

# **1320525 Neogene Sedimentary Fringe, West of Indo-Burma Ranges in Western Myanmar: Some Evidences for Late Cenozoic Synorogenic Sedimentation in Himalayan-Bengal System**

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## **ABSTRACT**

The Arakan Basin is one of the representative clastic basins formed in the frontal part of the Himalayan orogenic belt since the Late Cenozoic. Defining one of the four major sedimentary basins of Myanmar, it is geomorphologically and tectonically differentiated from the others. The study area along the westernmost edge of Myanmar is separated from the Arakan Yoma (Indo-Burma Ranges) by a narrow coastal strip and is bordered by the Bay of Bengal to the west.

Regional stratigraphic correlation and the geological age of the siliciclastic sequences were established, based on planktonic foraminifera zonation. Deep marine slope and shelf environments during early Miocene to middle Miocene (about 21.5 to 11 Ma) southward prograded shelf-delta environment during late Miocene to Pliocene time were determined.

The early Miocene underthrusting along the Himalaya front is well documented by the forced-regressive sedimentation patterns in the slope and shelf systems, sediments of which derived from the paleo-Ganges-Brahmaputra river systems in the Bengal-Arakan Basins. Sequential evolution of the Miocene successions manifests in forced regressive wedged system tracts. These evolved through slope by-passing and slumping and, following deep-marine channel in-filling, began to accumulate an increased sediment load due to the rapid fall of the sea level by the uplifting in the hinterlands during the early- to early-middle-Miocene.

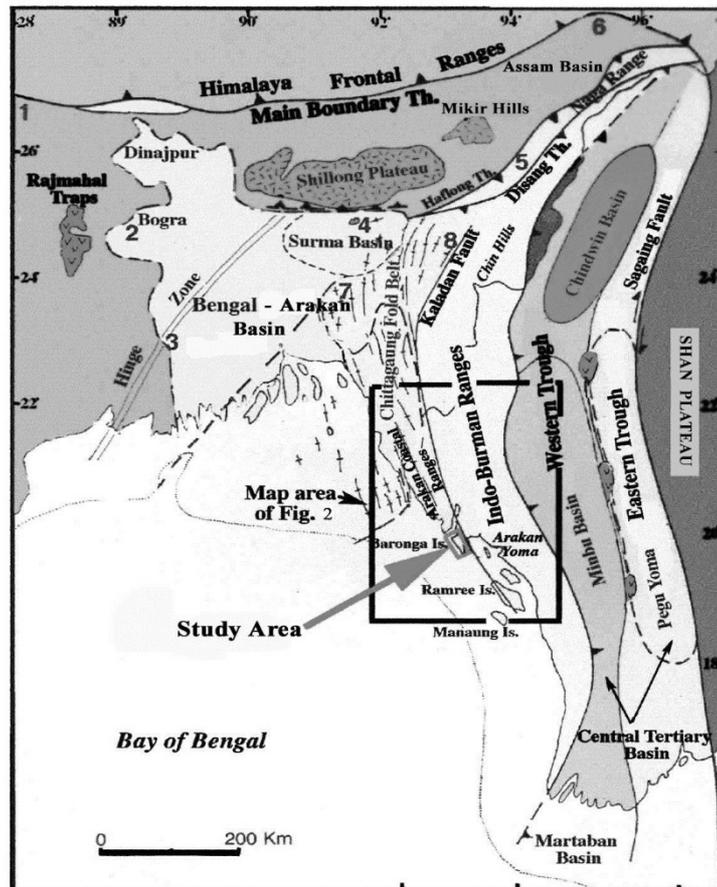
The formation of a shelf-delta system marks a dramatic shift in the evolution of the southward prograding delta system following a eustatic sea-level low. In the foreland areas, erosional off-loading with foreland uplifting caused a wide active fluvial system and formed transverse rivers distally in the late-middle- to late-Miocene.

## **Introduction**

In recent years, there have been an increasing number of studies aiming to interpret the link between tectonic events and sedimentary responses. In this context, a lot of effort has been devoted to subdividing syntectonic successions into genetic sequences, which reflect changes in parameters such as provenance, tectonically induced subsidence and uplift in sedimentary basins.

The Miocene Arakan Basin is located in the Arakan Coastal Ranges, situated at the key position between the India and Asia Plates (Figs. 1 and 2) The collision of these plates produced the Himalaya orogenic belts, the most profound tectonic event of the past 100 million years.

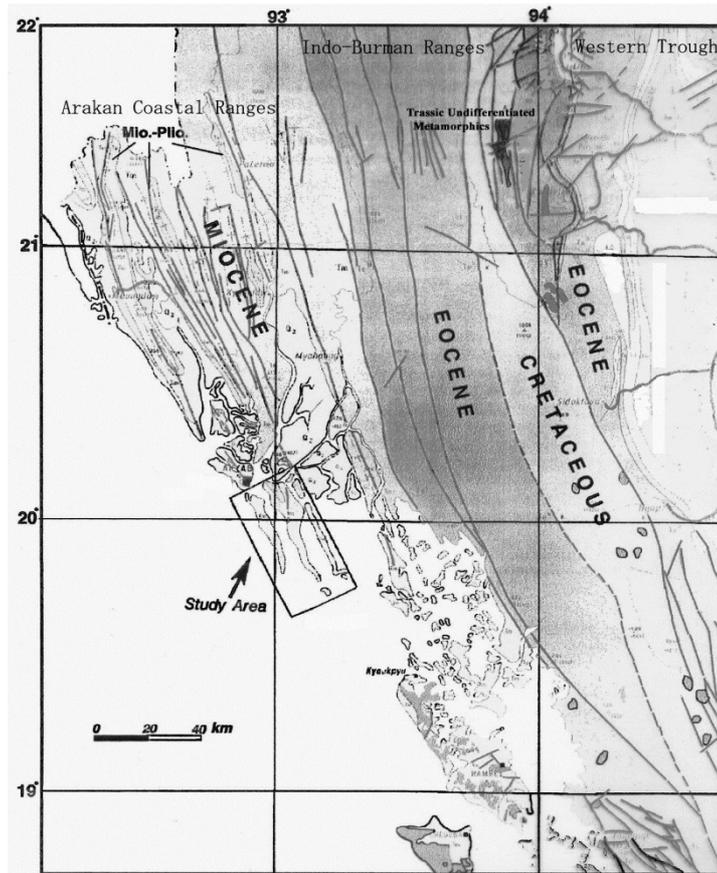
The collision history of the Himalayas is recorded in sediments deposited in subsiding foreland basins to the south (Burbank et al., 1996), including the Bengal Basin of Bangladesh (Uddin & Lundberg 1998a) and Bengal Fan (Curry 1991). The collision and arc-trench systems of northwestern Myanmar contain sedimentary basins developed since the late Cenozoic. Various models have been proposed for the tectonic evolution of the Himalayas and Tibetan Plateau relating to this late Tertiary foreland and foredeep sedimentation (e.g. Dewey & Burke 1973; Powell & Conaghan 1973; Powell 1986; Copeland & Harrison 1990; Burbank et al., 1993; Harrison et al., 1993; Beck et al., 1995; Harris 1995; France-Lanord & Derry 1997; Yin et al., 1999).



**Fig. 1.** Tectonic divisions of western Myanmar and associated foreland basins in the eastern India region.

Many papers have been published from various regions, using geological evidence to constrain the timing of the Indo-Asian collision; the western and eastern Himalayas (Searle et al., 1987; Beck et al., 1995; Yin et al., 1999), Siwalik ranges and Nepal regions (DeCelles et al., 1998; Harrison et al., 1993; Sakai 1997), Bengal Basin of Bangladesh (Johnson & Alam 1991; Uddin & Lundberg 1998a, 1998b), deep-sea Bengal Fan (Curry & Moore 1974) on two drilling legs DSDP Leg 22 and ODP Leg 116 (e.g., Copeland et al., 1990; France-Lanord et al., 1993, 1994; Cochran & Stow et al., 1989, Cochran 1990; Ingersoll & Suczek 1979; Amano & Taira 1992), and the northern Ninety-East Ridge on ODP Leg 121 (Klootwijk et al., 1992a, b).

On-land geological information of the Arakan Basin, in the eastern part of the Bengal Fan, however, has not been well documented. The relationship between the sedimentary evolution of the foreland basin that contains both pre-tectonic and syntectonic sequences and the unroofing history of the eastern Himalayas and Indo-Burma Ranges has been little understood. Many preliminary studies (Aung Khin & Kyaw Win 1966, 1967; Brunnschweiler 1974) interpreted that the provenance of the Miocene-Pliocene sequence was from both an ancestral Brahmaputra River system to the north and the Indo-Burma Ranges to the east.



**Fig. 2.** Location of the study area, Baronga Islands, Arakan Coastal Ranges, western Myanmar (modified map of Earth Sciences Research Division, 1977).

The purpose of this study is to shed some light on the sedimentation in the distal foreland basin of the Himalayan-Bengal System, related to control on timing and distribution of erosional fluxes derived from the uplifted Himalayas since the early Miocene. The results from the present study constrain these models by providing important information linking the syntectonic sedimentation in the proximal foreland basins and deep marine sediments with periodicity of uplifting and resulting erosional fluxes derived from the India-Asia collision.

This study contains the results of an integrated study of sequence stratigraphy on the Miocene sediments, and the relationship between tectonic denudation of the Himalaya orogenic belts and reciprocal sedimentation related to foreland thrusting of the Himalaya-Bengal System. The sedimentary evolution of the clastic shelf-slope system related to forced-regression in the early to middle Miocene and late Miocene deltaic progradation was discussed on the basis of vertical and lateral correlation of the measured sections. These data were used to constrain the link between the deltaic sedimentation in the Bengal Basin of Bangladesh and the deep-sea fan sedimentation of the Bengal Fan which was trapped as a remnant ocean-basin between the India and Asia Plates since the early Miocene.

### **Stratigraphy**

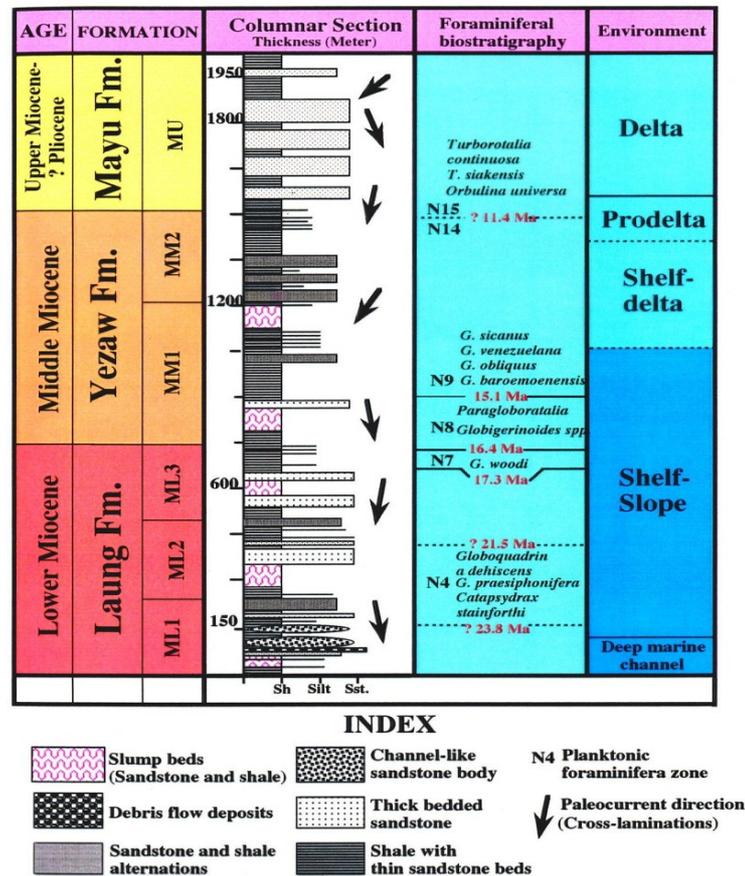
The stratigraphy of the Arakan Miocene Basin was initially established in the Assam and Arakan (Yakhine) oil regions in the 1940s and by lithostratigraphic correlation with type sections in Surma Valley, Assam and northeastern India (Sale & Evans 1940; Evans 1964). Brunnschweiler (1966, 1974) investigated selected areas of the Indo-Burma Ranges, and separated the outer molasse basin of the Arakan coastal region from the Indo-Burma Ranges as a structural zone, and adopted stratigraphic nomenclature by Evans (1964) of the Assam and Surma regions. According to Brunnschweiler (1974), the folded Eocene flysch sequences thin out beneath the thick mudstones of lower Miocene in the Arakan coastal region, and the Barails Series (Oligocene) unconformably underlie the Miocene Surma Group in the Surma Basin and Chin Hills in the northern regions.

The Miocene Arakan Basin is a narrow southern continuation of the Assam Basin, and its lithology is similar to that of the Central Tertiary Basin of Myanmar. These two basins may have formed as a

twin trough, (or a twin gulf) proposed by Stamp (1922) that was divided by the Indo-Burma Ranges, a mobile belt (a trench complex) which has undergone rather intense orogenic movements as manifested by large-scale westwards over-thrusting and tight folding of flysch units. The Indo-Burma Ranges consist mainly of Cretaceous to Eocene pelagic sediments overlain by thick Eocene to Oligocene turbidites and Miocene to Pliocene molasse (Brunnschweiler 1966; Ni et al., 1989).

A large sedimentary prism of the northern Arakan coastal region is composed of a thick section of Cretaceous-Eocene deep marine shale, claystones and greywackes (Brunnschweiler 1966, 1974; Aung Khin & Kyaw Win 1966). The section is located on the foothills of the Arakan Yoma east of the study area, and is overlain by a very thick (4500–5000 m), mostly shallow- to deep-marine Miocene-Pliocene succession of sandstones, siltstones, and shales.

The previous classification and correlation of Miocene to Pliocene rocks in the Miocene Arakan Basin in coastal areas was mainly based on lithological datasets with sparse paleontologic information (Brunnschweiler 1974; Aung Khin & Kyaw Win 1966, 1967; Than Nyunt & Chit Saing 1978). Composite stratigraphic succession for the Miocene-Pliocene is shown in Figure 4. In the Miocene to Pliocene stratigraphy compiled by Aung Khin and Kyaw Win (1966), five major units were defined. They include the Laung Formation (lower Miocene), Yezaw Formation (middle Miocene), Mayu Formation (upper Miocene), Ngasanbaw Formation (upper Miocene-Pliocene), and Kyauktan Formation (Pliocene). Most of the type sections are in the Mayu Range (northwestern part of Sittwe) and the Baronga area (study area) (see Figs. 3 and 4).



**Fig. 3.** Litho- and biostratigraphy, and paleoenvironments of Miocene sequences in Baronga Islands, Arakan Coastal Ranges, Western Myanmar.

### Sedimentary Facies and Sequence Stratigraphy

Five facies associations were discriminated in the Miocene succession of the Laung, Yezaw, and Mayu Formations. Facies associations 1 to 5 and are best characterized by mudstone, thinly alternating sandstone and mudstone, chaotic beds, amalgamated sandstone, and thick-bedded sandstone and shale, respectively. The first three associations are mudstone-dominated and they

typically represent the lower Miocene Laung Formation and lower Middle Miocene, Yezaw Formation. The last two facies associations commonly occur in the Yezaw Formation (Middle Miocene) and Mayu Formation (Upper Miocene).

The sedimentological data includes characteristics of lithologies, sedimentary and biogenic structures, paleocurrent data and slump fold measurements and fossil evidence on the 23 measured sections. Attention was paid to the recognition of major extensive, bounding surfaces formed in response to relative sea-level changes. The outcrop mapping and NW-SE correlation line, connecting most of the studied sections, provided a two-dimensional control of thickness and lithofacies changes.

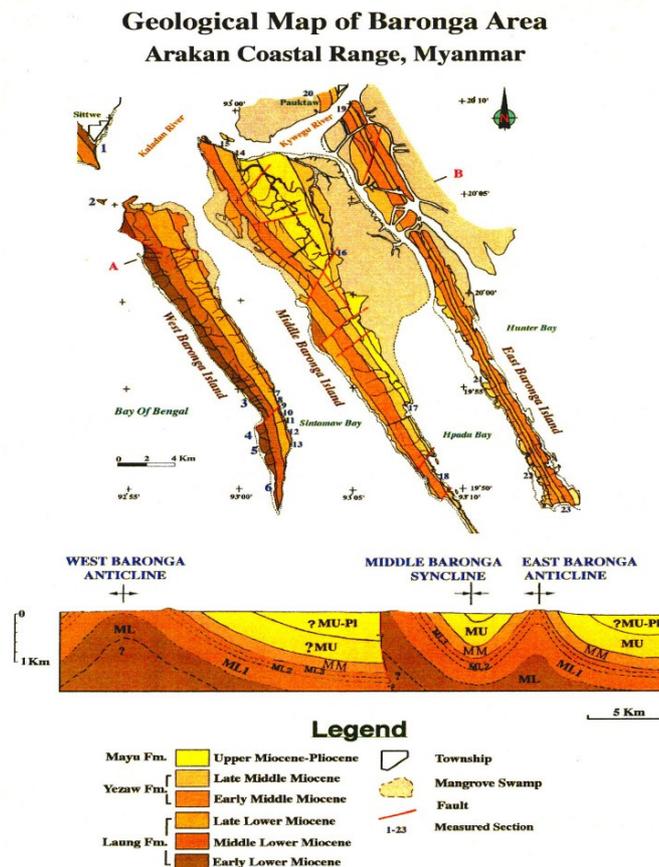


Fig. 4. Geological Map of the Baronga area, Arakan Coastal Ranges, western Myanmar.

### Forced regression and the position of the sequence boundary

According to the dip-sections and correlation from both west and east Baronga Anticlines, the siliciclastic slope to shelf-margin delta complex consists of a series of mainly basinward-stepping slope components which, based on facies- and dip- variations, can be subdivided as stranded parasequence sets bounded by transgressive mudstones and shales.

It has long been known that deep-marine sedimentation is most active during times of low sea level, when continental shelves are partially or fully exposed and fluvial systems deliver huge amount of detritus directly to a continental slope or the heads of submarine canyon. This formed the basis for a sequence model of submarine fans, which placed them in the lowstand and/or transgressive systems tracts. The lowstand systems tracts have been regarded as a sedimentary body of sediment-gravity flow, and the boundary surface with the overlying transgressive systems tract defined as a correlative surface of sequence boundary. However, Hunt and Tucker (1992, 1995) pointed out that submarine-fan systems are deposited during a sea-level fall as a result of progressive exposure and erosion of continental shelf. The sequence boundary, which records the

time of lowest sea level, should therefore be located above the lowstand fan deposits, not below them, as previously demonstrated in the Exxon sequence model (Miall, 1999).

Clastic slope systems are dynamic and major sites of sediment accumulation in tectonically active areas (Dam and Sonderholm, 1994; Lomas, 1999) but the literature contains a disproportionately small number of examples from ancient slope systems. A lack of clearly established depositional models for non-fan deep-water systems persists largely because of the scarcity of detailed case studies. Most ancient deposits interpreted as slope apron successions are non-cyclic accumulations of sediment gravity-flow deposits associated with synsedimentary slope failures (Pickering et al., 1989). However, the slope system of the study area shows the parasequence sets between slump zones and overlying undisturbed sand-bodies which were initially excavated largely by retrogressive slumping of unstable slope, as described by Dam and Sonderholm (1994).

Sea-level is a controlling factor not only on the timing and location of turbidite systems but on other factors, such as tectonic and climatic settings of the receiving basin. Feeder channels are actually initiated during lowstands by fluvial erosion of the shelf, but continue to evolve and deepen by submarine mass wasting during the subsequent sea-level rise (Miall, 1999). Submarine fan sedimentation may continue during sea-level highstand if the sediment supply to the continental slope is high. In the evolution of very large fans, such as the Indus, Bengal, and Amazon Fans, the depositional slope and sediment supply are less sensitive to sea-level change than they are in small fans.

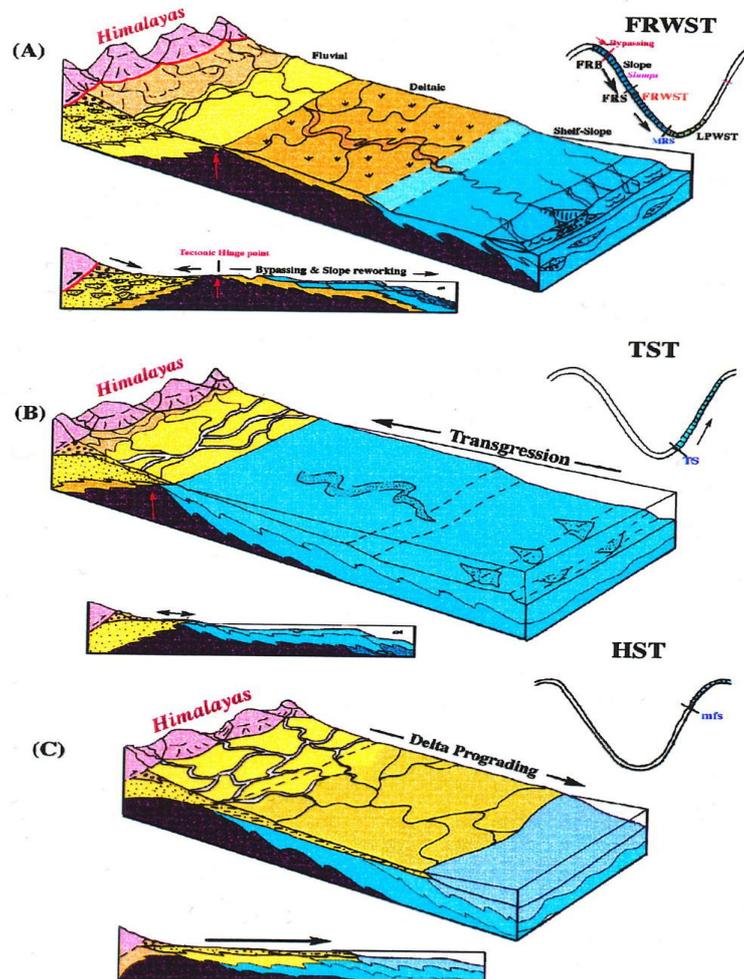
The Exxon sequence model contains four basic systems tracts: the lowstand systems tract (LST), transgressive systems tract (TST), highstand systems tract (HST), and shelf-margin systems tract (SMST) (Posamentier et al., 1988). However, Van Wagoner et al. (1987) stated that the terms lowstand and highstand are not meant to imply a unique period of time or position on a cycle of eustatic or relative change of sea-level. The actual time of initiation of a systems tract is interpreted to be a function of the interaction between eustasy, sediment supply, and tectonics (Miall, 1999).

The present study has demonstrated that important erosional and depositional events occur in the deep-marine environments during the falling stage of the relative sea-level curve, that were not included in the original Exxon models. There was a new term, 'forced regression' introduced by Plint (1988) to explain sharp-based shoreface sandstones deposited in upper shelf environments. Later, Hunt and Tucker (1992) incorporated these beds into a newly proposed falling-stage systems tract (FSST), also termed forced-regressive wedge systems tract (FRWST) and lowstand prograding wedge systems tract (LPWST) for deep-marine deposits, including submarine fans located at the base of a slope. They pointed out the problem with the placement of the sequence boundary relative to the falling stage and lowstand deposits in the original Exxon model of Posamentier et al. (1988), and proposed that it should be located between the FSST and LPWST.

An alternative sequence model, termed the genetic stratigraphic sequence, defined by Galloway (1989), supposed philosophical differences between his model and the Exxon model. Galloway's preference is to draw the sequence boundary at the maximum flooding surface, claiming that they are more prominent in the stratigraphic record and thus more easily mapped than an unconformity. Some studies (e.g. Plint et al., 1986; Bhattacharya, 1993) reveal that the marine flooding surface (transgressive surface, TS) actually coincides with the sequence boundary. Embry (1993) also defined sequences in shelf and slope successions on the basis of their contained transgressive surfaces and referred to them as transgressive-regressive sequences (sequence type B of Helland-Hansen and Gjelberg, 1994). In the present area, these transgressive surfaces are readily identifiable because they represent a distinct change in facies and contain planktonic foraminiferal assemblages which can give the possible geological age resolution. Jacquín and Graciansky (1998) also point out that the building blocks of transgressive/regressive facies cycles are 3rd-order depositional sequences including four types of depositional sequences within a 2nd-order transgressive/regressive facies cycles. These four end-members are infilling and forestepping during the regressive phase and aggrading and backstepping during the transgressive phase. At the cratonic scale, some of the characteristic surfaces and events are very synchronous. This synchronicity suggests a tectono-eustatic control (Devlin, et al., 1993; Yoshida, et al., 1996;

Jacquín and Graciansky, 1998).

In terms of the higher order (4th order), the systems tracts and sequence bounding surfaces (boundaries) of the deep-marine (slope), lower shelf and deltaic sediments were thoroughly studied to identify the sequential evolution related to sedimentation and tectonics in the Miocene Arakan Basin, western Myanmar. A proposed sequence stratigraphic interpretation was based on 23 measured sections, outcrop mapping and outcrop photographs (Figs. 5.A, B, C).



**Fig. 5.** Schematic diagrams showing the sequential development of depositional systems and their relationship with the Himalayan uplift. **(A)** Forced-regression, **(B)** Transgression, **(C)** Delta prograding.

### Forced Regression related with Himalayan Tectonics

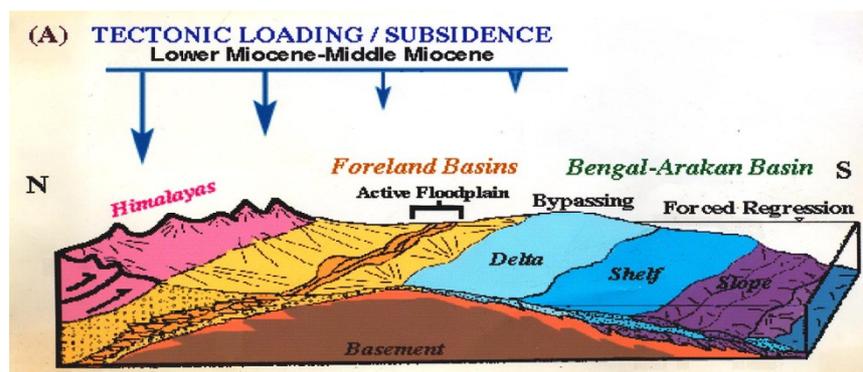
There are many studies on sedimentation and tectonics, especially on the relationship between the basin evolutions of foreland areas and thrusting (Price 1973; Beaumont 1981; Jordan 1981, 1995; Quinlan & Beaumont, 1984; Flemings & Jordan 1990; Burbank 1992; DeCelles & Giles 1996; Catuneanu et al., 1997). Barrell (1917) firstly realized that "the thick, non-marine strata of the Gangetic Plains accumulated in space made available by subsidence of the Indian crust beneath the mass of thrust plates of the Himalayan Range" (Jordan 1995). Later, Burbank & Beck (1991) pointed out that the formation of aggradation versus progradation patterns in the Indo-Gangetic foreland basins interplay between the rate of net sediment accumulation and the rate of basin subsidence related with the timing of Himalayan thrust movement (Fig. 6).

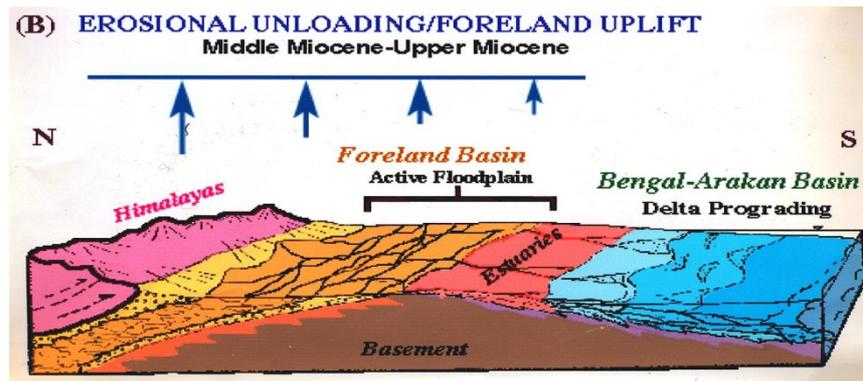
In the sequence stratigraphic context, Posamentier & Allen (1993) first defined the relationship between the subsidence rate and relative sea-level changes in foreland basins and demonstrated the stratal stacking patterns within shelf depositional sequences depending on tectonically controlled subsidence rates on a regional scale.

The pattern of a seaward-decreasing subsidence rate of a foreland basin results in characteristic longitudinal facies and stratal patterns with relative sea-level changes. The distal part of a foreland basin is characterized by forced regressions and by deposition primarily of lowstand and transgressive systems tracts (Posmentier & Allen 1991). Due to the active crustal loading, when the foredeep is deepening, the forebulge undergoes uplift and causes forced regression in the forebulge and backbulge regions (Fig. 6A), whereas at times of tectonic quiescence and/or erosional unroofing with denudation in uplifted regions, the foredeep undergoes isostatic uplift and the forebulge subsides (Fig. 6B). This reciprocal sedimentation also controls the timing and distribution of erosional fluxes from the uplifted hinterland area. The empirical model for the sedimentary evolution of the Himalaya foreland fluvial system and the Bengal-Arakan Basin were synchronized with the Himalayas uplifting.

There were no prominent depositional breaks in the Assam region in the lower Eocene to upper Miocene. Unconformities in other regions have been reported between the Eocene and Oligocene. These major regional depositional breaks support the difference in the subsidence history of Bengal-Arakan foreland systems occupied in the eastern Himalayas. According to the reinterpretation on the sedimentologic and stratigraphic framework of the entire Assam-Surma-Arakan regions, the complex inter-relationships between palaeoweathering, sediment supply, sea-level change and subsidence support the evolution of a late Cenozoic collision-related foreland system in the eastern Himalayas and Bengal-Arakan Basin (Figs. 6.A, B).

When thrusting and supracrustal loading processes were active, flexural subsidence and accommodation were high in the foredeep and proforeland areas including Assam and the northern parts of the Shillong regions were filled with thick accumulation of sediment supply. Distal portions such as backbulge areas (Bengal-Arakan) received a relatively limited sediment supply from the uplifted hinterland. At this time uplifting of the forebulge, the Shillong Plateau regions caused forced regression in the backbulge regions. When quiescent thrusting and erosional unloading changed the sedimentation pattern in foreland areas, a high sediment supply from the hinterlands led to overfilled conditions with river systems playing an important role for the transportation of coarse-grained sediment to marine basins extending across the forebulge and onto backbulge areas. At that time the episodic provenance trends represented a high sediment-input from the Himalayas recorded in the lower to upper Miocene sequences of the Arakan Basin, western Myanmar.





**Fig. 6.** Empirical models for the evolution of foreland basins and the Bengal-Arakan Basin at backbulge areas related with Himalayas tectonics, **(A)** Tectonic Loading and Subsidence, **(B)** Erosional Unloading and Foreland Uplift.

### Concluding Remarks

A sequence stratigraphic study of the Miocene siliciclastic sequences preserved in the Baronga Islands of the Arakan Coastal Range in western Myanmar has yielded the following significant results.

On the basis of regional stratigraphic correlation and geological age determination based on the planktonic foraminifera zonation of the siliciclastic sequences in this study area, the Laung and Yezaw Formations were deposited in the deep marine slope and shelf environments from early Miocene to middle Miocene (about 21.5 Ma–11 Ma). Although the studies lacked accurate foraminiferal age resolution, the age of lower and upper bounding units suggests that the Mayu Formation was deposited in the southward prograded shelf-delta environment during the late Miocene to possible Pliocene.

The early Miocene underthrusting along the Himalaya front is well documented by the forced-regressive sedimentation patterns in the slope and shelf systems in the Bengal-Arakan Basins.

Sequential evolution of the Miocene clastic successions suggests that the forced regressive wedged systems tracts, which evolved slope by-passing, slumping and following deep-marine channel infilling, began to accumulate the increased sediment load due to the rapid rise of base level during the early- to early-middle Miocene.

The formation of a prograding shelf-delta system marks a dramatic shift in the evolution of the southward-extended delta system following a eustatic sea-level low. In the foreland areas, erosional off-loading with foreland uplifting caused a wide active fluvial system and formed transverse rivers to distal parts in the late-middle Miocene to late Miocene.

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