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Integrated Paleogene Sequence Stratigraphy of the Kohat Basin, Northwest Pakistan.

ABSTRACT

In this paper we present how synthesis of the Palaeogene foraminiferal biostratigraphy and sedimentological information augment the understanding of evolution of the depositional sequences in a very crucial time in the tectonic history of the Kohat Basin, north-western Pakistan. The foraminiferal biostratigraphy helped in constraining the geological ages of the stratigraphic units and its integration with the facies data provided insight into the stratigraphic framework for the identification and interpretation of the synchronous depositional sequences. The identified depositional sequences of the Kohat Basin in this study are defined as SK 1-2 and are separated by SBK 1-2 sequence boundaries. The depositional profile of the study area is consistent with a distally steepened carbonate ramp platform.

A comparison of sea level changes with the Eustatic Sea Level Charts revealed a close match up between eustatic sea level fall around 49.5 (m.a) and a proto closure of the basin is indicated while a complete closure of the basin took place at 41.2 (m.a) which implies that full collision of India-Asia took place at this time.

INTRODUCTION

The paleontological and sedimentological data help in constraining the sequence stratigraphic models (Gregory and Hart 1992). There are no fossils that are unique to certain system tracts/sequences to help in identifying position in systems tract (Gorsel 1988). Foraminiferal diversity and abundance in condensed sections can be used to constrain sequence boundaries and systems tracts (Rosen and Hill 1990). The arenaceous benthic forams (flysch fauna) reflect rapid mud deposition and characterize deep marine facies which are representative of a lowstand fan or distal lowstand wedge portion of a lowstand systems tract (Gorsel 1988). Transgressive systems tracts are dominated by marine processes (waves, tides), low water turbidity favoring the presence of larger forams, glauconitic/calcareous beds and reefal buildups (Gorsel 1988). In turbid water of highstand systems tract, fluvially dominated (HST) foraminifera like Ammonia and Pseudorotalia dominate in shallow parts while Bolivina dominates in deeper parts (Rosen and Hill 1990). Sequence boundaries calibrated with biostratigraphy can be correlated across the carbonate platform from proximal to distal positions, in comparison with the global sequence stratigraphic framework most exposure surfaces correlate with sequence boundaries. Biostratigraphy allow us to utilize the full suite of paleontological data for more detailed stratigraphic applications. Quantitative techniques result in more precise geochronology, the recognition of depositional environments, paleobathymetry, and key stratal surfaces (condensed intervals, maximum flooding surfaces and unconformities), rates of sediment accumulation, and climatic changes (Wescott and Ethridge 1980). Microfacies analysis aided by outcrop and fossils interpretation yields sufficient information about paleoenvironments and bathymetric changes and it is important for the construction of a sequence stratigraphic framework for carbonate/clastic mixed systems (Serra-Kiel et al., 2003). We use outcrop data for foraminiferal biostratigraphy and paleoecology that help in facies interpretation to delineate synchronous depositional sequences of the Paleogene rocks in the Kohat Basin of north-west Pakistan.

TECTONIC SETTINGS

The Kohat Basin forms a plateau in a structurally defined foreland fold and thrust belt also known as Kohat-Potwar fold and thrust belt (Figure 1). The Kohat plateau, an approximately 10,000 km2 area of rugged, unvegetated hills is bounded to the north by the Main Boundary Thrust fault system (MBT) (Pivnik and Wells 1996) which contains highly deformed, Pre-Cambrian-Cenozoic sedimentary rocks (McDougall and Hussain 1991). Potwar plateau in the northeastern part of Pakistan. The Kurram Fault forms the western boundary and the Indus River forms the eastern boundary, separating the Kohat Plateau from the topographically subdued Potwar Plateau (Khan, et al., 1990).

METHODS

In the selected key stratigrahic sections (Figure 2) Paleogene succession has been studied. The vertical stacking of the beds, biota and other sedimentary features (depositional and erosional) and missing biozones have been described to identify different depositional sequences. The systematic rock sampling covers 340 samples at 1ft-15ft interval for a detailed facies analysis at macro- and microscale. The lithofacies description is based on the outcrop investigations

and microfacies analysis is based on microscopic investigation of thin sections. The microfacies categories are based on the details of allochems (skeletal and non-skeletal grains), matrix and textural features, abundance, type and size of the foraminiferal tests as well as other skeletal grains (brachiopods, bivalves, gastropods, echinoids, and ostracodes and algae. The non-skeletal components (ooids, grapestones, peloids and intraclasts) provide valuable information for the interpretation of depositional environments. The identification and semi-quantitative data on the component distribution of thin sections was using Comparison Charts (Bosellini 1989).

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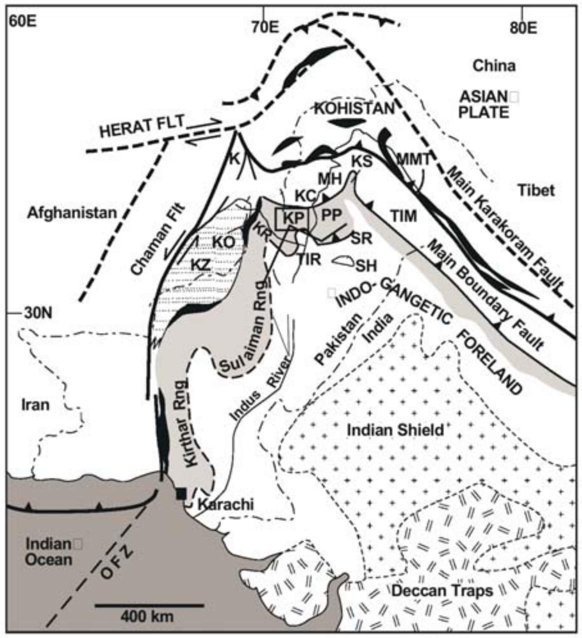

Figure 1 - Tectonic map of northern Pakistan showing location of the study area (KP) and position of the Asian Plate, the Kohistan Island Arc, the telescoped northern Indian Continental margin (TIM), major ophiolites (black), the deformed foreland basins (light shaded) , the undeformed Indo-Gangetic foreland and Indian Shield. Abbreviations are: K-Kabul Block; KC-Kala Chatta Range; KO-Khost Block; KP- Kohat Plateau; KR-Kurram River; KS- Kashmir Syntaxis; KZ-Katawaz Flysch Basin; MH- Margalla Hills; MMT- Main Mantle Thrust; OFZ- Ocean Fracture Zone; PP- Potwar Plateau; SH- Sargodhah High; SR- Salt Range Thrust ; TIR- Trans Indus Ranges (modified after Pivnik and Wells 1996).

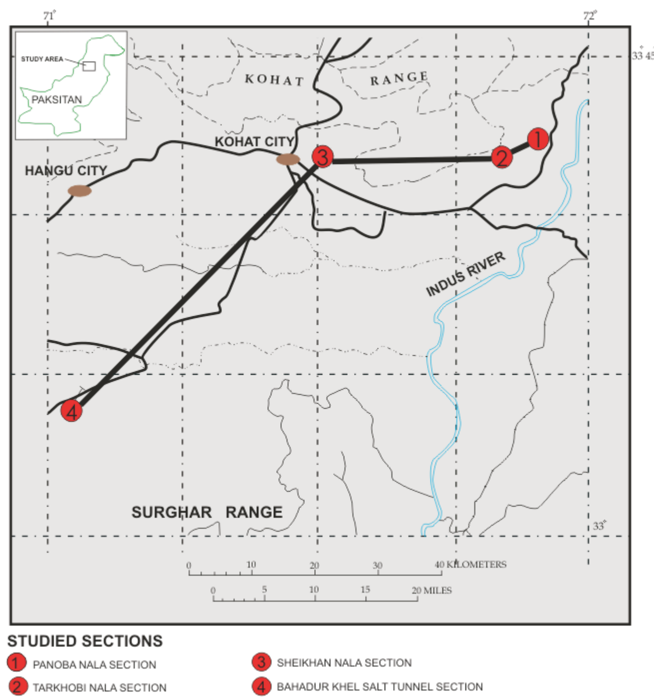

Figure 2 - Location map of the studied sections in the Kohat Basin.

BIOSTRATIGRAPHY

In this study biozonal scheme developed by Ahmad (2010) for the Paleogene rocks of the Kohat Basin is used. The first and the last occurrence / appearance of the age diagnostic species of Nummulitids and associated foraminifera provided the basis for establishing biozonal boundaries. These zonal boundaries divided Paleogene rocks of the Kohat Basin into six local biozones which are Taxa, Lineage and Assebmege types and abbreviated as BFZK (Benthic Foraminiferal Zones of the Kohat Basin) and are briefly described below.

BFZK 1 (Taxon Range Biozone)
Definition

Base of this biozone is taken at the first occurrence of Assilina granulosa and top is taken at the first occurrence of Assilina aff. pustulosa.

It is equivalent to the Standard Benthic Zone SBZ 4-5 (Serra-Kiel, et al., 1998) and represents Thanitian to lower Ilerdian 1 age.

BFZK 2 (Lineage Range Biozone)
Definition:

Base of this biozone is taken at the first occurrence of Assilina aff. Pustulosa / Assilina pustulosa and top of this biozone is marked at the first occurrence of Nummulites atacicus and Nummulites globulus leymerie.

It is equivalent to the Standard Benthic Zone SBZ 6-7 (Serra-Kiel, et al., 1998) and represents lower Ilerdian 2-middle Ilerdian 1, age.

BFZK 3 (Taxa Range Biozone)
Definition

The base of this zone is taken at the first occurrence of Nummulites globulus while the top is not clear due to overlying regressive facies of the Kuldana Formation.

It is equivalent to the Standard Benthic Zone SBZ 8 (Serra-Kiel, et al., 1998) and a middle Ilerdian 2 age is assigned to this biozone.

BFZK 4 (Assemblage Range Biozone)
Definition

The base of this zone is taken at the simultaneous first occurrence of Nummulites beaumonti, Nummulites acutus, Assilina pappilata and the top is taken at the first occurrence of Assilina exponense.

It is equivalent to the Standard Benthic Zone SBZ 14 (Serra-Kiel, et al., 1998) and middle Lutetian 1 age is assigned to this biozone.

BFZK 5 (Taxa Range Biozone)
Definition

The base of this zone is taken at the first occurrence Assilina exponense and the top is taken at the first occurrence of Assilina cancellata.

It is equivalent to the Standard Benthic Zone SBZ 15 (Serra-Kiel, et al., 1998) and middle Lutetian 2, age is assigned to this biozone.

BFZK 6 (Assemblage Range Biozone)
Definition

The first occurrence of Assilina cancellata marks the base of this biozone while the top of this biozone is marked at the last occurrence of Nummulites begalensis.

It is equivalent to the SBZ 16 (Serra-Kiel, et al., 1998) and upper Lutetian age is assigned to this biozone.

SEQUENCE STRATIGRAPHY

Integration of the biostratigraphic and facies information helped in deciphering two depositional sequences SK1 and SK 2 and two sequence boundaries SBK 1 and SBK 2 in the Kohat Basin (Figures 3-6). These are detailed as following.

Sequence SK 1

In the Kohat Basin SK1 sequence (Figures 3-5) is comprised of the Patala Formation (deep basinal to outer ramp facies), overlain by the Panoba Formation (offshore Clays) which in- turn overlain by the Shekhan Formation (platform carbonates) and Jatta Gypsum (Sabkha / lagoonal evaporites). In northeastern part of the basin, black shales and bluish grey fetid limestone of the Patala Formation (lower part of the biozone BFZK 1, representing Thanitian to lower Ilerdian 1 age) is well exposed in the Panoba Nala (Figures 3 and 4) and Tarkhobi Nala sections. The abundance of planktonic foraminifera indicates deposition of fetid limestone and black shales in a transgressive systems tract (TST 1) (Figure 3). In the lower part of the Patala Formation planktonic wackestone interbedded with black shales microfacies (PTK 1) marks the maximum flooding surface (mfs) (Figures 3, 4 and 6). During early Eocene (Upper part of the Biozone BFZK 1, Biozone BFZK 2 and Biozone BFZK 3 representing lower Ilerdian 1 to middle Ilerdian 2 age), deposition of the lower middle to upper part of the Patala Formation and the Panoba Formation on the basinal slope, the Shekhan Formation on a ramp platform, Bahadur Khel Salt and Jatta Gypsum Facies in a restricted lagoonal settings indicate a shallowing upward sequence of the highstand systems tract (HST 1) (Figures 3-6). In the Panoba Nala (Figure 3) and Tarkhobi Nala sections HST 1 is characterized by Nummulitic wackstone microfacies (PTK 2) in lower middle part of the Patala Formation (Figure 3). During highstand progradation a highly fossiliferous, resedimented limestone that represents a mixed faunal packstone to grainstone microfacies (PTK 3) grades upward into the bioclastic mudstone to wackstone microfacies (PTK 4) (Figure 3). This is a thick bedded limestone with interbedded shale with rarely preserved pelagic foraminifera representing a distal outer ramp setting (Figure 3). The green coloured Panoba Clays exposed in the Panoba Nala (Figure 3 and 4D), Tarkhobi Nala and Shekhan Nala sections overlies the PTK 4 moicrofacies and represents a continued progradation of the more proximal Bulimina (BF1) and Uvigerina (BF 2) biofacies on the Bathysiphon Gaudryina (BF3) representing the slope biofacies (Figure 3). In early Eocene (BFZK 2 biozone representing lower Ilerdian 2middle Ilerdian 2 age) shallow ramp carbonates/marls of the Shekhan Formation were deposited in a gradual shallowing upward sequence within the HST 1 (Figures 3 and 4). In the Shekhan Nala Section the lower part is characterized by inner ramp environment followed by an open marine middle ramp to

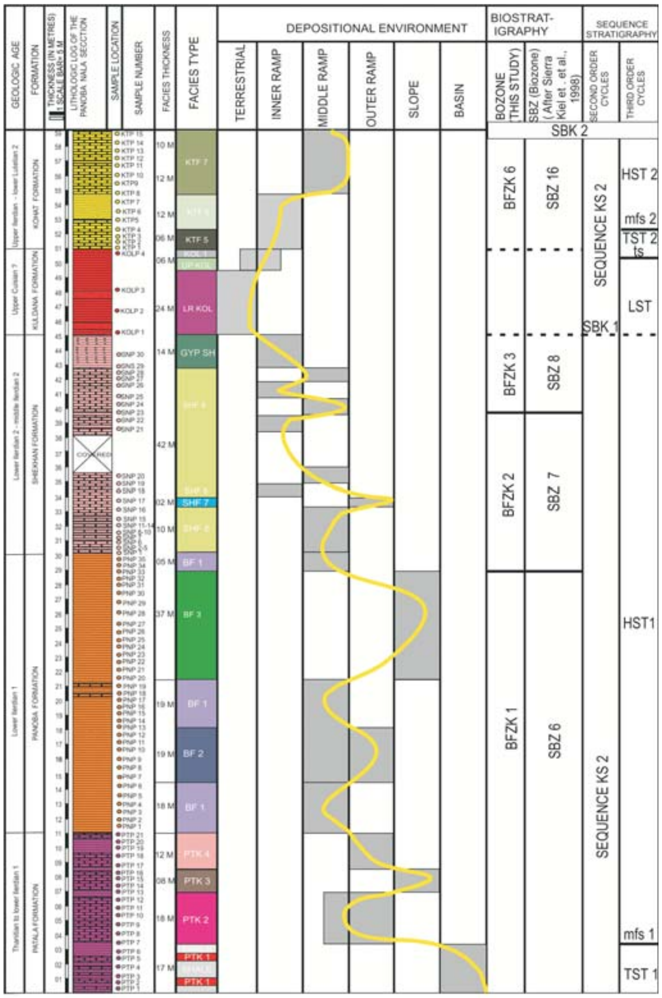

Figure 3 - Representative Paleogene integrated sequence stratigraphic chart showing the distribution of various depositional sequences(SK1-SK 2), Systems tracts (TSTs and HSTs), Sequence boundaries (mfs, SBK 1-2), Biostrtigraphic zones (BFZK 1-6) and facies distribution along with paleoenviromental interpretation in the Panoba Nala section of the Kohat Basin.

restricted inner ramp environment. In the Panoba Nala section (Figure 3) greater subsidence rate provided increased accommodation space and outer ramp facies are deposited in lower part while in the middle part interbedded clays and limestone were deposited. These rocks grades upward into the thick bedded dolomicrites deposited in a sabkha environment during late stage of HST 1. The characteristic foraminiferal fauna of the open marine carbonate plateform in the HST 1 includes Assilina granulosa, Nummulities plnfoldi, Assilina daviesi, Assilina dandotica, Discocyclina sella, Discocyclina dispensa, Discocyclina fortisie, Discocyclina roberti, Discocyclina scalaris and Lepidocyclina.

Sequence Boundary SBK 1

The coastal subkhas forming along the margin of the Shekhan carbonate platform enabled deposition of the Shekhan dolostones and gypsiferous shales in the northeast and thick Jatta Gypsum and Bahadur Khel Salt in the south (representing lower Cusian 2 age) indicate a widespread but short lived regression causing complete absence of marine conditions in the upper Cuisian (latest Ypresian) time in the Kohat Basin (Figures 3-6) that marks the first Sequence boundary SBK 1 in the study area.

Sequence SK 2

Sequence (SK 2) represents fluvial facies of the lower Kuldana Formation and marine carbonates of the Kohat Formation (Figures 3, 5 and 6). Following the early Eocene (middle Ilerdian 2) regression the Kuldana red beds prograded and were deposited in a subsequent lowstand systems tract (LST) (Figure 3). The red coloured fluvialchannel sandstone, flood plain red clays, pebbly conglomerates and enriched mammal bones indicates deposition in terrestrial conditions. Continued subsidence in the Kohat Basin allowed re-establishment of the sea in the middle Eocene that deposited the Upper Kuldana incised valley fill deposits and lower part of the Kohat Formation in a transgressive systems tract (TST 2) (Figure 3 and 6). During the early TST 2 deposition, a purple grey /greenish grey coloured dolomitic limestone with oysters rich bed in the upper part of the Kuldana Formation (lower part of the Biozone BFZK 4 which represents lower Lutetian 2 age) marks the Transgressive Surface (TS) (Figures 3 and 6). In the Shekhan Nala section the maximum flooding surface (mfs) is represented by a highly fossiliferous shale in the lower part of the Kohat Formation (upper part of the biozone 4 which represents middle Lutetian 1 age) while in the Panoba Nala section (Figure 3) and the Bahadur Khel Salt Tunnel section rapid uplift and possibly subsequent erosion did not allow preservation of the Assilina rich bioclastic packstone microfacies which show deposition during maximum transgression. Foraminiferal fauna that characterizes the maximum flooding surface (mfs) includes Assilina granulosa, Assilina subspinosa, Assilina pappiltata, Assilina sub pappilata, Nummulities beaumonti and Nummulities globulus. Subsequent highstand systems tract (HST 2) is represented by a thick sequence of thinly bedded grey coloured nodular limestone in the Shekhan Nala section that shows continuation of the HST 2 deposition on the carbonate ramp which is recorded by the biozone BFZK 4 -BFZK 6 , representing lower Lutetian 2 to upper Lutetian age (Figure 6). Due to local tectonics / uplift of the Kohat Basin a brief period of non deposition (from lower Lutetian 2 to middle Lutetian 1) in the Panoba Nala section (Figure 3) and the Bahadur Khel Salt Tunnel section is recorded by the absence BFZK 4 and BFZK 5 biozones. Thick bedded to massive limestone in the Bahadur Khel Salt Tunnel and the Panoba Nala sections only records biozone BFZK 6, representing deposition in upper Lutetian age (Figure 3). During the HST 2 the bioclastic mudstone to wackestone microfacies (KTF 3) and the Operculina rich bioclastic mudstone to wackestone microfacies (KTF 4) are well developed in the Shekhan Nala section while the gastropod rich mudstone to wackstone microfacies (KTF 5), Nummulitic mudstone to wacksetone microfacies (KTF 6) and the Alveolinid rich bioclastic wackestone microfacies (KTF 7) dominates in the Panoba Nala (Figure 3) and the Bahadur Khel Salt Tunnel section.

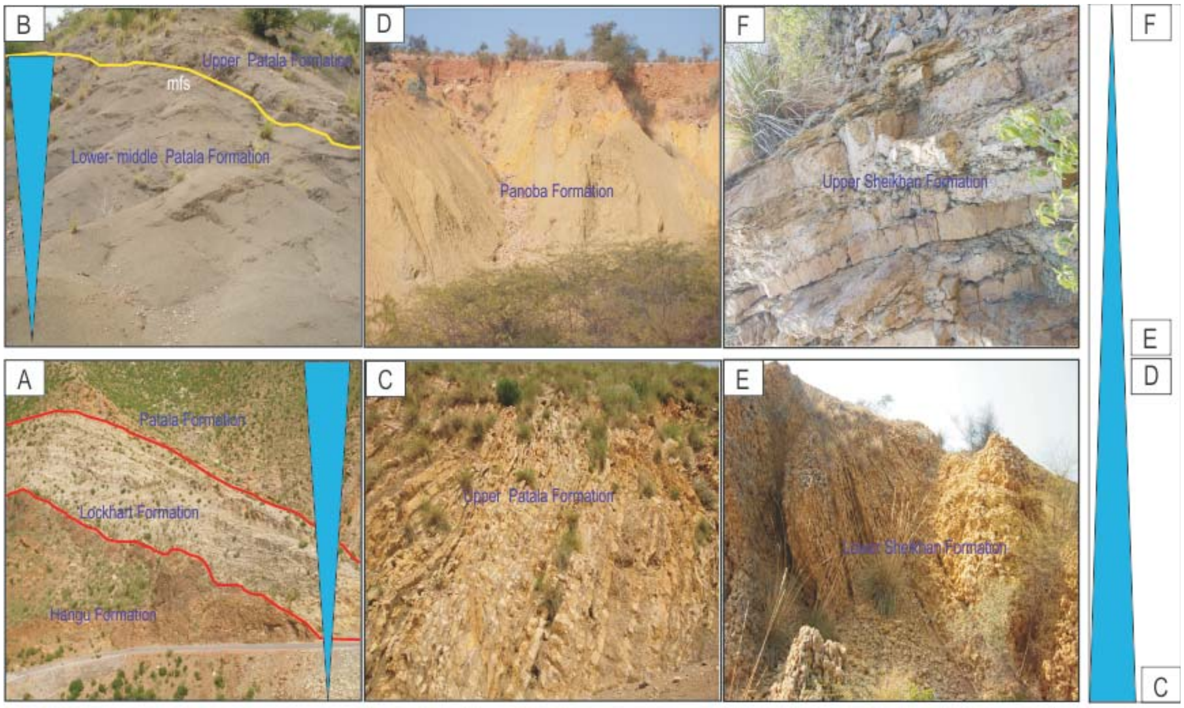

Figure 4 - Photo mosaic of the Sequence SK 1 A) Deepening upward facies trend during Palaeocene TST 1 B) deep marine pelagic shales representing maximum flooding surface (mfs) of TST 1 within the Patala Formation C) Interbedded limestone and shale in upper part of the Patala Formation. A Gradual shallowing upward sequence during HST 1 is represented by the D) Panoba Offshore clays (E), Shekhan ramp carbonates (F) and subkha carbonates and gypsiferous shales (F) exposed in the Shekhan Nala section.

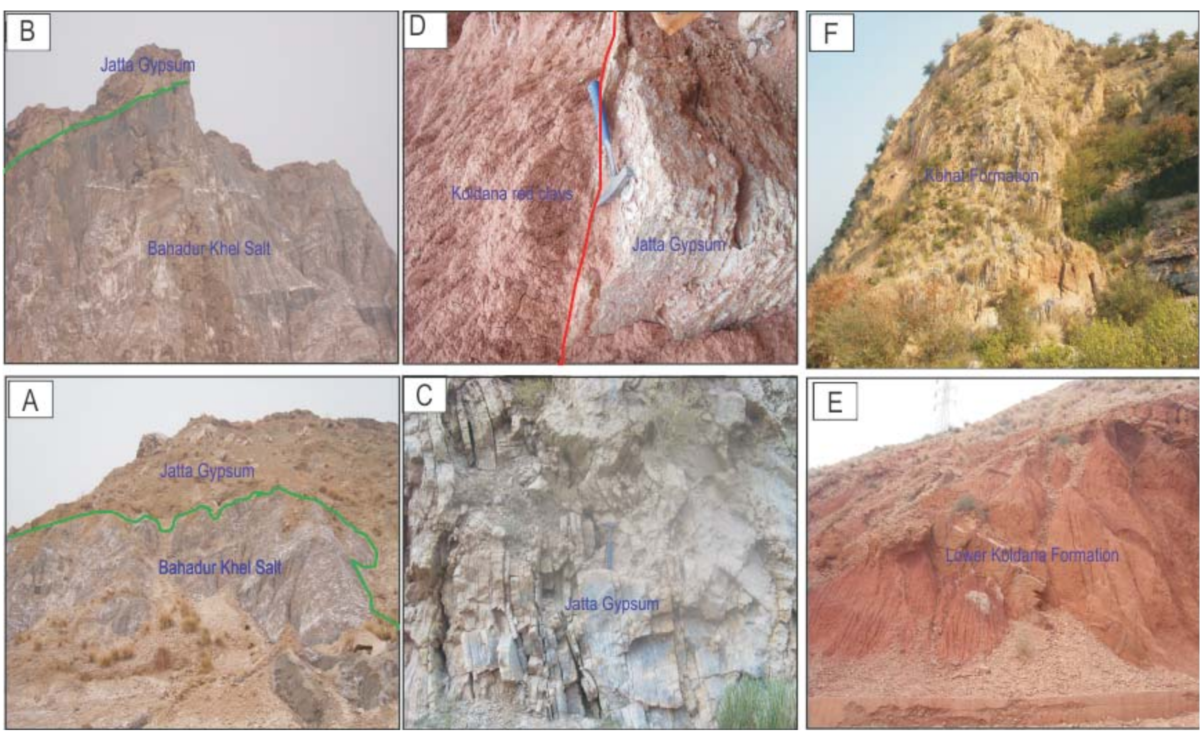

Figure 5 - Photo mosaic of the Sequence Boundary SBK 1 and Sequnece SK 2. A B) Thick lagoonal salt and gypsum facies deposited during regression of the sea C) Close- up view of the Jatta gypsum facies D) emergent gypsum facies and flood plain deposits E) Deposition of the continental red muds in lower Kuldana Formation, F) platform carbonates of the Kohat Formtion.

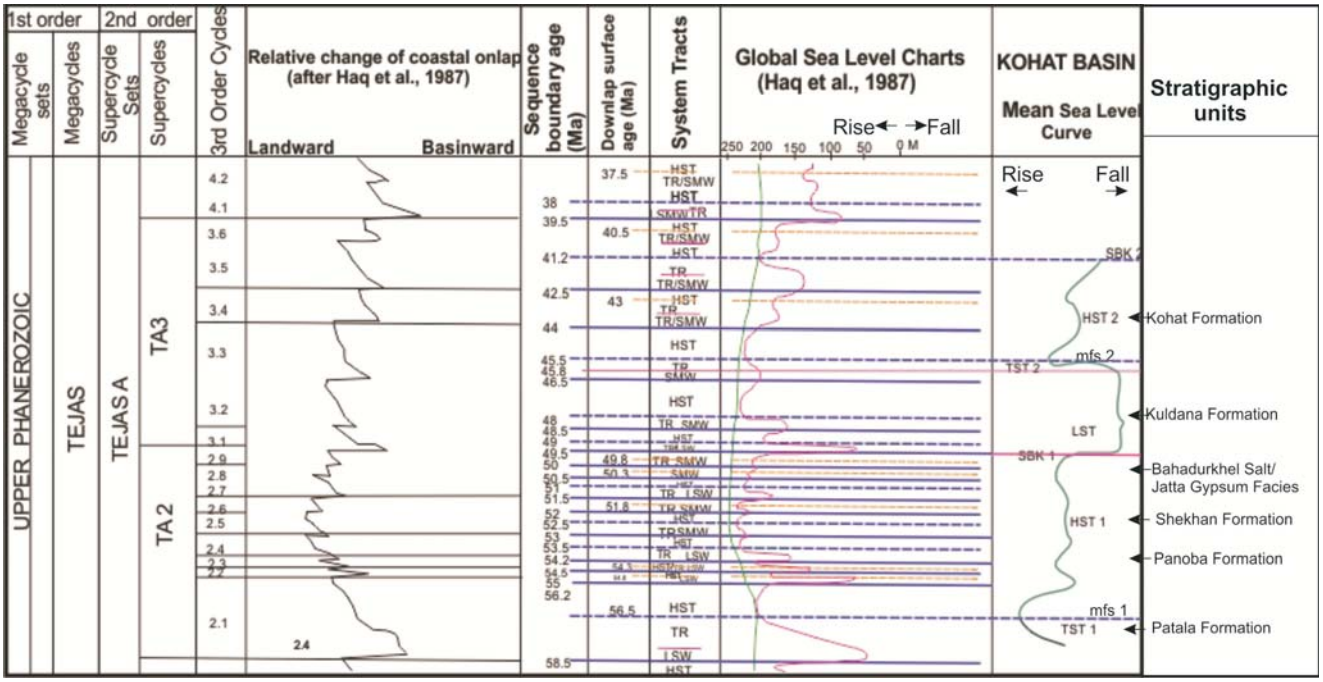

Figure 6 - Comparison of the relative sea level fluctuations inferred from the microfacies and faunal analysis of the Paleogene rocks of the Kohat Basin with the Eustatiic sea level charts (Haq et al., 1987).

Sequence Boundary SBK 2

In the Kohat Basin marine conditions vanished in Upper Lutetian time a hiatus is marked between Middle Eocene and Miocene to Pliocene molasses sedimentation that records the Sequence Boundary (SBK 2) in most part of the basin (Figures 3 & 6).

COMPARISON WITH EUSTATIC SEA LEVEL CHARTS

The comparison of the depositional sequences deposited during Palaeogene in the Kohat with the Eustatic Sea Level Charts (Haq et al., 1987) provides valuable information and evidence for correlation to the world wide Geological Time Scale (Figure 6). The Palaeocene (Tahitian) stratigraphic cycle (Haq et al., 1987) TEJAS A (TA 2.1) represents high sea level which deposited a transgressive systems tract (TST) followed by a highstand systems tract (HST). The transgressive systems tract (TST) in TEJAS A (TA 2.1) is correlated with the SK 1 sequence in the Kohat Basin (Figure 6). The SK 1 sequence is comprised of a transgressive systems tract (TST 1) and a highstand systems tract (HST 1) (Figures 3 and 6). The lower part of the Patala Formation was deposited during TST 1 and on the basis of planktonic foraminifera a maximum flooding surface (mfs) in lower middle part is dated as 56.5 Ma (Figure 6). The subsequent highstand system tract (HST 1) in SK 1 sequence is represented by Panoba Formation, overlain by Shekhan ramp carbonates and subkha / lagoon evaprites (Jatta Gypsum/Bahdur Khel Salt) representing shallowing upward sequence. The Biozones BFZK 1BFZK 3 date the HST 1 between 56.2 and 52.2 Ma (from lower Ilerdian 1 lower Cuisian 2) (Figure 6).The marginal marine gypsum and salt deposition is younger and may represent 52.2 to 49.5 Ma (middle Cuisian). A major regression at the end of early Eocene around 49.5 Ma is represented by TEJAS (TA 2-TA3) stratigraphic cycle (Haq et al., 1987). This was also a time of regression in the Kohat Basin which was possibly driven both by collisional tectonics and the eustatic sea level fall around 49.5 Ma (Figure 6). The intervening lowstand systems tract after this eustatic regression is represented by stratigraphic cycle TEJAS A TA 2, 3.1. This can be correlated with the lower part of the Sequence SK 2 which consists of the lower Kuldana Formation in the Kohat Basin (Figure 6). During lower Lutetian 2 to upper Lutetian (49.5 -41.2 Ma), Upper Kuldana and lower part of the Kohat Formation was deposited in a transgressive systems tract (TST 2) (Figure 6). It is followed by thick carbonates in the upper part of the Kohat Formation during highstand systems tract (HST 2) which can be correlated with the eustatic sea level rise in TEJAS A TA 3 stratigraphic cycle (Haq et al., 1987). The TEJAS A TA 3 stratigraphic cycle begins with transgression and deposited a transgressive systems tract followed by a highstand systems tract (Figure 6). There are various fluctuations in the sea level during TEJAS A TA 3 stratigraphic cycle mostly TST and HST are deposited and intervening lowstand are also common (Figure 6). The intercontinental nature of the lower Lutetian 2 transgression is supported by the presence of age diagnostic benthic foraminiferal species at the same time in the Indo-Pacific, Europe and Middle East regions.

SUMMARY AND CONCLUSIONS

Tectonic uplift and subsidence played an important role in the Palaeogene depositional architecture of the Kohat Basin. In the northeastern Panoba, Shekhan and Tarkhobi

Nalaevaporites (Bahadur Khel Salt and Jatta Gypsum) as seen in the Bahadur Khel Salt Tunnel section. A thick sequence of the continental red muds and transitional marine facies overlies the gypsum facies throughout the basin. Continued subsidence after the deposition of terrestrial flood plain deposits favored deposition of the marine carbonates in the Kohat Basin. Two depositional sequences SK 1 and SK 2 are identified which are separated by a short lived but widespread regressive phase that has deposited continental

muds and correlates well with a eustatic sea level fall around 49.5 Ma (Haq et al., 1987). The Sequence SK 1 constitutes TST 1 and HST 1 that is followed by the 49.5 Ma sea regression. Although local tectonics in the study area have mimic the effects of a global sea level rise in the Lutetian 2 age, some major sea level perturbations are recorded and represented by a TST 2 followed by a HST 2 carbonate deposition.

The last episode of the marine sedimentation continued from middle Lutetian 1 to Upper Lutetian time in the region. Subsequent Himalayan orogeny followed by molasses sedimentation in post Oligocene time deposited thick clastic facies throughout the region representing second Sequence Boundary SBK 2 in the area.

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