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Sedimentologic and biostratigraphic analyses of the Late Cretaceous Kawagarh Fm., Upper Indus Basin, Pakistan

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Summary

The Kawagarh Formation is a carbonate-dominated lithostratigraphic unit in the Upper Indus Basin, Northern Pakistan. The basin consists of several sub-basins separated by tectonic discontinuities related to the convergent tectonics which have generated the Himalaya Mountains. This study addresses the Kawagarh Formation in the Hazara, Nizampur and Kohat sub-basins of the Upper Indus Basin. The formation is conformably underlain by the sandstones of the Lumshiwal Formation and unconformably overlain by the Paleogene Hangu Formation. Thus, the Kawagarh-Hangu contact forms the Cretaceous-Tertiary (K/T) boundary. Field and petrographic analyses of the Kawagarh Formation allow recognition of four lithofacies: Bioclastic mudstone to packstone (Lf-1), Bioclastic dolomudstone to packstone (Lf-2), sandy to silty limestone (Lf-3) and marly shale (Lf-4). The formation is highly fossiliferous with planktonic foraminifera and subordinate calcisphers. The dolostone lithofacies (Lf-2) is a dolomitized version of the Lf-1. The Lf-3 and Lf-4 also contain planktonic organisms. In the studied sections, the formation is almost exclusively barren of benthic organisms; it also lacks any depositional facies indicating agitated hydrodynamics (e.g., no cross beddings, no ripple marks, etc.). The recognized planktonic foraminifera include *Dicarinella concavata, Dicarinella asymetrica, Globotruncanita elevata,, Globotruncana ventricosa***.** Two biozones are identified, which indicates an age spanning the early Santonian to the middle Campanian. The fine-grained textural properties and the abundance of planktonic fossils suggest deposition in a relatively deep, quiet offshore ramp setting. The dolostone lithofacies (Lf-2) occurs in different intervals, whereas Lf-3 occurs close to the upper contact of the formation. The upper contact of the Kawagarh Formation is erosional, defining a disconformable contact with the overlying Paleocene Hangu Formation. The presence of Lf-3 in the upper part of the formation suggests siliciclastic influx during the later stage of the sedimentation. This is probably related to a progradational system which culminated to the shelf-wide exposure and the onset of the K/T unconformity. This unconformity is concomitant with the late Maastrichtian-Early Paleocene global sea level drop.

Introduction

The Late Cretaceous was a period of significant geological and biological changes marked by fluctuating sea level and climatic shifts (Haq et al., 1988). In the northern Pakistan region, along the northern margin of the Indian Plate, the Kawagarh Formation represents a Late Cretaceous marine sedimentary succession that records important aspects of these changes. The Kawagarh Formation is among the Late Cretaceous rocks of the Upper Indus Basin and constitutes the youngest strata of the Cretaceous System in the basin. The formation occurs in different sub-basins within the Upper Indus Basin, such as Hazara, Kohat, Potwar, Nizampur. (Fig. 1A). The study area is located in the Orakzai District within the Kohat region, Nizampur, and Hazara (Fig. 1B). The Kawagarh Formation has lower conformable (Rehman et al. 2021; to unconformable (Asim et al, 2014) contact with the Early Cretaceous Lumshiwal Formation (Fig. 2; Fig. 3A). The formation is locally absent where the Paleocene Hangu Formation lies disconformably over the sandstones of the Lumshiwal Formation (Khan et al., 2021). The

formation is overlain by the Early Paleocene Hangu Formation and the contact between the two formations marks the Cretaceous-Cenozoic boundary of the region (Fig. 2, 3B). Different work has been done on the sedimentologic and paleontologic attributes of the Kwagarh Formation (and its equivalents); an age range of Turonian to Maastrichtian has been proposed for the formation (Fatmi, 1973; Shah, 2009; Sameeni et al, 2007, Ahsan et al, 2015; Rehman et al, 2021, Khan et al., 2025). This work attempts to study the lithofacies properties, paleoenvironmental setting and biostratigraphic age dating of the Kawagarh Formation from the three sub-basins of Kohat, Nizampur and Hazara (Fig. 1B). The thickness of the formation varies among the three sub-basins; it is at least 45 m in the Nizampur sub-basin (Khattack et al., 2018), and as thick as 96 m in the Kala Chitta range (Wadood et al., 2019).

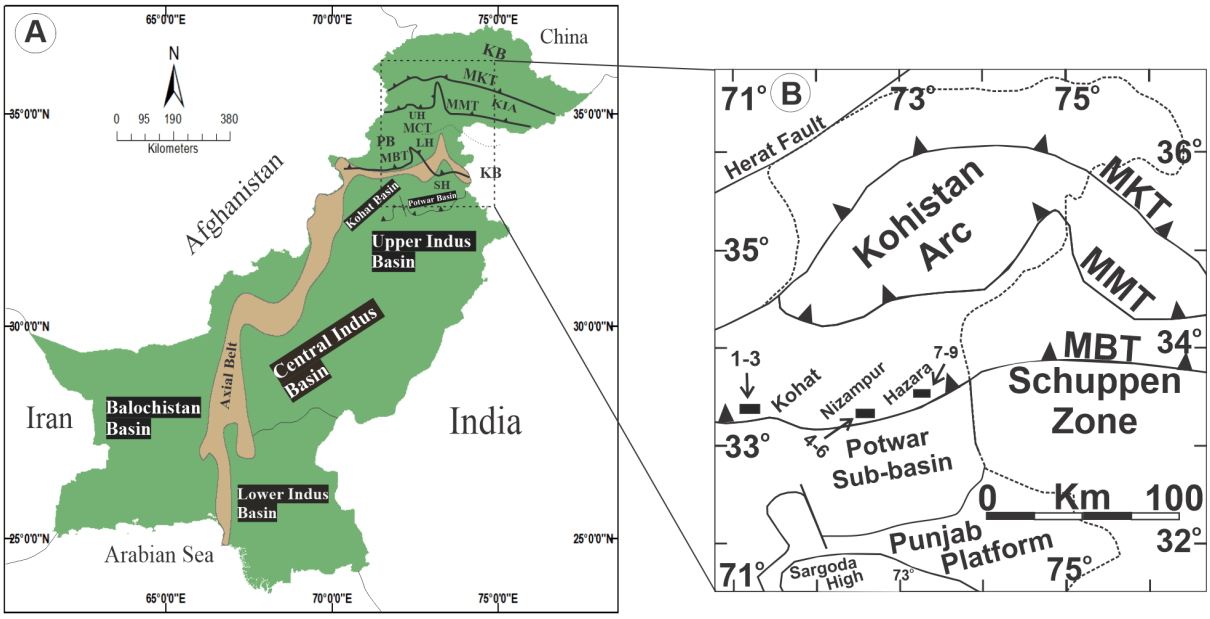


Fig. 1. A) Simplified map of Pakistan and locations of the different basins and tectonic elements. B: Map showing the tectonic features of northern Pakistan and locations of the three sub-basins (Kohat, Nizampur & Hazara). A total of 9 sections (three sections from each sub-basin) were logged. The coordinates of the nine sections are shown in Table 1.

Locality Number	Name of the sections	Coordinates	
		Latitude N	Longitude E
1	Kotal road section	33°37'59.14"N	71°27'44.66"E
2	Hamaal section	33°40'16.49"N	70°59'43.19"E
3	Kalaya road section	33°41'53.50"N	70°55'32.05"E
4	Tora stana road section	33°43'21"N	71°57'57"E
5	Nizampur road section	33°50'50.86"N	72° 1' 2.78"E
6	Khwari khwar section	33°48'49.27"N	72° 3'27.44"E
7	Barkot section	33°51'50.83"N	73°10'30.53"E
8	Darkot section	33°52'14.69"N	73° 9'39.02"E
9	Khaira gali section	33°59'3.94"N	73°23'49.19"E

Table 1. Summary of stratigraphic sections, with geographic coordinates of the study area.

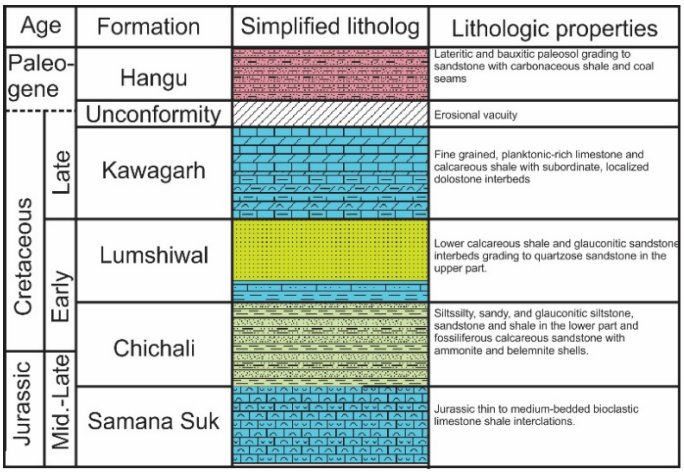


Fig. 2. Stratigraphic chart showing Samana Suk to Hangu formations of the Upper Indus Basin. The contact between the Kawagarh and Hangu formations define the Cretaceous-Paleogene unconformable contact driven by global sea level drop (Haq et al., 1987).

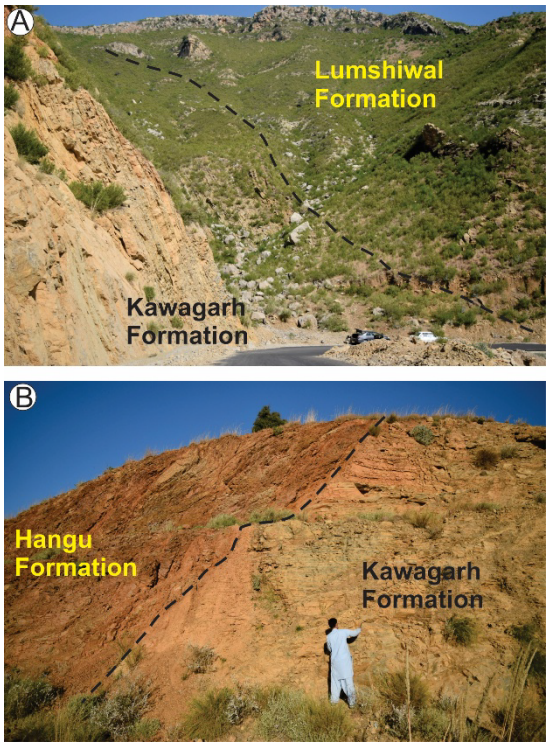


Fig. 3. Field photos showing the lower and upper contacts of the Kawagarh Formation. A) An overturned outcrop exposing the contact between Lumshiwal and Kawagarh formations. B) Kawagarh – Hangu erosional contact across the K/T boundary.

Sedimentologic properties of the Kawagarh Formation

In the study area, the Kawagarh Formation is exposed, and nine sections were logged, described, and sampled for petrographic and biostratigraphic analyses (Fig. 1B). Integration of the field and petrographic studies allows recognition of different lithofacies for the formation. The four major lithofacies recognized within the formation are Bioclastic mudstone to packstone (Lf-1), Bioclatic dolomudstone to dolopackstone (Lf-2), Sandy to silty limestone (Lf-3) and Marly shale (LF-4).

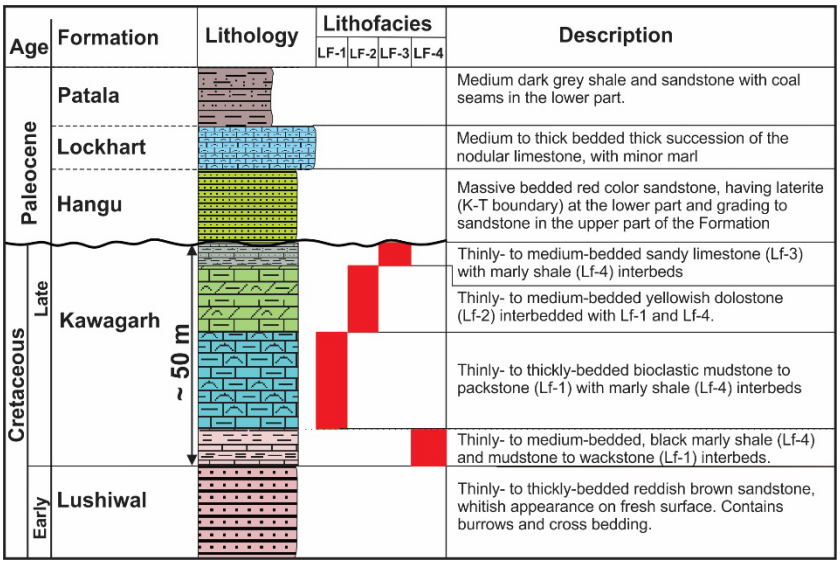


Fig. 4. Composite stratigraphic log showing the Cretaceous to Paleocene stratigraphy with an unconformity at the Kawagarh-Hangu contact and the vertical distribution of the various lithofacies of the Kawagarh Formation. The intervals for the different lithofacies indicate the prevalence of such lithofacies but other lithofacies also coexist.

2.1 Bioclastic mudstone to packstone (LF-1)

The LF-1 is represented by thinly to thickly-bedded, fine grained grey limestone (Fig. 5A). The weathered surface varies between light grey and yellowish-grey to yellowish-brown appearance. This is the most common lithofacies of the Kawagarh Formation and occurs throughout the formation. In certain intervals, the lithofacies has a nodular aspect and tectonic boudinage in some places. Rare horizontal burrows (?*Planolites*) are locally present. Pyrite nodules are also present. In some places, this lithofacies is interbedded with the dolostone lithofacies (Fig. 5B). Under the petrographic microscope, this lithofacies contains prolific planktonic foraminifera and subordinate calcispheres set in a micritic mud (Fig. 5C). These framework grains give the rocks various degrees of mudstone, wackestone and packstone textures.

2.2 Bioclastic dolomudstone to dolopackstone (LF-2)

In the field, LF-2 is characterized by thinly to thickly-bedded, brown-colored calcareous dolomudstone to dolopackstone. Although this lithofacies is a dolomitized version of LF-1, it is more compacted and harder than its predecessor. The two lithofacies are interbedded in several intervals (Fig. 5B, 5D). Under petrographic analysis, this lithofacies is primarily composed of dolomite and bioclasts. The dolomite rhombs are fine to coarse-crystalline with partially recognizable planktonic organisms of the original limestone. This lithofacies is more common in the upper part of the formation.

2.3 Sandy to silty limestone (LF-3)

In the field, this lithofacies (LF-3) is characterized by grey limestone that weathers to distinct yellowish tint. It frequently exhibits distinct calcite veins and pyrite concretions. The bedding is typically thin to medium, with certain areas displaying a nodular texture which appears to have resulted from varying cementation. The LF-3 lithofacies, under the petrographic microscope, is characterized by a predominance of fine-grained peloids and silt to sand grains (Fig. 5E) within a micritic mud. This lithofacies is present in upper part of the formation below the dolomitic facies.

2.4 Marly shale (LF-4)

This lithofacies is characterized by black to dark grey, thinly-bedded calcareous shale that occasionally gives a marly texture. It is present throughout the formation but more common in the lower part. It is interbedded with all three other lithofacies, particularly with LF-1 (Fig. 5F). This is an important facies indicating high fine clastic input and reduction of the bio-productivity, although it most likely contains planktonic organisms that are present in the other lithofacies.

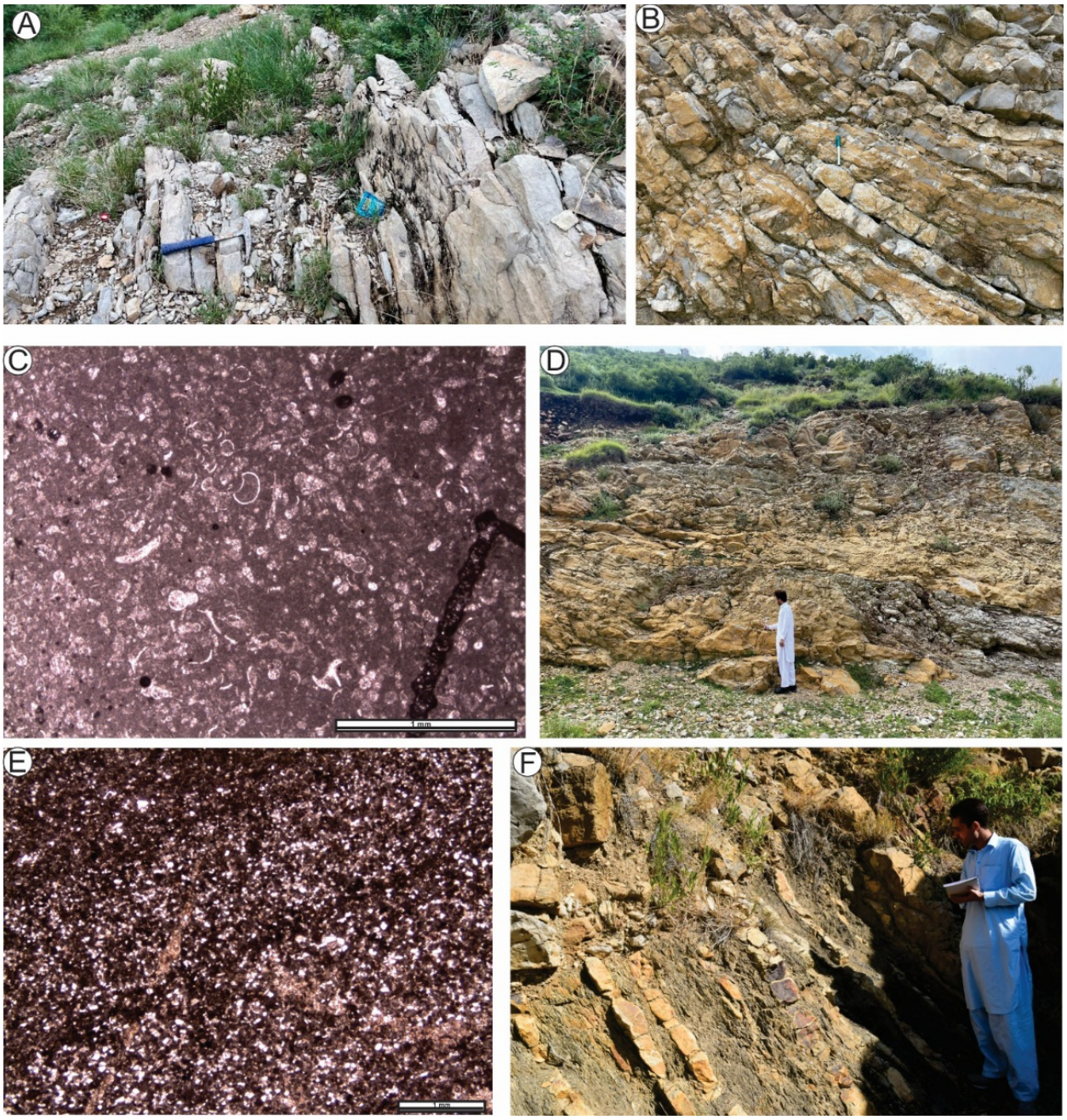


Fig. 5. Field and thin section images of the various lithofacies at Kawagarh Formation. A) Medium- to thickly-bedded planktonic-rich lime mudstone to packstone (LF-1). B) Interbedded LF-1 (grey) and LF-2 (yellowish brown). C) Thin section photomicrograph of LF-1 with plenty of planktonic foraminifera set in a carbonate mud matrix. D) LF-2 in the lower yellowish part and LF-1 in the upper grey part. Note the undolomitized grey lens (lower right) “sandwiched” between two dolomitized layers. E) Silty to sandy, peloidal limestone (LF-3); the two diagonal dark lines indicate lamination surfaces. F) Black to grey shale (LF-4) interbedded with LF-1.

Depositional environment

The Kawagarh Formation is regarded as an outer ramp deposit which accumulated within the southern shelf of southeastern Tethyan foredeep prior to the onset of the Himalayan Orogeny (Fig. 6). The fine textural properties of the Kawagarh Formation, its planktonic content, presence of horizontal burrows (?*Planolites*) and lack of high energy depositional features suggests deposition in a quiet environment. The latter is envisaged to be a deep shelf setting with high planktonic production and fine-grained siliciclastic influx from the continent. Although most of the formation accumulated in a deep marine setting, presence of the sandy/silty limestone in the upper part of the formation suggests relative sea level drop and arrival of sandier facies in the depositional site. It is well documented that global sea level drop separates the Cretaceous and the Paleogene periods (Haq et al., 1987). The sea level drop continued until the shelf was exposed and the K/T boundary evolved as a disconformable contact between Kawagarh and Hangu formation.

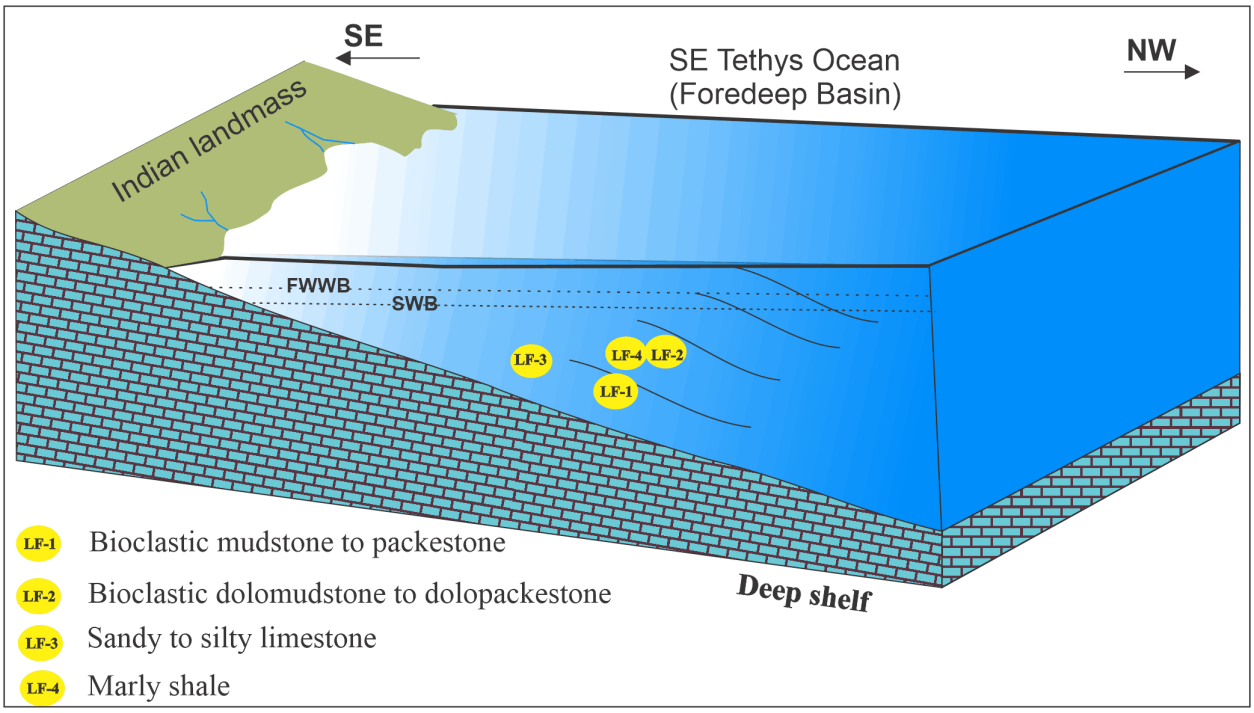


Figure 6: Depositional model for the Kawagarh Formation in the study area.

Biostratigraphy of the Kawagarh Formation

In the Kawagarh Formation of the study area, two distinct planktonic foraminiferal biozones have been identified, reflecting Santonian to middle Campanian age range. The *Dicarinella asymetrica* Total Range Zone, originally defined by Postuma (1971) and equivalent to the *Globotruncana concavata carinata* Zone, encompasses the complete stratigraphic range of *Dicarinella*

asymetrica range zone. Overlying this biozone, the *Globotruncanita elevata* Partial Range Zone, introduced by Dalbiez (1955), spans the interval from the last appearance datum (LAD) of *Dicarinella asymetrica* to the first appearance datum (FAD) of *Globotruncana ventricosa*. This zone is indicative of an early Campanian age and records a significant faunal turnover marking the Santonian–Campanian transition within the Kawagarh Formation. Although more thorough analysis of more sections and samples is needed, this age range of the Kawagarh Formation may indicate absence of the Maastrichtian stage in the study area.

Conclusions

Within the study area, the Kawagarh Formation is characterized by a substantial sequence of pelagic carbonates. The lower contact of this formation is conformable with the Lumshiwal Formation, while the upper contact with the Hangu Formation is unconformable, indicated by the presence of Lateritic sediments that constitute the basal part of the Hangu Formation. The contact between the two formations defines the K/T boundary. Investigations across nine stratigraphic sections in the Hazara, Nizampur and Kohat sub-basins of the Upper Indus Basin, uncover a diverse assemblage of carbonate and mixed carbonate–siliciclastic lithofacies, indicative of significant vertical and lateral facies variability. The formation consists of four lithofacies that include: Bioclastic mudstone to packstone (Lf-1), Bioclastic dolomudstone to packstone (Lf-2), sandy to silty limestone (Lf-3) and marly shale (Lf-4). The integrated lithofacies and bioclastic content indicates that the formation was deposited in a quiet, deep shelf, ramp-type deposi, depositional environment. The planktonic organisms in the formation are dominated by foraminfera, such as *Dicarnella concavata, Dicarinella asymetrica, Globotruncanita elevata, Globotruncana ventricosa***.** These fossils indicate that the formation was deposited during Santonian to Campanian ages. The current data indicate that Maastrichtian stage is missing possibly due to erosional vacuity after the deposition of the Kawagarh Formation and before the Paleocene Hangu Formation.

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