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## Lithofacies properties, biostratigraphy and depositional setting of the Paleocene Lockhart Limestone, Hazara and Potwar Sub-basins, Northeast Pakistan

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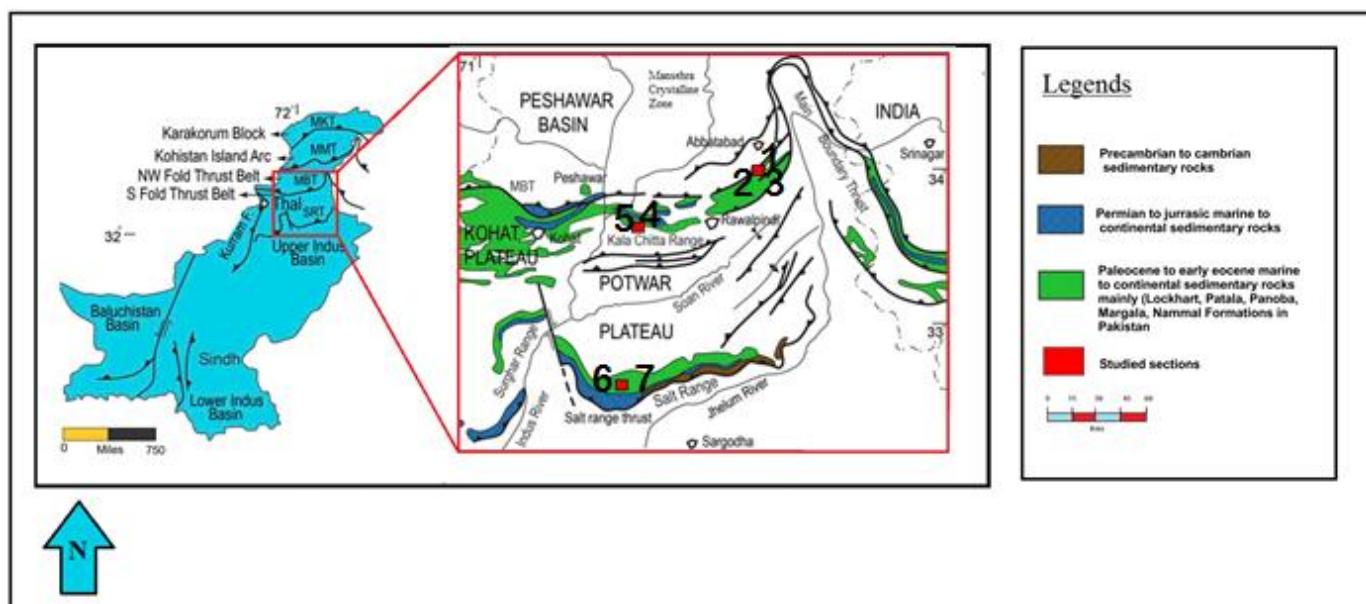
### Summary

The Indian Subcontinent was a shallow marine depositional site in most of the Paleocene and Eocene epochs before its collision with Eurasia. The Indus Basin formed the Pakistani portion of the subcontinent where carbonate deposition was prominent. The Lockhart Formation is among the carbonate-dominated lithologic units developed in the Indus Basin. The latter has been divided into sub-basins due to the tectonic disturbance related to the Indian-Eurasian collision. In the northern part of the Indus Basin, the sub-basins Kohat, Potwar and Hazara constitute the upper Indus Basin. The study area is located in the Potwar and Hazara sub-basins. The Lockhart Formation overlies early Paleocene Hangu Formation and is overlain by latest Paleocene to early Eocene Patala Formation, both with conformable contacts. The Lockhart Formation is about 50 meters thick in the Potwar Sub-basin and 115 meters thick in the Hazara Sub-basin. Seven sections, three from Hazara area and four from Potwar area were studied for their lithofacies and biostratigraphic properties. Seven lithofacies were recognized to constitute the formation; they include planktonic-bearing mudstone (Lf1), miliolid-bearing mudstone (Lf2), mixed benthic foraminiferal wackestone to packstone (Lf3), algal-foraminiferal wackestone to packstone (Lf4), *Lockhartia-Miscellanea* wackestone-packstone (Lf5), *Discocyclina-Ranikothalia* wackestone (Lf6) and fossiliferous calcareous shale (Lf7). These lithofacies can be grouped into four lithofacies associations (LA-1 to LFA-4) deposited in a quiet to moderately-agitated ramp setting. LA-1 is formed by Lf1 and Lf7 and represents an outer ramp deposits, LA-2 includes Lf3, Lf5 and Lf6, which accumulated in middle ramp depositional site. The LA-3 is represented by Lf4; it is envisaged as sand shoal inner ramp deposits while the LA-4 is characterized by Lf2 which indicate restricted to semi restricted lagoonal environment. The larger benthic foraminifera in the formation include some good index fossils that are useful for biostratigraphic age determination. Recognized index fossils include *Lockhartia conditi*, *L. haimei*, *Miscellanea miscella*, *Ranikothalia sindensis*, and *Discocyclina* sp. These fossils suggest middle to late Paleocene (Selandian to Thanatian) age for the formation.

### Introduction

The Lockhart Limestone is deposited throughout the upper Indus basin which is located in Northern Pakistan. This basin is divided into three sub basins; Hazara, Potwar and Kohat. The study is focused on the Hazara and Potwar Sub-basins. The Hazara Mountains form the northern border that separates the Hazara sub-basin from the Potwar sub-basin. In the study area, the formation is exploited for aggregate production but equivalent units in the lower Indus Basin include reservoirs that produce hydrocarbon. The Paleocene-Eocene strata in the northern upper Indus Basin have high hydrocarbon potential and exploration companies have recently showed interest in these rocks. Previous work on the

Paleocene-Eocene strata was mainly in the form of regional mapping. The region of the upper Indus basin is highly tectonized and distinguishing among the lower Cenozoic carbonate-dominated units is highly challenging. Detailed local Lithostratigraphic and biostratigraphic studies are thus very important to accurate discriminate among these seemingly similar lithologic units. This study intends to decipher the lithofacies properties, biostratigraphic age constraints and depositional setting of the Lockhart Limestone in the Hazara and Potwar sub-basins of upper Indus Basin. Seven sections, three in the Hazara, two in the Kala chitta and two in salt range area were studied (Fig. 1). The three sections in the Hazara Basin are Dhudial (Section A) (Lat.  $34^{\circ}10' 07$ , Long.  $73^{\circ}16' 54$ ), Khaira gali (Section B) (Lat.  $33^{\circ}59'01$ , Long.  $73^{\circ}23'59$ ), Darkot section ( $73^{\circ}09'15'$ ,  $33^{\circ}52'15'$ ). The four sections from the Potwar Basin are Kahi section ( $33^{\circ}48' 42$ ,  $72^{\circ}40'92$ ), Askari cement factory section ( $33^{\circ}48'10'$ ,  $72^{\circ}56'05$ ), Nammal Gorge ( $32^{\circ}39' 58.3''$  N;  $71^{\circ}47' 49.9''$  E) and Kalabagh ( $32^{\circ}57' 10.0''$  N;  $71^{\circ}34' 30.9''$  E). The Lockhart Limestone is composed of bioclastic limestone with shale intercalations. The formation lies over the Hangul Formation and is overlain by the Patala Formation. Both upper and lower contacts are conformable. The Lockhart Formation is well-exposed and well-developed throughout Kohat and Potwar regions (Latif, 1970; Shah, 1977). The fossils of the formation are dominated by foraminifera, mollusks, algae and echinoids (Raza, 1967; Cheema, 1968; Latif, 1970). The larger benthic foraminifera dominate the framework content of the formation. Cheema (1968) and Latif (1970) have recorded various species of *Miscellanea miscella*, *Alveolina* sp., *Lockhartia* sp., *Discocyclina* sp., *Rotalia* sp. and *Ranikothalia* sp. from the formation. The occurrence of the larger benthic foraminifera in the Lockhart Limestone indicates a shallow marine depositional environment in a carbonate ramp platform (Akhter and Butt, 1999). The study area is a tectonized mountainous region with difficult access to study. This has limited previous researchers to perform a more detailed work on this formation, as well as other associated formations. Recent road-cuts expose new sections (e.g., Fig. 2) offer an easy access to study these rocks. Therefore, the present study aims a more detailed sedimentological, Lithostratigraphic and biostratigraphic investigation of the Lockhart Formation, infer its deposition setting and correlate with coeval regional (in Pakistan) and inter-regional (circum-Tethyan Ocean) zones. The senior author is working on this project as an MSc thesis project and the preliminary results based on the seven sections so far logged and studied are presented here.



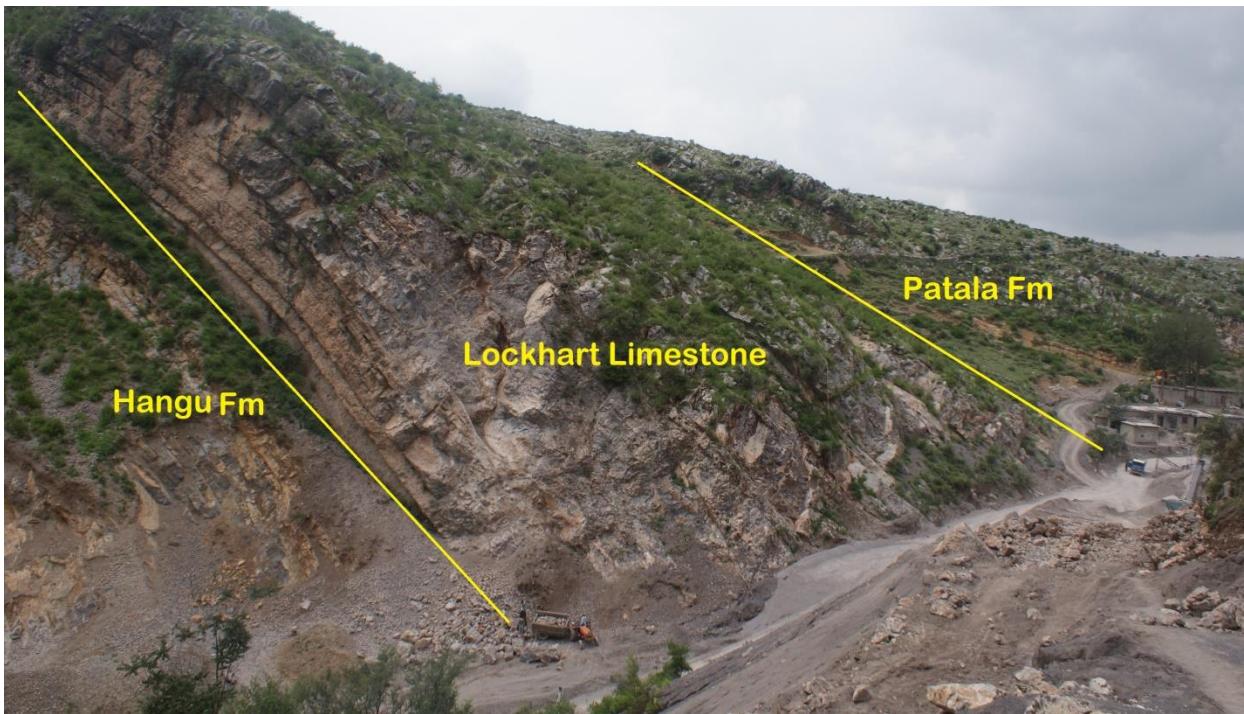
**Figure: 1** Map of Pakistan shows the study area in the upper Indus Basin. The numbers shows the seven sections in study areas in Hazara and Potwar basins.

## Lithofacies properties

The field and petrographic analysis of the Lockhart Formation from the seven studied sections revealed that formation consists of 7 lithofacies. These lithofacies units include: planctic-bearing mudstone (Lf1), miliolid-bearing mudstone (Lf2), mixed benthic foraminifera wackstone-packstone (Lf3), algal-foraminefra wackstone-packstone (Lf4), *Lockhartia- Miscellanea* Wackstone- packstone (Lf5), *Discocyclina-Ranikothalia* wackstone (Lf6), and fossileferous calcareous shale (Lf7). Brief descriptions of the various lithofacies and interpretation of their depositional environments are summarized in Table 1. These lithofacies units are grouped into three lithofacies associations (LA-1, LA-2, LA-3 and LA4); they are envisaged to have accumulated in low to moderate energy ramp platform.

#	Lithofacies	Description	Depositional Energy and Environment
Lf1	Plantonic-bearing mudstone	Nodular, Orangish yellow, medium to thick bed, mudstone.	Deep marine and low depositional energy.
Lf2	Miliolid-bearing mudstone	Sprsley nodular, yellowish grey, medium to thick bed, mudstone	Shallow marine, low depositional energy,
Lf3	Mixed benthic foraminifera wackstone-packstone	Non nodular,intercalation of shale, grey, thick bed, Wackstone -packstone.	Open marine and moderate depositional energy.
Lf4	Algal-foraminefra wackstone-packstone	Thick bedded, Light grey, Wackstone-Packstone	Open marine and Moderate to high depositional energy.
Lf5	<i>Lockhartia- Miscellanea</i> Wackstone- packstone	Nodular, thick bedded, wackstone- Packstone.	Open Marine moderate-high depositional energy.
Lf6	<i>Discocyclina-Ranikothalia</i> wackstone	Thick bedded, light grey, wackstone	Open-Deep marine and low depositional energy.
Lf7	Fossileferous calcareous shale	Composed of light to-dark brown-black, Fossileferous shale.	Deep marine and low depositional energy.

**Table 1:** Brief description of the seven lithofacies units that constitute the Lockhart Limestone in the study area, Interpretation of the depositional environments and level of marine water energy are shown.



**Figure: 2:** The photograph shows Lockhart limestone overlain and underlain by Hangu Formations and Patala Formation respectively in Dhudial section (A) section.

## Biostratigraphy

The very preliminary biostratigraphic study of the formation shows certain number of foraminiferal index fossils (mainly larger benthic foraminifera) that are useful for biostratigraphic age dating. The recognized genera and species include *miscellanea miscella* and *Lockhartia Conditi*, *Discocyclina sp*, and *Ranikothalia sindensis*. The age range of these species is SBZ 3 to SBZ 4. Further biostratigraphic analysis from more samples will be conducted and further refinement of the age of the formation and its local and regional correlations will be considered.

## Conclusions

The study area encompasses two Paleogene basins, namely Hazara and Potwar in the northern part of Pakistan. Due to the Himalayan collision, the study area is deformed, and most of the strata are tectonically folded. However, recent road-cuts offer fresh sections that are accessible for study. The Paleocene strata in the Hazara and Potwar basins consist of Hangu Formation, Lockhart Limestone and Patala Formation. The Lockhart Limestone contains different limestone lithofacies with shale intercalations. The formation lies conformably over the earliest Paleocene Hangu Formation and overlain, also conformably, by latest Paleocene to early Eocene Patala Formation.

The outcrop examination combined with petrographic study permits identification of seven lithofacies units (Lf1-Lf7) for the formation. These lithofacies units are: planctic-bearing mudstone (Lf1), miliolid-bearing mudstone (Lf2), mixed benthic foraminifera wackstone-packstone (Lf3), algal-foraminefra wackstone-packstone (Lf4), *Lockhartia-Miscellanea* Wackstone-packstone (Lf5), *Discocyclina-Ranikothalia* wackstone (Lf6), and fossiliferous calcareous shale (Lf7). The fossil associations of these lithofacies and physical and biological sedimentary structures suggest deposition in a low to moderate

energy carbonate ramp setting. The Lf1 & Lf7 (lithofacies association 1) represents outer ramp, Lf2 & Lf4 (lithofacies association 2 &3) represents lagoon and sand shoals inner ramp respectively, Lf3, Lf5 and Lf6 (lithofacies association 3) represent mid ramp.

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