# Synopsis of the Thesis entitled

## *Sequence Stratigraphic Analysis of the Bagh Group of Gujarat, Western India*

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# Sequence Stratigraphic Analysis of the Bagh Group of Gujarat, Western India

The NNW-SSE movement between Africa and the eastern Gondwana comprising Seychelles, India, Madagascar, Antarctica, and Australia initiated the separation of Gondwana due to the Karoo plume (Eagles and König, 2008; Gaina et al., 2013; Gaina et al., 2015; Nguyen et al., 2016; Reeves et al., 2016). With this, many Precambrian lineaments were reactivated, and rift basins in the continents evolved. The Cretaceous period in the earth's history has witnessed a series of global events like the rifting of continents, eustatic sea-level changes, large-scale Deccan volcanism, evolution, and extinction of flora and fauna. The sea level rose was around 250m higher than the present day and flooded the continents, depositing chalk worldwide. During the Early Cretaceous, reactivation of the Son-Narmada lineament in the Indian peninsula resulted in the regional uplift with an intervening graben (Kaila, 1986; Racey et al., 2016). Reactivation along the ENE-WSW trending rift formed the Narmada Basin, and encroachment of the sea during the Cretaceous laid down a thick marine sequence (Biswas, 1987). The Lower Narmada Valley (LNV) preserves marine and non-marine sediments, which are well-exposed in the Madhya Pradesh and Gujarat states, and for convenience, it is divided into Eastern Lower Narmada Valley (ELNV) and Western Lower Narmada Valley (WLNV), respectively. The Cretaceous sedimentary rocks of ELNV are described as Bagh Group, and the same nomenclature is followed for the WLNV, which is distinct from the younger Cretaceous Lameta Group. The Bagh Group rocks are studied at 36 localities in the LNV (Fig. 1), namely (1) Songir, (2) Ghantoli, (3) Chosulpura, (4) Chametha, (5) Vajeriya, (6) Agar, (7) Naswadi, (8) Devaliya, (9) Uchad, (10) Sultanpura, (11) Bilthana, (12) Bhekhadiya, (13) Bhadarwa, (14) Navagam, (15) Gulvani, (16) Mathsar, (17) Karvi, (18) Ambadongar, (19) Vajepur, (20) Mogra, (21) Chikhli, (22) Galesar, (23) Mohanfort, (WLNV) (24) Sejagaon, (25) Rampura, (26) Naingaon, (27) Jaminyapura, (28) Risawala, (29) Sitapuri, (30) Avral, (31) Badiya, (32) Chakdud, (33) Atarsuma, (34) Dhursal, (35) Borghata, and (36) Jeerabad (ELNV).

The study area, Western Lower Narmada Valley, lies between 21° 42' 00" to 22° 27' 00" N latitudes and 73° 30' 00" to 74° 06' 00" E longitudes (Fig. 1). The Bagh Group rocks in WLNV are exposed from ChhotaUdepur-Kawant in the east to Songir-Chosalpur in the west. The Bagh Group rocks rest unconformably over the Precambrian basement and are covered by Deccan Traps and Quaternary alluvium. The Bagh Group rocks exposed, as detached outcrops, are studied in detail at localities 1-23 (Fig. 1) of the WLNV.

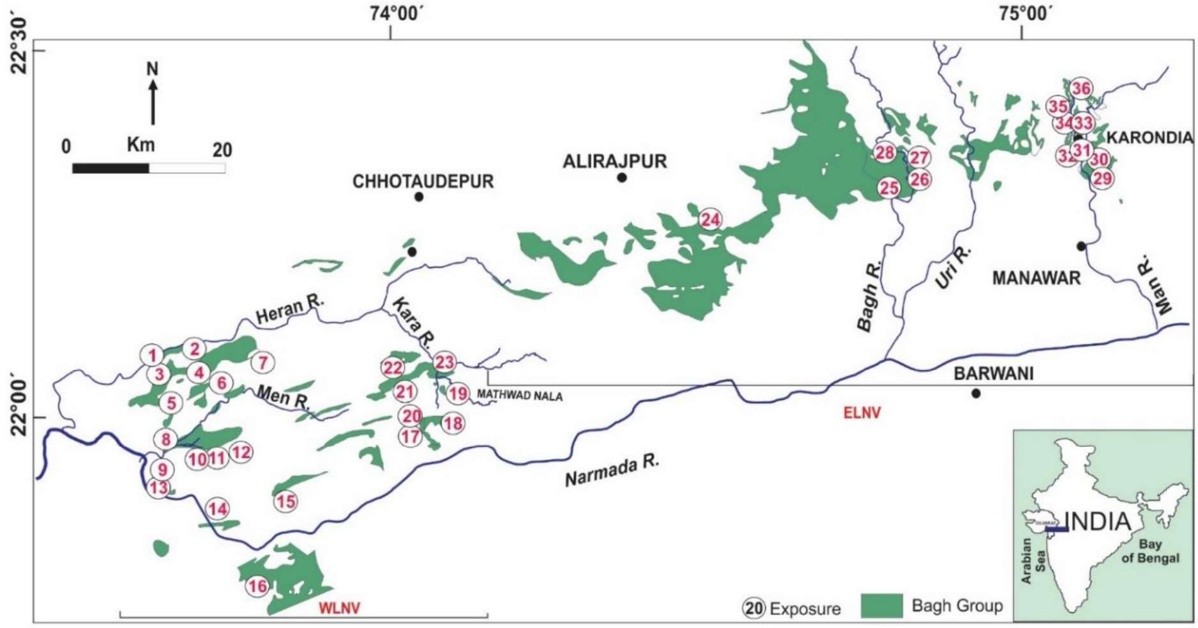


**Figure 1.** Map showing the studied sections of the Bagh Group of WLNV (location no. 1-23) and ELNV (location no. 24-36).

## 1. Aim and objectives

The study aimed to investigate the Bagh Group sequence of the WLNV on sedimentological and ichnological aspects and reconstruct the sequence stratigraphy.

The objectives of the thesis are:

1. To formalize the lithostratigraphy and analyze the sedimentological characteristics.
2. To document the trace fossils and analyze for paleoecological parameters.
3. To integrate sedimentological and ichnological data to delineate the sequence stratigraphic (boundaries, surfaces, and system tracts) and reconstruct the sequence architecture of Bagh Group rocks of Lower Narmada Valley of Gujarat.

## 2. Methodology

To achieve the above objectives following methodologies have been adopted:

1. Stratigraphic sections have been measured at different localities, and lithologs were prepared.
2. Systematic sample collection and documentation of sedimentary structures (physical and biological) was done.

3. Petrographic study of the samples was done for textural parameters and mineralogical composition.
4. Based on field observations and laboratory studies and the observed vertical and lateral lithological variations, lithostratigraphy is revised as per the International Subcommission on Stratigraphic Classification.
5. Lithofacies analysis has been done based on field and laboratory data.
6. Trace fossils were identified at the ichnospecies level, and their stratigraphic position was marked.
7. Density and diversity of the trace fosssils were observed; ethological, ichnoassemblage, and ichnofacies analysis was done to interpret the palaeoecological parameters.
8. Based on ichnological and sedimentological data, various sequence stratigraphic surfaces, boundaries, and system tracts are evaluated; a sequence stratigraphic model was constructed.
9. The sequence of the WLNV was compared with the pervasive Tethyan basins to understand the various geological events.

The present research work is divided into eight chapters briefly described below.

Chapter 1: This chapter provides background information on the phases of the Gondwana breakup and paleogeographic position of India, global sea-level changes, Deccan volcanism, and extinction events of the Cretaceous Period. The concepts of stratigraphy and lithostratigraphy, stratotypes, methodology to establish new units, lithostratigraphic units, their characteristics, and correlation, followed by concepts of sequence stratigraphy, sedimentary facies, microfacies, ichnofacies, ichnoassemblages, and application of trace fossils to sequence stratigraphy are briefly described. Descriptions were supported by various figures, maps (location and paleogeography), and flow charts.

Chapter 2: This chapter deals with the general geology of the Narmada Basin, its tectonic history, and evolution with a brief description of the Precambrian rocks, Bagh Group, Lameta Group, Deccan Trap, Quaternary deposits, along with supporting geological, structural, and paleogeographic maps and table.

Chapter 3: This chapter describes the Cretaceous lithostratigraphy of the Bagh Group rocks. Several authors have geographically divided the Lower Narmada Valley into the

ELNV and WLNV, which comprises of coeval deposits; however, show lateral lithological variations. A discussion on the lithostratigraphy of the Bagh Group rocks proposed by several authors either separately or combined for the ELNV and WLNV is provided in comprehensive tables, which forms the base of the next chapter.

Chapter 4: Over the last century, stratigraphy for the Bagh Group rocks has been proposed by many workers (discussed in chapter-3) based on observations supplemented by local variations depending on the area. The western and eastern part of the LNV basin consists of informal lithostratigraphic units; the multiplicity in nomenclature was caused due to lack of mapping and emphasis on local geographical names by workers.

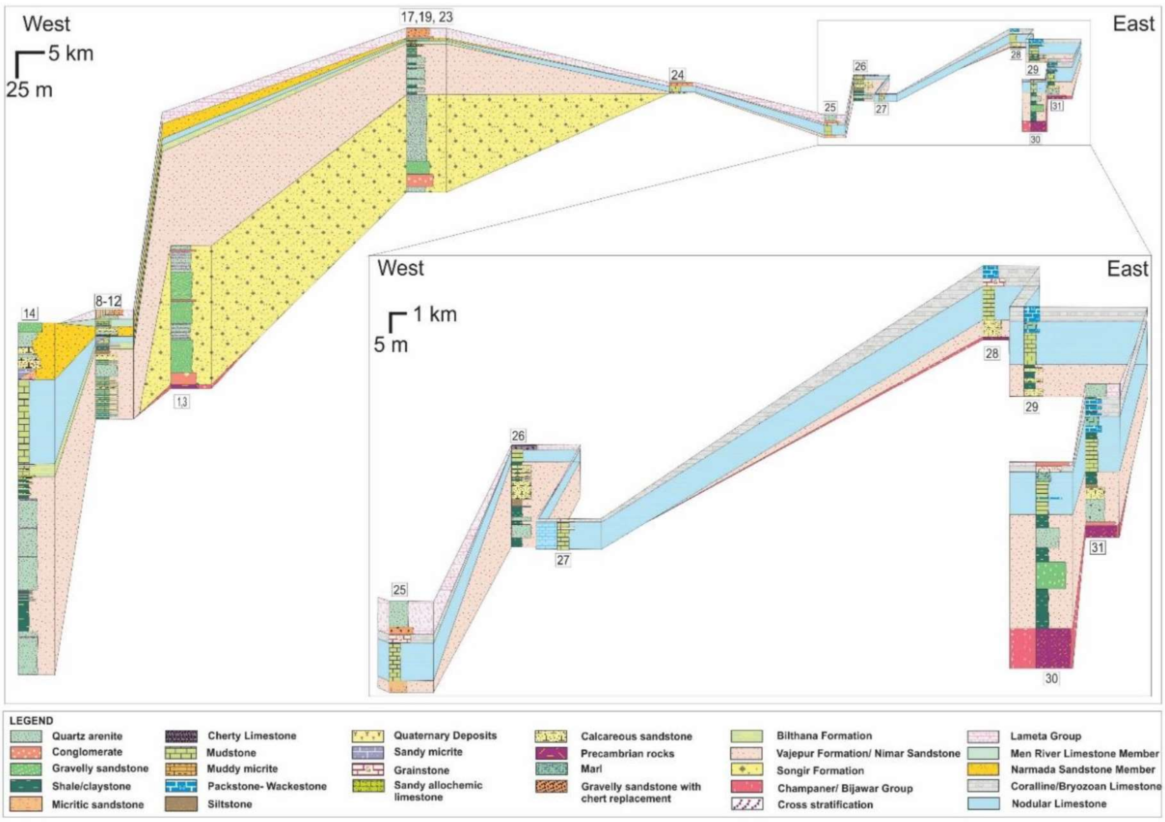


**Figure 2:** Stratigraphic correlation of the Cretaceous Bagh Group rocks sections in the Lower Narmada Valley; Men River Valley (8-12) and Mohanfort-Vajepur (17, 19, 23) are the composite profiles (Shitole et al., 2021).

To overcome the prevailing disparity in the usage of the lithostratigraphic units, the author has revised the Cretaceous succession of the WLNV according to the standard stratigraphic norms of ISSC. Each unit is described systematically, considering the historical background, intent and utility, designation, description, stratotypes, boundaries, age, and depositional environment. The exposed sequence is correlated amongst the different sections of WLNV and facilitate further correlation in the basin; comparisons have been made with the ELNV sections to observe the continuity and variation of facies of the given time slice (Fig.2). Based on sedimentological, stratigraphical and paleontological data, formal lithostratigraphy of the Cretaceous sequence was proposed (Table.1). The Bagh Group was assigned to the Cretaceous succession of the WLNV and was further subdivided into the Songir, Vajepur, Bilthana, Nodular Limestone, and Uchad formations (Table.1). It ranges from Berriasian? (Neocomian) to Coniacian in age and was deposited in a fluvio-marine environment.

| Age | Group | Formation | Member |
|---|---|---|---|
| Coniacian | Bagh | Uchad (57m) | Men Nadi Limestone (7m) |
| | | | Narmada Sandstone (50m) |
| Turonian | | Nodular Limestone (80m) | |
| Cenomanian-Turonian | | Bilthana (9m) | |
| Albian- Cenomanian | | Vajepur (46m) | |
| Berriasian? (Neocomian)-Aptian | | Songir (127m) | |

**Table. 1:** Lithostratigraphy of the Bagh Group sedimentary succession, Western Lower Narmada Valley (Shitole et al., 2021).

Chapter 5: The Bagh Group rocks have been studied by several authors for their rich faunal assemblage (cephalopods, gastropods, bivalves, echinoids, oysters, bryozoans, brachiopods, foraminifers, dinosaur remains, shark teeth, etc.) and trace fossils. To analyse the sedimentological characteristics, 23 localities of the WLNV (Fig. 1) are studied for detailed lateral and vertical variation, which reveals siliciclastic, carbonates, and mixed siliciclastic-carbonate composition. Fourteen sedimentary facies have been identified (conglomerate, planar and trough cross-stratified sandstone, horizontal-thinly bedded sandstone, massive sandstone, bedded quartz arenite, shale, calcareous sandstone, micritic sandstone, sandstone-siltstone-shale, sandy/silty allochemic limestone, fossiliferous limestone, sandy/silty micrite, mudstone, and muddy micrite) and interpreted. The fluvial facies association suggests deposition in alluvial fan and braided channel environments due to debris flow, sheet flood, migration of subaqueous dunes, and sediment gravity flow. The overlying facies of marginal-marine to marine environment suggests deposition in foreshore to the offshore environment.

Chapter 6: This chapter is dealt with ichnological study; trace fossils are identified, marked their stratigraphic position, and analyze for paleoecological parameters. The trace fossils are mainly recovered from the fine-grained sandstone-siltstone, calcareous sandstone, planar cross-stratified sandstone, sandy allochemic limestone, bedded quartz arenite, mudstone, fossiliferous limestone, and micritic sandstone facies. Identifiable trace fossils specimens reveal the presence of twenty-six ichnospecies belonging to seventeen ichnogenera (*Apectoichnus, Archaeonassa, ?Arenicolites, Bergaueria, Conichnus, Conostichus, Didymaulichnus, Gordia, Helminthoidichnites, Lockeia, Oniscoidichnus, Palaeophycus, Ptychoplasma, Planolites, Skolithos, Taenidium* and *Thalassinoides*).

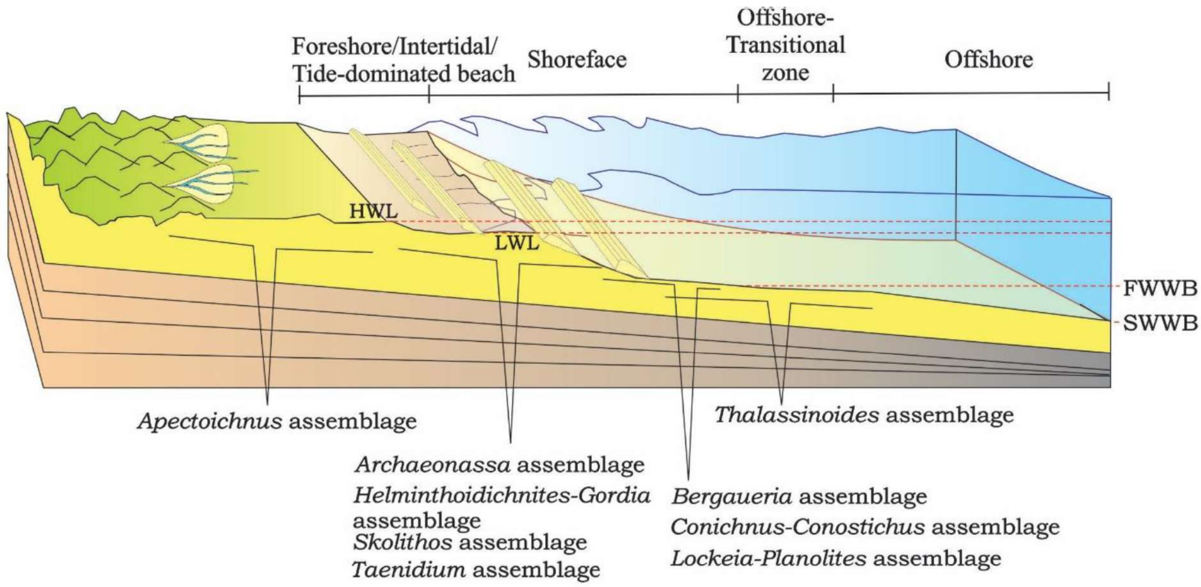


**Figure 3:** Schematic 3-dimensional diagram representing ichnoassemblages in the shallow marine depositional environment of the Western Lower Narmada Valley.

These trace fossils genera are categorized into five ethological groups, represented by cubichnia, pascichnia, domichnia, repichnia, and fodinichnia observed at different stratigraphic levels (Table 2). Trace fossils are grouped into nine ichnoassemblages named

| Ichnotaxa | Frequency | | | | Stratinomy | | | Ethology | | | | | Lithofacies | | | | | | | | Trophic | | | Probable Trace maker | Stratigraphic range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Very rare (1 specimen) | Rare (2-5 specimens) | Common (6-20 specimens) | Abundant (>20 specimens) | Epirelief | Fullrelief | Hyporelief | Cubichnion | Repichnion | Domichnion | Fodichnion | Pascichnion | Fine-grained sandstone-Siltstone | Calcareous sandstone | Planar cross-stratified sandstone | Sandy allochemic limestone | Bedded Quartz arenite | Mudstone | Micritic Sandstone | Fossiliferous limestone | Suspension feeding | Deposit feeding | Predation | | |
| *Apectoichnus* | | | | x | | x | | | | x | | | | | | | x | | | | | x | | Bivalves | Early Cretaceous-Miocene |
| *Archaeonassa* | | | x | | x | | | | x | | | x | x | x | | | | | | | | x | | Mainly Gastropods and possibly arthropods and echinoderms in marine env. Annelids or mollusks in non-marine env. | Cambrian-Recent |
| *?Arenicolites* | | | | x | | x | | | | x | | | | | | | | x | | | x | x | | Polychaetes or crustaceans | Cambrian-Recent |
| *Bergaueria* | | | | x | | | x | x | | x | | | | | | x | | | | | x | | | Actinarian or ceriantharian coelenterates | Precambrian-Miocene |
| *Conichnus* | | x | | | | | x | x | | x | | | x | | | x | | | | | x | | | Actinarian (sea anemones) | Cambrian-Tertiary |
| *Conostichus* | | x | | | | | x | x | | x | | | x | | | x | | | | | x | | | Actinarian (sea anemones) | Ordovician-Cretcaeous |
| *Didymaulichnus* | x | | | | x | | | | x | | | | x | | | | | | | | x | x | | Gastropods, bivalves or arthropods | Precambrian-Cretaceous |
| *Gordia* | x | | | | x | | | | x | | x | x | | | x | | | | | | | x | | Worms, insect larvae or gastropods | Precambrian-Recent |
| *Helminthoidichnites* | x | | | | x | | | | | | | x | | | x | | | | | | | x | | Arthropods, nematomorphs or insect larvae | Precambrian to Pleistocene |
| *Lockeia* | | | x | | x | | | x | | | | | | x | | | | | | | | x | | Bivalves | Ediacaran-Eocene and Late Cambrian-Pleistocene |
| *Oniscoidichnus* | | x | | | x | | | | x | | | | | x | | | | | | | | | x | Isopod | Paleozoic-Recent |
| *Paleophycus* | | | x | | x | | | | | x | | | x | x | | x | | | | | x | x | x | Polychaetes | Ediacaran-Recent |
| *Planolites* | | x | | | x | | | | | | | x | x | x | | x | | | | | | x | | Worms or arthropods in terrestrial env. | Precambrian-Recent |
| *Ptychoplasma* | x | | | | | | x | | x | | | | x | | | | | | | | | | | Wedge-foot bivalves | Ordovician-Recent |
| *Skolithos* | | | | x | | x | | | | x | | | | | | | | | x | x | x | | x | Annelids or phoronids in marine env. or by insects and spiders in terrestrial env. | Precambrian-Recent |
| *Taenidium* | | x | | | | x | | | | | x | x | | x | | | | | | | | x | | Arthropods (terrestrial myriapods), insects, annelids (earthworms) or variety of organisms | Cambrian-Recent |
| *Thalassinoides* | | | | x | | x | | | | | x | | | x | | x | | x | | x | x | x | | Infaunal crustaceans or other kind of arthropods | Cambrian-Recent |

**Table 2:** Trace fossils abundance, preservation, behavior, trophic type, trace makers are shown in the various facies of Bagh Group, and their stratigraphic range.

after the dominant ichnogenus- *Apectoichnus, Archaeonassa, Bergaueria, Conichnus-Conostichus, Helminthoidichnites-Gordia, Lockeia-Planolites, Skolithos, Taenidium,* and *Thalassinoides* (Fig. 3) representing *Skolithos, Cruziana,* and *Glossifungites* ichnofacies. These ichnofacies revealed the palaeoecological parameters such as oxygenation, hydrodynamic conditions, substrate conditions, salinity, food supply, and bathymetry during the deposition of the sediments of the WLNV.

Chapter 7: This chapter is divided into two parts; in the first part, the concepts of sequence stratigraphy (parasequence, systems tract, base-level, accommodation, transgression, regression, stratal stacking patterns, sequence stratigraphic model, surfaces, boundaries, methodology, and hierarchy) are briefly discussed. The second part deals with the sequence stratigraphic analysis of the Bagh Group rocks. The author has made a first attempt to analyze the Cretaceous sequence of the WLNV for sequence stratigraphy based on sedimentological and ichnological aspects. For analyzing the succession, the Genetic Sequence model is used to define the sequential filling of the WLNV. The fluvio-marine Bagh Group of the WLNV represents intracratonic rift and comprises the genetic sequence of the 1$^{st}$ order. The 1$^{st}$ order sequence is further divided into five 2$^{nd}$ orders depositional events based on stacking pattern which includes HAST, LST, TST-I, HST-I, and TST-II (Fig. 4) separated by a Sequence Stratigraphy Surface, Systems Tract Boundary, Sequence Boundary (Maximum Flooding Surface) and two Within-Trend Flooding Surfaces. These depositional events are further subdivided into seventeen 3$^{rd}$ order events identifying the processes-related facies. The sequence stratigraphic analysis of the Bagh Group rocks displayed an overall progradational, aggradational, and retrogradational stacking pattern. The illustrated sea-level curve of the WLNV compared with the eustatic sea-level curve marked the impact of the global events in the basin-fill sediments.

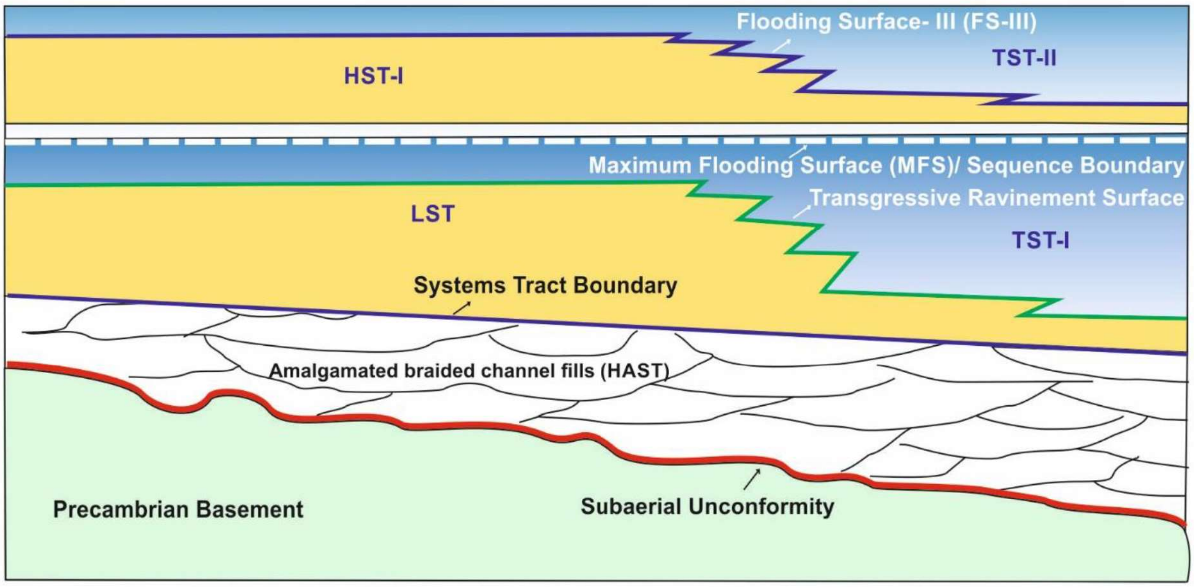


**Figure 4:** Conceptual sequence stratigraphic model of the Cretaceous Bagh Group rocks, WLNV showing stratal stacking pattern.

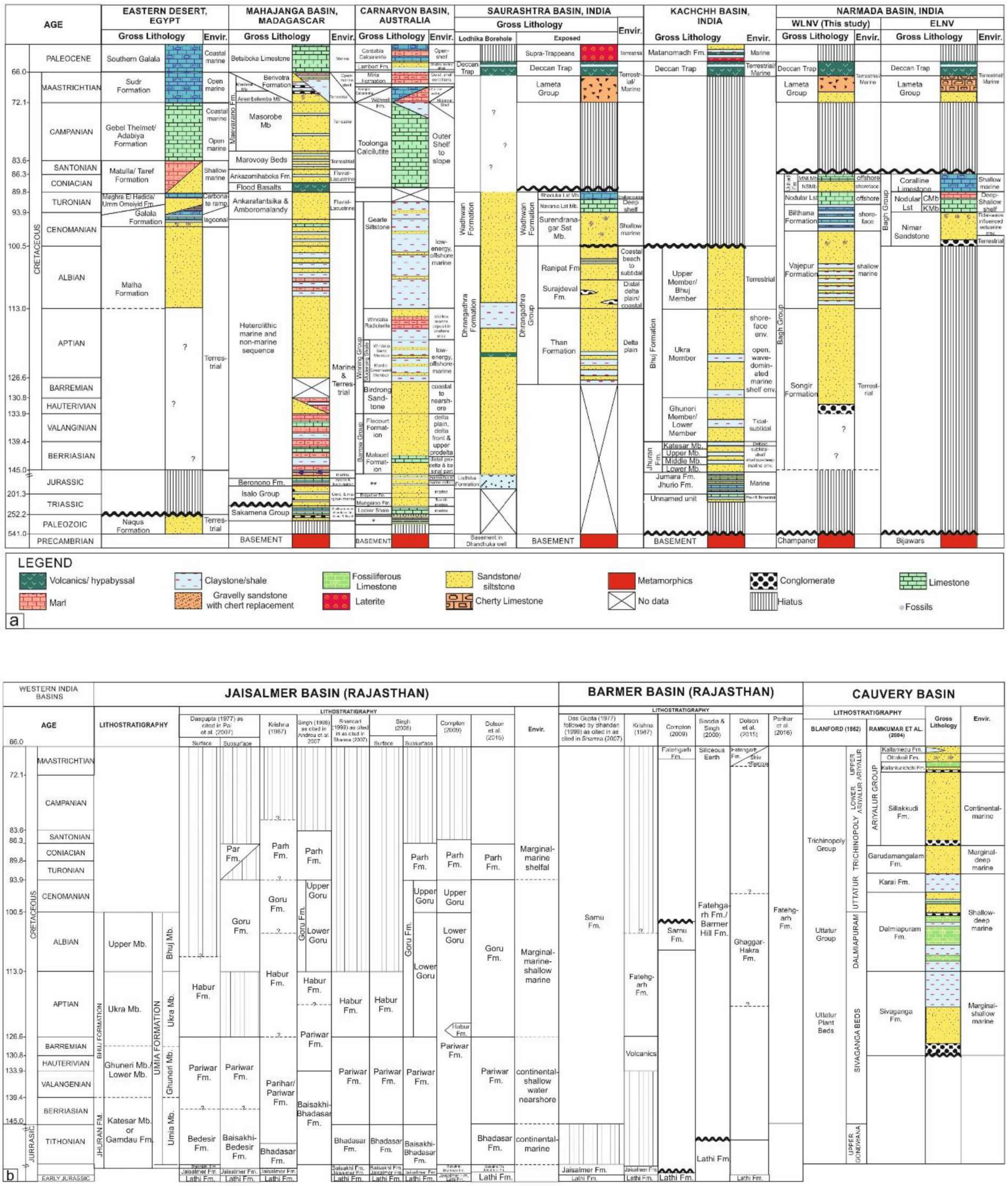


**Figure 5:** Generalized stratigraphic succession and the depositional environments of the Cretaceous Tethyan basins. a. Eastern Desert, Mahajanga, Carnarvon, Saurashtra, Kachchh and Narmada and b. Jaisalmer, Barmer, and Cauvery (modified after Shitole et al., 2021).

Chapter 8: The position of the Indian subcontinent was discussed in context to the Gondwanaland during the Cretaceous. The Tethyan basins comprise the pre-, syn-, and postrift basins filled with fluvio-marine sediments. The WLNV deposits of Narmada Basin are compared with the pervasive Tethyan basins like the Eastern Desert (Egypt), Mahajanga (Madagascar), Carnarvon (Australia), Saurashtra, Kachchh, Eastern Narmada, Jaisalmer, Barmer, and Cauvery (India) (Fig. 5) to understand the sedimentology, stratigraphy, and tectonics.

Rifting started in the Early Cretaceous in the Narmada, Mahajanga, Cauvery, and Saurashtra basins and deposited the early-rift Songir Formation, Malha Formation, Sivaganga Formation, and the Than Formation, respectively (Shitole et al., 2021). Deposition of Early Cretaceous terrestrial and Late Cretaceous marine sediments are common to the Eastern Desert, Saurashtra, and Narmada Basin is suggests a similar role played by tectonics, and Cenomanian-Turonian transgression. During Early Cretaceous highstands of sea-level deposited the marine sediments in the Carnarvon, Cauvery, Kachchh, and Mahajanga basins while Eastern Desert, Saurashtra, and Narmada basins were experiencing the continental environment. The Early Cretaceous terrestrial succession was overlain by the shallow marine non-clastic rocks deposited during the Late Cretaceous encroachment of the Tethys Sea in the Narmada and Saurashtra basins. The age of the youngest unit observed in the Bagh Group (Coralline Limestone in the ELNV and Men Nadi Limestone Member in the WLNV) coincides with the rift event of India from Madagascar and outpour of flood basalts in the Mahajanga Basin (Storey et al., 1995; Rogers et al., 2000).

Finally, the conclusions are listed, drawn from various studied aspects of lithostratigraphy, sedimentology, ichnology, and sequence stratigraphy of the Bagh Groups of the Western Lower Narmada Valley.

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