

CHAPTER 4

LITHOSTRATIGRAPHY OF THE STUDY AREA

4.1 INTRODUCTION

Several workers proposed theseparate lithostratigraphic classification of Lower Narmada Valley forthe Eastern Lower Narmada Valley and Western Lower Narmada Valley (WLNV) (Dassarmaand Sinha, 1975; Poddar, 1964; Sastry andMamgain, 1971); the same viewpoint for a lithostratigraphy for both parts of the basin is also supported by the Shitole et al. (2021).Poddar (1964), is the first worker who has proposed two separate groups for the Cretaceous sequence of WLNV, the lower Songir and the upper Navagam. However, a gradational contact has been observed between the lower siliciclastic dominated, and the upper carbonate dominated unit (Shitole et al., 2021; Chiplonkar et al., 1977a). Further, Navagam Limestone (Albian-Cenomanian) and Gulvani Limestone (Turonian) of Navagam Group were described at a different stratigraphic level (Poddar, 1964), and the Rajpipla Limestone (Sastry and Mamgain, 1971; Dassarma and Sinha, 1975) was described much younger (Santonian-Campanian) (Table 3.1), although field check of these three units revealed them to be isochronous deposits (Shitole et al. 2021). The Late Cretaceous fluviomarine sequence was considered Bagh Group (ELNV), with age ranging from Cenomanian to Coniacian (Jaitly and Ajane, 2013; Kumar et al., 2016; Prasad et al., 2017).

Considering the earlier view, field and laboratory study, and the ISSC (1994) norms, the lithostratigraphy for WLNV is amended, and the name ‘Bagh,’ well-established and deeply entrenched in the Indian geological literature, is retained. The Cretaceous fluviomarine sequence of the WLNV is revised and upgraded as to ‘Bagh Group’. The constituent units differ in the WLNV compared with the ELNV; however, priority was given to retaining the old names. The retention of existing units and the establishment of new units were emphasized wherever necessary; stratotypes are also defined following all the stratigraphic norms.

The revision of lithostratigraphy of the Bagh Group rocks is done on extensive fieldwork, intensive regional mapping, measurement of sections, and a systematic sampling

carried out at 23 locations in the WLNV and 9 locations in ELNV. The detailed sedimentological, stratigraphical, and palaeontological data are acquired and correlated, which have helped in describing and erecting the new lithostratigraphic units (Table 4.1) for the Cretaceous sequence of the Western Lower Narmada Valley.

4.2 STRATIGRAPHIC NORMS

The lithostratigraphy of the WLNV, the Bagh Group, is amended based on the ISSC norms, which has laid a set of procedures for establishing and revising the stratigraphic units, which are briefly stated below:

Name: The geographic name of the unit should be derived from a permanent or an artificial feature near the unit and should be spotted in the standard published maps. The name is combined with the rank in the case of group and formation, whereas for nomenclature of members, the geographic name is to be combined with the lithology and the rank of the unit. The geographic name should be unique, and its spelling once established, should not be changed; however, the associated rank and lithology can be changed. Multiple names assigned to a unit can be reduced if the correlation is established, prioritizing the earlier proposed name. The ISSC emphasizes retaining traditional well-established names and clarifies that the disappearance of the geographic name does not imply establishing a new name.

Intent and Utility: According to ISSC, a revision or redefinition of an established unit without changing its name requires a strong justification and utility. The unit's rank can be changed, keeping its original definition, geographic name, and boundaries the same.

Stratotype: The stratigraphic units must be well developed and exposed at the locality, where their identity is defined. Stratotype (type section), when serves as a standard reference for definition and /or characterization of a layered stratigraphic sequence, is known as unit-stratotype. When it contains a specific point establishing the boundary between the two units, it is known as Boundary-Stratotype. The unit stratotypes, when combined, are known as Composite-Stratotype. The type locality is where the unit was originally described and/or named. The type area constitutes both the stratotype and type locality.

Description of Unit at Stratotype or Type Locality: The stratotype should be described geologically and geographically in detail. The unit- and boundary-stratotypes should be marked at a permanent geographic and geological feature. The study should provide an accessible stratotype and should ensure its preservation.

Unit Description: It includes the extent of the unit, its geomorphic expression, thickness, lateral lithological variation, stratigraphic relation, relation to other units, dimension, shape, distinctive or identifying features that can be used to extend the unit away from its stratotype and boundary-stratotypes. The details like measured sections, well logs, and maps in the description of the new unit.

Geologic Age: Other than the chronostratigraphic units, the age is not compulsory in the definition of the lithostratigraphic units but should be given wherever possible.

Depositional Environment: Discussion on the depositional environment includes interpretation of the origin and environmental facies.

4.3 LITHOSTRATIGRAPHY

The Bagh Group of the WLNV is characterized by rudaceous and arenaceous rocks in the lower part, while the upper part comprises shales, limestones, and mixed siliciclastic-carbonate rocks (Plate 3.2) and is divided into five formations- Songir, Vajepur, Bilthana, Nodular Limestone, and Uchad; the Uchad Formation is further subdivided into the Narmada Sandstone Member and the Men Nadi Limestone Member (Table 4.1).

According to Shitole et al. (2021), the Bagh group sequence of WLNV is comparable with the ELNV, but its lower limit is extended up to Albian (Chiplonkar et al., 1977; Chiplonkar, 1983) and Hauterivian based on plant fossils (Murty et al., 1963). The Western part of the Lower Narmada valley (WLNV) preserves the fluvio-marine sequence and allows studying the older sequence of Bagh Group spanning in age from Berriasian to Coniacian as compared to its eastern counterparts.

Age	Group	Formation	Member	Lithology
Coniacian	Bagh	Uchad	Men Nadi Limestone (7m)	Mudstone, Muddy micrite, Shale
			Narmada Sandstone (50m)	Micritic sandstone, Calcareous sandstone, Sandy micrite, Shale, Quartz arenite, Gravelly sandstone
Turonian		Nodular Limestone (80m)	Mudstone, Sandy micrite, Muddy micrite, Wackestone	
Cenomanian - Turonian		Bilthana (9m)	Shale, Sandy allochemic limestone, Muddy micrite, Wackestone, Grainstone, Mudstone, Calcareous sandstone, Siltstone	
Albian-Cenomanian		Vajepur (46m)	Calcareous sandstone, Micritic sandstone, Quartz arenite, Shale, Siltstone	
Berriasian? (Neocomian) - Aptian		Songir (127m)	Conglomerate, Gravelly sandstone, Quartz arenite	

Table 4.1 Lithostratigraphy of the Bagh Group sedimentary succession, Western Lower Narmada Valley (Shitole et al., 2021).

4.3.1 BAGH GROUP

Historical background: Dangerfield (1818) first introduced the word ‘Bagh’ in the literature, which discussed the lithology of the sandstone near Bagh Town, Madhya Pradesh (Fig 3.1a). Later Blanford (1869) named them Bagh Beds based on a systematic survey of the Cretaceous rocks of the Narmada Valley. Subsequently, the word ‘Bagh Beds’ was used by many workers for the marine sequence of the Narmada Valley in their lithostratigraphic

classifications (Bose, 1884; Rode and Chiplonkar, 1935; Roy-Chowdhary and Sastri, 1962). Murty et al. (1963) elevated the rank and considered it the Bagh Group, which was later followed by Biswas and Deshpande (1983) and Poddar (1964) for the marine succession.

Intent and Utility: Murty et al. (1963) divided the ELNV Cretaceous succession of the Jhabua district into the Nimar Group (comprising Umralli Flagstone and Nimar Sandstone) and Bagh Group (comprising Amlipura Oyster Bed, Sejagaon Limestone, and Kanasgali Grit). Later, Poddar (1964) divided the Cretaceous sequence of ELNV into the lower Nimar Group (comprising Nimar Sandstone and Umralli Flagstone) disconformably overlain by the Bagh Group. The Bagh Group is comprised of Amlipura Oyster Bed, Kanasgali Grit, Sejagaon Limestone, and Bagh Formation in the ELNV. A similar explanation was provided for the separation of the Songir Group (comprising the Songir Sandstone, the Uchad Flagstone) and the Navagam Group (comprising the Bilthana Oyster Bed, the Navagam Limestone, and the Gulvani Limestone) in the WLNV. However, according to Chiplonkar et al. (1977a) and based on field investigation by Shitole et al. (2021), it was inferred that the Cretaceous sequence of LNV showed a single episode of deposition with a conformable contact between the two groups. Hence, the separation of the sequence into two groups is unwarranted according to the lithostratigraphic norms. Also, the name “Bagh” (Dangerfield, 1818) has been deeply entrenched in Indian literature for more than two centuries, and it would not be appropriate to replace it. Hence, owing to the invalidity of Poddar’s proposed groups and considering the strong historical background and usage of the term ‘Bagh Group’ for the Cretaceous sequence of ELNV (Jaitly and Ajane, 2013; Prasad et al., 2017), the term “Bagh Group” was formalized for WLNV with variable component formations by Shitole et al. (2021).

According to the ISSC (1994) norms, formations making up a group need not necessarily be the same everywhere. The lower sandstone unit was found to wedge out towards the southern side and the upper carbonate towards the northern side of the basin. Hence, their study justifies the reduction of the rank of the Songir Group to the Songir Formation and the Navagam Group to the Nodular Limestone.

Designation: The unit was previously referred to as Bagh Beds, Nimar Group, Songir Group, Navagam Group, Bagh Group, and Nimar Sandstone (Table 3.1a-d) in the WLNV, and its status is considered as Bagh Group.

Boundary. The lower boundary of the Bagh Group is unconformable with the Precambrian (Plate 4.1a), and the upper boundary is unconformable with the Lameta Group /Deccan Trap Formation, respectively.

Age: Berriasian? (Neocomian) to Coniacian (Gangopadhyay and Bardhan, 1998; Jana et al., 2013).

Depositional environment: The lower part of the Bagh Group comprises conglomerates of sediment gravity flow (Plate 4.1b-d) which progressively grade into gravelly sandstones to sandstones deposits of probably channel lag and braided bar (Plates 4.1e-f, 4.2a). Medium- to coarse-grained cross-bedded sandstone suggests vertical accretion of channel sand bars, and carbonaceous shale indicates the floodplains and back swamps/marshy conditions. Marine influence is observed in the sequence marked by the mixed siliciclastic-carbonate deposits of the marginal marine environment, further overlain by shallow marine carbonate rocks (Plates 4.3-4.4).

4.3.1.1 Songir Formation

Historical background: Foote (1898) referred to the marine Cretaceous rocks exposed in Gujarat State as Bagh Beds and, for the first time, assigned the slabby cross-bedded sandstone exposed near Songir village a term ‘Songir Sandstone,’ where they were extensively quarried. Earlier reports described the unit also as the Nimar Sandstone in the Narmada Basin; later, the Nimar Sandstone and the Songir Formation were used for sandstone exposures in the eastern and western part of the LNV sequence, respectively (Biswas and Deshpande, 1983; Poddar, 1964). The Songir Formation occurs as a consistent sandstone-dominated unit extending laterally from the Barwah in Madhya Pradesh westwards to the Songir-Chosalpura villages in Gujarat (Plates 2.1, 4.1, 4.2a). The lower sandstone-dominated unit was widely referred to as Songir Sandstone Formation (Bhatt et al., 2016), Songir Sandstone (Bhosle et al., 2019; Foote, 1898; Merh, 1995; Poddar, 1964), and Songir Group (Biswas and Deshpande, 1983; Poddar, 1964; Racey et al., 2016) in the WLN. Merh (1995) correlated the Songir Sandstone of Vadodara with the Himmatnagar Sandstone, Nimar Sandstone of Nimar Valley (Madhya Pradesh), Dhrangadhra Formation of Saurashtra, and Bhuj Formation of Kachchh.

Intent and Utility: The Nimar Formation was termed for the lower part of the Bagh Group and was considered a single lithological unit by many authors; Chiplonkar et al. (1977a) extended it to include the overlying oyster limestone bed. Poddar (1964) considered the Nimar Sandstone of ELNV equivalent to the Songir Sandstone of the WLNV. Dassarma and Sinha (1975) and Sastry and Mamgain (1971) classified the lower sandstone-dominated unit in the WLNV as Nimar Sandstone and Calcareous Sandstone (Upper Nimar), whereas Poddar (1964) classified into as upper Uchad Flagstone and lower Songir Sandstone. It was classified as upper Umrali Flagstone and lower Nimar Sandstone in ELNV by Biswas and Deshpande (1984), Murty et al. (1963), and Poddar (1964). The Nimar Sandstone Formation was recently classified as lower Bagh Cave Member and upper Baria/Bariya Member in the ELNV by Kumar et al. (2016) and Tripathi (2006). Singh and Dayal (1979) also supported the division of Nimar Sandstone into lower fresh water and upper marine unit. Thus, the lower part of the sandstone-dominated unit in the WLNV has already been separated from its upper part by previous workers, and the separation was also proposed for the ELNV (Table 3.1a-d). Several workers have designated this lower part of the sandstone-dominated unit as a formation or group. It is widely recognized as Songir in the WLNV (Bhosle et al., 2019; Biswas and Deshpande, 1983; Foote, 1898; Merh, 1995; Poddar, 1964; Raccy et al., 2016). However, its status as a formation or group is still unclear. It was considered as Songir Formation, utilizing the name ‘Songir’ from the earlier works (Shitole et al., 2021). However, the suffix ‘sandstone’ as described in Foote (1898) and Poddar (1964) was removed to acknowledge the dominance of conglomerate and gravelly sandstone in the unit. Murty et al. (1963) and Sastry and Mamgain (1971) described this unit as Nimar Sandstone in WLNV. However, no stratotype or boundaries were assigned.

Designation: Formation

Stratotype: The unit was earlier described as Songir Sandstone (Foote, 1898; Poddar, 1964) for the rocks exposed around Songir village without designating a type section. The stratotype for this formation is well exposed at Songir-Chosalpura villages of the Chhota Udepur District of Gujarat (N 22°05’01” E 73°38’00”) and attains a thickness of approximately 127 m. It exhibits a distinct rock assemblage of conglomerates at the base, followed upward by gravelly and coarse-grained sandstones (Plates 4.1, 4.2a). This formation

is also well exposed around Ghantoli, Mohanfort, Chametha, Vajeriya, Agar, Naswadi, and Sinhada villages (Platc 4.1, 4.2b).



Plate 4.1 Outcrop view of the Songir Formation showing a. Angular contact of sandstones with the Precambrian rocks, Ghantoli village. b. Cobble-rich (clasts impression) conglomerate; Songir village (length of hammer = 32 cm). c. Gravelly sandstone with interbedded conglomerate; Vajeriya village (length of hammer = 34.5 cm). d. Matrix-supported conglomerate, Ghantoli village. e. Large-scale planar cross-stratification in gravelly sandstone; Songir village (length of hammer = 32 cm). f. Planar cross-bedding in

coarse-grained sandstone at Mohanfort section (length of hammer = 32 cm). Scale bar represents 1m.

Description of unit: The Songir Formation (WLNV) rests unconformably over the Precambrian rocks and comprises a thick, coarse clastic sequence, as compared to its ELNV counterpart, the Nimar Sandstone. It is characterized by predominately arenaceous rocks with a subordinate amount of rudaceous deposits (Plates 4.1, 4.2a). The lower part of the formation consists of clast/matrix-supported oligomictic/polymictic conglomerate, gravelly sandstone, fine- to coarse-grained horizontally-bedded and cross-bedded sandstones (Plate 4.1c-d). The conglomerate is poorly sorted and consists of subangular to subrounded granules, pebbles, and cobbles of quartz, jasper, and feldspar minerals. The conglomerates at Songir are about 5 m thick. The sequence grades into gravelly sandstone and coarse- to very coarse-grained sandstone, where the former is frequently repeated in the sequence. The upper part of the unit is dominated by cross-bedded gravelly sandstone (Plate 4.1e), which are discontinuous and pinch out at a very short distance, while the overlying coarse-grained sandstones are horizontally bedded (Plate 4.2a) and cross-stratified (Plate 4.1f) with occasional occurrence of conglomerate (Plate 4.1b). The sandstones are white, yellow, reddish-brown and consist of small gravels scattered throughout the sequence. Petrographically, they are mature sandstones and consist of more than 97% quartz grains, which are poorly sorted, angular to subangular, bounded by a siliceous cement, and show evidence of pressure solution and overgrowth.

Boundaries: The lower boundary of the formation has an unconformable contact with the Precambrian igneous (granite) and metamorphic rocks (phyllites, quartzites, and gneiss) (Plate 4.1a) and is best seen around Agar, Naswadi, Sinhada, Ghantoli, and Vajeriya villages of Narmada and Chhota Udepur districts of Gujarat. The upper boundary is conformable with the overlying calcareous sandstone of the Vajepur Formation, observed at Vajepur village.

Age: Bose (1884) suggested the siliciclastic-dominated sequence beneath the Nodular Limestone from the Ambadongar and surrounding regions (WLNV) to be of Neocomian age. Plant fossils have been recorded by Murthy et al. (1963) from the lower fluvial portion of the Songir Formation (Nimar Group) of Jhabua district, Madhya Pradesh which suggests a Hauterivian age (Early Cretaceous). Kumar (1994) recorded palynomorphs from the carbonaceous clays of the lower part of the fluvial portion of the Nimar Sandstone (Songir

Formation) at Umrli village (Jhabua District), suggesting a broad age range of Late Jurassic–Early Cretaceous. Recently, Jana et al. (2013), based on a plant fossil assemblage *Allocladus–Brachyphyllum–Pagiophyllum* assemblage [zone 9], reported from the Gardeshwar Formation assigned it an Early Cretaceous age. Rajanikanth and Chinnappa (2016) correlated the Gardeshwar Formation (Narmada district, WLNV) with the Dhrangadhra (Saurashtra) and Bhuj formations (Kachchh) and assigned a Neocomian to Aptian age. Based on floral evidence and thick sandy conglomeratic sequence, the Songir Formation's age is considered Berriasian? (Neocomian) to Aptian (Early Cretaceous).

Depositional environment: The lower part of the Songir Formation is characterized by coarse-grained clastic materials of channel gravels and sand bar deposits, characteristic of a braided river. Conglomerates at the base of the sequence characterized by a variable proportion of clast/matrix ratio suggest sediment gravity flows of a fluvial environment. The overlying strata are characterized by thick sandstone; the massive sandstone bodies observed generally at the bottom of the sequence suggest short-lived debris-flow deposits. The occurrence of planar and trough cross-stratification indicates the migration of subaqueous dunes in the lower flow regime of channels. The planar stratified sand bodies intervened by gravel deposits are interpreted as bar deposits. The lithological properties of the rocks in the Songir Formation suggest high bedload and fluctuating discharge characteristics of a braided river environment (Shitole et al., 2021) and debris flow deposits of the alluvial fan.

4.3.1.2 Vajepur Formation

Historical Background: The formation is named after the Vajepur village of Chhota Udepur district, situated at the confluence of Kara River and its tributary, Mathwad Nala. It is well exposed in the Kara River section under the bridge and its E-W trending tributary near Vajepur village (Plate 4.2b, e). Poddar (1964) divided the Songir Group into the Songir Formation and the Uchad Flagstone and incorporated the sandstone-shale unit as part of the Songir Formation, while the Upper Calcareous Sandstone unit was referred to as Uchad Flagstone, also described as Calcareous Sandstone/Upper Nimar by Dassarma and Sinha (1975) and Sastry and Mamgain (1971) in the WLNV. In the ELNV, the upper calcareous sandstone unit is described as Umrli Flagstone (Biswas and Deshpande, 1983; Poddar, 1964), the Upper Nimar Formation (Dassarma and Sinha, 1975; Racey et al., 2016; Sastry

and Mamgain, 1971), the Nimar Formation (Jaitly and Ajane, 2013; Prasad et al., 2017) and Bariya Member (Kumar et al., 2016; Tripathi, 2006).



Plate 4.2 Outcrop view of Songir and Vajepur formations. a. Horizontally-bedded coarse-grained sandstone with granules and pebbles, Songir Formation, Songir village. b. Cross-bedded sandstone and shale of the Vajepur Formation, Vajepur village. Sandstone-shale intercalation of Vajepur Formation exposed at c. Sultanpura-Devaliya village (Scale bar = 1 m) and d. Navagam village. e. The basal sandstone-shale sequence of the Vajepur Formation,

Mathwad Nala, a tributary of Kara River near Vajepur village. f. Thickly-bedded sandstones; Vajepur Formation, Navagam village (Scale bar= 5 m). Length of hammer = 32 cm.

Intent and Utility: Poddar (1964) informally used the term Uchad flagstone, the thinly-bedded rippled sandstone that overlies the Songir Formation, wherein neither the type sections nor the formal description of the unit was given. Field investigation in the studies of Shitole et al. (2021) revealed at least a 40 m-thick intercalated sandstone-shale succession and rippled sandstone which is sandwiched between the Uchad flagstone as described by Poddar (1964) and the underlying Songir Formation, which is exposed in the Navagam, Vajepur, Uchad, Devaliya, Bilthana and Sultanpura sections (Plate 4.2b-e). Therefore, a new lithostratigraphic unit, 'Vajepur Formation' was introduced to formalize the aforesaid unit and encompass the additional thick sedimentary package, which has laterally consistent lithological characteristics. The new unit Vajepur Formation has a different lithological assemblage and bed geometry and therefore differs from the underlying Songir Formation.

Designation: The unit was earlier referred to as Uchad Flagstone, Calcareous Sandstone Upper Nimar with oyster and shark teeth, Calcareous Sandstone (Upper Nimars), and Upper Nimar in the WLVN (Table 3.1a-d). It is considered herein as the Vajepur Formation (Shitole et al., 2021).

Stratotype: The stratotype for this formation was selected for rocks exposed near Vajepur village (Plate 4.2e) of Chhota Udepur district (N 22° 03'31" E 74°05'10"). It has gradational contacts, the lower contact exposed in Kara River east of the Mohan Fort section. The upper contact is exposed near Vajepur village in the Mathwad Nala. It is 46 m thick and comprises white to grey colored sandstone and purple shale sequence capped by rippled sandstone.

Description of unit: The Vajepur Formation comprises of intercalated thickly-bedded sandstone and shale succession in its lower part (Plate 4.2b-e), thickly-bedded sandstone in the middle part (Plate 4.2f), which further grades to flaggy and rippled calcareous sandstone in the upper part (Plate 4.3a-b). The maximum formation thickness (180 m) is observed in the Navagam section. The sandstone bands show the presence of planar, trough, and hummocky cross-stratifications. The calcareous sandstones in the upper part are fine- to medium-grained, flaggy in nature, characterized by ripple marks on each bed, bioturbated, and fossiliferous. Several fossils viz., algae (Badve and Nayak, 1984; Kundal and Sangarwar, 1998a), bivalves (Chiplonkar and Badve, 1976; Dassarma and Sinha, 1975; Nayak, 2000a), foraminifera

(Nayak, 1987; Rajshekhar, 1991), gastropods (Gangopadhyay and Maiti, 2012) and trace fossils (Badvc, 1987; Chiplonkar and Badvc, 1972; Gharc and Badvc, 1980; Kundal and Sanganwar, 1998b, 2000; Nayak, 2000b, Patel et al., 2018; Sanganwar and Kundal, 1997; Singh and Dayal, 1979) were reported from the different sections. Abundant burrows of sea anemones (*Conichmus* and *Conostichmus*) were observed in the uppermost part of the unit (Patel et al., 2018). Petrographically, it is composed of more than 70% fine- to coarse-grained angular quartz grains and subordinate polycrystalline quartz grains with plagioclase feldspar, microcline, chert, glauconite, and ooids. The unit is also observed around Sultanpura, Bilthana, Mathsar-Kanji, Gulvani, Uchad, Navagam, and Karvi villages, Men River section near Devaliya, and fringes of Ambadongar Carbonatite Ring Complex (Shitole et al., 2021).

Boundaries: The upper and lower boundaries of the Vajepur Formation are gradational; coarse-grained pebbly sandstones of the Songir Formation grade upwards to the fine- to coarse-grained quartz arenite and calcareous sandstone of Vajepur Formation in the Kara River section. The upper boundary of the Vajepur Formation grades to the shale of the overlying Bilthana Formation (Plate 4.3b), which is well exposed on either side of the Mathwad Nala near Vajepur village and also observed at Uchad, Sultanpura, Navagam, Karvi, and Gulvani villages.

Age: The Upper Nimar (equivalent to Vajepur Formation) was considered Cenomanian-Turonian in age based on bivalves and calcareous algae (Dassarma and Sinha, 1975; Kundal and Sanganwar, 1998a; Nayak, 2000a). Chiplonkar et al. (1977a) observed placenterid ammonites in the overlying Nodular Limestone and Coralline limestone and assigned the basal Nimar Formation as Albian to Cenomanian. Chiplonkar (1982), based on trace fossils, oysters, and other fossils such as the gastropod *Turritella*, bivalve *Astarte*, and ammonoids *Baghiceras* and *Malwiceras* from the upper part of the Nimar sandstone, suggested its Cenomanian age, based on foraminifera from the calcareous top of the Nimar sandstone unit assigned the Albian-Cenomanian age (Nayak, 1987). Later, Rajshekhar (1995) examined Nayak's collection and found some characteristic forms such as *Miliannina manitovenssis*, *Gavelinella plummerae*, and *G. intermedia* supporting an Albian to Cenomanian age. Based on the above-mentioned fossil evidence, the age of the Vajepur Formation was considered Albian to Cenomanian (Shitole et al., 2021).

Depositional environment: Rocks of the Vajepur Formation are calcareous in nature and contain marine fossils (Dassarma and Sinha, 1975; Murty et al., 1963; Poddar, 1964; Sastry and Mamgain, 1971; Tripathi, 2006). Marine signatures reported from the ELNV and WLNV were tidal evidence (Bhattacharya and Jha, 2014; Dassarma and Sinha, 1975; Sarkar, 1973), sedimentary structures (Bose and Das, 1986), microfossils (Jafar, 1982; Nayak, 1987; Rajshekhar, 1991); calcareous algae (Badve and Nayak, 1984; Kundal and Sanganwar, 1998a); bivalves (Bose, 1884; Chiplonkar and Badve, 1976; Dassarma and Sinha, 1975; Nayak, 2000a) and trace fossils (Chiplonkar and Badve, 1980; Ghare and Badve, 1980; Kundal and Sanganwar, 1998b; Nayak, 2000b; Patel et al., 2018; Sanganwar and Kundal, 1997). Sedimentological and paleontological evidence indicates that the rocks were deposited in a marginal marine to shallow marine environment.

4.3.1.3 Bilthana Formation

Historical background: Poddar (1964) proposed the name 'Bilthana' for the first time for the oyster embedded limestone in WLNV. The calcareous sandstone and oyster bed with shark teeth was designated as Upper Nimar (Jaitly and Ajane, 2013; Racey et al., 2016; Sastry and Mamgain, 1971; Tripathi, 2006) or Bariya Member (Tripathi, 2006); while the oyster bed was recognized as a separate unit by Murty et al. (1963), Poddar (1964), and Verma (1968). Dassarma and Sinha (1975) separated the Bagh beds into three units, Calcareous Sandstones, Oyster Bed, and Rajpipla Limestone; the last two units were placed at higher stratigraphic levels i.e., Coniacian and Senonian, respectively. The oyster-bearing bands were variously named as Oyster Bed (Bose, 1884; Roy-Chowdhary and Sastri, 1962; Verma, 1968) and Amlipura Oyster Bed (Murty et al., 1963; Poddar, 1964) in ELNV, whereas they are recognized as Bilthana Oyster Bed (Poddar, 1964) and Oyster Bed (Dassarma and Sinha, 1975) in WLNV. The Bilthana Oyster Bed was considered equivalent to the Amlipura Oyster Bed of ELNV by Poddar (1964).

Intent and Utility: The unit is characterized by different lithological and paleontological characteristics compared to the underlying unit (Vajepur Formation) and the overlying unit (Nodular Limestone). This unit possesses a degree of internal lithic homogeneity and distinctive lithic features, i.e. intercalation of oyster limestone and shales (Plate 4.3b). Previously, it was described as the Bilthana Oyster Bed (Poddar, 1964) and the Oyster Bed (Dassarma and Sinha, 1975).

Designation: The formation was earlier referred to as Bilthana Oyster Bed, Calcareous Sandstone Upper Nimar (oyster and shark teeth), and Oyster Bed in WLNV. It was formalized as Bilthana Formation (Shitole et al., 2021).

Stratotype: The stratotype of this unit is well exposed in the tributary of Men River, near Sultanpura village, ~500 m east of Bilthana village (N 21° 57'52" E 73° 39'57"). The stratotype section is 9 m thick and comprises about nine oyster-bearing limestone bands intercalated with shale. The maximum thickness of an oyster limestone band is ~20 cm, while the intervening shale bands are relatively thick, and their thickness varies from 30 to 80 cm (Shitole et al., 2021).

Description of unit: The Bilthana Formation consists of an intercalated sequence of oyster limestone and shale (Plate 4.3b-c). The oyster bands are hard, yellow in color, and pinch out at a short distance. The limestone bands are usually centimeters thick, but the exposed band's maximum thickness (20 cm) is observed in the type locality. The intervening shale is grey to dull yellow, fissile, with variable thickness, and the maximum thickness is 80 cm. It is a highly fossiliferous unit and consists of abundant oyster species *Bosostrea* (Chiplonkar and Badve, 1976) with shark teeth (Dassarma and Sinha, 1975; Verma, 1965), gastropods, foraminifers, and ostracods. It is also highly bioturbated (Ghare and Badve, 1980) and mainly consists of *Thalassinoides* and plug-shaped (*Bergaueria*, *Conichmus*, *Conostichmus*) burrows (Patel et al., 2018, Shitole et al., 2019). Oysters are also observed at a higher stratigraphic level i.e., on the top of the Nodular Limestone; however, the occurrence is localized. Petrographically, the Bilthana Formation is composed of abundant shell fragments of oysters with echinoderms, foraminifers, ostracodes with subordinate quartz, and plagioclase feldspar grains embedded in a micritic matrix.

Boundaries: The Bilthana Formation shows a gradational contact with the underlying sandstones of the Vajepur Formation (Plate 4.3b), while the upper boundary of shale grades to the Nodular Limestone. Both the upper and lower contacts of the unit are well exposed at Bilthana, Sultanpura, Uchad, Mathsar, Kanji, Chikhli, Karvi, Gulvani, and Vajepur sections.

Age: Verma (1965) reported shark teeth from the Oyster bed of the Ambadongar area (WLNV) and assigned a Cenomanian-Senonian age to it; later, in 1969, Verma revised the age to Cenomanian-Turonian. Dassarma and Sinha (1966, 1975) reported *Ostrea*, *Turritella*, and shark teeth from the Oyster Bed of Alirajpur area (ELNV) and assigned a Cenomanian

age. Sastry and Mamgain (1971) in WLNV merged the Oyster Bed in the Calcareous Sandstone Upper Nimar and assigned a Cenomanian-Turonian age based on the fossils contained in it.

The Oyster beds are observed at two different stratigraphic levels in the Bagh Group. The upper oyster bed is observed at the top of the Nodular Limestone and is localized in nature. The lower oyster beds occur above the flaggy sandstone of the Vajepur Formation and consist of abundant species of *Bosostrea* (Badve and Ghare, 1978; Chiplonkar and Badve, 1978). Chiplonkar et al. (1977a) considered the oyster bed of the Ambadongar region in WLNV equivalent to the oyster bed of Amlipura, Phata, and Bagh of ELNV, based on ammonites and shark teeth. The shark species *Onchopritus indicus* collected from the Oyster Bed of Ambadongar region in WLNV showed affinities to the *Onchopritus* sp. from the Sahara of Albian-Cenomanian age (Chiplonkar et al., 1977a). The overlying conformable horizon consisting of *Astarte-Turritella* with *Cardium* was assigned a Cenomanian-Turonian age. These authors assigned the Cenomanian-Turonian age for the upper part of Nimar Sandstone (Oyster Beds) till the Upper Coralline Limestone, whereas the Albian age was suggested for the lower part of the Nimar Sandstone (Table 3.1b). The Bilthana Formation shows similar fossil affinities with ELNV and is considered Cenomanian-Turonian in age.

Depositional environment: The formation is characterized by intercalated oyster limestone–shale sequence, with the basal part comprising argillaceous sedimentary rocks. It is immediately overlain by a bed of sandy allochemic limestone containing abundant molluscan shells (marine bivalves), echinoids, and trace fossils. The shell beds suggest deposition in shallow marine conditions. The increase in carbonate content, concentrations of oysters, and argillaceous intervals suggest an increase in water depths compared with the underlying calcareous sandstone of the Vajepur Formation. The increase in the shell fragments towards the top of the oyster limestone bands i.e., from sandy allochemic limestones to bioclastic grainstone/packstone, suggests high-energy conditions. The sedimentological and paleontological evidence suggests that the sequence was developed in low- to high-energy conditions of a transgressive shallow marine environment.

4.3.1.4 Nodular Limestone

Historical background: The name ‘Nodular Limestone’ was first proposed by Bose (1884) and subsequently followed by several workers in the LNV (Table 3.1a-d). Bose (1884) observed the uniform nodular appearance of the lithology in the LNV, except in the eastern and western

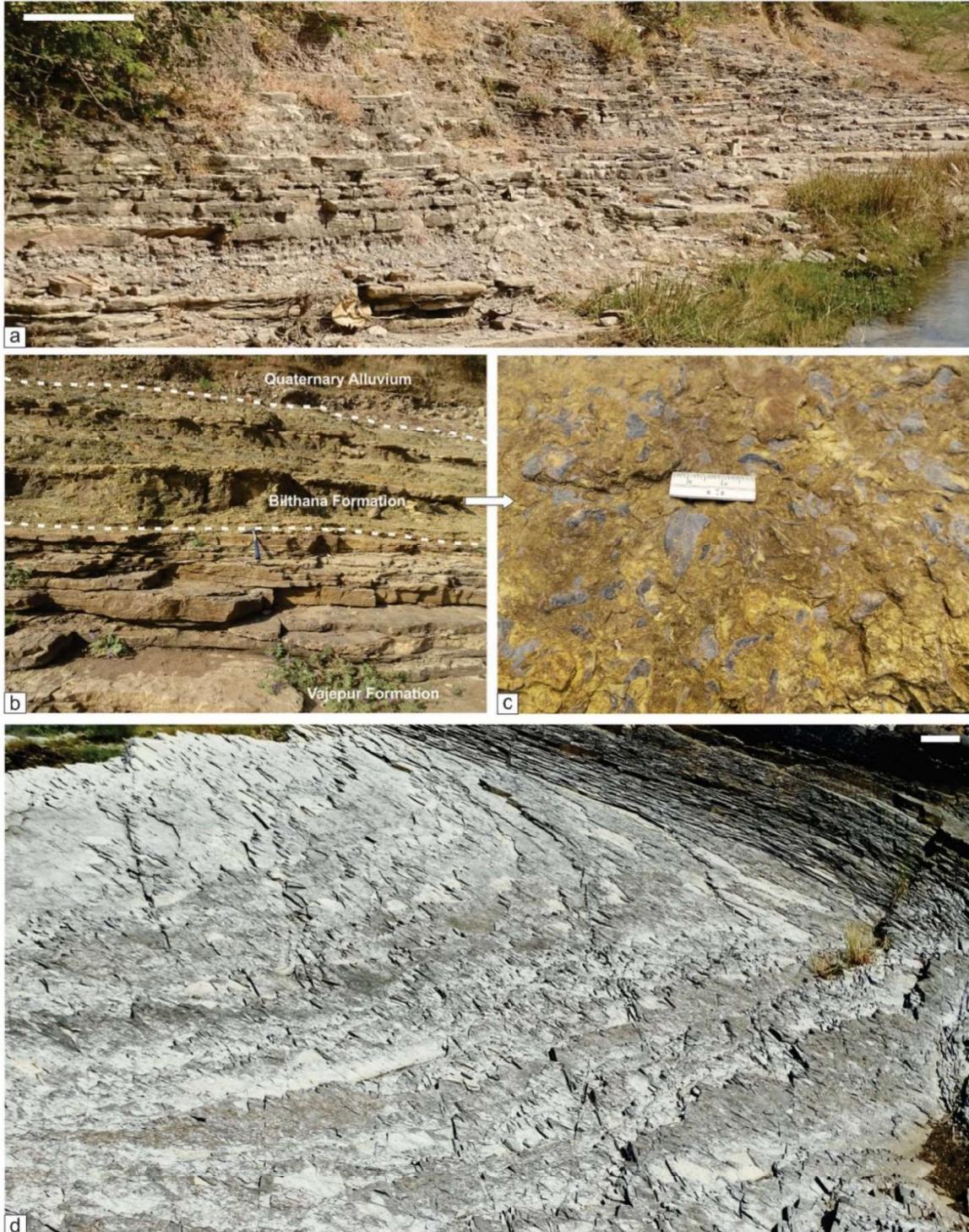


Plate 4.3 Outcrop view of Vajepur Formation, Bilthana Formation, and Nodular Limestone.

a. Flaggy, rippled calcareous sandstone, top of the Vajepur Formation exposed in the tributary of Men River, Sultanpura village. b. Contact of flaggy rippled calcareous sandstone of the Vajepur Formation with the overlying sandy allochemic limestone of Bilthana Formation, Uchad village (length of hammer = 32 cm). c. Close-up view of the fossiliferous limestone bands of the Bilthana Formation showing disarticulated oyster shells. d. Thinly-bedded Nodular Limestone, Narmada River, Navagam village. Scale bar represents 1m.

extremities of Barwah, and Kawant, respectively. Bose (1884) suggested the name owing to a lack of towns or features of importance to give a geographic name. Nodular Limestone is the most consistent lithounit observed in the Narmada Basin (Blanford, 1869; Bose, 1884; Chiplonkar, 1982; Rajshekhar and Aptalkar, 1995). The unit was referred to as Sejagaon Limestone in Jhabua district, Madhya Pradesh by Murty et al. (1963) and correlated it with the Nodular Limestone in ELNV. Poddar (1964) assigned it 'Navagam' name and the status of a group as well as formation.

This unit is variably described as Gulvani Limestone and Navagam Limestone (Poddar, 1964), Rajpipla Limestone (Sastry and Mamgain, 1971 and Dassarma and Sinha, 1975), and the Rajpipla Limestone and Nodular Limestone (Rajshekhar, 1997) in WLNV and as Sejagaon Limestone (Murty et al., 1963; Poddar, 1964), Cave Nodular Limestone (Pal, 1971), Karondia Limestone (Akhtar and Khan, 1997; Guha, 1976), Nodular Limestone Member (Singh and Srivastava, 1981), Karaundia Member (Tripathi, 1995), Nodular Limestone Formation and Karondia Member (Jaitly and Ajane, 2013; Kumar et al., 2016; Ruidas et al., 2018; Tripathi, 2006), Lower *Inoceramus* Bed, Nodular Limestone (Vaidyanathan and Ramakrishnan, 2010), Nodular Limestone Formation (Racey et al., 2016) and Nodular Limestone (Karondia Member) (Prasad et al., 2017) in the ELNV. Later, the unit was redefined as Rajpipla Limestone in the WLNV and considered the youngest unit of the Bagh Group (Dassarma and Sinha, 1975; Sastry and Mamgain, 1971). Biswas and Deshpande (1983) revised the stratigraphy and considered it Nodular Limestone for the entire Lower Narmada Basin. Field investigation of the WLNV succession revealed isochronous deposits and is considered Nodular Limestone (Shitole et al., 2021).

Intent and Utility: The unit has been named variably in the literature and bears many synonyms and homonyms. The Navagam Limestone was first proposed by Poddar (1964) as part of the Navagam Group for the Cretaceous marine sequence of the WLNV and divided

the group into three units, Bilthana Oyster Bed, Navagam Limestone, and Gulvani Limestone. The Navagam Limestone within the Navagam Group are homonyms and lead to confusion. The Navagam Group, which was separated from the rest of the Bagh Group, showed a gradational contact with the underlying Bilthana Formation and was therefore incorporated in the Bagh Group (Shitole et al., 2021). Pascoe (1959) also observed that the Oyster bed would grade into the overlying Nodular Limestone. This Nodular Limestone is laterally traceable and mappable in the LNV and has characteristic lithological features different from the underlying Bilthana Formation and the overlying Narmada Sandstone Member of the Uchad Formation. Limestone exposed in the Narmada River and south of it lacked the typical nodular structure and was described as Rajpipla Limestone (Dassarma and Sinha, 1975; Pascoe, 1959; Sastry and Mamgain, 1971). Biswas and Deshpande (1983) described it as the Nodular Limestone, a part of the Navagam Group. Rajshekhar (1995), based on the field and microfaunal evidence, suggested that although different stratigraphic nomenclatures are used for the Nodular Limestone of the Bilthana (WLNV) and Man River sections (ELNV), both are equivalent. Rajshekhar and Aptalkar (1995) suggested that the Navagam Limestone of Poddar (1964) and the Rajpipla Limestone of Dassarma and Sinha (1975) are equivalents. Also, field investigations of all the proposed units revealed them to be stratigraphically and compositionally similar and have been variably named based on local observations. Blanford (1869), Bose (1884), and Rajshekhar and Aptalkar (1995) suggested that the nodular appearance was not uniform in the basin, and the name Nodular Limestone was open to objection, but the name Nodular Limestone was entrenched in the literature since the past century and was extensively used in the LNV. Therefore, to avoid multiplicity in the nomenclature, the name of the formation was retained in the WLNV, and the names Gulvani Limestone, Navagam Limestone, and Rajpipla Limestone were abandoned (Shitole et al., 2021).

Designation: Previous studies recognized this unit as Gulvani Limestone, Navagam Limestone, Rajpipla Limestone, and Nodular Limestone Formation in the WLNV (Table 3.1a-b, d). The name Nodular Limestone is retained in the present study, and the unit is designated as a formation.

Stratotype: The stratotype for the Nodular Limestone is chosen in the Narmada River Channel (Plates 4.3d, 4.4a) near Statue of Unity, Navagam village, Narmada district of Gujarat (N 21° 50'52" E 73° 42'18"). The stratotype section comprises 80 m of grey limestone, which

grades upward to shaly limestone. It is thinly-bedded; however, the hard bands show a nodular appearance towards the top. The lower and upper contact of the formation grades from the Bilthana Formation and the Uchad Formation, respectively (Plate 4.4a-b). The Nodular Limestone is also exposed in Uchad, Sultanpura, Bilthana, Bhadarwa, Vajepur, Gulvani, Galesar, Mogra, Chikhli, Karvi, Mathsar, and Kanji villages of Gujarat.

Description of unit: This Nodular Limestone is mainly comprised of thick carbonate-dominated rocks with shaly limestone and attains a maximum thickness of ~80 m in the Narmada River channel (Plate 4.3d). The formation is of variable thickness at many localities. It is characterized by black-colored mudstone and sandy micrite rocks. The type section lacks the nodular feature (Plates 4.3e, 4.4a), but it is observed at other localities (Plate 4.4b). The upper part of the formation, which has a typical nodular appearance, occasionally shows the presence of oyster shells. The sparse occurrence of the oyster shells is also observed at different levels in the type section. Sporadic occurrence of ammonites, bivalves, ostracods, foraminifers, echinoid species, and *Thalassinoides* burrows are also observed. Petrographically, the formation is composed mainly of micrite with a subordinate amount of quartz and allochems.

Boundaries: The Nodular Limestone conformably overlies the Bilthana Formation and is overlain by calcareous sandstone of the Narmada Sandstone Member of the Uchad Formation (Plate 4.4a-b). The upper and lower contacts of the units are well exposed at localities such as Uchad, Sultanpura, Bilthana, Vajepur, Gulvani, Galesar, Chikhli, Karvi, Mathsar, and Kanji villages of Gujarat.

Age: Several ammonite species have been reported from the Nodular Limestone in the ELNV viz. *Placenticerias mintoi*, *Prinocyclus germari*, and *Placenticerias kaffarium* (Bose, 1884; Chiplonkar and Ghare, 1976; Dassarma and Sinha, 1975; Ganguly and Bardhan, 1993; Jaitly and Ajane, 2013; Kennedy et al., 2003; Vredenburg, 1907). *Namadoceras* described from Bagh by Vredenburg (1907) was later considered similar to *Coilopoceras* Hyatt, 1903 of Middle to Late Turonian in age (Chancellor et al., 1994; Cobban and Hook 1980; Pervinquière, 1910). *Prinocyclus germari* recorded from the Upper Nodular Limestone was dated Late Turonian (Kennedy et al., 2003). Sastry and Mamgain (1971), based on ammonites from the WLNV, assigned the Rajpipla Limestone (Nodular Limestone) and Oyster Bed with *Coilopoceras* and *Proplacenticerias* a Santonian-Campanian age. However, Chiplonkar et al. (1977a) suggested a Turonian age based on megafossils.

Smith (2010) collected abundant species of echinoderms from the upper part of the Nodular Limestone, the Coralline Limestone, and the lower part of the Deola-Chirakhan Marl and suggested the age of the Coralline Limestone and upper part of the Nodular Limestone be Turonian. The echinoid species *Mecaster mutabilis* reported from the Nodular Limestone of the Bilthana village in WLNV (Srivastava et al., 2011) and also from the upper part of the Nodular Limestone, Man-Sukar Nala rivers region to the south of Zeerabad in ELNV (Smith, 2010) was assigned a Cenomanian-Turonian age. Jaitly and Ajane (2013) collected abundant specimens of *Placenticerias mintoï* from different levels of the Nodular Limestone and assigned a Turonian age. The ammonoids *Prinocyclus germari* (Kennedy et al., 2003) and *Placenticerias kaffarium* (Bardhan et al., 2002) are considered to be an ecophenotypic variation of *Placenticerias mintoï*. Bardhan et al. (2002) recorded *Placenticerias kaffarium* and the inoceramid bivalve *Volviceras involutus* from the middle and upper part of the Nodular Limestone and assigned it an Early-Middle Coniacian age. Recently Ruidas et al. (2018) reassessed the *Placenticerias kaffarium* and *Volviceras involutus* from the Nodular Limestone and bracketed its age from upper Turonian-lower Middle Coniacian. Two poorly preserved ammonite specimens were collected from this unit near the Uchad village are apparently identical to the genus *Placenticerias*. The stratigraphic position, lithological and paleontological characteristics of the Nodular Limestone of WLNV are identical to ELNV, hence considered a coeval deposit and assigned a Turonian age.

Depositional environment: The sequence of the type area mainly consists of bedded limestone with fissile shaly limestone, usually unfossiliferous, except for the top layers, which consist of abundant oysters (Fig. 4.1). The limestone bands are compositionally homogeneous and chiefly comprise micrite, while shaly limestone consists of silt-size quartz particles. The accumulation of limestone bands marks the episodes of shallow shelf starvation from terrigenous sediment, but the presence of fine-grained quartz suggests the intervening agitative phases. Rajshekhar (1991), based on the high frequency of agglutinated foraminifera from the Nodular Limestone of Ambadongar region (WLNV), suggested a reducing depositional environment. The presence of pyrite minerals in the Nodular Limestone suggests euxinic conditions (Badve and Ghare, 1978). The limestone progressively grades upward to shaly limestone with thin bands of shale-oyster layers at the top, indicating a subtidal environment.

4.3.1.5 Uchad Formation

Historical background: The Uchad Formation is a newly defined unit based on the variable lithology encountered above the Nodular Limestone. It is the youngest formation of the Bagh Group. The name Uchad Formation is derived from Uchad village, situated on the confluence of the Men River and its unnamed tributary, where it is best developed and well exposed.

Intent and Utility: Up to now, the succession younger than the Nodular Limestone in the Bagh Group was not described in the WLNV. This lithostratigraphic unit is well developed near Uchad village and comprises micritic sandstone, calcareous sandstone, quartz arenite, mudstone, muddy micrite, and shale. Considering the distinctive physical appearance and composition of this lithounit compared to the underlying Nodular Limestone Formation, this sedimentary package can be considered as a separate lithounit. Thus, it is defined as a new separate stratigraphic unit, 'Uchad Formation.' This formation is further subdivided into a lower sandstone-dominated Narmada Sandstone Member and an upper carbonate-dominated Men Nadi Limestone Member. The formation differs from the Coralline Limestone (youngest unit in ELNV) by lack of bryozoan-rich assemblage.

Designation: The unit is designated herein as a formation.

Stratotype: The stratotype for the Uchad Formation was chosen at the NW-SE trending small tributary of Men River, north of Uchad village, Narmada district of Gujarat (N 21° 56'56" E 73° 38'10"). The stratotype section exposes yellow to brown-colored sandstones of Narmada Sandstone Member (Plate 4.4d) overlain by buff-colored shale, muddy micrite, and mudstone rocks of Men Nadi Limestone Member (Plate 4.4e).

Description of unit: The total thickness of the formation is 13 m at the type section. Arenaceous and calcareous rocks characterize the Uchad Formation. The lower part of the formation consists of coarse-grained siliciclastics showing wavy-bedding, cross-bedding, and graded-bedding. The upper part consists of carbonate-dominated rocks. The formation attains a thickness of ~50 m at the Navagam section consisting entirely of siliciclastics of the Narmada Sandstone Member.

Boundaries: The boundaries of the formation are well defined. The lower boundary is gradational at Bilthana, Navagam (Plate 4.4a), Vajcpur, and Ambadongar, while sharp with the Nodular Limestone near Uchad village (Plate 4.4b). The upper boundary of the formation is unconformable with the Lameta Group exposed at Bhekhadiya and Bhadarwa.

Age: The Coralline Limestone rests conformably over the Nodular Limestone in ELNV (Plate 3.1b-c) and is assigned a Coniacian age (Jaitly and Ajane, 2013). Similarly, the Uchad Formation rests conformably over the Nodular Limestone in the WLNV. This unit shows a lateral lithological variation with the ELNV and is unfossiliferous, but it occurs at the same stratigraphic level and hence, is assigned a Coniacian age.

Depositional environment: The Uchad Formation comprises two distinctive types of lithology. The lower part is characterized by micritic sandstone and quartz arenite with different types of cross-bedding indicating a foreshore to shoreface environment. The upper part comprises muddy micrite and mudstone with occasional juvenile bivalve shell fragments suggesting a calm, low-energy shoreface environment.

4.3.1.5.1 Narmada Sandstone Member

Historical background: It is a newly defined unit based on the distinct lithological, stratigraphic position, and field characteristics observed. The name 'Narmada' is based on the Narmada River near Navagam village (WLNV), which exposes thick sandstone above the Nodular Limestone (Plate 4.4a, c). This sandstone forms a small hillock in the Narmada River channel over which recently the Statue of Unity was constructed.

Intent and Utility: The uppermost unit of the Bagh Group is well developed in ELNV and described as Coralline/Bryozoan Limestone (Biswas and Deshpande, 1983; Bose, 1884; Dassarma and Sinha, 1975; Gangopadhyay and Maiti, 2012; Jaitly and Ajane, 2013; Murty et al., 1963; Prasad et al., 2017; Taylor and Badve, 1995; Tripathi, 2006; Sastry and Mamgain, 1971; Verma, 1968). The equivalent unit in the WLNV was overlooked by earlier workers who described the Bagh Group up to the Nodular (Rajpipla) Limestone (Dassarma and Sinha, 1975; Poddar, 1964; Sastry and Mamgain, 1971). The unit in the WLNV bears distinct lithological characteristics differentiating it from the underlying carbonate-dominated

Nodular Limestone. Thus, it was considered a separate unit from the underlying Nodular Limestone and named Narmada Sandstone Member (Shitole et al., 2021).

Designation: The unit is designated as a member.

Stratotype: The stratotype for this unit was chosen in the Narmada River channel (Plate 4.4a, c), near the Statue of Unity, Narmada district Gujarat (21°50' 34"N, 73° 42' 52"E). The section is 50 m thick and comprises micritic sandstone at its base, overlain by calcareous sandstone, gravelly sandstone, thinly-bedded quartz arenite (Plate 4.4c) characterized by planar, herringbone cross-stratification, and ripple marks, capped by the gravelly sandstone (Shitole et al., 2021).



Plate 4.4 Field photographs of Uchad Formation. a. Gradational contact of the Nodular Limestone with the overlying Narmada Sandstone Member of the Uchad Formation, Narmada River, Navagam village. b. Sharp contact of the Nodular Limestone with the Narmada Sandstone Member of Uchad Formation, Uchad village. c. Thinly-bedded, rippled sandstone occurring in the middle part of the Narmada Sandstone Member, Narmada River, Navagam village. d. Thickly-bedded Narmada Sandstone Member in the tributary of Men River, Uchad village. e. Men Nadi Limestone Member of the Uchad Formation in the tributary of Men River, Uchad village (length of hammer = 32 cm). Scale bar represents 1m.

Description of unit: The type section of the Narmada Sandstone Member consists of bioturbated micritic sandstone at the base containing abundant *Skolithos* tubes, which further grade into thinly- and thickly-bedded sandstones (Plate 4.4c) and gravelly sandstones. The thinly-bedded sandstones are characterized by ripple marks (Plate 4.4c), while the thickly-bedded sandstones show sedimentary structures such as cross-bedding and graded-bedding. Petrographically, it shows fine- to coarse-grained, moderate to poorly sorted quartz grains with subordinate microcline, plagioclase feldspar, and polycrystalline quartz grains bonded with ferruginous, siliceous, or calcareous cement (Shitole et al., 2021).

Boundaries: This member conformably overlies the Nodular Limestone (Plate 4.4a) and is unconformably overlain by the Deccan Traps. It is also well exposed near Uchad village, where the lower boundary is sharp and shows an erosional contact (Plate 4.4b), while the upper boundary grades to Men Nadi Limestone Member. The lower contact of the Narmada Sandstone Member is observed at Sultanpura, Navagam, Vajapur, and Ambadongar villages, while the upper contact with the Men Nadi Limestone Member is observed only at Uchad village.

Age: The stratigraphic position of the member is equivalent to the cross-bedded Coralline Limestone of Bose (1884) or Bryozoan Limestone Formation of Gangopadhyay and Maiti (2012) in the Elnv but differs in lithology. Gangopadhyay and Bardhan (1998) and Jaitly and Ajane (2013) assigned the Coniacian age to the Coralline Limestone based on its stratigraphic position and the presence of ammonite *Barroisiceras onilahyense* Basse, 1947. This unit has gradational contact with the underlying Nodular Limestone and lacks age-diagnostic fossils. Based on its stratigraphic position, the Narmada Sandstone Member was considered similar to the coralline limestone of Elnv and was assigned Coniacian age (Shitole et al., 2021).

Depositional environment: The unit has a sharp and conformable contact with the underlying Nodular Limestone. It grades upward into thinly-bedded rippled sandstone to planar and herringbone cross-stratified sandstone beds. The lithology changes from micritic sandstone, siliceous sandstones at the bottom, to gritty/gravelly sandstone towards the top of the unit, suggesting shallowing of the sea. With the lithology, bed geometry, sedimentary structures, and presence of the abundant vertical *Skolithos* burrows, a high-energy shoreface environment with tidal influence, was inferred for the unit (Shitole et al., 2021).

4.3.1.5.2 Men Nadi Limestone Member

Historical background: Name of the unit was derived from the Men River, a tributary of the Narmada River referred to as 'Men Nadi' in the Geological Survey of India toposheet no. 46G/9. The Men Nadi Limestone Member is the topmost unit of the Bagh Group and is newly defined. Srivastava et al. (2011) first reported a limestone band younger than the Nodular Limestone in the WLVN and referred to it as the Navagam/Rajpipla Limestone in WLVN. However, field investigations of the Uchad section revealed that the limestone band is younger than the Nodular Limestone and is separated from it by a 6-m-thick sandstone unit belonging to the Narmada Sandstone Member. Due to its distinct lithological characteristics and stratigraphic position, it was separated from the Narmada Sandstone Member and named Men Nadi Limestone Member (Shitole et al., 2021).

Intent and Utility: It is the youngest stratigraphic unit of the Bagh Group, resting conformably over the Narmada Sandstone Member. This member is a carbonate-dominated sedimentary unit that can be easily differentiated from the underlying sandstone-dominated Narmada Sandstone Member. It also differs from the Nodular Limestone of a lower stratigraphic level by its lack of nodularity (Plate 4.4c) and its stratigraphic position. This youngest unit of the Bagh Group in the WLVN was unreported. The Men Nadi Limestone Member is preserved in the tributary of Men River near Uchad village and at Bhekhdiya village. It was assigned the separate status of an upper member in the Uchad Formation of the Bagh Group succession based on its well-defined lithological characteristics.

Designation: Member.

Stratotype: The stratotype for the member lies in the NW-SE flowing tributary of Men River (Plate 4.4e), north of Uchad village (21°56' 52"N, 73° 38' 12"E).

Description of unit: The unit is yellowish-white colored, thickly-bedded mudstone in its upper part (Plate 4.4e), while it appears intercalated with shale in its lower part. It is 7 m thick and observed in the Uchad and Bhekhadiya villages of the Narmada district. Petrographically, the member consists of muddy micrite, which grades up into mudstone. The member is poorly fossiliferous; occasionally, a few delicate shell fragments are found in the mudstone. The top of the member is composed dominantly of micritic mud, while the base

shows the presence of mixed siliciclastic-carbonate rocks wherein the fine-grained quartz grains are bounded in micritic cement.

Boundaries: The lower boundary of the unit is conformable with the Narmada Sandstone Member and is observed in the tributary of Men River near Uchad village. The Men Nadi Limestone Member is overlain by Quaternary alluvium and friable ferruginous sandstone and gravelly sandstones with chert replacement of the Maastrichtian Lameta Group near Uchad and Bhekhadiya villages.

Age: The Men Nadi Limestone Member of the WLNV and Coralline Limestone of ELNV are the youngest lithostratigraphic units of the Bagh Group. Gangopadhyay and Bardhan (1998) have reported the Late Turonian-Coniacian ammonite, *Barroisiceras onilahyense* Basse, 1947 from the top oyster-rich bed (Coralline Limestone) along with inoceramid bivalves have suggested a Coniacian age, which was subsequently followed by Jaitly and Ajane (2013) and Prasad et al. (2017).

Depositional environment: This member conformably overlies the thick Narmada Sandstone Member and is dominated by carbonate rocks. The lower part of the unit comprises muddy micrite, which progressively grades upward into mudstone. It is poorly fossiliferous and consists of rare, delicate bivalve shell fragments. Sedimentological and paleontological evidence suggests calm water, a carbonate-prone shoreface environment and marks a second transgression in the WLNV during the Late Cretaceous. The unit was previously informally recognized

4.4 SUMMARY

Several authors (Dassarma and Sinha, 1965; Poddar, 1964 and Sastry and Mamgain, 1971) who have worked in both parts of the basin have separated the lithostratigraphy of WLNV from the ELNV. Songir Formation consists of mappable coarse-grained clastic rocks which lie unconformably above the Precambrian rocks in the WLNV (Plate 4.1a) and is a well-established unit in the WLNV. The equivalent part of the Songir Formation is very thin in the ELNV and hence not recognized as a separate unit in the Nimar Sandstone (Fig. 4.1; Plate 3.1a). Shitole et al. (2021) have identified Vajepur Formation as a distinct unit with

heterogeneous lithology, which differs from the underlying Songir Formation. Thus, it justifies a separate status of the Vajepur Formation.

The unit was previously informally recognized as Calcareous Sandstone (Dasarma and Sinha, 1975), Upper Nimar (Sastry and Mamgain, 1971), Uchad Flagstone (Poddar, 1964), and Umrali Flagstone (Murty et al., 1963; Poddar, 1964) in the WLNV and is correlated with the Nimar Sandstone (Bose, 1884), Nimar Sandstone Formation (Tripathi, 1995; Nayak, 2000b, 2004; Tripathi, 2006; Jaitly and Ajane, 2013), Calcareous Sandstone (Sastry and Mamgain, 1971; Dassarma and Sinha, 1975), and Upper Nimar (Dassarma and Sinha, 1975; Racey et al., 2016) in the ELNV (Table 3.1a-d). Moreover, the Nimar Sandstone of ELNV is equivalent to the Songir Formation and the Vajepur Formation of WLNV.

The overlying Bilthana Formation is recognized as Bilthana Oyster Bed and Oyster Bed in WLNV. It is very thinly developed in ELNV and informally referred to as Oyster Bed or Amlipura Oyster Bed (Murty et al., 1963), which is often merged with the Nimar Sandstone (Table 3.1a-d) (Bose, 1884; Sastry and Mamgain, 1971). This unit has distinct lithological and paleontological characteristics compared to Vajepur Formation in WLNV and Nimar Sandstone in ELNV and cannot be considered its part; moreover, it is widely mappable in the WLNV. As per the lithostratigraphic nomenclatorial guideline, the name of the formation constitutes the geographic name combined either with the rank or the lithology and is not solely based on the paleontological characteristics. Therefore, only a minor part of the content of the originally established unit and its rank and the original geographic name 'Bilthana' is retained.

Since the name Nodular Limestone is deeply entrenched in the literature and shows lateral continuity with an identical lithology in ELNV and WLNV, its name is retained. The ammonite- and echinoderm-bearing Nodular Limestone (Fig. 4.1; Plate 3.1e) is overlain by cross-bedded Coralline/Bryozoan Limestone in the ELNV (Fig. 4.1; Plate 3.1b-c), whereas in the WLNV, it is overlain by a sandstone-dominated unit (Fig. 4.1; Plate 4.4a-b). The Coralline/Bryozoan Limestone of ELNV (Plate 3.1c-d) lacks mappability in the WLNV (Plate 3.2). In the same way, units overlying the Nodular Limestone in WLNV also lack mappability in the eastern counterpart. The Uchad Formation is the youngest unit of the WLNV

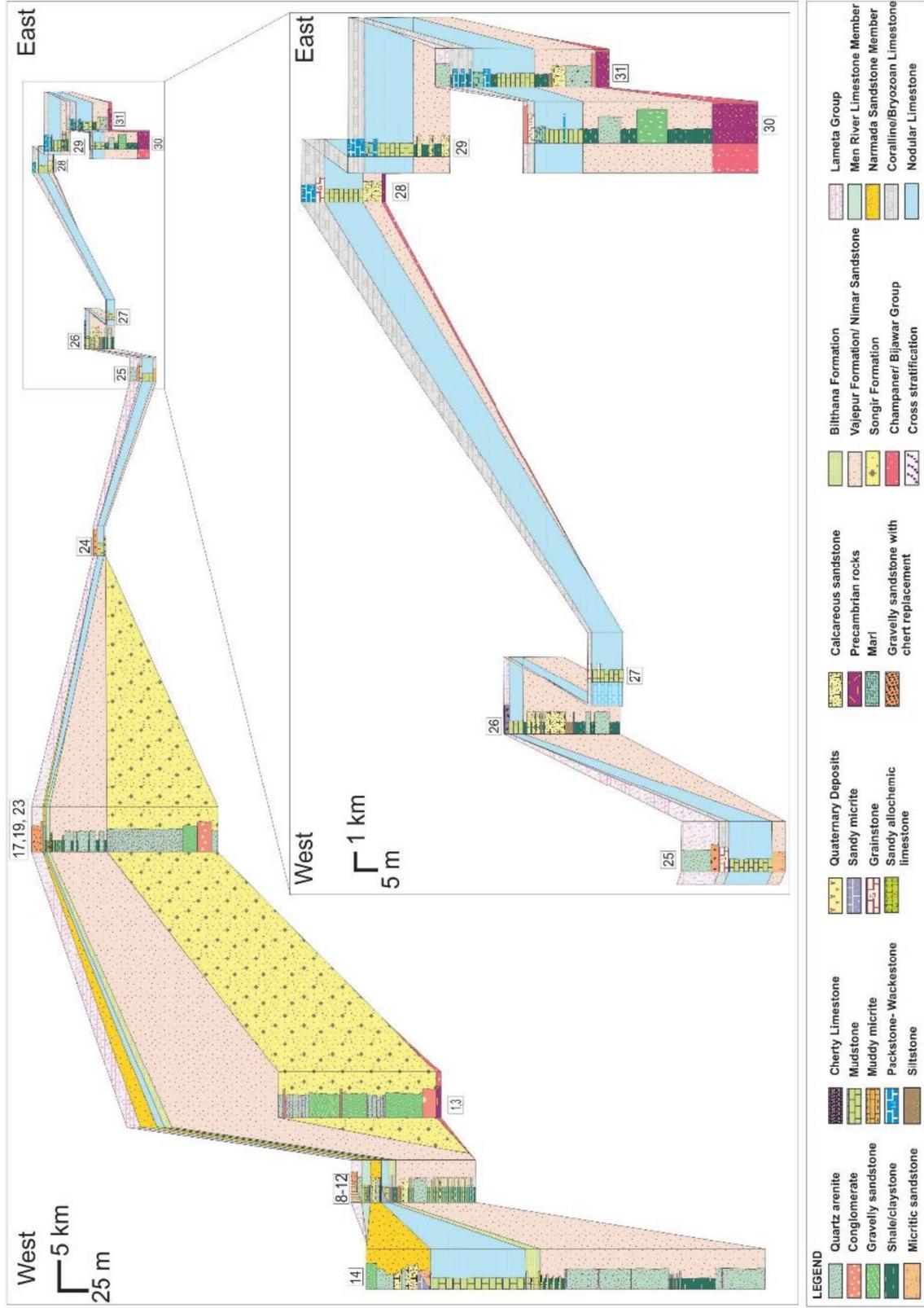


Figure 4.1 Stratigraphic correlation of the Cretaceous Bagh Group rocks sections along the profile A-A' (Figure 2.1) in the Lower Narmada Valley; Men River Valley (8-12) and Mohanfort-Vajepur (17, 19, 23) are the composite profiles (Shitole et al., 2021).

which overlies the carbonate-dominated Nodular Limestone. It is newly introduced in the lithostratigraphic succession of the WLNV due to its distinct sedimentary characteristics, which is further subdivided into two members, Lower Narmada Sandstone and upper Men Nadi Limestone. The Late Cretaceous Lameta Group caps the Coralline Limestone in ELNV and the Uchad Formation in WLNV. The succession of WLNV is characterized by distinct gross lithology compared to its eastern counterparts, which do not fit into the earlier proposed lithostratigraphic schemes. Finally, the author has been able to discriminate lithological succession of ELNV and WLNV, maintain the status of both considering the geographic limits, amend the lithostratigraphy of the WLNV discussed herein, and published (Shitole et al., 2021).