Geol. Bull. Univ. Peshawar, Vol. 34, pp. 83-104, 2001

The Eocene redbeds of the Kala Chitta Range (Northern Pakistan) and its stratigraphic implications on Himalayan Foredeep Basin

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ABSTRACT:*The Eocene redbeds unit of the Western Himalayas Foredeep basin are critical in two aspects: first, it is the oldest Tertiary sequence containing detritus unequivocally derived form the incipient Himalayas and secondly, it contains a diverse fauna key for understanding the evolution of several modern mammal groups. This sequence is known as the Kuldana Formation in the Kohat-Potwar region (=Upper Indus Basin) and the Upper Subathu formation in Kashmir and Himachal Pradesh. This paper focuses on the lithostratigraphic details of the Kuldana Formation from the Kala Chitta Range (Kohat-Potwar region), which also has yielded the best Eocene mammalian fauna in the region. It is a mudstone dominant unit, mainly red to purple in the Lower Kuldana but green in the Upper Kuldana. The Lower Kuldana also contains channel sandstone, immature paleosols and fresh-water limestone with molluscs (Planorbis) and algae (Chara), suggestive of terrestrial deposition regime with shallow channels, ephemeral lakes and wide floodplains. The Upper Kuldana has relatively thicker limestone interbeds with common oysters and rare benthic foraminifera, indicating return to marginal and shallow marine environment as existed before the onset of Kuldana Formation. This marine transgression, correlated with the early Lutetian highstand, deposited the overlying limestone-dominant Kohat Formation. The Kuldana-Kohat couplet was restricted to the Kala Chitta and Kohat regions whereas the rest of the Western Himalaya foredeep turned into a lowland after the Kuldana and Upper Subathu deposition. The shift from marine to terrestrial environment as witnessed in the Kuldana/Upper Subathu sequence is related to early Eocene Himalayan orogeny, when the incipient Himalayas became highland and started shedding sediments to the Foredeep basin. By early late Eocene, the Neotethys drained out from the Paleogene foredeep and shifted to the Katawaz-Makran basin in the west, which then was the main depocenter for the sediments shed from the Himalayan orogene highlands. These tectonic events produced a chain of highlands along the north and western margin of the Indian plate, providing filter bridges for dispersal and migration of mammals to and from South Asia. The Eocene mammalian fauna from the Foredeep and also from the Ladakh basin is a curious blend of some endemic and a few migrants of Eurasian and North American affinities.*

INTRODUCTION

The Paleogene sediments of the Foredeep basin record the collisional history of the Himalayas developed along the region once occupied by the west-northwest-south-southeast Tethys Ocean. The Foredeep basin extends throughout the southern flank of the Himalayas that continues in the west to the Indus Basin in Pakistan (Fig. 1). The outcrop

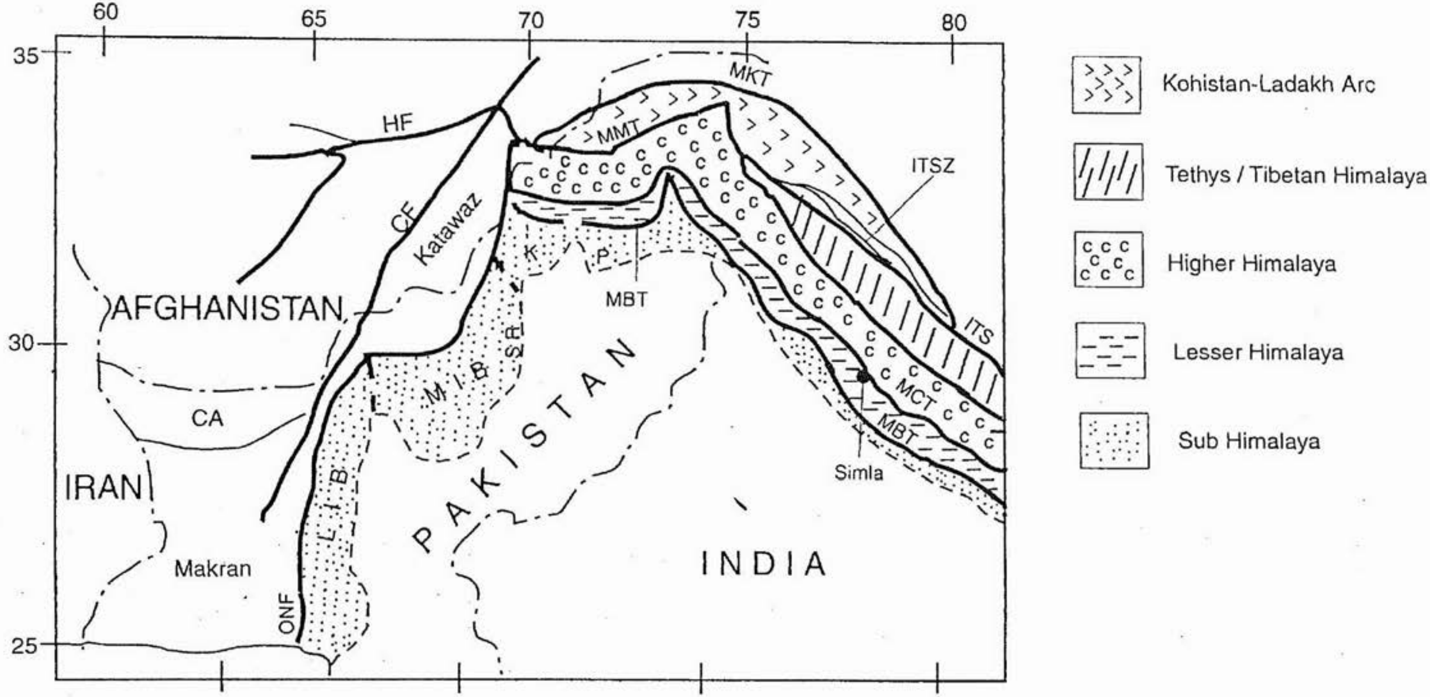

Fig. 1. Generalized geological map of Western Himalayas and surrounding regions. Thick lines indicate faults and the dashed line marks the limits of the outcrops. Faults/Thrusts: CF, Chaman Fault; HF, Herat Fault; ITSZ, Indus-Tsangpo Suture zone; MBT, Main Boundary Thrust; MCT, Main Central Thrust; MKT, Main Karakoram Thrust; MMT, Main Mantle Thrust; ONF, Ornach-Nal Fault. Basins/Terranes: CA, Chagai Arc; LIB, Lower Indus Basin; MIB, Middle Indus Basin; K, Kohat sub-basin; P, Potwar sub-basin; SR, Sulaiman Range The region marked K & P are often collectively called as the Northern/Upper Indus Basin and also as the Kohat-Potwar Province. The Lesser Himalaya region to the east of the Potwar sub-basin are informally referred to here as the 'Subathu basin'. The Pakistani ophiolite belt (= Bela-Zhob-Waziristan Ophiolite belt) is a string of outcrops along the western border of the Kohat sub-basin, the Middle Indus Basin and the Lower Indus Basin.

belt is more than 100 km wide along a series of lobes in Pakistan (Kohat-Potwar, Sulaiman, and Kirthar regions) in contrast to India and Nepal where the width of the fold-and-thrust belt is less than 50 km (Fig. 1). The western part of the Foredeep basin contains about 500m to 1800m of shallow marine mudstone-carbonate sediments deposited during the Paleocene to middle Eocene interval. These sediments demonstrate distinctive lithofacies associations reflecting the changes in the basinal topography of the shelf developed through time in response to Himalayan tectonics. The focus of this paper is the 'redbed facies associations' marking the terminal (or near terminal) Eocene depositional episode in the Western Himalayan foredeep. This red mudstone-dominated marginal-marine to fluvial unit is generally known as the Kuldana Formation in the Kohat-Potwar basin (northern Indus Basin) and as the Upper Subathu formation (or Red Subathu formation) in Kashmir and Himachal Pradesh (Fig. 2). The Kuldana and Upper Subathu formations also contain a diverse vertebrate fauna giving important clues to Eocene mammal radiation and evolution in South Asia. The best-studied regions in this respect are the outcrops of the Kuldana Formation in the Kala Chitta Range (Thewissen et al. 1998, 2001, and references therein).

This paper presents details of lithostratigraphy of the Kuldana Formation in the Kala Chitta Range. The study is based on three stratigraphic sections measured in the Ganda Kas area (Fig. 3) and the two sections from Jhalar area in eastern Kala Chitta Range described by Hussain et al. (1978) and by Wells (1984). It is followed by a brief review of the Kuldana-coeval stratigraphy from other parts of Western Himalaya emphasizing contemporary lithofacies development. Finally, the Eocene stratigraphy of the Foredeep is related to the broader context of early Paleogene Himalayan tectonics giving some topographic relief to the incipient Himalaya. The informal term 'Western Himalayas' used here denotes the portion of the Himalayas west of 77°E, circumscribed in Pakistan by the "Bela-Zhob-Waziristan Ophiolite Zone" in the west and north (Fig. 1).

KULDANA FORMATION

Background

Wynne (1874) first used the name "Kuldana beds" for the red and green shales and marls overlying his "Nummulitic series" in the Murree Hills and the surrounding regions in southern Hazara. The name is derived from the small village of Kuldana, at about 45-km northeast of Islamabad (Fig. 3). A much thicker sequence in the same stratigraphic position in the Kala Chitta Range was named "Chharat series" by Pinfold (1918) and subsequent workers (for example Davies, 1926; Cotter, 1933; Pascoe, 1963). Pinfold documented the type section from a stream east of the Chharat village in southern Kala Chitta Range (Fig. 3) into the following three units between his "Hill Limestone" and "Fatehjang zone':

Fatehjang zone or Basal Murrees	Burdigalian (Early Miocene)
3. Nummulitic shales	Middle Khirthar or Lutetian (Middle Eocene)
2. Thin bedded limestone and green shales	Lower Khirthar or Lutetian (Middle Eocene)
1. Variegated shales with bleached limestone bands	Laki or Ypresian (Early Eocene)
Hill limestone	Ypresian (Early Eocene)

Pinfold (1918) and Cotter (1933) considered the 'Variegated shales with bleached

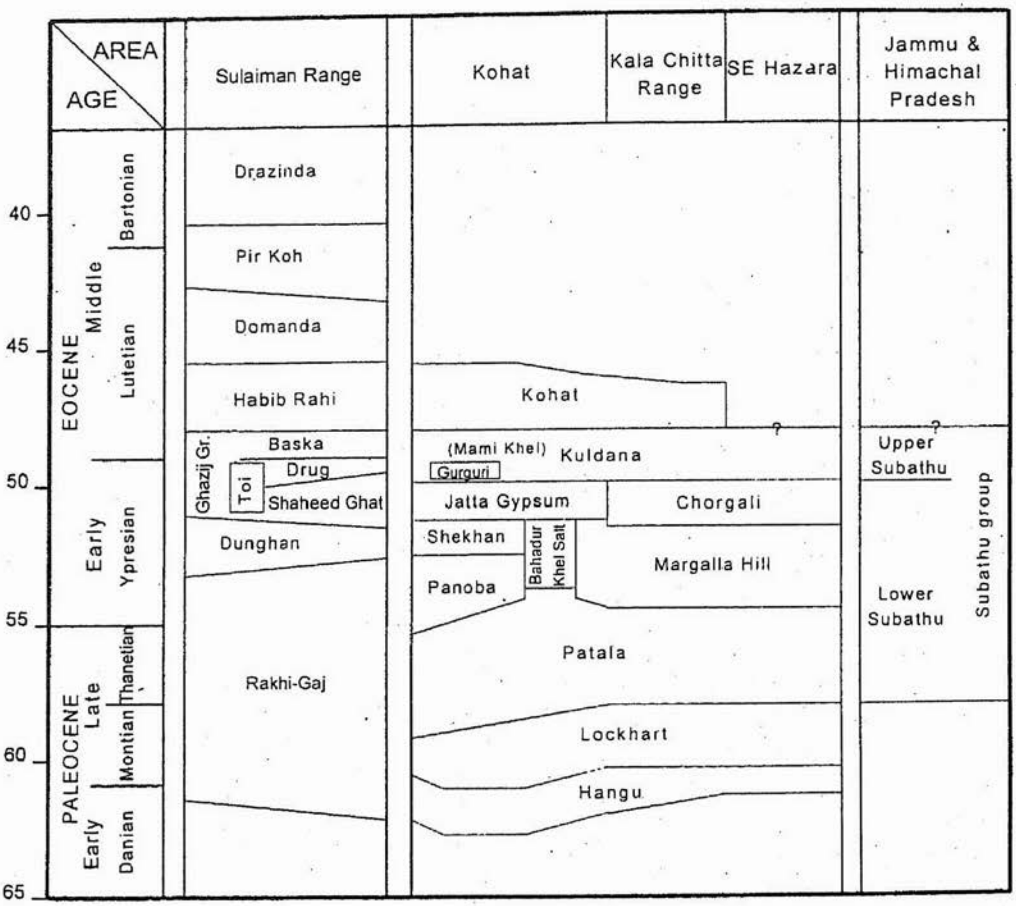

Fig. 2. Stratigraphic chart for the Paleocene-Eocene sedimentary rocks in Western Himalayas. All the names have the "Formation" ending , otherwise noted in the Chart. Modified after Fatmi (1973) and Shah (1977) except for Jammu and Himachal Pradesh after Nanda & Kumar (1998).

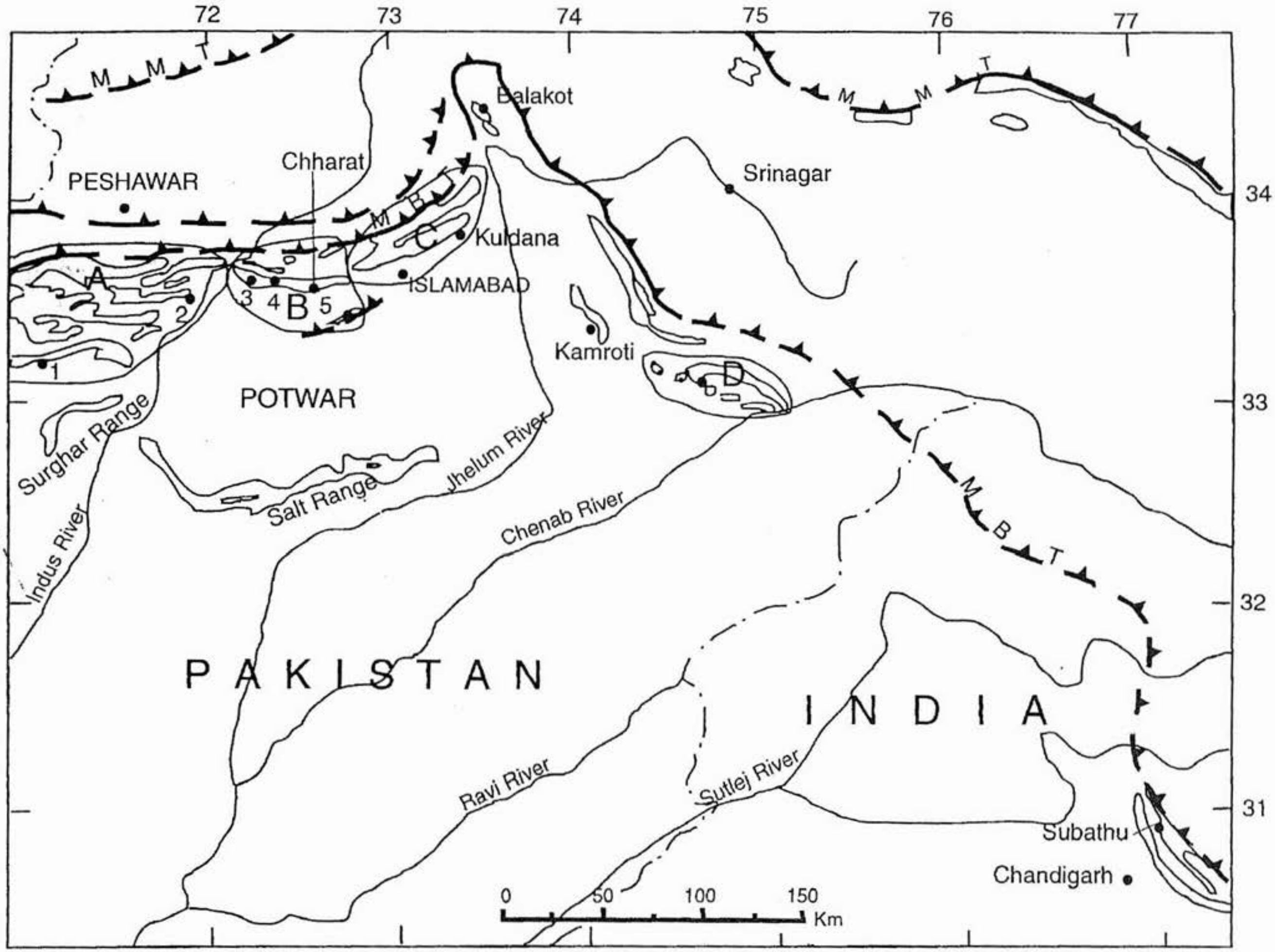

Fig. 3. Map of a portion of the Western Himalayas showing areas having vertebrate fossil localities in the Kuldana/Upper Subathu formations. Gray-shade indicate outcrop belts of Mesozoic and/or lower Tertiary rocks. The regions encircled by letters are: A. Kohat sub-basin, B. Kala Chitta Range, C. Southeastern Hazara, and D. Jammu area. Numbers indicate general vicinity of vertebrate fossil localities; 1. Banda Daud Shah, 2. Chorlakki, 3. Ganda Kas. 4. Jhalar, 5. Gali Jagir. The area marked D is also the Kala Kot fossil locality area.

limestone bands' coeval with the Kuldana beds of southeastern Hazara, a proposition agreed to by all the later workers (Fig. 4).

Eames (1952) extended the name "Chharat' for the broadly similar middle Eocene rocks of the Kohat sub-basin, where the sequence is much thicker and is divisible into several laterally extensive lithofacies sub-units (Fig. 4). Meissner et al. (1974) while mapping the Kohat region, introduced the name Mami Khel Clays for Eames' Lower Chharat and grouped the Upper Chharat with Kohat Limestone (Fig. 4). Pivnik and Wells (1996) favored a substantially modified version of Meissner's classification emphasizing a blend of some regional similarities and a few area-specific lithofacies associations (Fig. 4). The Stratigraphic Committee of Pakistan, following the principle of nomenclature priority, extended the name Kuldana Formation for the 'Variegated beds' in the Kala Chitta Range, and for the 'Lower Chharat'/Mami Khel Formation of Kohat sub-basin (Fatmi, 1973; Shah, 1977). Similarly the overlying 'Kohat limestone' of Davies (1926) was redefined to include all the marine units above the Kuldana and below the Murree Formation in the Kala Chitta and Kohat region (Fig. 2).

The Kuldana Formation is mainly developed in the hill ranges north of the Potwar Plateau, extending from southeastern Hazara through the Kala Chitta to Kohat sub-basin. In Hazara and further to the east, the Kuldana Formation and its coeval Upper Subathu beds constitute the highest Eocene units overlain disconformably by terrestrial Neogene sequence. But in the Kala Chitta and Kohat areas, the marine Kohat Formation conformably overlies the Kuldana Formation. It is the Kohat Formation in this region which has unconformable contact with the early Miocene Murree Formation. The Eocene-Miocene unconformity is one of the major Himalayan hiatuses during which the geological set-up of the South Asian landmass was completely reorganized.

The Kuldana Formation is structurally incompetent, and undisturbed stratigraphic sections are rare. The soft lithology, few hard sandstone and limestone beds, and lack of marker beds/units further hinder proper stratigraphic logging and lateral correlation. It is reported to be generally between 120m to 200m in the Kala Chitta Range (Eames, 1952; Fatmi, 1973 & Shah, 1977) but Wells (1984) measured 600m of Kuldana Formation in the Jhalar area, central-southern Kala Chitta Range. In the subsurface south of the Kala Chitta Range, the Kuldana has been reported to swell to several hundred meters thickness; being in tight tectonic regime of Northern Potwar. In the Kohat sub-basin, it is best developed in the central part where it is 100m-150m thick but thins out to the west, east and south; for instance it is only 40m thick in the Panoba section in the east (Eames, 1952; Pivnik & Wells 1996).

Lithology

The Kuldana Formation is essentially a red mudstone facies with minor gray limestone and brown to red sandstone interbeds deposited in a fluvial and coastal environment. The Kuldana Formation in the type Kuldana-Murree area dominantly consists of red and green shales and marls with a few thin gray limestone and red fine grained sandstone beds. Some lenticular limestone beds in the green shales in the upper reaches of the formation contain a few poorly preserved benthic foraminifers (Latif, 1970a & b, 1976). Here and also in the Kala Chitta Range, the Kuldana Formation has gradational lower contact with marine green-gray shales and marls of the Chorgali Formation (Fatmi, 1973; Jurgen & Abbas 1991). The Kuldana Formation extends

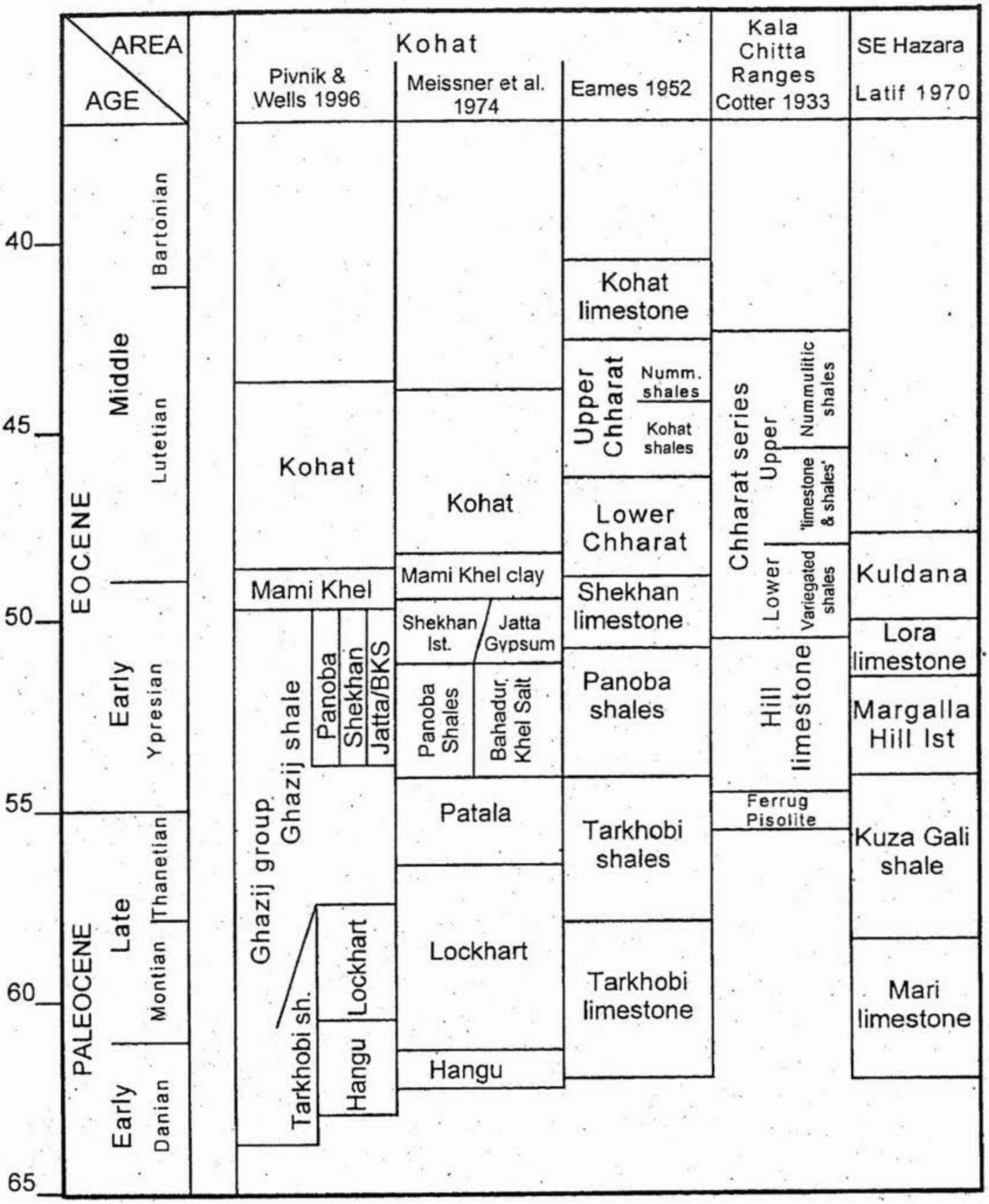

Fig. 4. Stratigraphic chart showing a selection of previous nomenclature for the Paleocene-Eocene sequence of the Kohat sub-basin, Kala Chitta Range and the Southeastern Hazara. Most of the names, though valid 'lithostratigraphic names' in modern stratigraphic usage, were proposed in consideration of their respective local stratigraphic details. The Stratigraphic Committee of Pakistan, after a thorough review, had greatly simplified the lithostratigraphic scheme for these regions (see Fatmi, 1973), but some of the local names still resonate in recent publications.

westwards through a string of low red hills north of Islamabad and vicinity to the Kala Chitta Range (Fig. 3).

Lithofacies details in the Kala Chitta Range: The Kuldana Formation in the Ganda Kas-Thatta and adjoining areas in southern Kala Chitta Range is a predominantly red to purple mudstone unit (90-95% of bulk lithology) with minor interbeds of limestone (3-6%) and sandstone (2-5%) (Fig. 5). It can broadly be divided into a much thicker Lower Kuldana of red and purple mudstone and a relatively thinner Upper Kuldana composed of green and brown calcareous mudstone and shales. The Lower Kuldana limestones commonly contain freshwater gastropods, bivalves and ostracodes and the thin channel-form sandstone have occasional vertebrate fossils. Limestone beds with shallow marine fauna are much thicker and more frequent in the Upper Kuldana.

Mudstones in the Lower Kuldana are mostly red in color changing to a dominant purple color upsection and range from clay to fine siltstone. They are devoid of any bedding pattern on weathering surfaces, highly fractured and shows a variety of pedogenic features at various stratigraphic levels. They form several decimeter thick units and had there been better exposures, one could identify several depositional cycles within these units. Beds with green, gray, and purple mottling, common carbonate nodules, roots and rhizome fillings, worm burrows/trails and silckensidings are some of the common features defining development of paleosols in mudstone units. Some of such beds have a hard concretionary, usually calcareous, mottled appearance which distinguishes them from otherwise soft weathering mudstone. A typical paleosol unit in the Lower Kuldana contains the following succession (Aslan & Thewissen, 1996):

6.	Limestone, gray, bedded, well cemented, ostracodal.	60cm.
*5.	Mudstone, purple to black, poorly cemented.	40cm.
*4.	Mudstone, clayey, red, gray, mottled, slickensides, rare carbonate nodules.	40cm
*3.	Sandstone, clayey, red, abundant carbonates nodules.	60 cm.
*2.	Conglomerate, silty matrix, red with common gray mottles.	70cm
1.	Sandstone, red, poorly cemented, gray mottles, common slickensides.	+70 cm.

(* Units 2 through 5 constitute the paleosol.)

These paleosols were developed over the time interval of less than 10^5 and probably closer to 10^3 years under generally dry, oxidizing, and alkaline conditions (Aslan & Thewissen, 1996).

Limestone intercalations in the Lower Kuldana occur in quick successions of units less than one-meter thickness each within 15 to 30 meter thick interval of red or purple mudstone. Limestones are mostly developed in the lower part of the Lower Kuldana (Fig. 5). Limestone units, 20cm to 90cm thick, are gray, micritic, nodular to massive, often bioturbated and usually contain freshwater *Planorbis*, other molluscan shell fragments and ostracodes. Some of the beds also have *Chara*, a distinctive mostly freshwater but also brackish algae. A shell-rich nodular 70-cm thick limestone unit at 27 m in Valley B section has also some thin chert lensoid veins, which Wells (1984), from other areas, has interpreted to be a deposit of saline/alkaline lagoons and/or saline lakes. There is no sequential trend in limestone interbeds to define any deepening or shallowing of the basin except that these were deposited in small, short-lived isolated ponds developed in fairly shallow depressions on the floodplain. However, a few of the thicker

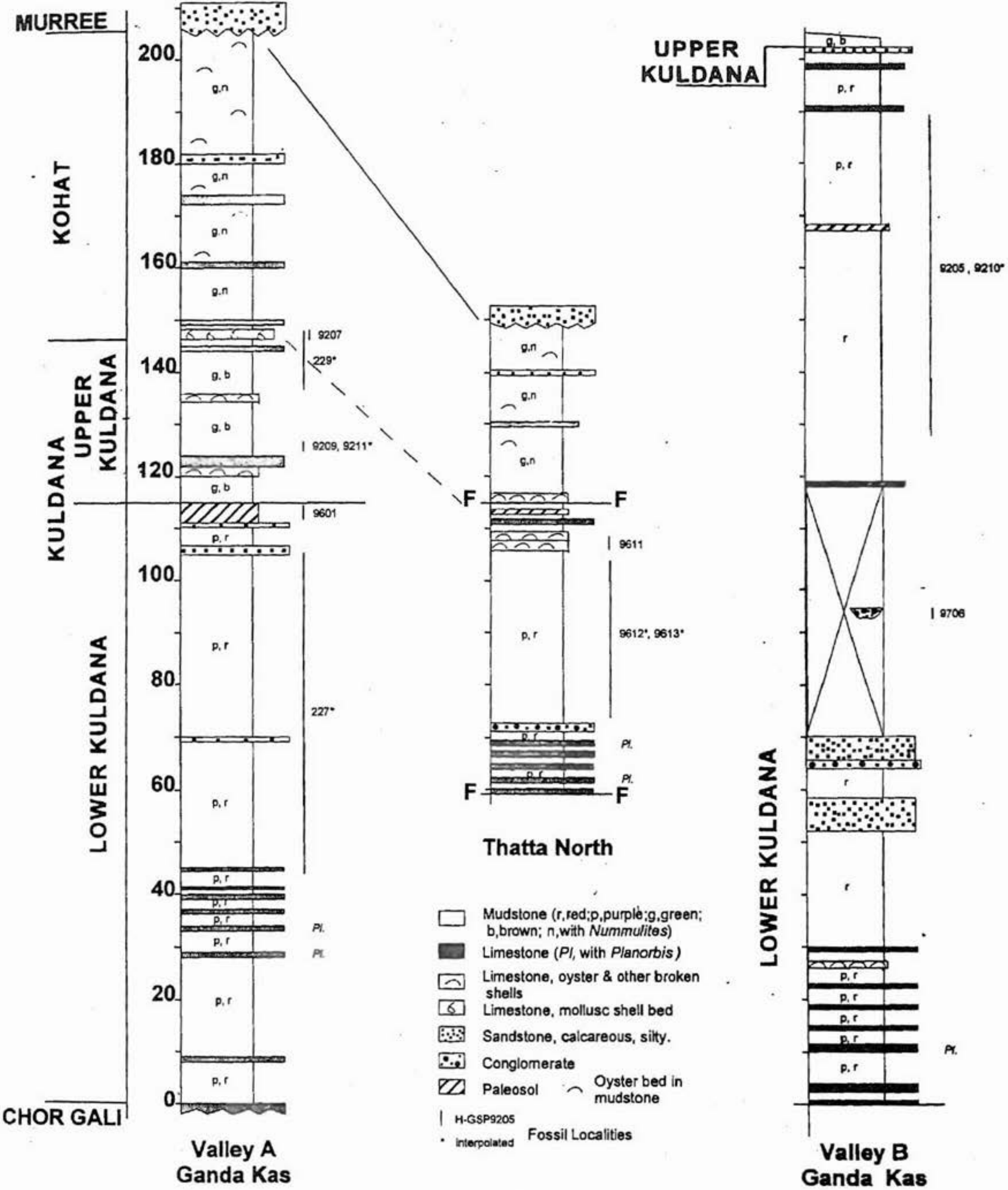

Fig. 5. Stratigraphic sections of the Kuldana and Kohat Formations measured at three locations in the Ganda Kas area in southern Kala Chitta Range. Thewissen et al. (1998) divided the NW-SE trending outcrops in the vicinity of Ganda Kas village into five broadly defined valleys, named A through E, from north to south. The Valley B section is about 1.5 km south of the valley A section. The Thatta North section is another 1.5 km south of the Valley B section. Note the excessive thickness (203m) of the Lower Kuldana in the Valley B section is most likely due to structural complications. For location of the Ganda Kas area , see mark 3 in Fig. 3.

units are massive in the lower part but develop nodularity upward along with hematite-stained fractures and burrows; suggesting the possibility of large, longer-lived freshwater lakes. Limestone intervals have sharp lower and upper contacts with the intervening mudstone.

Sandstone units are restricted to the Lower Kuldana. There are three bands ranging from 60 cm to 1.4 m thickness in the Valley A section and two exceptionally thick units (4.3m & 6.3 m thickness) in the Valley B section (Fig. 5). The sandstone is gray, laminated to thin bedded, cross-bedded, fine to very fine grain and often grade into siltstone. The Valley A sandstone couplet with intervening mudstone shows a coarsening and thickening upward trend with trace fossils and some carbonized plant remains in the basal beds. The intervening purple mudstone is highly bioturbated and has common green and gray mottling. The sandstone units in the Valley B section is more channel-form and much thicker than the one just described. The lower 6.4-m thick sandstone unit occurs at 52m above the base of the section. With an intervening 5.3 m thick red mudstone, the upper 5.7-m thick sandstone has about 1.5 m of granulestone conglomerate at the base. The sandstone is brown, very fine to fine grained, large trough cross bedded to ripple laminated upwards, and form 1 to 2 m thick bed-sets. The lower contact with the underlying mudstone is sharp and erosional whereas upwards with decreasing grain-size the sand passes up to red mudstone. The brown conglomerate is almost entirely composed of hematite-stained calcareous nodules (granules) and a few broken bones. There is no visible sedimentary structure in the conglomerate suggesting an episodic 'flash-flood' type deposit. The sandstone in the Valley A and Valley B represent two different modes of deposition. The Valley A sandbodies with intervening purple mudstone are lake and inland delta deposits, which have been permanent features of the Kuldana floodplain. The Valley B sandbodies are typical channel deposits, perhaps of non-meandering shallow rivers wandering into a relatively flat, aggrading basin (Wells, 1984). Because the sandbodies in the two sections cannot be correlated due to structural complexity, it is difficult to interpret the two depositional modes in the larger context of Kuldana landscape. However, it is tempting to postulate the Valley B small shallow channels were draining inland into the ephemeral lakes of the valley A. This might have been the general scenario of the Kuldana landscape.

The Upper Kuldana consists mainly of green and brown calcareous mudstone and shales with a few limestone interbeds. However, limestone interbeds in this part are much thicker than those in the Lower Kuldana and constitute about 20% of the lithology. They generally contain oysters, gastropods, and benthic foraminifers, a sure indication of brackish to marine setting. There is always a 50cm to one meter thick limestone unit at the top of the Kuldana Formation that is full of oysters and other mollusc shell fragments. Oysters in this unit are usually well-preserved, some heavily bored and some still in life-position, indicating a sudden burial in mud. These oyster beds are always overlain by the limestone or green shales with abundant marine benthic foraminifera of the Kohat Formation. The lithofacies association of the Upper Kuldana suggests that extensive oyster banks and restricted mud-filled bays gradually gave way to open shallow marine environments of Kohat shales.

The overall lithofacies associations of the Kuldana Formation, such as geometry of sandstone and conglomerate beds, abundance of mudstones and, fewer, rather immature development of paleosols, suggest for a mosaic of floodplains, lakes and inland draining shallow channels. The Kuldana landscape was rather a muddy floodplain with shallow perennial channels bringing sediments from the low highlands in the north and draining into shallow small lakes. The lakes were a permanent feature of the landscape but did not have much topography and perhaps were filled up with finer sediments with occasional coarser sediments during wetter periods of higher discharge in the inland rivers. The floodplain was drowned rapidly in the Upper Kuldana interval establishing open marine environment for the succeeding Kohat shales.

The lithological composition of Kuldana Formation in southeastern Hazara resembles to the Kala Chitta Range sequence. It is likely that same depositional environment was in existence in both of these regions and may in fact constitute one continuous sub-basin for the Kuldana interval. The nature of the Kuldana-coeval landscape in other adjacent sub-basins is the next topic investigated here.

COMMENTS ON REGIONAL STRATIGRAPHY

Lithostratigraphy of the Kuldana and coeval sequence in adjoining regions

The terminal Eocene stratigraphy of other areas of Western Himalayas is briefly reviewed to understand the contemporaneous development of various lithofacies association in the region (Fig. 3). The Kuldana Formation forms an almost continuos east-west trending outcrop belt from southeastern Hazara through the Kala Chitta Range to Kohat sub-basin (Fig. 3). It also extends to the northeast from Hazara to the Balakot areas where it is a part of highly tectonized sedimentary sequence in the Hazara-Kashmir Syntaxis (Fig. 1). Beyond the Balakot areas, the Kuldana Formation *per se* cannot be recognized but rather becomes a part of the Subathu-type sequence.

The Himalayan foreland basin east of the Hazara-Kashmir Syntaxis during the Paleocene-Eocene interval has a rather mudstone-shale dominated sequence. The sediments, generally called Subathu Group, range in thickness from 170m to 400m and at places are divisible into two or more formations (Fig 2; Nanda & Kumar, 1998). Sedimentation in the Subathu sub-basin began in late Paleocene continued to early middle Eocene (Mathur & Juyal, 2000). The upper part is a red bed unit, also designated as Red Subathu, which has been considered coeval with the Kuldana Formation. The redbed unit consists of variegated (gray, green & red) shale and mudstone with thin intercalations of gray oyster-bearing limestone, very fine sandstone, and occasional ferruginous pisolitic granulestone beds. It contains pulmonate gastropods and a land-dwelling vertebrate fauna. The vertebrate fauna comes from one or two discrete stratigraphic levels in the upper 20 m of the Red Subathu. These bone beds serve as a good marker horizon for chronostratigraphic correlation in the Subathu outcrop-belt (Nanda & Kumar, 1998). The red bed unit is overlain by green or white orthoquartzitic sandstone of the Murree/Dagshai formation of late Oligocene to basal Miocene age (Najman & Garzanti, 2000). The sharp change from the red mud of the Upper Subathu to the white fluvial sandstone of the Neogene Murree/Dagshai sequence marks the pervasive terminal Eocene unconformity of the Himalayas. The Subathu Group largely is a shallow marine deposit with several short regressive episodes when near shore to tidal flat environments prevailed in the region. The upper Red Subathu is a near shore to fluvial channel-floodplain deposit with clastic inputs from the rising Himalayas in the north, similar to the Kuldana depositional regime of the neighboring Hazara-Kala Chitta Ranges.

To the west of the Kala Chitta Range in the Kohat sub-basin, the Eocene stratigraphy is quite different, perhaps being directly affected by the tectonics of the Waziristan-Khost ophiolite belt in the immediate vicinity (Fig. 1, Tables 1 & 2). Pivnik and Wells (1996) while putting the Paleocene-Eocene stratigraphy of the Kohat sub-basin within the framework of the regressive Tethys seaway have identified two main lithofacies associations of the Kuldana coeval sequence, namely the Mami Khel Formation and the Gurguri Sandstone. Following Meissner et al. (1974), they retained the name Mami Khel Formation for the red and green clays with thin bands of calcareous granulestone and red sandstone (Fig. 4). The uppermost part of the Mami Khel Formation is generally composed of variegated shales, limestone, sandstone, siltstone, and localized gypsum that is transitional with the overlying Kohat Formation. The Mami Khel Formation is recognizable in most parts of the basin except in the northwest portion. Here, the 'Gurguri Sandstone', composed of red cross-stratified sandstone and pebble-to-boulder conglomerate consisting of chert and limestone clasts, is developed. Pivnik and Wells (1996) contend that the Mami Khel Formation and the Gurguri Sandstone are the distal and proximal parts, respectively, of a local fluvial-delta system prograding from the northwest. The uppermost portion of the Mami Khel Formation, however, shows a gradual return to marine conditions, from lagoonal-coastal plain environment to the open shallow marine conditions of the Kohat limestone. The Kohat marine transgression also extended eastwards to southern Kala Chitta Range where the top Kuldana brackish to marine beds give way to open shallow marine Kohat shales with abundant foraminifers. The Kohat sub-basin in the Eocene gradually became a restricted shallow marine basin culminating into the coastal plain to fluvial deposit of the Mami Khel-Gurguri suite. The marine transgression responsible for Kohat foraminiferal shales and limestones prograded from the Waziristan-Sulaiman region in south-southwest where stable marine conditions prevailed for most of the Paleocene and Eocene times.

The most complete Paleocene-Eocene sequence in terms of thickness and time in Western Himalayas, is developed in the Waziristan and Sulaiman ranges, which form the north and eastern part of the Middle Indus Basin (Fig. 1; Eames, 1952; Kazmi & Jan, 1997). The Paleocene to early Eocene sequence is broadly similar to the western Kohat stratigraphy. The Ghazij Group rocks of early Eocene age are dominantly green gray shale and mudstone (Shaheed Ghat Formation) with relatively thinner limestone (Drug Formation) followed upsequence by mudstone-gypsum (Baska Formation) units (Fig. 2; Shah, 1990). The sequence indicates deposition in open marine relatively deeper waters with gradual shallowing up of the basin resulting into the sabkha-like situation in the uppermost portion. At the same stratigraphic level, farther to the west, a thick sequence of mudstone, sandstone and occasional fine conglomerate with several coal beds (the Toi Formation) is present. The Toi Formation is a part of a delta-floodplain system, which may well have extended into the western part of the Kohat sub-basin where Gurguri Sandstone was deposited. The Toi Formation is also overlain by the gypsum-bearing Baska Formation. Another red-brown mudstone and shale sequence with two prominent thick gray and white limestone and marl units of middle to late Eocene age complete the marine deposition in this region. These are the Habib Rahi (gray limestone dominant), Domanda (red mudstone with rare gypsum beds in the upper portion), Pirkoh (white marl and limestone) and Drazinda (red mudstone dominant) formations (Fig. 2). The lithology and foraminiferal faunas of the Paleocene-Eocene sequence of the Sulaiman Range indicate presence of several transgressive-regressive cycles that has been correlated with global eustatic sea-level changes (Afzal et al., 1997; Jones, 1997; Warraich et al., 1997).

It appears that on a regional scale in the Western Himalayas there was a major shift in sedimentation pattern recorded in the Upper Subathu, Kuldana, Toi and Baska formations. All these formations were deposited in marginal marine to fluvial environments. This transition has been related with the Himalayan orogeny but it is also likely that the end-Ypresian global eustatic lowstand accentuated a major regression in the Foredeep. In the Subathu sub-basin extending westwards to southeastern Hazara, they represent the last depositional episode related with the Neotethys seaway. Further to the west, from the Kala Chitta Range to Kohat sub-basin, and from there to the Sulaiman Range, the marine conditions returned for a short period until the Neotethys seaway was completely squeezed out of the region by early late Eocene.

Age of the Kuldana and Upper Subathu formations

The exact age determination of the Kuldana and coeval beds is important for understanding the evolution and dispersal of mammals in South Asia. And also as these formations contain clastic sediments of definite Himalayan provenance, their age assessment has a bearing on the timing of the continent-to-continent collision of the Indian plate with the Asian plate(s). Earlier students of Indian Tertiary geology considered the age of the Kuldana Formation in the Kala Chitta Range and 'Lower Chharat' in the Kohat area as late 'Laki' (=Ypresian) or early 'Kirthar' (=Lutetian) based on larger foraminifera from the overlying Kohat Formation (Pinfold, 1918; Davies, 1926; Cotter, 1933). The larger foraminiferal assemblages from the underlying Chorgali and Margalla Hill Formations in the Kala Chitta Range and the Shekhan Formation in the Kohat sub-basin give an early Eocene age (Eames, 1952; M. Akhter, Person. Commun.). The Upper Kuldana does contain a few milliolids and other benthic foraminifers but these are not diagnostic for any age determination. The age of the Kuldana Formation based on its stratigraphic position, thus, can be assessed as ranging from latest Ypresian to early Lutetian. Similarly, early Lutetian age (Zone P10/SBZ 13) has been suggested for the vertebrate-bearing Upper Subathu formation on the basis of larger foraminifera and ostracoda in the underlying sediments (Mathur & Juyal, 2000). These Upper Subathu beds like the Kuldana Formation of the Kala Chitta Range, besides mammals also contain a few broken non-diagnostic molluscs. It is overlain unconformably by the green and purple sandstone of the Dagshai formation that has recently been dated by $^{87}Sr/^{86}Sr$ to be about 25 Ma (Najman et al., 2000). A general consensus among those who trust the Himalayan larger foraminiferal biochronology is that the Kuldana and its coeval Upper Subathu are of latest Ypresian to early Lutetian age, approximately corresponding to Planktonic zone P9 to lower P10. This assessment also coincides with the eustatic lowstand at the Ypresian/Lutetian transition. The marine transgression noted in the Upper Kuldana continuing to the shallow marine fossiliferous Kohat Formation can, then, be correlated with the prominent global flooding event in early Lutetian, the TA 3.2 sequence, of Haq et al. (1987).

Thewissen et al. (2001) has reconsidered the age of the Kuldana and Upper Subathu formations exclusively on the basis of mammalian faunas contained therein. Their continued paleontologic research on the Kuldana Formation exposed in the Kohat, Kala Chitta Range and the Murree-Kuldana areas have provided a much larger database to compare the Himalayan mammalian fauna with early Tertiary faunas of Asia, Europe and North America (for more details see Thewissen et al., 2001). They identified five local faunas in the Kuldana-Upper Subathu sequence, namely, the Banda Daud Shah and the Chorlakki in Kohat, the Ganda Kas in Kala Chitta Range, the Gali Jagir in Khairi Murat Range, and the Kala Kot local fauna in Jammu (Fig. 5). Based on the mammal assemblages from each of these local faunas, they assigned ages comparable to the Bumbanian-Irdinmanhan Land Mammal ages of Asia equivalent to the Wasatchian to Bridgerian of North America land Mammal age. They considered the Banda Daud Shah as the oldest (Early/Middle Wasatchian), the Ganda Kas (Late Wasatchian) and the Gali Jagir and Kala Kot faunas (Bridgerian). However, the Chorlakki local fauna, located halfway between Banda Daud Shah and Ganda Kas, is the largest mammal locality and has a mix of faunal elements of all the other local faunas. Their age assessment is a substantial departure from the generally perceived age of these beds. They suggested that the Kuldana-Upper Subathu are diachronous on the order of about 4 my, the oldest in Kohat (Banda Daud Shah) of early Ypresian (=Early Wasatchian) and youngest is early Lutetian (=Bridgerian) in Jammu (Kala Kot) in the east. Their analyses also implied a much older age (early Ypresian) for the Kuldana (=Mami Khel) Formation of Kohat sub-basin. The Kuldana Formation of the Kala Chitta Range, which has yielded the best fauna, is assigned a late Wasatchian age corresponding to late Ypresian. The suggested chronology of Thewissen et al. (2001) demands another look on the paleogeographic development of the Himalayan foredeep and timing of the uplift of the incipient Himalayas.

The regional tectonostratigraphic frame, the foraminiferal assemblages of the underlying and overlying units and the broad similarity with the Eocene eustatic sea-level changes favor late Ypresian to base Lutetian age for the Kuldana and Upper Subathu formations in Western Himalayas. However, the chronology based on mammalian faunas suggest different ages for the outcrops of the Kuldana Formation in Kohat sub-basin and the Kala Chitta Range,. and for the Upper Subathu formation in the Subathu belt. It is interesting to note a consensus on a late Ypresian age for the Kuldana Formation of the Kala Chitta Range. Thewissen et al. (1998) documentation of vertebrate faunal localities from the Kuldana Formation in the Kala Chitta Range shows that both the Lower and Upper Kuldana are fossiliferous. Notwithstanding the structural complexity hindering stratigraphic interpolation of localities, it is most likely that fauna is coming from a number of stratigraphic levels. Thewissen et al. (2001) emphasized grade of evolution for relative ages though aware of ecological, environmental and taphonomic biases in vertebrate faunal localities. It is likely that additional vertebrate faunal collections in the Kohat and Subathu basins may require another biochronological reassessment of the Kuldana/Upper Subathu sequence.

SYNTHESIS

An overview of the Paleogene history with reference to developments in the Kohat-Potwar region is presented here. The objective is to demonstrate the relationship between the sediments deposited in the Foredeep and the Himalayan orogeny, a topic which, among others, has recently been discussed by Pivnik & Wells (1996) with stratigraphic details from the Kohat sub-basin. The Paleogene sediments of the Pakistani Himalayas preserve the passive continental shelf part of the Foredeep where changes in the basinal topography are well reflected in the spatial-temporal development of various lithofacies associations.

The initial collision phase of Himalayan orogeny causing the obduction of ophiolite melange on the northwestern margin of the Indo-Pakistan produced the Foredeep basin along the south side of the Suture Zone. The Western Himalayas portion of this Foredeep Basin contains about 500m to as much as 1800m of shallow marine mudstone-carbonate sediments deposited during Paleocene to middle Eocene interval. The depocenter during this interval was apparently shifting in a westerly-southwesterly direction. Shelf mudstone remains the dominant facies but thicker carbonate-rich units, constituting locally to as much as 40% of the total sequence, are mostly restricted to the central portion corresponding to the Hazara-Kala Chitta-Potwar region. Lithofacies details further show that local tectonics also had affected sedimentation within each of the sub-basins. The Paleocene sequence is generally a mix of carbonates and mudstones with minor proportions of sandstone. Thicker sandstone units occur in the basal part (Hangu Formation) and also as thin interbeds associated with carbonaceous shale/coal beds in the Upper Paleocene Patala Formation. Some thinner carbonaceous shale interbeds also occur at the base of the Subathu Group of Kashmir and Himachal Pradesh. Open marine conditions returned in the region by latest Paleocene to earliest Ypresian interval depositing thick shelf carbonates and green gray shales (Margalla Hill and other coeval formations). This subsidence event is most likely related with the beginning of continent-to-continent collision around the Paleocene-Eocene boundary (Najman & Garzanti, 2000).

Similar evidence of lithospheric flexural subsidence on the northwestern margin comes from the Paleocene argillaceous sediments of the adjoining Kohat sub-basin (Beck et al., 1995; Pivnik & Wells, 1996). The Patala coeval rocks in the Kohat area (the Tarkhobi shales of Eames, 1952; Fig. 4) are organic rich black shales with common 'brecciated limestone' intercalations containing broken larger foraminifera and algae. The deposition of the Tarkhobi shales in a deeper euxinic basin with carbonate debris flow from the nearby eastern shelf indicates a sudden deepening of the Kohat sub-basin adjacent to the shallow shelf margin. A similar development of deeper water euxinic shales is also reported in upper Patala Formation in the western Salt Range (Afzal & Daniels, 1991), arguing for a regional subsidence event. In the Kohat sub-basin, the Tarkhobi shales pass imperceptibly into a much thicker green gray Panoba shales sequence which in the western part spans the entire Paleocene-early Eocene interval (Wells 1984). The open marine Panoba-like gray-green mudstone sequence continues farther to the west and south in the Waziristan-Sulaiman ranges, where it is known as the Rakhi-Gaj Formation. In the Sulaiman Range and the areas to the west, open marine deposition continued unhindered from late Paleocene through middle Eocene (Afzal et al., 1997; Warriach et al., 1997).

Sometimes in middle to late Ypresian, all the sedimentary facies association in the Western Himalaya (be it carbonate-rich Margalla Hill/ Sakesar or mudstone rich Subathu and Panoba formations) show shallowing upwards trend. Accompanied with it are the local developments of evaporites (Bahadur Khel Salt and Jatta Gypsum in

Kohat, 'Eocene gypsum' in western Salt Range), intertidal to supratidal dolomites and mudstone (Chorgali Formation in Khairi Murat Range), and relatively thicker coarser grained siliciclastics interbeds in the upper Panoba and the Middle Subathu formations. This general regression is an indication of ongoing convergence after the contact with the northward subduction zone had occurred. However, there is no evidence for the detrital sediment input from the north in any of these formations, even though the passive shelf margin was perhaps within a few tens of kilometers from the site of incipient Himalayas (Rowley, 1996). For instance, clay geochemistry of a 3-20 m thick mudstone unit between the Bahadur Khel Salt and the Jatta Gypsum in southern Kohat suggest highly acidic source rocks (similar to granite) with very little contribution form basic rocks (Saleemi & Ahmed, 2000). The most likely provenance for such granite massif is the nearby Proterozoic Indian shield landmass in the east. The implication is that the Himalayas was yet to attain a topographic relief for becoming the main detrital sediment source.

The overlying red mudstone-sandstone units, the Kuldana Formation and the Upper Subathu Group, are the first near-shore to fluvial sequence, that also contain clastics from a northern provenance. The petrography and heavy mineral assemblages of sandstone interbeds are remarkably similar throughout the outcrop belt from the Subathu of Simla in Himachal Pradesh to the 'Gurguri sandstone facies' in western Kohat (Wells 1984; Pivnik & Wells 1996; Nizamdin et al., 1998; Najman & Garzanti, 2000; Najman et al., 2000, 2001). Quartz constitute 46% to 60% of total framework grains and are dominantly of monocrystalline type. Lithic fragments, the second-most abundant constituent, comprise 35% to 52% of the total framework-grain population. Sedimentary rocks fragments form the majority of the lithics whereas metamorphic- and volcanic-lithics are almost absent to rare. Feldspar occur in negligible amounts, ranging from 0.5% to 5%. All these parameters plot in the recycled orogene provenance field of Dickinson (1985). However, there are subtle differences in mineral composition in sandstones of Upper Subathu and those of the Kuldana Formation. For example, volcanic grains constitute the bulk of the lithics in the Upper Subathu but are totally absent in the Kuldana sandstones of Kohat. Similarly, feldspars make $<1\%$ of total composition in Kohat sandstones but are around 5% to as much as 9% in the Subathu. It is interesting to note that in the adjacent northern Middle Indus Basin, the sandstones of the coal-bearing Toi Formation of similar mineralogy have almost no feldspars but an abundance of volcanic lithics (Warwick et al., 1998). The concentration and isotopic composition of detrital Spinel group minerals found in all sandstone units also suggest some input from ophiolitic and mafic source rocks (Warwick et al., 1998; Najman et al., 2000). Sandstone petrography, heavy mineral composition, and paleocurrent data suggest the source rock was in the north and northwest in the newly risen proto-Himalayas. The sedimentary, volcanic, and ultramafic rocks of the Indus-Tsangpo Suture Zone and the sedimentary rocks of the adjacent Tibetan Sedimentary Series are the likely provenance for the Upper Subathu formation (Gaetani & Garzanti, 1991; Garzanti et al., 1996; Najman & Garzanti, 2000). The Zhob-Waziristan-Khost Ophiolite Zone, bordering the Indus Basin in the west were the highlands providing the bulk of detritus for the Kuldana sandstones and also for the Toi sandstone in the northern Middle Indus Basin (Nizamdin et al., 1998; Warwick et al., 1998). However, the abundance of sedimentary lithics (dominantly limestone and chert) and absence of igneous and volcanic rock fragments in the Kuldana sandstones suggest that erosion mainly affected the cover sediments of the Waziristan-Khost Ophiolite Complex and did not go deep down to the ophiolitic sequence (Beck et al., 1996; Nizamdin et al., 1998). But further to the west, there was not much cover sediment as the Maastrichtian-Paleocene Zhob-Muslimbagh ophiolites were contributing mafic and volcanic detritus to the Toi sandstones (Warwick et al., 1998). The Kuldana Formation, Upper Subathu formation and the Toi sandstone are, thus, among the oldest syncollisional deposits preserving the earliest record of the Himalayan orogeny.

The Kuldana and the Upper Subathu formation are the terminal Eocene sediments for a large portion of Western Himalaya east of Longitude 72°50'E, extending from southeastern Hazara to the entire Subathu outcrop belt. The Paleogene Foredeep turned into a non-deposition lowland region and remained so until another dominantly terrestrial sedimentation episode depositing the Dagshai/Murree formations began in late Oligocene to early Miocene times. However, marine conditions temporarily returned to the Kala Chitta Hills and Kohat sub-basin. The topmost beds of Kuldana Formation record a return to marine conditions, which was fully established in the limestone-dominant Kohat Formation. The Kohat Formation is better developed in Kohat region where it is in strike-continuity with the Habib Rahi Formation of the Sulaiman Range (Shah, 1977; Table 1). The lower 'Nummulitic shale' part of the Kohat Formation extends in to the Kala Chitta Hills where it forms a thin wedge (~5 to 10 m) of green gray shales with abundant *Nummulites*. The Kala Chitta region was thus the coastal part of the 'Kohat limestone basin', which in the southwest was connected with the Sulaiman Range Eocene basin. There is no apparent correlation for this early Lutetian transgression with any notable Himalayan tectonic event. It is likely related to the early Lutetian highstand of the global sea level, which accompanied by movements along the Chaman Fault system in the west, may have caused a flexural subsidence in the Middle and Lower Indus Basin of Pakistan, extending northwards to the Kohat sub-basin. The depocenter of the Foredeep for the retreating Neotethys seaway remained in the Middle Indus Basin through middle to early late Eocene interval (Table 1). The Oligocene marine sedimentation was restricted further south to the Lower Indus Basin while the rest of the Indus Basin and the Subathu belt remained as a vast (non-depositional) lowland till the beginning of the Neogene mollase deposition.

The terrestrial sediments of the Kuldana and Upper Subathu formations have another important aspect, as they contain the detritus of Himalayan provenance. The transition from shallow marine to fluvial sedimentation in the Suture zone and the Foredeep is considered to have occurred as a consequence of the final India-Asia collision giving birth to the Himalaya orogene highlands and causing the demise of the Neotethys seaway (Rowley, 1996; Searle et al., 1997; Hodges, 2000). Other geological evidences for this inference come from the timing of eclogite-facies metamorphism of Tibetan zone rocks (~50-55 Ma) and the onset of middle Eocene to Miocene Ladakh mollase developed in the intermontane basin south of the Indus-Tsangpo suture zone (Searle et al., 1997). The near-shore to fluvial Kuldana and Upper Subathu formations are, hence, the oldest Tertiary sequence to contain the sediments shed from the early Himalayan highlands. In this scenario, the development of early Eocene to middle Miocene Balakot Formation in the Hazara-Kashmir Syntaxis (northern Pakistan) was an anomaly. Bossart and Ottiger (1989) named Balakot Formation for a >8 km thick unfossiliferous red mudstone-shale sequence with a few foraminiferal limestone-marl units of late Paleocene to early Eocene age in a complexly tectonized area. The Balakot Formation not only contains ophiolite-derived material from the Suture zone but also from the metamorphic rocks of the Higher Himalayas (Critelli & Garzanti, 1994). It was thus interpreted to be the oldest continental sedimentary succession that contains detritus shed from the Higher Himalayan metamorphic belt. However, the influxes of metamorphic detritus elsewhere in the Foreland are not known earlier than late Oligocene/early Miocene Dagshai and coeval formations. The implication was that the collision was much earlier in the northwest, by about 20 myr than elsewhere, with very rapid exhumation/erosion of the Higher Himalayas and deposition of detritus in the fast sagging terrestrial foredeep in the Hazara-Kashmir Syntaxis and surrounding areas. Najman et al. (2001) has recently clarified this anomaly by asserting that the limestone-marl units containing late Paleocene to early Eocene foraminifers are in tectonic contact with the red-beds of Balakot Formation. Najman et al. (2001) using ^{40}Ar-^{39}Ar dating on detrital white mica grains from the Balakot Formation suggested an age of <35 Ma, as the mica population age is 36-40 Ma for the time of cooling and exhumation in the Himalayan source region. A similar age bracket is given for the detrital mica from the Dagshai sandstone unconformably overlying the Subathu group in its type area in Himachal Pradesh (Najman et al., 2000). It is interesting to note that Wadia (1928) while mapping the Hazara-Kashmir Syntaxis region, had also suggested a structural relationship for thin slivers of 'Paleocene Nummulitic Limestone' interspersed within thicker imbricated red beds of 'Murree formation' (=Balakot Formation).

This early Eocene phase of Himalayan orogeny mainly affecting the northwestern margin of the Indian plate also disrupted the Neotethys seaway that, since the Triassic, had separated the Indian subcontinent from Asia. By early middle Eocene, the Foredeep basin (now forming the Western Himalayas) was a vast lowland and the proto-Himalayas, including the Pakistan 'Ophiolite belt', was a mountain chain of some topographic relief. The Neotethys was, thus, much restricted but still separated the western margin of the Indian Plate from the Afghan block. A branch of the Neotethys continued to remain on the passive shelf margin of the Middle and Lower Indus Basin, bordered in the north and west by the Ophiolite belt highlands. The Neotethys, on the other side of the Pakistan Ophiolite belt, developed another deeper and much larger longitudinal basin bordered on the north and west by the Lut-Afghan microplates. This new configuration, called the Katawaz-Makran basin, became the main depocenter for the sediment shed from the Himalayas for most parts of the Tertiary times beginning from middle Eocene (Qayyum et al., 1997). The Makran-Katwaz basin, hosting several kilometers of flysch sediments, was fed by an east-to-west axial fluvial system draining the proto-Himalayas. This fluvial system deposited the Ladakh mollase from middle Eocene to early Miocene interval.

On another note, the early Eocene tectonic developments provided filter land bridges for migration and dispersal of mammals between the Indian and Eurasian landmass. The mammalian fauna of the Kuldana/Upper Subathu in the Foredeep shows a mixture of endemic elements with a few of Asian, European and North American affinities (Thewissen et al., 2001). The lower part of the Ladakh mollase has also yielded a small late Eocene and Oligocene mammalian fauna, which has endemic small mammals with Kuldana ancestry but larger mammals that are a mix of Eurasian and North American elements (Kumar et al., 1996). However, continued convergence expanded the land but gradually uplifted the Himalayan ranges into a formidable topographic barrier precluding any migration from the northern passages by middle Miocene.

CONCLUSIONS

The red mudstone-dominant Kuldana and Upper Subathu formations in the Western Himalaya represent the terminal filling of the shallow marine Foredeep basin which developed as the India-Asia collision began with the obduction of ophiolites on the Indian continental shelf during late Cretaceous to early Paleocene. Though the convergence continued in the Indus-Tsangpo Suture zone, the shelf regions largely remained unaffected until late early Eocene, subsiding passively to allow deposition of shallow marine fossiliferous carbonates and shales. In terms of time and thickness (i.e. sedimentation rate), it appears that Subathu Group has a rather condensed sequence but better temporal completeness is evidenced farther west in the Hazara-Kala Chitta region. It is by middle to late Ypresian that the Himalayan orogene attained some topographic relief and thereby began shedding sediments in the Foredeep. This rapid sediment influx choked the Foredeep turning it into lowland and forcing Neotethys to recede westwards. It is on this lowland with fluctuating shorelines, lagoons and shallow channels that the Kuldana and Upper Subathu formations were deposited. This non-marine phase may have perhaps taken a relatively short period of only 3 or 4 million years to fill the Foredeep and convert the entire region into a non-deposition plane. The situation in Kohat sub-basin is slightly different where the Gurguri/Mami Khel facies was evidently deposited in a continental foreland basin setting. The region was in much closer proximity with the uplifted Waziristan-Khost ophiolite zone which directly affected the development of this local 'embryonic terrestrial foreland basin' (*sensu* Pivnik & Wells, 1996). The entire Pakistan Ophiolite zone was a narrow highland belt in early Eocene separating the Indus Foredeep in the east from the open marine relatively deeper Katawaz-Makran basin of the Neotethys in the west. The newly risen Himalayan highlands apparently underwent 'immediate' weathering contributing immature clasts to the nearby basins. During this reorganization, the deposition loci shifted to the north, close to the suture zone, where an axial fluvial system depositing the Ladakh Mollase developed by late middle Eocene. The Ladakh fluvial system drained west to Katawaz-Makran flysch basin, which was the main depocenter of early Himalayan marine sediments prior to deposition in the Indus Fan during Neogene. There were also several localized deltaic-fluvial depocenters along the Ophiolite zone in the early Eocene; the Gurguri-Mami Khel system in the Kohat sub-basin is one of the best documented. These systems were completely revamped by early/middle Eocene transgression submerging a substantial portion of the Ophiolite belt as well. As stated before, the early Lutetian (middle Eocene) transgression was not triggered by any tectonic event, but may be there was some intrinsic relation with the initiation of the Ladakh mollase deposition, such as lowering the base level for degradation, and the global eustatic highstand cycle at base Lutetian. By early late Eocene, the entire Western Himalayan Foredeep was a peneplain as the Neotethys depocenter shifted to the newly created Katawaz-Makran basin to the west and north of the Pakistani Ophiolite belt outside the realm of the Indian plate.

Acknowledgements: Special thanks are to Dr. J. G. M. Thewissen, Ms. Ellen Byron, Dr. Andres Aslan and Mr. M. Arif for sharing their field notes and unpublished data on the Eocene sediments of the Kala Chitta Range. Dr. A. Aslan measured the stratigraphic sections presented in Fig. 5. Ms. Lauren Stevens drew Figures 1 and 3. Critical reviews by Dr. Mary Maas and Dr. Hans Thewissen substantially improved an earlier draft of this manuscript. Support for fieldwork was provided by the National Science Foundation grant to Dr. J. G. M. Thewissen and Dr. S. Taseer Hussain.

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