

<https://doi.org/10.26565/2410-7360-2026-64-02>

UDC 552.54:551.83:553.98

Integrated Facies Analysis and Stratigraphic Correlation of the Wargal Limestone: Insights into Outcrop Data and Depositional Environments along the Paleotethys

Ayesha Amir^{1,2},  <https://orcid.org/0009-0003-2295-7188>, e-mail: ayeshaamir.geol@gmail.com
MS (Geology), Department of Earth Sciences,

Syed Haroon Ali^{1,3},  <https://orcid.org/0000-0002-8619-7005>, e-mail: haroon.ali@uos.edu.pk
PhD (Geosciences), Assistant Professor (Geology) Department of Earth Sciences, Interdisciplinary Research Center for One Health (IRCOH)

Hafiza Mamona Nazir¹,  <https://orcid.org/0000-0002-0998-6369>, e-mail: mamona.nazir@uos.edu.pk
PhD (Statistics), Assistant Professor, Department of Statistics, Interdisciplinary Research Center for One Health (IRCOH)

Ahmed Abd El Aal⁴,  <https://orcid.org/0000-0001-9077-6897>, e-mail: ahmed_aka80@yahoo.com
PhD (Engineering Geology), Associate Professor, Civil Engineering Department

Yasir Bashir⁵,  <https://orcid.org/0000-0002-4614-796X>, e-mail: dryasir.bashir@live.com
PhD (Geophysics), Assistant Professor, Department of Geophysical Engineering, Faculty of Mines

Numair Ahmed Siddiqui⁶,  <https://orcid.org/0000-0002-6703-0699>, e-mail: numair.siddiqui@utp.edu.my
PhD (Geology), Associate Professor, Department of Geosciences

Noureen Shoukat⁶,  <https://orcid.org/0009-0000-6843-1104>, e-mail: noureen.geologist@gmail.com
MS (Geology), Researcher, Department of Geosciences

Ihtisham Islam Khan⁷,  <https://orcid.org/0000-0003-2443-8034>, e-mail: ihtisham.islam@sbbu.edu.pk
PhD (Geology), Assistant Professor, Department of Geology

Adnan Khan⁸,  <https://orcid.org/0000-0001-6607-4190>, e-mail: adkhan@uk.edu.pk
PhD (Geology), Associate Professor, Department of Geology

Naveed Rehman⁹,  <https://orcid.org/0000-0001-9962-9447>, e-mail: rehman@cug.edu.cn
PhD (Geology), Key Laboratory of Tectonics and Petroleum Resources Ministry of Education

¹ University of Sargodha, Sargodha, Pakistan

² Unconventional Oil and Gas Research Institute, Northeast Petroleum University, Daqing, Heilongjiang China

³ School of Earth Sciences, University College Dublin, Dublin, Ireland

⁴ College of Engineering, Najran University, Najran, Kingdom of Saudi Arabia

⁵ Istanbul Technical University, Istanbul, Turkey

⁶ Universiti Teknologi PETRONAS, Perak, Malaysia

⁷ Shaheed Benazir Bhutto University, Sheringal, Dir Upper, Pakistan

⁸ University of Karachi, Karachi, Sindh, Pakistan

⁹ China University of Geosciences, Wuhan, China

ABSTRACT

Problem statement. Wargal Limestone plays a significant role due to its substantial reservoir potential. A more in-depth analysis of this formation can be helpful in identifying elusive geobodies. Wargal limestone is a reservoir rock of Permian age in Pakistan. It has proven the reservoir in the Dhurnal field that proves its reservoir facies. In Pakistan, the Western Salt Range presents a wonderful opportunity to study this Permian limestone.

ARTICLE INFO

Manuscript received 27 November 2025
Revised manuscript received
13 January 2026
Manuscript accepted 25 May 2026
Available online 30 May 2026

In cites:

Amir Ayesha, Ali Syed Haroon, Nazir Hafiza Mamona, Abd El Aal Ahmed, Bashir Yasir, Siddiqui Numair Ahmed, Shoukat Noureen, Islam Khan Ihtisham, Khan Adnan, Rehman Naveed (2026). Integrated Facies Analysis and Stratigraphic Correlation of the Wargal Limestone: Insights into Outcrop Data and Depositional Environments along the Paleotethys. *Visnyk of V. N. Karazin Kharkiv National University, Series Geology. Geography. Ecology*, (64), 18–31. <https://doi.org/10.26565/2410-7360-2026-64-02>



© Amir Ayesha, Ali Syed Haroon, Nazir Hafiza Mamona, Abd El Aal Ahmed, Bashir Yasir, Siddiqui Numair Ahmed, Shoukat Noureen, Islam Khan Ihtisham, Khan Adnan, Rehman Naveed, 2026
This work is licensed under a Creative Commons Attribution 4.0 International License

Purpose. This study aims to examine the facies and depositional environment of late Permian limestone in Upper Indus Basin by characterizing the geological, mineralogical proxies of rock samples collected from various localities. The geobodies and sedimentary architecture of Wargal Limestone was deciphered using field observation.

Methods. Facies analysis, stratigraphic logging, and lithological correlation were used to interpret outcrop data and reconstruct the depositional environments. On the basis of fossils present in lithofacies, its depositional environment is elaborated. Sedimentology was studied using section measurement along with high resolution field photographs were collected using the facies heterogeneity and architecture. The facies were then plotted on high resolution field photographs. The dataset generated includes sedimentological logs, samples, and field photographs to enable reproducibility and future comparative stratigraphic studies.

Results. The common facies are carbonaceous shale, sandy limestone, argillaceous limestone, fossiliferous limestone, and dolomitic limestone. Fossils such as bryozoans, brachiopods, bivalves, gastropods, and trilobites date it to the mid-late Permian Five sections of Wargal limestone have been taken to correlate. Lateral facies changes of these facies shows stratigraphic continuity but with some obvious changes in lithology and thickness. We observed the geobodies in the formation, whether it has reefs, sheets, lenses, or channels. There is a chance to locate zoned reservoirs for potential hydrocarbon extraction because of stratigraphic variations. The diverse depositional environments of this formation, which range from lagoonal to reefal settings, are widely known for representing a highly active and diverse paleotethys system. The paper supports Sustainable Development Goal (SDG) 9 by advancing geological knowledge relevant to resource assessment and sedimentary basin analysis, SDG 13: through improved understanding of climatic and earliest environmental settings.

Conclusions. As the formation is made up of different types of rock, including fossiliferous limestone and porous dolomite, and since it is situated in a Salt Range, it has good potential for oil and gas exploration in the adjacent Potwar, Kohat and Bannu basins. The findings of this study are recommended for analogues as a guide in developing a framework for future studies of comparable carbonate rock successions in the study region.

Keywords:

lithofacies, lagoon, reefs, correlation, Wargal Limestone, Geobodies, reservoir, basin dynamics, sea-level fluctuations, sedimentary architecture, SDG 9, SDG 11.

Introduction. Pakistan's Permian rocks signify a rare chance to study both Paleo-Tethys and Gondwanaland deposits [2]. The siliciclastic rocks of the Nilawahan group and the carbonate-dominated sequence of the Zaluch group belong to the Permian succession of the Indus Basin. The Early Permian strata of the Nilawahan Group were created from the continent, which mainly belongs to the Gondwana system. Zaluch Group of Late Permian sequence denoted Tethys completely marine sediments. These carbonates are present in Middle East, Turkey, eastern Europe, Russian Platform and the Urals and correspond to the Guadalupian (Middle Permian) stage. Three formations, namely, Amb Formation, Wargal Limestone, and Chiddru Formation, are from the Zaluch group. Outstanding outcrops for field studies are present in the Salt Range with a well-developed Permian sequence. Lower contact of the Wargal is conformable with the Amb formation and has upper contact with Chiddru that is transitional (Fig. 1) [19].

The past sedimentological investigations of the Wargal Limestone lacked integration of the outcrop-based facies architecture and microfacies analysis for a sequence stratigraphic modeling in the study area. The present study is intended to integrate outcrop data, utilizing microfacies techniques as a useful tool for a dynamic depositional modelling of the Wargal Limestone [17]. Wargal Limestone's hydrocarbon reservoir categorization and diagenetic fabric are

also examined. At type locality its thickness is 183 m, while the average thickness throughout the Khisor and Marwat Ranges is about 174 m. Wargal Limestone at the Zaluch Nala Section has a thickness of 174-179 m [8]. In the study area of Middle to Late Permian Wargal Limestone covers the fossiliferous limestone and dolomite. Bryozoans, brachiopods, bivalves, gastropods, foraminifera, corals, molluscs are present in this limestone. In the inter-bedded clays pollen and spores have been discovered (Fig. 2) [12].

The primary objectives of this paper:

- To interpret the depositional environment of the Wargal Limestone based on facies.
- To make stratigraphic correlations between sections to know lateral and vertical facies variations along the margin of the Paleotethys.

Geology and tectonics. One of the most famous tectonic wonders associated with the Indian Plate is the ongoing collision with the Eurasian Plate, which is responsible for the formation of the Himalayas [9]. The convergent boundary where the Indian plate subducts beneath the Eurasian plate drives the uplift of the Himalayas, forming the world's tallest mountains [6]. This convergence also raises the Tibetan Plateau, sometimes called the "roof of the world".

In the Sub-Himalayas the Salt Range in Pakistan offers a fascinating glimpse into the tectonic and sedimentary history of the Indian plate's northern edge, revealing the story that begins well before

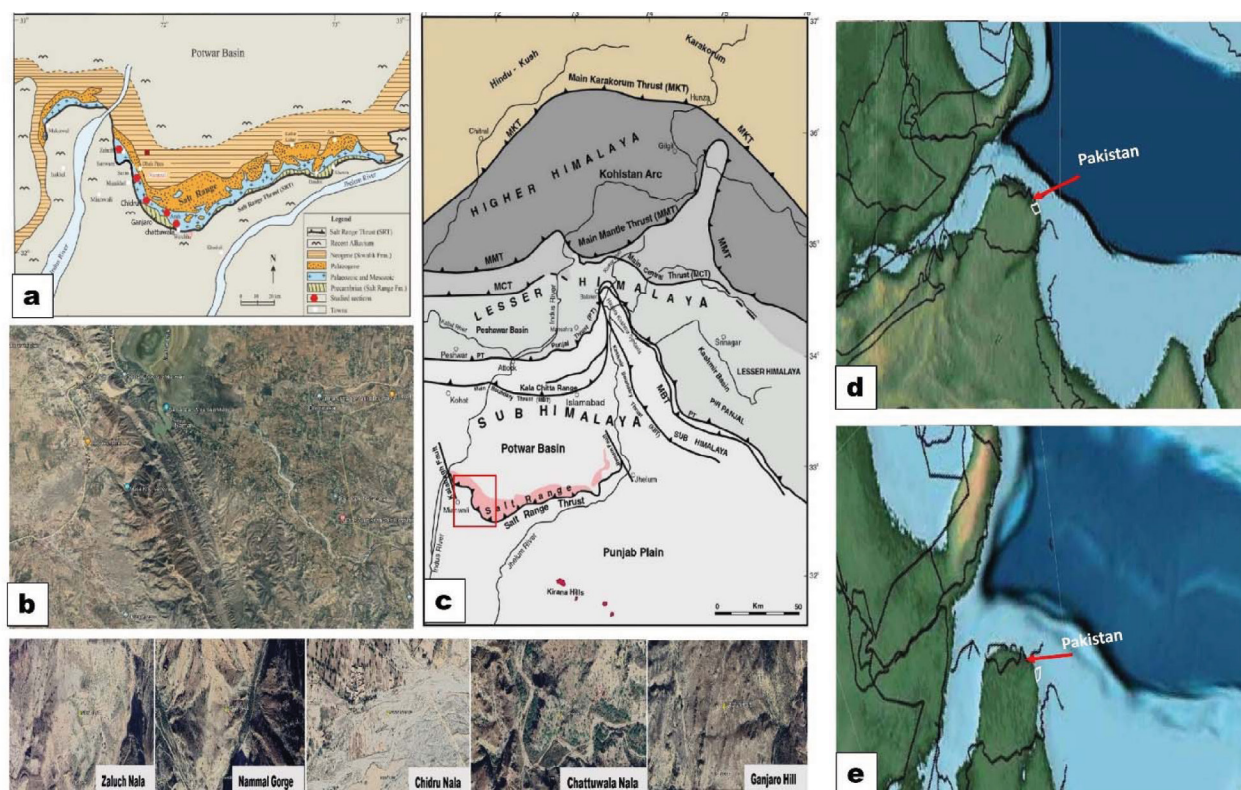


Fig. 1. (A) The Geological Map of the Salt Range and adjoining ranges, represent the geological setting of the study area [5]. Study areas are represented by red circles. (B) Satellite Image of Wargal Limestone, in five section and whole view. (C) Generalized tectonic map of northern Pakistan, showing subdivisions of the Himalayan Mountains (modified after [3, 4, 7]). (D) Paleogeography of Wargal Limestone at the time of deposition. (E) Paleogeography of Wargal Limestone after deposition of it.

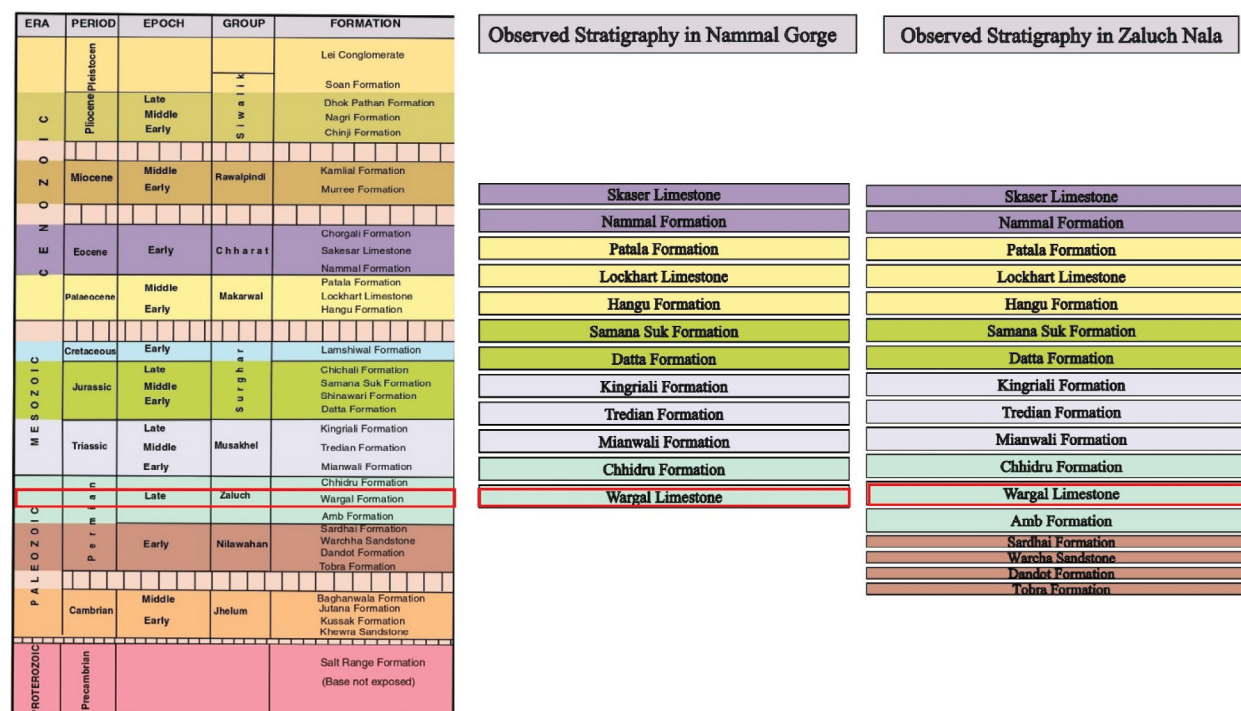


Fig. 2. Generalized stratigraphic units with major breaks in deposition in the Salt Range, Pakistan (after [4])

the Himalayas ever existed (Figs 1 and 2). Back in Precambrian times a shadow lifted basin formed along this margin, where thick layer of salt and gypsum were laid down in highly evaporative conditions what now knows as Salt Range

Formation. This salt later played a critical role in shaping the region's structure complexity. During the Permian period, the area that is now Pakistan, including the Salt Range, was part of the southern supercontinent called Gondwana. This landmass

was located close to the South Pole at that time. The climate was cold at first, but as Gondwana slowly moved northward, the region started to experience warmer and drier conditions. This shift played a big role in how the rocks of the Salt Range area were formed.

One of the most important parts of this time was the Murghabian Stage, which occurred around 264 to 266 million years ago, during the Middle Permian. During this stage, the region was covered by a shallow sea, and the climate was becoming more arid. This setting allowed for the deposition of thick limestone and dolomite layers, which today make up important formations in the Salt Range such as the Wargal Limestone and parts of the Chiddru Formation. These rocks formed in warm, shallow marine environments like lagoons and carbonate platforms [5].

Moving forward into the Permian period, the area was submerged under warm, tropical seas, allowing for development of broad carbonate platforms. Wargal limestone began to accumulate, with its Fossil rich layers recording fluctuations in sea level and energy conditions across the shallow Marine shelf. But this peaceful sedimentation phase changed the dramatically when Indian plate started drifting northward, eventually colliding with the Eurasia around 55 million years ago. This massive convergence triggered the Himalayan orogeny, causing the sedimentary cover of the Indian Plate to compress and slide southward. The presence of the ductile salt beneath the overlying rocks acted almost like lubricant, allowing the rocks to be pushed forward along a major structure called the salt range thrust (SRT) a fault now defines the frontal boundary of the range. Other tectonic features like backthrust, pop-up structures and salt-cored folds, further complicate the geology. The study area is part of the field museum of geology called Salt Range. The Salt Range is divided into three parts: eastern, central, and western Salt Range based on structure, stratigraphy, and sedimentation [4].

The Salt range is contributing three styles; eastern, western, and central based on the sedimentation, stratigraphy, and structure [13]. The studied sections consisting of Nammal, Zaluch, Ganjaro, Chiddru, and Chattuwala Nala lie in the western salt range. The Salt range is formed as a result of the collision of Indian and Eurasian plate that convergence results major devastation; Himalayan-Tibetan orogeny and generation of north dipping thrust faults trending from North to south [20]. These are Main Karakorum Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), and Main Frontal Thrust (MFT). The Salt range is present on the frontal Thrust of sub Himalayas bounded by Salt Range Thrust in the south that is producing decoupling of sediments from basement

along salt strata [9]. Thick salt underlies the Salt Range's fold and thrust belt, which are bordered by the dextral Kalabagh Fault in the west and the sinistral Jhelum Fault in the east [20].

Gorges and sections are expose rocks from Permian to Eocene strata as a result of uplifted as a result of large anticlines or domal uplift associated with small normal faults that has later been carved by streams along the axial plane [22].

The Nammal Gorge Section is situated in Punjab, Pakistan, close to District Mianwali, in the Western Salt Range. The Nammal Gorge has good exposure of the Upper Permian, Mesozoic, and Cenozoic rocks. Marine siliciclastic-carbonate mixed lithofacies from the Amb Formation, Wargal Limestone, and Chiddru Formation, respectively, make up the Upper Permian, Zaluch Group [15].

The Wargal Limestone likely formed in a marine environment during a period of tectonic stability, when sedimentation and the deposition of limestone occurred. The boundary between the Permo-Triassic is delineated by the Chiddru Formation and the Mianwali Formation that lies above it, both part of the Musakhel Group.

The Mianwali Formation, Tredian Formation, and Kingriali Dolomite are all part of the Triassic Musakhel Group. A paraconformity separates the Permian and Triassic [10]. Above the Musakhel Group is a sizable layer of the Jurassic Surghar Group, which includes the Datta and Samana Suk formations. The Paleocene succession is positioned above the Surghar Group in an unconformable manner, and the Cretaceous succession is lacking. In a younging up sequence, the Patala Formation, the Lockhart Limestone, and the Hangu Formation make up the Makarwal Group.

The K-T Boundary (Cretaceous-Tertiary) is missing here and Tertiary (Makarwal Group) directly overlies the Jurassic (Surghar Group). The Eocene succession includes the Chharat Group that consists of the Nammal Formation and Sakesar Limestone. The Miocene Murree and Kamlial formations of the Rawalpindi Group and the younger fluvial/alluvial sediments of the Chinji, Nagri, Dhok Pathan and Soan formations constitute the molasses sedimentation of the Siwaliks Group [4]. The Eocene sequence comprises the Chharat Group, which includes the Nammal Formation and the Sakesar Limestone. The Miocene-aged Kamlial Formation, belonging to the Rawalpindi Group, along with the younger fluvial and alluvial deposits of the Chinji, Nagri, Dhok Pathan, and Soan formations, represent the molasse-type sedimentation of the Siwaliks Group [5].

Materials and Methods

In addition to it we correlate the Wargal Limestone into five sections; Nammal, Zaluch,

Ganjaro, Chiddru and Chattuwala Nala. It shows heterogeneity of facies throughout five stratigraphic sections. Also studied its porosity and permeability to check its reservoir potential.

The studied sections Nammal Gorge (32°39'24"N 71°47'40"E), Zaluch Nala (32°47'03"N 71°38'37"E), Chattuwala section (32°35'20"N 71°45'30"E), Ganjaro Hill (32°35'20"N 71°49'50"E) and Chiddru section (32°32'39"N 71°50'41"E) present on western salt range, Mianwali Pakistan. The thickness of Nammal is 150 m, Zaluch is 150, Chiddru, Chattuwala, and Ganjaro. The Wargal Limestone at the studied section is parted into nine lithological divisions based on lithology and basic sedimentary features. After making observations with respect to field, we created a lithological log that thoroughly explains the large features, including lithological units, fossils, and patterns of deposition. In order establish the microfacies eleven thin slices of the Wargal Limestone were chosen and examined using a polarizing microscope at the centre of excellence, Islamabad. Thin slices were examined as cross-polarizing light (XPL) and plane polarizing light (PPL) to detect allochems, matrix as well as the amounts of each. Furthermore, the X-ray diffraction (XRD), analysis was done on four powder samples from the intended beds to learn these rocks' mineralogy.

Results

Lithofacies Analysis. Wargal limestone's lithofacies are classified as carbonates. Later,

the grain-supported lithofacies were divided into skeletal and non-skeletal components according to grain type [14, 18]. The mud-supported facies were categorized as mud stone. Based on this criteria nine distinct lithofacies across all examined sections, delineated by their lithology and primary sedimentary characteristics. These lithofacies are denoted by the WF code, where 'W' signifies the Wargal Limestone and 'F' denotes the respective facies, numbered from 1 to 8. The identified lithofacies are below (Table 1).

WF-1: sandy limestone.

WF-2: fossiliferous limestone.

WF-3: argillaceous limestone.

WF-4: dolomite.

WF-5: sandy dolomite

WF-6: cherty dolomite

WF-7: argillaceous dolomite.

WF-8: shale

Outcrop Section. In western salt range, by visiting the Wargal Limestone. Measuring the whole section and gather outcrop pictures to get the best record of field. Wargal has coal seams in its base, organic shale and sandy limestone spot in the bottom of the section. Passage ahead different types of bedding having various ranges of thickness observed. Minor faults and nodular limestone also seen in this section. This is the richly fossiliferous limestone having samples of brachiopods, bryozoa and molluscs (Fig. 3).

At the base, shale rich in organic content is found, indicating potential hydrocarbon generation. The shale layer is bedded in a sandy

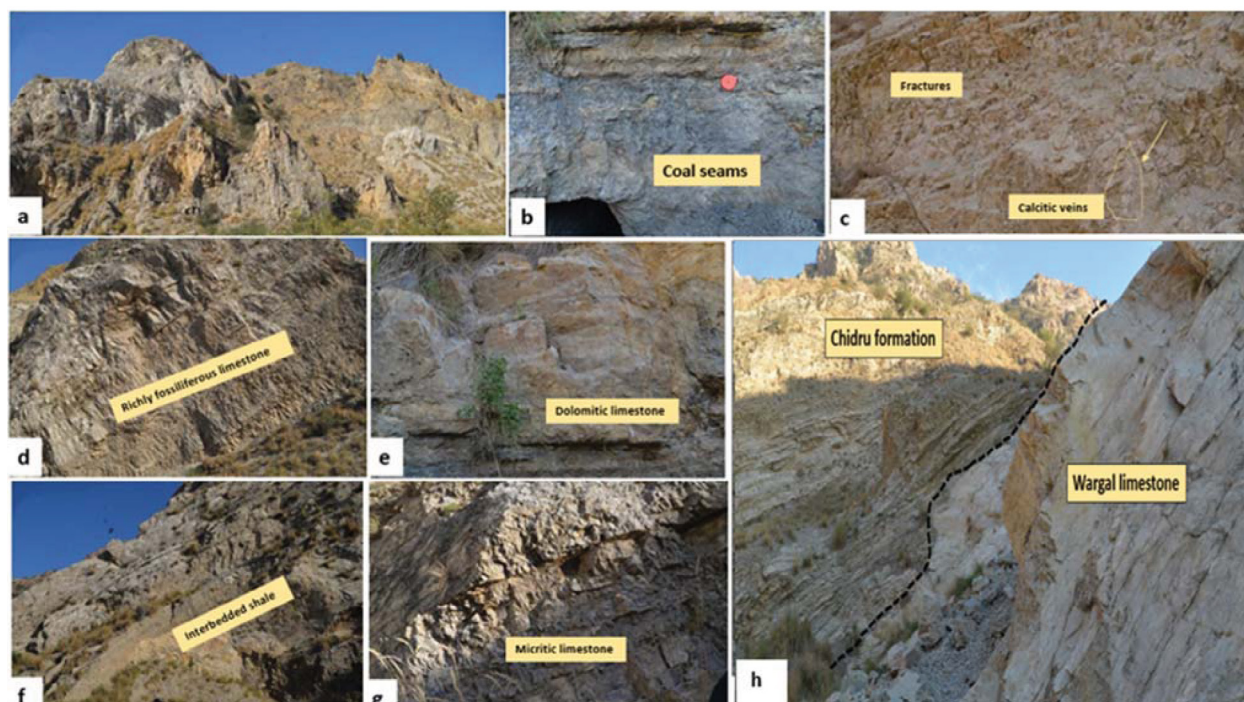
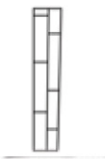


Fig. 3. (A) Outcrop image of Wargal limestone. (B) Coal seams at the basement of Wargal Limestone. (C) Highly Fractured Wargal limestone. (D) Thick bedded limestone that is highly fractured. (E) Thick bedded limestone overlying carbonaceous shale. (F) Stratal dipping style of Wargal Limestone. (G) Very thin bedded micritic limestone of Wargal limestone. (H) Contact mark between Wargal Limestone and Chiddru Formation.

Table 1

Description of the eight lithofacies types in the Permian age, Wargal Limestone

Facies	Sandy limestone	Fossiliferous limestone	Argillaceous limestone	Dolomite	Sandy dolomite	Cherty dolomite	Argillaceous dolomite	Shale
Lithology	Abundance of quartz in sandy limestone	Brachiopods and bryozoa are richly present	Rich in brachiopods	Carbonate minerals and	Interbedded shale and limestone matrix	Crinoids and mollusc debris in a dense framework	carbonate matrix	Clay and mud
Color	Light grey to gray	Olive grey	Light grey	Pinkish grey	Greyish orange	Light pink	Olive grey	grey
Thickness	Thin to medium beds	Thick beds	Medium to thick beds	Thick beds	Medium beds	Thick beds	Medium beds	Medium
Sedimentary Structures	Massive bedding, bioturbation	Massive, syntextural overgrowth cement	Stylolites and calcitic veins	Massive bedding	Stylolites and drusy calcite	Brecciated and massive	Medium bedding	Inter-bedding
Grain Size	Medium size	Fine	Fine to medium	Very fine	Fine to medium	coarse	Medium to fine	Very fine
Sorting	Moderate	Poor	Poor-sorted	Poor	Moderate	Poor	Well-sorted	Well-sorted
Texture	Quartzose grain-sone texture	Packstone	Packstone	Mud-supported texture	Packstone	Grain-supported	Grain-supported	Clay-supported
Porosity	Low to moderate	High	low	Moderate to high	Moderate	High	High	Low
Water Energy	Low to moderate	High	High	Moderate to high	Moderate	High	High	Low
Depositional Environment	Shallow marine, low-energy	Shallow marine-moderate energy	Shallow marine-back reef moderate energy	Lagoonal, moderate-energy	Lagoonal, moderate-energy	Reefal, high-energy	Shoal	Shelf-shoal
Geometry	Sheet	Reef	Channel	Sheet	Lens	Reef	Channel	Lens
								

limestone, indicating that it was deposited in a mixed siliciclastic-carbonate environment. The Wargal Limestone, which is also found in this area, has organic matter in it that may be able to produce coal seams in the right conditions. The combination of the sandy limestone and the organic-rich shale reveals a dynamic depositional environment where different energy levels and sediment sources have contributed to the formation of the rock record. After it, Wargal Limestone changing into argillaceous limestone as thin to thick bedding. This facies is notable by a clay-rich matrix that gives the limestone an argillaceous texture. The thin-to-thick bedded structure indicates variations in the energy and supply of dumped sediment, which are probably impacted by irregular shifts in the environment deposited. This argillaceous limestone is present in the Wargal Limestone sequence, indicating a dynamic and diverse sedimentary environment. Periods of enhanced siliciclastic input, probably from adjacent terrestrial sources, are interspersed with more normal carbonate deposition.

As it goes, comes to nodular limestone, which is identified by the presence of different fossils and its irregularly shaped nodules. There are fractures in this limestone that are connected to a minor fault, signifying that there has been tectonic activity close. The bedding style of this nodular limestone is characterized by varying dip angles, reflecting the influence of geological forces over time. Additionally, calcitic veins are visible, cutting through the limestone and filling

fractures with crystalline calcite. These features suggest a complex depositional and diagenetic history, where biological, sedimentary, and tectonic processes have interacted to shape the current structure and composition of the rock.

Facies Description of Wargal Limestone having Facies in Nammal Gorge. A faulted anticline's north-eastern limb has a well-exposed piece of Wargal Limestone, which is part of Nammal Gorge (Fig. 4). Nevertheless, the lowest few meters in the anticline's centre are hidden. 154 meters measured thickness was investigated, compared to 146 meters reported by [11, 15]. The layers incline northeast. Turn left onto a dirt road towards Nammal Dam after driving past Musa Khel on the east side of Mianwali to reach the portion. The portion starts at the northwest side of the canyon, at the foot of the cliff. The depth of 154 meters revealed a colonial coral zone.

Wargal Limestone in Zaluch Nala. Teichert [16] surveyed and characterized the Wargal Limestone section at Zaluch Nala (Fig. 5). He designated it as a provisional standard until more research was done on the formation near the Wargal settlement, which he thought to be a suitable type locality. The formation is 174 meters thick overall, including the highest nodular beds. Teichert (1966) reported that 179 meters was the section's thickness. The slight variation in thickness is probably the result of different interpretations of the faulted portion located about 40 meters above the base. To get to

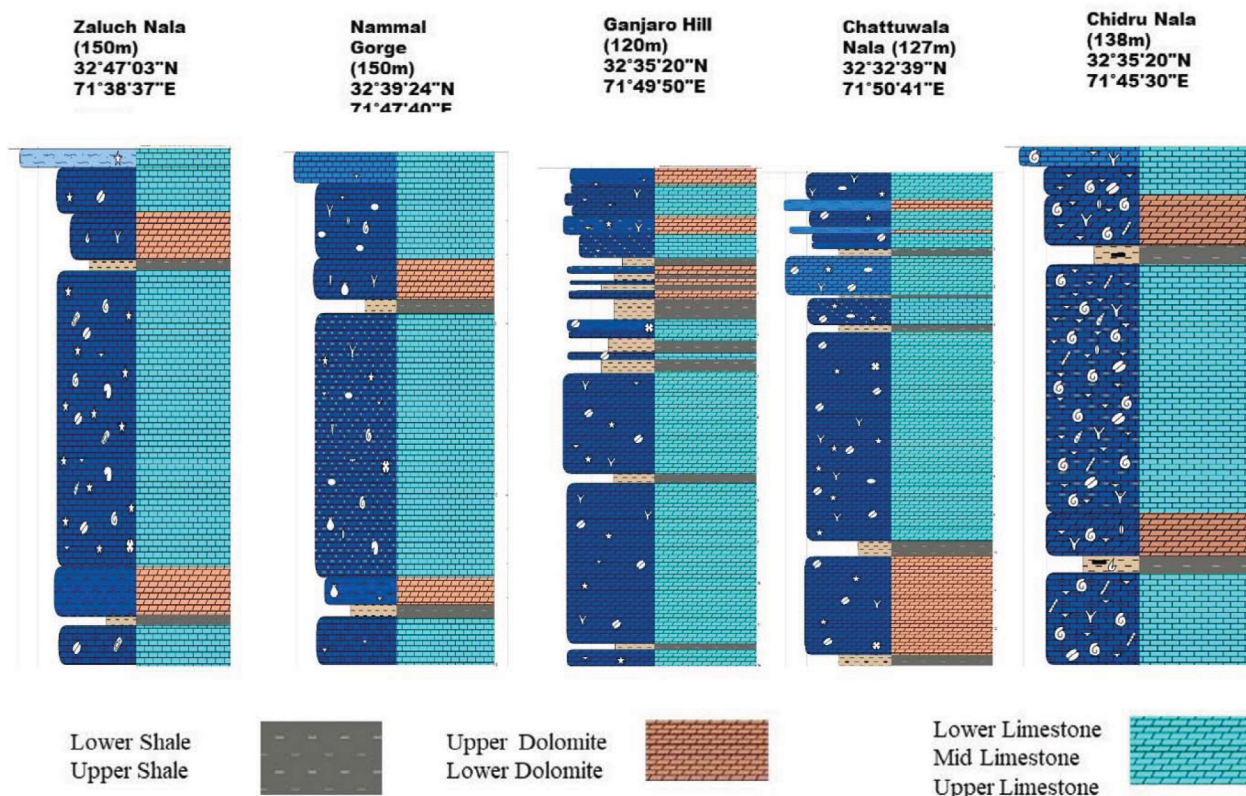


Fig. 4. Lithological logs of Wargal limestone at Nammal gorge, Zaluch nala, Chiddru, chattuwala nala and Ganjaro Hill, having the limestone, dolomite and shale. There are many fossils in these sections, including a large number of brachiopods, bryozoans, molluscs, crinoids, and other families

the part, take a car from Mianwali north to the village of Paikhel, and then drive east for about 10 km to Zaluch Nala. The east side of the canyon has the majority of the formation fully exposed, but only the upper on the west side of the canyon, nodular beds were measured.

Wargal limestone in Chiddru nala. The Chiddru Nala section, situated near Mianwali, Pakistan, provides a well-exposed outcrop of the Wargal Limestone on the northeast side of the nala, with the uppermost few meters covered by alluvial sediments (Fig. 6). The Chiddru Formation overlays the Wargal Limestone on the southwest side. At this location, the Wargal Limestone, including the upper nodular beds, is at least 130 meters thick, supporting the observation that the formation thins eastward through the Salt Range. To access the section, drive east from Mianwali, pass Musa Khel for approximately 5 kilometers, turn right onto a dirt road, proceed for 4 kilometers, turn right again, and continue for 1.5 kilometers. The section is located east of the road. This detailed examination aligns with [11] findings and highlights the geological significance and reservoir potential of the Wargal Limestone in the Salt Range.

Wargal Limestone in Chattuwala Nala. The Chattuwala Nala section, 6.5 kilometers northeast of Chiddru, is well exposed on the northeast side of the nala, though the upper few meters are covered by alluvial sediments (Fig. 5). The Chiddru Formation overlies the Wargal Limestone on the southwest side. The

Wargal Limestone at Chattuwala is at least 130 meters thick, consistent with [11] observation of eastward thinning through the Salt Range. To access the section, drive east from Mianwali past Musa Khel for 5 kilometers, turn right onto a dirt road, proceed 4 kilometers, turn right again, and continue 1.5 kilometers. The section is east of the road. Two colonial coral zones were collected at 5.2 meters and 126.5 meters.

Wargal Limestone in Ganjaro Hill. The Ganjaro Hill section, 3 kilometers northeast of Chattuwala Nala, begins at the edge of a jeep road and extends up the hill (Fig. 5). The Wargal Limestone here is at least 124 meters thick. To reach it, drive east from Mianwali for 26 kilometers (5 kilometers past Musa Khel), turn right onto a dirt road, and continue southeast for 6.2 kilometers until the road ends. Walk 1.5 kilometers to the section base, starting just after the last zigzag. A colonial coral zone is at 14 meters.

Correlation. The Wargal Limestone within the salt range of Pakistan exhibits a variety of lithological units that changes throughout the different sections from Nammal to Ganjaro that shows prominent heterogeneity. Seven different units were identified after correlation; lower shale, upper shale, upper dolomite, lower dolomite lower, middle and upper Limestone units (Fig. 5). The sequences stratigraphy of these sections reveals both transgressive and regressive phases, which reflect fluctuations in sea level and offer a glimpse how Tethys Ocean evolved into

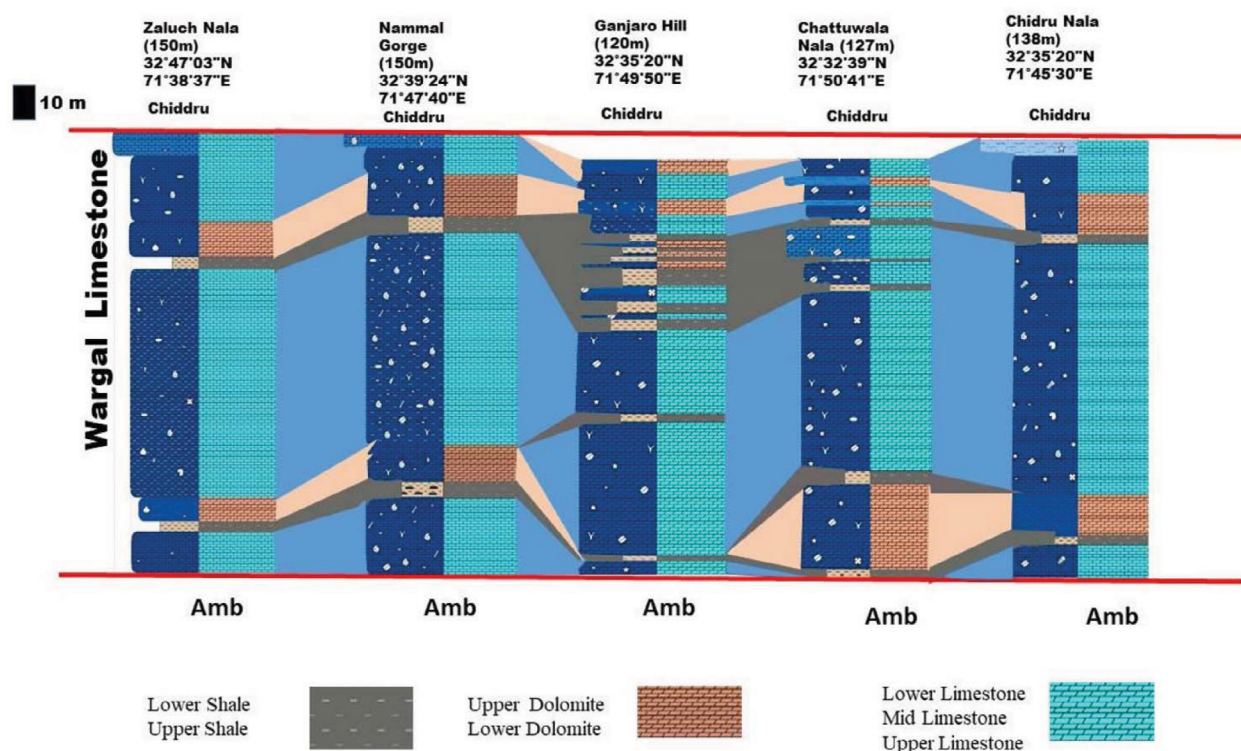


Fig. 5. Representative lithologs from the study outcrop sections showing vertical facies relationships, vertical scale in meters

fine carbonates sequences during Permian. In figure fossiliferous limestone interbedded porous dolomitic layers suggesting significant diagenetic alteration that could impact the reservoir quality. Additionally minor coal bearing shales are present. But advance research shows it is capable to hold reservoir of hydrocarbon.

Transgressive-regressive cycles of this formation are associated with relative rise and fall of sea level, which are important to sequence stratigraphy [13]. As a result of these cycles, hydrocarbon accumulation depends on the development of various sedimentary habitats, from shallow shelves to deeper basins. The trapping mechanisms created by these sequences, together with dolomitization, fossil content and carbonate phase development, set the stage for hydrocarbon reservoir potential. Understanding reservoir characteristics such as porosity and permeability requires understanding how the Wargal Limestone transformed from a siliciclastic-dominated unit to a carbonate-dominated unit. This transformation is reflected in changes in deposition energy.

Depositional model. The Wargal Limestone, which is mostly exposed in Salt Range Pakistan,

is a significant carbonate sequence that was deposited between the Middle and Late Permian. This formation is well known for its varied depositional habitats, which represent a very active and varied marine system and vary from lagoonal to reefal settings (Fig. 6 and Table 2).

1. Lagoonal Environment: Lagoonal areas are typically located landward of coral reefs and are characterized by restricted circulation and poor energy conditions. The fine-grained micritic limestone found in the Lagoon Wargal sediments is most likely overlain by layers of dolomitic strata, indicating a period when water flow was restricted. This area is shown in the image by the dark blue section, which suggests a calmer, more sheltered depositional environment. Bone fragments, agglomerated foraminifera, and algae are typical of the fauna and sediment types found in this environment, and the lithology is dominated by fine-grained mudstone.

2. Reef Environment: The most dynamic and diverse parts of the sedimentary system are the reef facies. Reef structures serve as dividers between lagoon and open ocean habitats and were probably built from fragments of coral and bone. In the Wargal Limestone, bioclasts such

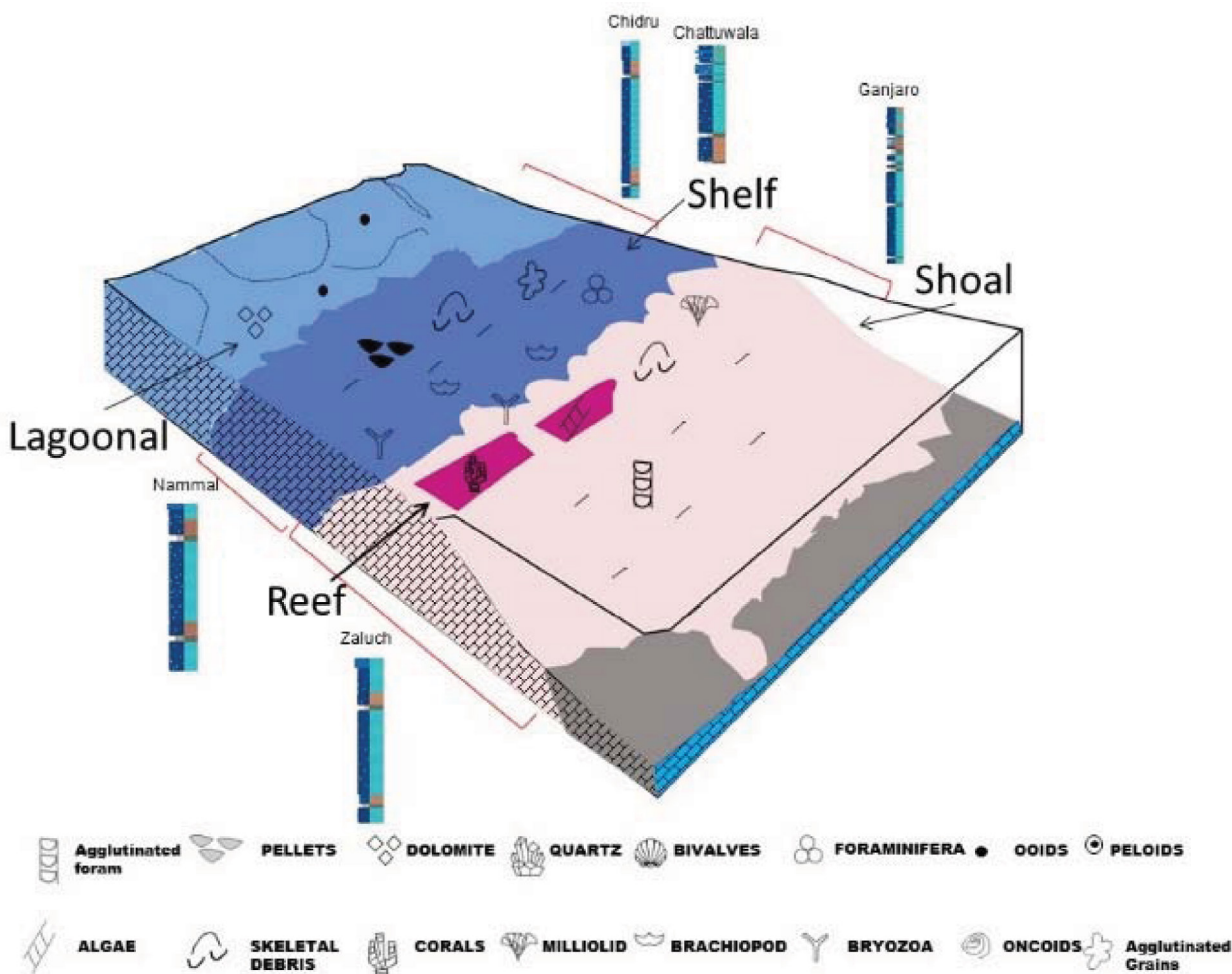


Fig. 6. Depositional Environment distribution across all five sections having fauna representation.

Table 2

Comparison of Wargal Limestone with other stratigraphic units in the Tethys Region

	Wargal Limestone Pakistan	Panjal Traps India	Chia Zairi Formation Iraq	Dalan Formation Iran	Gharif Formation Oman
Age	Middle to Late Permian (Guadalupian to Lopingian)	Early to Middle Permian (Cisuralian to Guadalupian)	Late Permian (Lopingian)	Late Permian (Wuchiapingian to Changhsingian)	Late Permian (Lopingian)
Lithology	Limestone with interbedded shale and dolomite	Basaltic lava flows with intercalated sedimentary layers	Limestone with minor dolomite and shale	Thick carbonate sequences with subordinate evaporites	Sandstone, siltstone, and shale with minor carbonate
Color	Light gray to gray	Dark gray to black	Pale gray to dark gray	Light gray to beige	Reddish-brown to gray
Thickness	150–200 m	500–800 m	200–250 m	300–400 m	300–350 m
Grain Types	Fine to medium-grained carbonates	Basaltic grains with interbedded clay	Micritic and bioclastic carbonates	Crystalline and oolitic carbonates	Dolomitic and fine-grained carbonates
Dominant lithofacies	Carbonate	Volcanic	Carbonate	Carbonate platform	Clastic
Depositional environment	Shallow marine shelf	Continental flood basalts	Shallow marine shelf	Shallow marine carbonate platform	Fluvial to shallow marine environments
Reservoir potential	Potential hydrocarbon reservoir	Limited reservoir potential due to volcanic nature	Potential hydrocarbon reservoir	Significant gas reservoirs, especially in the South Pars field	Significant oil reservoirs
Basinal distribution	Upper Indus Basin	Kashmir Basin	Northern Iraq	Zagros Basin	Interior Oman Basin
Paleogeography	Positioned at the northern margin of the Indian Plate during the Permian	Associated with the rifting of the northern margin of the Indian Plate	Situated on the northern edge of the Arabian Plate during the Permian	Part of the southern margin of the Paleo-Tethys Ocean	Deposited in fluvial to shallow marine settings on the eastern margin of the Arabian Plate

as bryozoans, brachiopods, and corals, which are abundant in the Permian carbonate system region, were often used to build coral reefs [1]. This Reef referred as a geo-body, that significantly present in area of Nammal Gorge and Zaluch Nala. The blue area between the lagoon and shoal in the figure represents the reef zone, which illustrates the energy transfer from a low-energy (lagoon) to a high-energy (shoal) ecosystem (Fig. 6).

3. Shoal Environment: The higher energy conditions known as shoals are where coarse-grained material is deposited. The shoal deposits in the Wargal Limestone will consist of ooids, peloids and oncoids, limestones supported by grains [13]. This setting is represented by the pink to light area in the diagram. Oolitic limestone is common here, with characteristics such as large grain size and cross-bedding. This habitat is defined by tidal currents and wave action, which continuously transform the sediments.

4. Shelf Environment: The continental shelf is an example of a shallow marine environment, susceptible to tides and waves, and is usually relatively open. More granular limestone mixed with quartz and bioclasts may have been deposited on the shelf of the Wargal Limestone [14]. This depositional environment represented by the lightest pink area in the image, which

moves outward and toward deeper marine environments. The area affected by scattered storms and tempests.

Discussion. Facies studies of the Wargal Limestone and correlations between the Nammal Gorge, Zaluch Nala, Chiddru Nala, Chattuwala Nala and Ganjaro Hill sections provide important new information on the Late Permian sedimentary dynamics and sedimentation environment of the Tethyan region. Each section exhibits a unique lithological composition, reflecting the varying depositional environments across the Pakistan Salt Range. Several different lithofacies are found in the Wargal limestone, such as shale, dolomite, sandy limestone and fossiliferous limestone. For example, the Nammal Gorge area is composed of dolomite (10%), sandy limestone (12%), and limestone (56%). In the Zaluch Nala and Chiddru Nala areas, shale and dolomite formations are interbedded with limestone. Nine different lithofacies, with support ranging from mud-supported to grain-supported, illustrate the depositional changes in the formation. Different sedimentary energy and environmental conditions in different periods are reflected in changes in particle size, fossil content and diagenesis of different phases.

Correlation of these sections shows stratigraphic continuity but with some obvious changes in

lithology and thickness. For example, the thickness varies from 150 meters at Nammal and Zaluch to about 130 meters at Chiddru and Chattuwala. Chattuwala has a higher proportion of dolomitic limestone (75%) than Nammal and Zaluch. These differences show differences in sea-level fluctuations during deposition, tectonic effects, and sediment supply in different areas. The depositional habitat of the Wargal Limestone is primarily marine, ranging from lagoons to coral reefs and shoal environments. Fossil assemblages such as corals, molluscs, brachiopods and bryozoans indicate the presence of a strong marine environment [13]. Interbedded dolomite, limestone, and shale show periods of restricted circulation and salinity fluctuations that characterize the transition from lagoon habitat to an open marine environment. Changes in sea level are reflected in the strata through transgression-regression cycles, thereby affecting sedimentary facies.

In order to establish a thorough depositional model, the phase distribution and correlation of these sections are critical and have implications for hydrocarbon development [21, 23]. The presence of fossiliferous limestone and porous dolomitic layers suggests that diagenesis improved reservoir quality. The tectonic and climatic environment that formed the salt range during the Permian period can be understood from the observed heterogeneity in depositional patterns.

The formations of the Wargal Limestone exhibit important transgressive-regressive cycles that are driven by changes in sea level and may be influenced by tectonic activity or global climate change. The transition from low-energy lagoon deposition to high-energy reef-flat habitats is characterized by periodic shallowing and deepening phases, which regulate sediment accumulation from siliciclastic-dominated phases to carbonate-rich phases [8].

Fossil limestone and dolomite dominate the carbonate lithofacies, indicating deposition in a shallow marine environment. Fossils are abundant, indicating the presence of powerful marine life in stable shallow waters, creating bioclast-rich reef and shoal facies in a high-energy environment of currents and wave action [14].

Folds and faults seen in the outcrop show that tectonic forces were the primary factor in the deposition of the Wargal Limestone. The distribution and thickness of limestone units are determined by compressional structures, which also play a role in diagenetic processes such as dolomitization, altering permeability and porosity. Older strata were also exposed by tectonic uplift, which helped provide sediment during the formation of the Wargal Limestone.

The initial appearance of the Wargal Limestone has changed due to diagenetic processes such as dolomitization and the production of chert dolomite.

These changes result in improved reservoir quality of the rock and are primarily caused by changes in secondary porosity as well as pore water chemistry, compaction and tectonic stress. The different phases, diagenetic changes and structural style of the Wargal Limestone make it a promising source of hydrocarbons. Dolomitization and fossil dissolution improve the reservoir quality of porous dolomitic formations, especially in Chattuwala and Ganjaro. Interbedded dolomite, shale, and limestone can also create stratigraphic traps containing hydrocarbons. Fossil limestone, rich in bioclasts, has high porosity because dissolution of skeleton component. This provides an optimal environment for hydrocarbon migration and trapping, combined with secondary porosity created by diagenesis. Certain sections have fractures and calcite-filled veins that increase permeability and facilitate fluid movement. The tectonic setting of the Salt Range creates the structural traps necessary for hydrocarbon accumulation. Folds and faults in the Wargal limestone may have been effective in trapping hydrocarbons within porous dolomitic units. Due to stratigraphic changes between sections, there is an opportunity to find sealed reservoirs for possible hydrocarbon extraction.

Conclusion

The combined facies analysis indicates the Wargal Limestone was deposited in various shallow marine environments, from inner ramp to middle-ramp settings, which reflects dynamic paleoenvironmental conditions controlled by relative changes in sea level along the Paleotethys margin. Extensive stratigraphic correlation across multiple outcrop sections provides evidence for lateral facies continuity and supports a uniform regional depositional framework, which enhances the comprehension of the space-time evolution of carbonate systems in the Permian.

The integration of facies architecture, sedimentary structures, and fossil content is useful in revealing the paleoenvironmental conditions and tectonic stability of the northern Gondwanan shelf and making contributions to more general reconstructions of the Paleotethys paleogeography.

In the end, studies of facies and sedimentation environments of the Nammal, Zaluch, Chiddru, Chattuwala and Ganjaro sections provide important insights into the stratigraphy of the Wargal limestone. Correlations are needed to grasp the depositional history and reservoir potential of the area, which indicate major lateral phase changes and reservoir potential, as evidenced by its depositional history. Due to its various facies, particularly fossiliferous limestone and porous dolomite formations, and its structural location within a salt range, the formation is a viable target for hydrocarbon development.

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

REFERENCES

- Ali S. K., Janjuhah H. T., Shahzad S. M., Kontakiotis G., Saleem M. H., Khan U., Antonarakou A. (2021). Depositional sedimentary facies, stratigraphic control, paleoecological constraints, and paleogeographic reconstruction of late Permian Chhidru Formation (Western Salt Range, Pakistan). *Journal of Marine Science and Engineering*, 9(12), 1372. <https://doi.org/10.3390/jmse9121372>
- Esmaili R., Ao S., Shafaii Moghadam H., Zhang Z., Griffin W L., Ebrahimi M., Bhandari S. (2022) Amphibolites from makran accretionary complex record Permian-Triassic Neo-Tethyan evolution. *International Geology Review*, 64(11), 1594-1610. <https://doi.org/10.1080/00206814.2021.1946663>
- Gansser A. (1981) The geodynamic history of the Himalaya. *Zagros Hindu Kush Himalaya Geodynamic Evolution*, 3, 111-121. <https://doi.org/10.1029/gd003p0111>
- Ghazi S., Ali S. H., Sahraeyan M., Hanif T. (2015) An overview of tectonosedimentary framework of the Salt Range, northwestern Himalayan fold and thrust belt, Pakistan. *Arabian Journal of Geosciences*, 8, 1635-1651. <https://doi.org/10.1007/s12517-014-1284-3>
- Ghazi S., Ali, S. H., Shahzad, T., Ahmed, N., Khalid, P., Akram, S., & Sami, J. (2020). Sedimentary, structural and salt tectonic evolution of Karoli-Nilawahan area, Central Salt Range and its impact for the Potwar Province. *Himalayan Geology*, 41(2), 145-156.
- Hughes N.C., Myrow P.M., Ghazi S., McKenzie N.R., Stockli D.F., DiPietro J.A. (2019) Cambrian geology of the Salt Range of Pakistan: Linking the Himalayan margin to the Indian craton. *GSA Bull.*, 131(7- 8), 1095–1114. <https://doi.org/10.1130/b35092.1>
- Kazmi AH., & Rana RA., (1982): Tectonic map of Pakistan. Scale 1:2000000, first edn. Geological Survey of Pakistan, Quetta.
- Rehman, N., Jaing, A. N., Ali, S. H., (2024) Effect of diagenetic processes and depositional facies on reservoir quality of the Eocene Carbonate Sequence (Sakesar Limestone) in the Central Salt Range, Pakistan, *Journal of Earth Sciences, Journal of Earth Science*, 36(3), pp. 1129–1148. <https://doi.org/10.1007/s12583-024-0105-1>
- Khan, H. A., Ali, S. H., Bashir, Y., Ghazi1, A. H., Zahid, M. A, Mustaqeem, M., Ghazi, S. & Shah M. A. Shah (2025) **Semi Quantitative Facies Analysis, Depositional Environment And Renewable Energy Potential Of Early Jurassic Datta Formation, Pakistan**, *Journal of Natural and Applied Sciences Pakistan*, 7 (1), 2073-2088.
- Kummel B., Teichert C. (1966) Relations between the Permian and Triassic formations in the Salt Range and Trans-Indus ranges, West Pakistan. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, Stuttgart, Band, 125, 297–333.
- Sarwar, U., Ghazi, S., Ali, S. H., Mehmood, M., Jahangir, M., Zaheer, A., Arif, S. J., (2024) Sedimentological And Sequence Stratigraphic Analysis Of Late Eocene Kirthar Formation, Central Indus Basin, Pakistan, *Eastern Tethys, Earth Sciences Research Journal, Earth Sci. Res. J.* 28(1), 29-38. <https://doi.org/10.15446/esrj.v28n1.108562>
- Malkani M. S., & Mahmood Z. (2017) Stratigraphy of Pakistan. *Geological Survey of Pakistan, Memoir*, 24, 1-134.
- Riaz M., Ghazi S., & Waqas M. (2024) Sedimentology and Sequence Stratigraphy of the Late Permian Wargal Limestone: Implication for Reservoir Potential in the Salt Range, Pakistan. *Journal of the Geological Society of India*, 100(6), 887-900. <https://doi.org/10.17491/jgsi/2024/173919>
- Saw, B. B., Schlaich, M., Pöppelreiter, M. C., Ramkumar, M., Lunt, P., Vintaned, J. A. G., & Ali, S. H. (2019). Facies, depositional environments, and anatomy of the Subis build-up in Sarawak, Malaysia: implications on other Miocene isolated carbonate build-ups. *Facies*, 65(3), 1-14. <https://doi.org/10.1007/s10347-019-0571-6>
- Teichert C. (1965) Nomenclature and Correlation of the Permian "Productus Limestone", Salt Range, West Pakistan. *Geol. Surv. Pakistan Rec.*, 15, 1–20.
- Teichert, C. (1966). Stratigraphic nomenclature and correlation of the Permian "Productus limestone", Salt Range, West Pakistan. *Geological Survey of Pakistan Records*, 15, 1-19.
- Ali S. K., Janjuhah H. T., Shahzad S. M., Kontakiotis G., Saleem M. H., Khan U., Antonarakou A. (2021). Depositional sedimentary facies, stratigraphic control, paleoecological constraints, and paleogeographic reconstruction of late Permian Chhidru Formation (Western Salt Range, Pakistan). *Journal of Marine Science and Engineering*, 9(12), 1372. <https://doi.org/10.3390/jmse9121372>
- Esmaili R., Ao S., Shafaii Moghadam H., Zhang Z., Griffin W L., Ebrahimi M., Bhandari S. (2022) Amphibolites from makran accretionary complex record Permian-Triassic Neo-Tethyan evolution. *International Geology Review*, 64(11), 1594-1610. <https://doi.org/10.1080/00206814.2021.1946663>
- Gansser A. (1981) The geodynamic history of the Himalaya. *Zagros Hindu Kush Himalaya Geodynamic Evolution*, 3, 111-121. <https://doi.org/10.1029/gd003p0111>
- Ghazi S., Ali S. H., Sahraeyan M., Hanif T. (2015) An overview of tectonosedimentary framework of the Salt Range, northwestern Himalayan fold and thrust belt, Pakistan. *Arabian Journal of Geosciences*, 8, 1635-1651. <https://doi.org/10.1007/s12517-014-1284-3>
- Ghazi S., Ali, S. H., Shahzad, T., Ahmed, N., Khalid, P., Akram, S., & Sami, J. (2020). Sedimentary, structural and salt tectonic evolution of Karoli-Nilawahan area, Central Salt Range and its impact for the Potwar Province. *Himalayan Geology*, 41(2), 145-156.
- Hughes N.C., Myrow P.M., Ghazi S., McKenzie N.R., Stockli D.F., DiPietro J.A. (2019) Cambrian geology of the Salt Range of Pakistan: Linking the Himalayan margin to the Indian craton. *GSA Bull.*, 131(7- 8), 1095–1114. <https://doi.org/10.1130/b35092.1>
- Kazmi AH., & Rana RA., (1982): Tectonic map of Pakistan. Scale 1:2000000, first edn. Geological Survey of Pakistan, Quetta.
- Rehman, N., Jaing, A. N., Ali, S. H., (2024) Effect of diagenetic processes and depositional facies on reservoir quality of the Eocene Carbonate Sequence (Sakesar Limestone) in the Central Salt Range, Pakistan, *Journal of Earth Sciences, Journal of Earth Science*, 36(3), pp. 1129–1148. <https://doi.org/10.1007/s12583-024-0105-1>
- Khan, H. A., Ali, S. H., Bashir, Y., Ghazi1, A. H., Zahid, M. A, Mustaqeem, M., Ghazi, S. & Shah M. A. Shah (2025) **Semi Quantitative Facies Analysis, Depositional Environment And Renewable Energy Potential Of Early Jurassic Datta Formation, Pakistan**, *Journal of Natural and Applied Sciences Pakistan*, 7 (1), 2073-2088.
- Kummel B., Teichert C. (1966) Relations between the Permian and Triassic formations in the Salt Range and Trans-Indus ranges, West Pakistan. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, Stuttgart, Band, 125, 297–333.
- Sarwar, U., Ghazi, S., Ali, S. H., Mehmood, M., Jahangir, M., Zaheer, A., Arif, S. J., (2024) Sedimentological And Sequence Stratigraphic Analysis Of Late Eocene Kirthar Formation, Central Indus Basin, Pakistan, *Eastern Tethys, Earth Sciences Research Journal, Earth Sci. Res. J.* 28(1), 29-38. <https://doi.org/10.15446/esrj.v28n1.108562>
- Malkani M. S., & Mahmood Z. (2017) Stratigraphy of Pakistan. *Geological Survey of Pakistan, Memoir*, 24, 1-134.
- Riaz M., Ghazi S., & Waqas M. (2024) Sedimentology and Sequence Stratigraphy of the Late Permian Wargal Limestone: Implication for Reservoir Potential in the Salt Range, Pakistan. *Journal of the Geological Society of India*, 100(6), 887-900. <https://doi.org/10.17491/jgsi/2024/173919>
- Saw, B. B., Schlaich, M., Pöppelreiter, M. C., Ramkumar, M., Lunt, P., Vintaned, J. A. G., & Ali, S. H. (2019). Facies, depositional environments, and anatomy of the Subis build-up in Sarawak, Malaysia: implications on other Miocene isolated carbonate build-ups. *Facies*, 65(3), 1-14. <https://doi.org/10.1007/s10347-019-0571-6>
- Teichert C. (1965) Nomenclature and Correlation of the Permian "Productus Limestone", Salt Range, West Pakistan. *Geol. Surv. Pakistan Rec.*, 15, 1–20.
- Teichert, C. (1966). Stratigraphic nomenclature and correlation of the Permian "Productus limestone", Salt Range, West Pakistan. *Geological Survey of Pakistan Records*, 15, 1-19.

17. Wadood B., Khan S., Li H., Wadood J., Ahmad S., & Khan, A. (2021) The Middle Permian (Capitanian) carbonate platform evolution and stratigraphic architecture of a Neo–Tethys rim basin, Central Pakistan. *Geological Journal*, 56(8), 4080–4101. <https://doi.org/10.1002/gj.4155>
18. Ghazi, S., Miraj, N., Ali, S. H., Waqas, M., (2024) An Appraisal of Microfacies and Depositional Environment of The Middle Eocene Habib Rahi Limestone, Sulaiman Range, Pakistan *Journal of Hydrocarbon Research*, 26, 49–63.
19. Suyarko, V. G., & Sukhov, V. V. (2013). Conceptual synergetic geological and hydrogeological model of suffusion and karst development in carbonate rocks on the territory of Svyatogirsk monastery. *Visnyk of VN Karazin Kharkiv National University. Series Geology. Geography. Ecology*, 38(1049), 63–68. <https://periodicals.karazin.ua/geoeo/article/view/7671>
20. Zahir M., Awais M., Ghani M., Mohibullah M., Salad Hersi O., Jan I. U., Iqbal H. (2021): Reservoir Quality Assessment of the Upper Permian Chhidru Formation, Salt and Surghar Ranges, Pakistan. *Acta Geologica Sinica–English Edition*, 95(6), 2120–2137. <https://doi.org/10.1111/1755-6724.14764>
21. Sukhov, V. V., Suyarko, V. G., & Chuienko, O. V. (2017). On connection of modern geodynamic processes in carbonate rocks with tectonic activation of Petrivs'k-Kreminna fault. *Visnyk of VN Karazin Kharkiv National University. Series Geology. Geography. Ecology*, (46), 56–61. <https://doi.org/10.26565/2410-7360-2017-46-07> [Сухов, В. В., Суярко, В. Г., & Чуєнко, О. В. (2017). Про зв'язок сучасних геодинамічних процесів у карбонатних породах з тектонічною активізацією Петрівсько-Кремінського розлому. *Вісник Харківського національного університету імені В. Н. Каразіна. Серія «Геологія. Географія. Екологія»*, (46), 56–61. <https://doi.org/10.26565/2410-7360-2017-46-07>]
22. Abir, I. A., Khan, S. D., Ghulam, A., Tariq, S., & Shah, M. T. (2015): Active tectonics of western Potwar Plateau–Salt Range, northern Pakistan from InSAR observations and seismic imaging. *Remote Sensing of Environment*, 168, 265–275. <https://doi.org/10.1016/j.rse.2015.07.011>
23. Moiseienko, R. (2025). Trace fossils from Serpukhovian (Mississippian) sediments of Mospanivska geological structure (Dniper-Donetsk depression). *Visnyk of V.N. Karazin Kharkiv National University. Series Geology. Geography. Ecology*, (63), 84–94. <https://doi.org/10.26565/2410-7360-2025-63-06>.
17. Wadood B., Khan S., Li H., Wadood J., Ahmad S., & Khan, A. (2021) The Middle Permian (Capitanian) carbonate platform evolution and stratigraphic architecture of a Neo–Tethys rim basin, Central Pakistan. *Geological Journal*, 56(8), 4080–4101. <https://doi.org/10.1002/gj.4155>
18. Ghazi, S., Miraj, N., Ali, S. H., Waqas, M., (2024) An Appraisal of Microfacies and Depositional Environment of The Middle Eocene Habib Rahi Limestone, Sulaiman Range, Pakistan *Journal of Hydrocarbon Research*, 26, 49–63.
19. Suyarko, V. G., & Sukhov, V. V. (2013). Conceptual synergetic geological and hydrogeological model of suffusion and karst development in carbonate rocks on the territory of Svyatogirsk monastery. *Visnyk of VN Karazin Kharkiv National University. Series Geology. Geography. Ecology*, 38(1049), 63–68. <https://periodicals.karazin.ua/geoeo/article/view/7671>
20. Zahir M., Awais M., Ghani M., Mohibullah M., Salad Hersi O., Jan I. U., Iqbal H. (2021): Reservoir Quality Assessment of the Upper Permian Chhidru Formation, Salt and Surghar Ranges, Pakistan. *Acta Geologica Sinica–English Edition*, 95(6), 2120–2137. <https://doi.org/10.1111/1755-6724.14764>
21. Sukhov, V. V., Suyarko, V. G., & Chuienko, O. V. (2017). On connection of modern geodynamic processes in carbonate rocks with tectonic activation of Petrivs'k-Kreminna fault. *Visnyk of VN Karazin Kharkiv National University. Series Geology. Geography. Ecology*, (46), 56–61. <https://doi.org/10.26565/2410-7360-2017-46-07> [Сухов, В. В., Суярко, В. Г., & Чуєнко, О. В. (2017). Про зв'язок сучасних геодинамічних процесів у карбонатних породах з тектонічною активізацією Петрівсько-Кремінського розлому. *Вісник Харківського національного університету імені В. Н. Каразіна. Серія «Геологія. Географія. Екологія»*, (46), 56–61. <https://doi.org/10.26565/2410-7360-2017-46-07>]
22. Abir, I. A., Khan, S. D., Ghulam, A., Tariq, S., & Shah, M. T. (2015): Active tectonics of western Potwar Plateau–Salt Range, northern Pakistan from InSAR observations and seismic imaging. *Remote Sensing of Environment*, 168, 265–275. <https://doi.org/10.1016/j.rse.2015.07.011>
23. Moiseienko, R. (2025). Trace fossils from Serpukhovian (Mississippian) sediments of Mospanivska geological structure (Dniper-Donetsk depression). *Visnyk of V.N. Karazin Kharkiv National University. Series Geology. Geography. Ecology*, (63), 84–94. <https://doi.org/10.26565/2410-7360-2025-63-06>.

Внесок авторів: всі автори зробили рівний внесок у цю роботу

Конфлікт інтересів: автори повідомляють про відсутність конфлікту інтересів

Декларація про використання генеративного штучного інтелекту: автори підтверджують, що під час підготовки рукопису не використовувалися інструменти штучного інтелекту.

Authors Contribution: All authors have contributed equally to this work

Conflict of Interest: The authors declare no conflict of interest

Declaration of use of generative artificial intelligence: The authors confirm that no AI tools were used during the preparation of the manuscript.

Інтегрований фаціальний аналіз і стратиграфічна кореляція варгальського вапняку: аналіз даних відслонень і середовищ осадження вздовж Палеотетису

Айша Амір^{1,2},  <https://orcid.org/0009-0003-2295-7188>, e-mail: ayeshaamir.geol@gmail.com

магістр (геологія), кафедра наук про Землю,

Саїд Харун Алі^{1,3},  <https://orcid.org/0000-0002-8619-7005>, e-mail: haroon.ali@uos.edu.pk

д. філософії (геологія), доцент (геологія), Міждисциплінарний дослідницький центр єдиного здоров'я (IRCOH)

Хафіза Мамона Назір¹,  <https://orcid.org/0000-0002-0998-6369>, e-mail: mamona.nazir@uos.edu.pk

д. філософії (статистика), доцент, департамент статистики, Міждисциплінарний дослідницький центр єдиного здоров'я (IRCOH)

Ахмед Абд Ель Аал⁴,  <https://orcid.org/0000-0001-9077-6897>, e-mail: ahmed_aka80@yahoo.com

д. філософії (інженерна геологія), доцент, кафедра будівництва

Ясір Башир⁵,  <https://orcid.org/0000-0002-4614-796X>, e-mail: dryasir.bashir@live.com

д. філософії (геофізика), доцент, кафедра геофізичної інженерії гірничого факультету

Нумайр Ахмед Сіддікі⁶,  <https://orcid.org/0000-0002-6703-0699>, e-mail: numair.siddiqui@utp.edu.my

д. філософії (геологія), доцент, кафедра геонаук

Нурін Шукат⁶,  <https://orcid.org/0009-0000-6843-1104>, e-mail: noureen.geologist@gmail.com

магістр (геологія), наук. співробітник відділу наук про Землю

Іхтішам Іслам Хан⁷,  <https://orcid.org/0000-0003-2443-8034>, e-mail: ihtisham.islam@sbbu.edu.pk

д. філософії (геологія), доцент, кафедра геології

Аднан Хан⁸,  <https://orcid.org/0000-0001-6607-4190>, e-mail: adkhan@uk.edu.pk

д. філософії (геологія), доцент, кафедра геології

Навід Рехман⁹,  <https://orcid.org/0000-0001-9962-9447>, e-mail: rehman@cug.edu.cn

д. філософії (геологія), Ключова лабораторія тектоніки та нафтових ресурсів

¹ Університет Саргоди, Саргода, Пакистан;

² Інститут досліджень нетрадиційної нафти і газу, Дацін, Хейлунцзян, Китай;

³ Школа наук про Землю, Університетський коледж Дубліна, Дублін, Ірландія

⁴ Інженерний коледж Наджранського університету, Наджран, Королівство Саудівська Аравія;

⁵ Стамбульський технічний університет, Стамбул, Туреччина;

⁶ Технологічний університет PETRONAS, Перак, Малайзія;

⁷ Університет Шахид Беназір Бхутто, Шерінгал, Дір Анпер, Пакистан;

⁸ Університет Карачі, Карачі, Сінд, Пакистан;

⁹ Китайський університет геонаук, Ухань, Китай

АНОТАЦІЯ

Це дослідження має на меті вивчити фації та середовище відкладень пізнього пермського вапняку в басейні Верхнього Інду шляхом характеристики геологічних і мінералогічних зразків порід, зібраних з різних місцевостей. Геотіла та осадову архітектуру вапняку Варгал розшифрували за допомогою польових спостережень. Методи досліджень – фаціальний аналіз, стратиграфічний каротаж і літологічна кореляція, які були використані для інтерпретації даних відслонень і реконструкції середовища відкладення. На основі скам'янілостей, наявних у літофаціях, розроблено середовище його відкладення. Седиментологію вивчали за допомогою вимірювання розрізів разом із польовими фотографіями високої розподільної здатності, які були зібрані з використанням неоднорідності фацій та архітектури. Потім фації були нанесені на польові фотографії високої розподільної здатності. Згенерований набір даних включає седиментологічні журнали, зразки та польові фотографії для забезпечення відтворюваності та майбутніх порівняльних стратиграфічних досліджень. Поширені фації вуглистих сланців, піщаних вапняків, глинистих вапняків, викопних вапняків і доломітових вапняків. Скам'янілості, такі як мшанки, плеченогі молюски, двостулкові молюски, червоні молюски та трилобіти, датують його середньо-пізнім пермським періодом. П'ять секцій варгальського вапняку були взяті для кореляції. Бічні зміни цих фацій показують стратиграфічну безперервність, але з деякими очевидними змінами в літології та товщині. Через стратиграфічні варіації існує можливість виявити зоновані резервуари для потенційного видобутку вуглеводнів. Різноманітні середовища відкладення цієї формації, які варіюються від лагунних до рифових, широко відомі тим, що представляють дуже активну та різноманітну систему палеотетису. Дослідження підтримує Ціль сталого розвитку (ЦСР) 9 шляхом поглиблення геологічних знань, пов'язаних з оцінкою ресурсів та аналізом осадових басейнів, а також ЦСР 13 – шляхом покращення розуміння клімату та найдавніших умов навколишнього середовища. Оскільки формація складається з різних типів порід, включаючи скам'янілий вапняк і пористий доломіт, і оскільки вона розташована в соляному хребті, вона має хороший потенціал для розвідки нафти і газу в прилеглих басейнах Потвар, Кохат і Банну. Результати цього дослідження рекомендовані для аналогів як керівництво при розробці основи для майбутніх досліджень порівняльних карбонатних порід у досліджуваному регіоні.

ІНФОРМАЦІЯ ПРО СТАТТЮ:

Рукопис надійшов

27 листопада 2025

Отримано після рецензування

13 січня 2026

Затверджено до друку

25 травня 2026

Опубліковано онлайн

30 травня 2026

Ключові слова:

літофації, лагуна, рифи, кореляція, варгальський вапняк, геотіла, резервуар, динаміка басейну, коливання рівня моря, осадова архітектура, ЦСР 9, ЦСР 11.