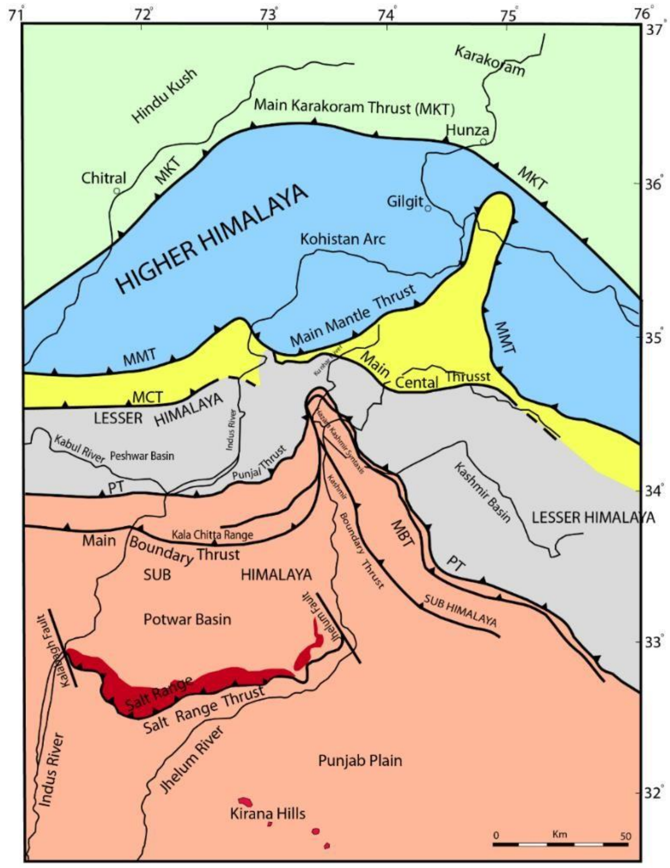

Figure 3: Salt Range regional tectonic map, Pakistan (modified after Kazmi and Rana 1982).

METHODOLOGY

The methodology employed in this study adheres to standard methodological procedures. The initial step involved preparing a base map of the study area by utilizing traditional cartographic techniques and topographic maps obtained from the Geological Survey of Pakistan (GSP). To achieve this, a base map was meticulously crafted from the topographic sheets using established tracing techniques. The topographic map encompassing the designated area served as a crucial tool for determining precise positioning and delineating contacts between adjacent geologic formations (as illustrated in Figure 4). Subsequently, this data was transformed to construct a comprehensive geological map. The primary data was imported into a geographic information system (GIS) using specialized software such as ArcGIS.

Coordinates values of the Base map are:

lang. 73^0 7’ 30’’to 73^0 15’ 00’’

lat. 32^0 42’ 00’’ to 32^0 45’ 00’’

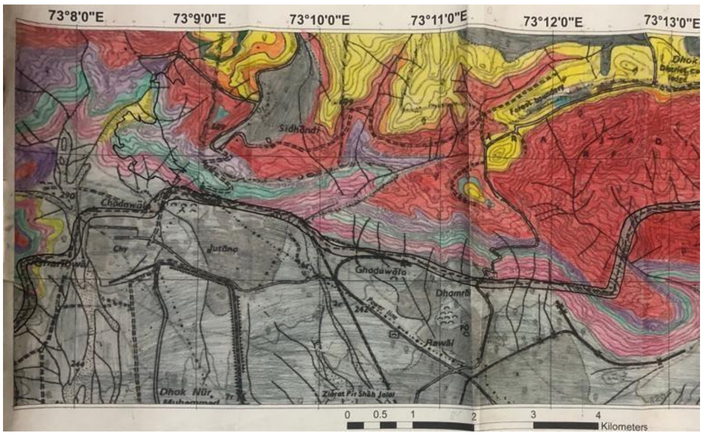

Figure 4: Base map of the study area.

FIELD WORK DATA

During our field work we observe different lithologies of formations which is shown on map by different colors and we als observe different features. We also mark contacts of formations and a formation differnet lithologies. Major and important features and contacts with changing lithologies are shown in Figure 5.

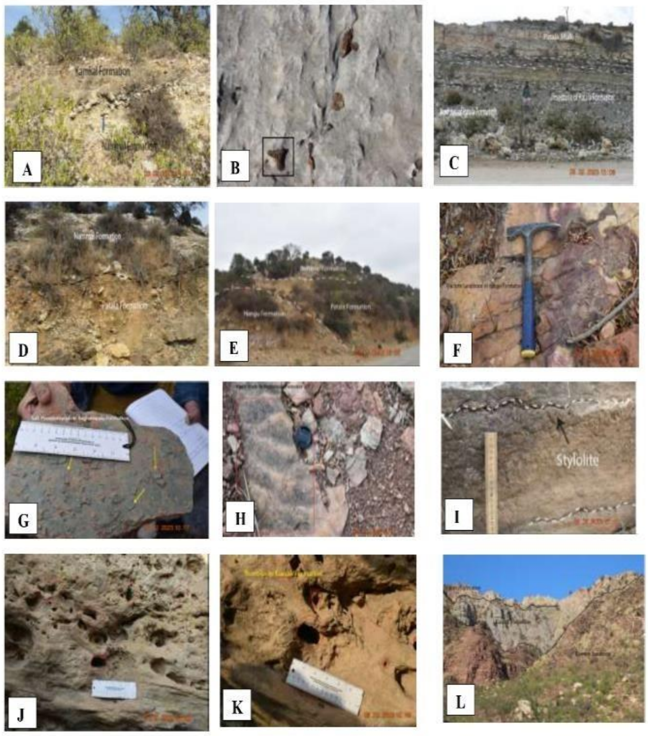

Figure 5: (A) Contact between Nammal Formation and Kamlial Formation, Dhok Wirk, Eastern Salt Range. (B) Chert nodules in upper part of Sakesar Formation, Kotli, Eastern Salt Range. (C) Shale and limestone of Patala Formation, Sidhandi village, Eastern Salt Range. (D) Contact between Nammal Formation and Patala Formation, Sidhandi village, Eastern Salt Range. (E) Contact of Hangu Formation with Patala Formation, Ara Nature Reserve, Eastern Salt Range. (F) Fracture Sandstone of Hangu Formation, Siki Wala section, Chakwal, Eastern Salt Range. (G) Salt Pseudomorph in Baghanwala Formation, Siki Wala section, Chakwal, Eastern Salt Range. (H) Ripple Marks in the Baghanwala Formation, Siki Wala section, Chakwal, Eastern Salt Range. (I) Stylolite in Dolomite of Jutana Formation, Siki village, Eastern Salt Range. (J) Vuggy Porosity in the Jutana Formation, Siki village, Eastern Salt Range. (K) Burrows in Kussak Formation. (L) Contact of the Kussak Formation with Khewra Sandstone and Jutana Formation, Baghanwala village, Eastern Salt Range.

RESULTS AND DISCUSSIONS

A combination of image enhancement techniques was employed to refine Landsat data imagery, enabling the conversion of lithological units and their contacts into a more digital and modern format. Multispectral color composites were generated by combining images from the green, red, and blue channels, each of which captures distinct spectral characteristics. Various color patterns were tested and found to be effective in differentiating lithological boundaries, leading to their selection for the digitization of different lithological units through visual image interpretation. The distinct textures, tones, and drainage patterns observed in satellite-derived data facilitated the identification of diverse rock lithologies. These interpretations were subsequently validated through field investigations. Table 1 shows the list of observed formations with their description.

Table 1: Observed column of Stratigraphy in study area at Eastern Salt Range.

Era	Period	Epoch	Formation
Cenozoic	Tertiary	Miocene	Kamlial Formation
		Eocene	Sakesar Limestone Nammal Formation
		Paleocene	Patala Formation Hangu Formation
Paleozoic	Permian		Warchha Sandstone
	Carboniferous Devonian Silurian Ordovician	Unconformity	
	Cambrian		Baghanwala Formation Jutana Formation Kussak Formation Khewra Sandstone
Precambrian			Salt Range Formation

GEOLOGICAL STRUCTURE PRESENT IN STUDY AREA

The primary objective of the field investigation was to conduct geological mapping and validate GIS-based data. Topographic maps serve as the foundation for geological mapping. Topographic sheet 34 N/3 of the Geological Survey of Pakistan was enlarged fivefold to facilitate detailed mapping. The project area is situated within the Salt Range, in proximity to the Surghar Thrust (SRT). Formations spanning from the Cambrian to the Miocene were examined, with the Lockhart Formation of Paleocene age being absent in the region. Two significant unconformities are present: one at the base of the Permian and the other at the base of the Tertiary.

Dhok Gujjar Anticline and Syncline

The Dhok Gujjar Anticline and Syncline is a geological feature located in the Central Salt Range of Punjab, Pakistan. It is a well-defined anticline with a northwest-southeast trending axis. The syncline is located to the northeast of the anticline. The Dhok Gujjar Anticline is composed of a thick sequence of limestone and shale of the Jurassic and Cretaceous ages. The syncline is filled with a sequence of shale and sandstone of the Jurassic and Cretaceous ages. It is shown in Figure 6 in the cross section B to B'.

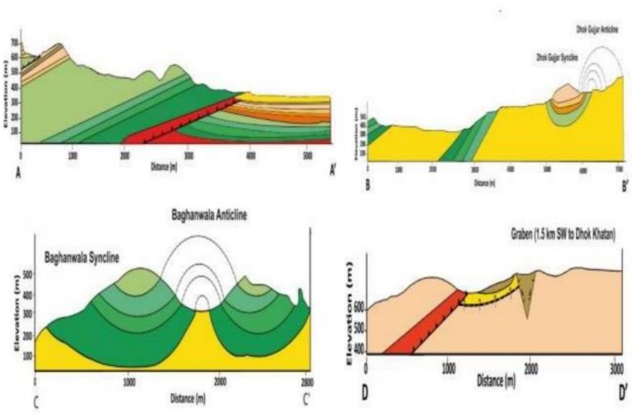

Figure 6: Showing the digitized cross sections of study area.

Baghanwala Anticline and Syncline

The Baghanwala Anticline is a major structural feature in the Central Salt Range. The core of the anticline is composed of Permian evaporates, which are overlain by Triassic and Jurassic sedimentary rocks. The anticline is flanked by synclines on both sides. The Baghanwala Syncline is a smaller structural feature that is located on the northern flank of the Baghanwala Anticline. The core of the syncline is composed of Triassic and Jurassic sedimentary rocks. It is shown in Figure 6 in the cross section C to C'.

A Graben

Graben are formed by normal faults which are parallel. In the graben the hanging wall experiences displacement in the downward direction, while the footwall experiences displacement in upward direction. A graben is also present within the study area, as depicted in Figure 6. In the cross-section D-D', the graben is clearly visible.

Study Area

A digitize study area shows the real look of the area. It shows that area is 16 to 25 degree dipping. It is shown in Figure 6 in the cross section A to A'.

Geomorphological analysis of the study area reveals significant deformation, as evidenced by the presence of lineaments, lithology, and drainage network patterns. This evidence corroborates the existence of a major tectonic structure in the vicinity of the Central Salt Range, aligning with previous studies by Abied (2008) and Abubaker (2015). This study highlights the instrumentality of remote sensing and GIS in delineating lithologies and lineaments in geologically active terrains with intricate topography, such as the Central Salt Range. The resultant map, as depicted in Figure 7, exemplifies the efficacy of these techniques in deciphering the geological landscape.

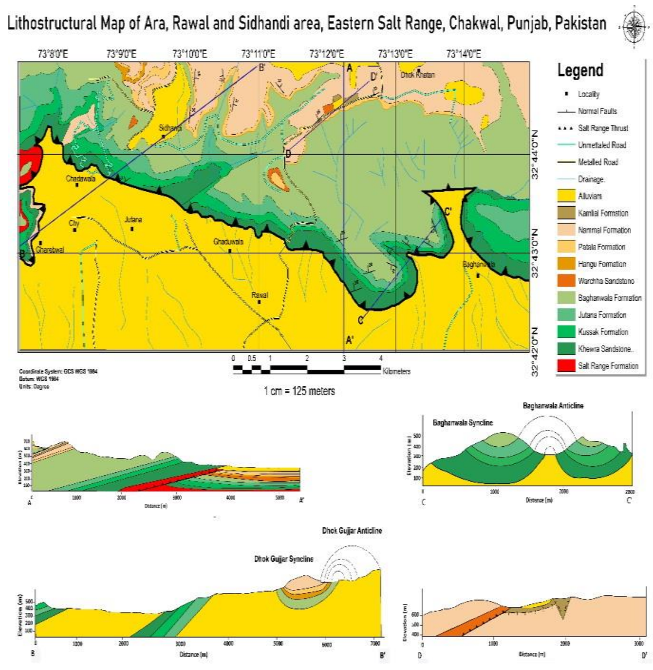

Figure 7: Structural map of Ara, Rawal and Sidhandi area, Eastern Salt Range, Chakwal, Punjab, Pakistan.

CONCLUSION

The integration of remote sensing and geographic information systems (GIS) offers a powerful approach for differentiating rock types and lineaments. High-resolution data serves as the foundation for these integrated interpretations. GIS spatial analysis facilitates the development of lithological maps by incorporating multiple information layers, while image processing techniques such as principal component analysis, visual image interpretation, filtering, and false color composites further enhance the analysis. The rock types identified using satellite data closely align with those depicted on existing conventional maps, encompassing limestone, conglomerate, shale, sandstone, and alluvium.Edge enhancement techniques can refine the accuracy and recognition of lineaments that are challenging to trace in the field. While satellite remote sensing for lithological mapping is not without its challenges, such as spectral similarities between certain lithological units due to shared vegetation cover, these difficulties can be effectively addressed through fieldwork.

Furthermore, lineaments, often difficult to discern on the ground, are frequently readily discernible in satellite imagery. Consequently, satellite imaging proves a valuable tool for enhancing the quality of lithological mapping and lineament identification.

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Conflicts of Interest

The author declares no conflict of interest.

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Ms. Rani Ummay Farwa, she received Gold Medal in Geology She has strong Academic Foundation and Software In 2022, she participated in the prestigious Imperial Barrel award, AAPG and secured an impressive 5th position in the competitive Asia Pacific region. Currently she received an offer as a development fellow at the Geological Survey of Pakistan, She is actively contributing to the advancement of geological sciences. Her dedication to research work is evident in her focus on pivotal areas such as tectonic studies, sedimentology, core digitization, and machine learning applications.

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He carries a rich experience of 13 years having worked in both Public Sector and International Non-Governmental Organizations. Before joining the Civil Services in 2018, he was working as Tehsil Municipal Officer with Local Government, Elections and Rural Development Department, Government of Khyber Pakhtunkhwa. He is committed to public service and has made significant contributions in the fields of general administration, economic development, and multitier governance.

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