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DEPOSITIONAL ENVIRONMENT OF THE UPPER VINDHYAN SEDIMENTS IN THE SATNA-MAIHAR AREA, MADHYA PRADESH, AND ITS BEARING ON THE EVOLUTION OF VINDHYAN SEDIMENTATION BASIN.

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ABSTRACT

Depositional environment of various lithological units of the upper Vindhyan sediments are discussed. The environmental interpretation is based on the observation of primary sedimentary structures, and their succession in profile. The depositional environment of various litho-units are: Rohtas limestone—carbonate tidal flat, Rohtas shale-carbonate lagoon, Kaimur sandstone (lower part)—fluvial, Kaimur sandstone (upper part)—shoal complex, Rewa shale—lagoon, Rewa sandstone—shoal-beach complex, Bhander limestone—carbonate tidal flat, Sirbu shale—lagoon, Maihar sandstone—tidal flat-shoal complex. The sedimentation is fairly continuous, and one lithological unit gradually changes to the other, accompanied also by a change in the energy of the environment. A hiatus is recorded at the base of Kaimur sandstone which in this area directly overlies the Rohtas shale. The intervening lower and upper quartzite, and Bijaigarh shale are absent. The domain of sedimentation fluctuated amongst shoal-sand bar, tidal flat, and lagoon. It is interesting to note that shelf-mud sediments and alluvial plain sediments are not encountered, and no typical coastal sand-shelf sequences are developed. Throughout the period of sedimentation in Satna-Maihar area an extensive shallow tidal sea was maintained with exceptionally stable sedimentary tectonics, where a delicate balance between subsidence of the basin and deposition was kept.

INTRODUCTION

Vindhyan sediments of central India represents an interesting succession of late Precambrian age on the peninsular India. Despite their age, Vindhyan sediments have been very little disturbed and show no effects of metamorphism. They exhibit exceptionally well-preserved primary sedimentary structures, which is the fundamental unit in the reconstruction of the depositional environment. After the pioneering works of Medlicott (1859), Oldham (1859), Mallet (1869), and Oldham Vredenberg and Dutta (1901), it was Auden (1933) who made a detailed lithostratigraphical study of the Son Valley Vindhyans, and attempted environmental reconstruction. Later on, Basumallick (1962 a, b) Banerjee and Sengupta (1964), Lahiri (1964), Misra and Awasthi (1962) Awasthi (1964), Mathur (1965) studied various sedimentological aspects of Vindhyan sediments. Misra (1969) provides a useful review of the Vindhyan sediments. Recently Singh (1973) made an attempt to reconstruct the depositional environment of the Vindhyan sediments in Son Valley area.

Chanda and Bhattacharyya (1974) studied the Bhander limestone of the Maihar area and suggested the depositional environment.

In the present paper an attempt has been made to reconstruct the environment of deposition of various litho-units of the Vindhyan sediments of the Satna-Maihar area, where predominantly upper Vindhyan sediments are exposed.

AREA OF STUDY

The Satna-Maihar area shows undulating topography with exposures in few nalas and hillocks. As the upper part of Bhander limestone is extensively quarried for steel and cement industry, excellent sections are available in these quarries.

In Satna, following quarries have been visited: Chaurasia limestone quarry, Bamhore quarry, Steel mine quarry, Birla cement factory quarry. Besides, several sections in the nalas and hillocks on Satna-Panna road have been studied.

In Maihar, upper part of Bhander limestone was studied in Emlia quarry, Tons river section, Lilji nala section. A traverse from Badanpur to Maihar provides a complete succession from Rohtas limestone, Rohtas shale, Kaimur sandstone, Rewa shale, Rewa sandstone, lower part of Bhander limestone. Sirbu shale is exposed around Maihar township, Sharda Devi hillock, 1990′ hill (north of Sharda Devi hillock), Lilji nala and Kasia hill. Maihar sandstone was studied in Sharda Devi hillock, 1990′ hill (north of Sharda Devi hillock), Kasla hill. Fig. 1 shows the location map

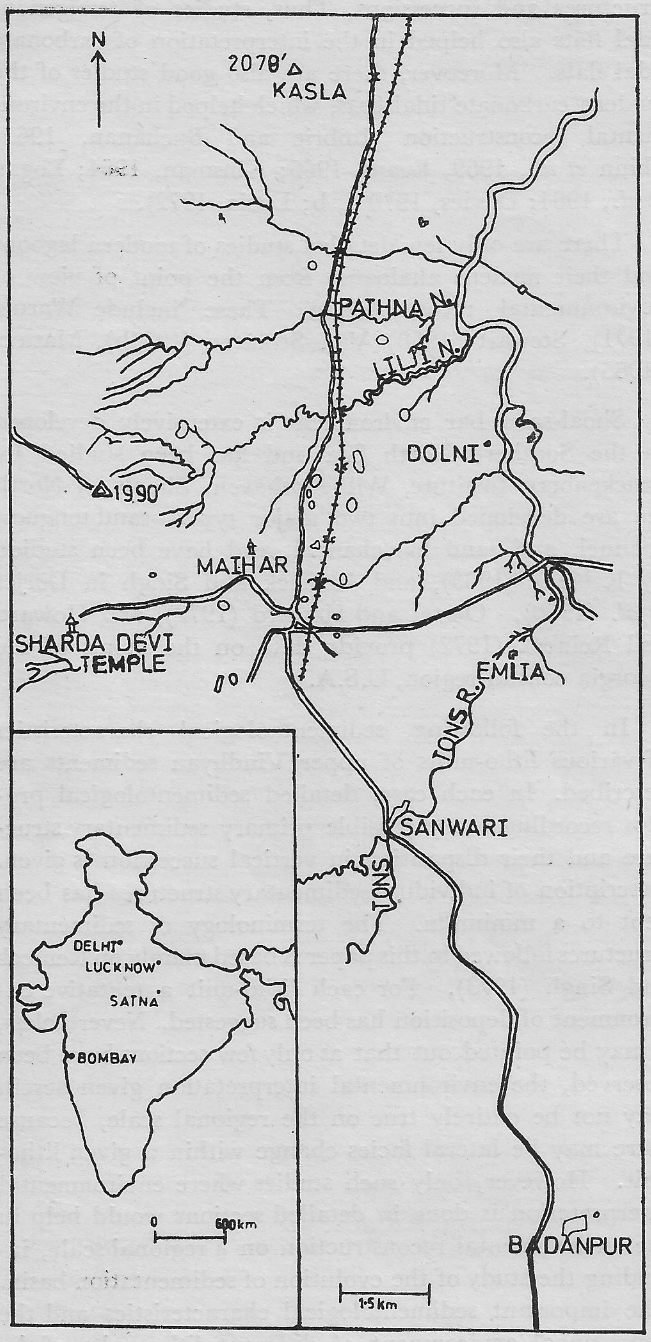

Fig. 1. Location map.

Table 1

General lithostratigraphic succession of Upper Vindhyan sediments, and lithostratigraphic succession in the Satna-Maihar area.

	General lithosatratigraphy (After Misra, 1969)	Lithostratigraphy of Satna-Maihar area (After Rao, 1949, Awasthi, 1964, and present study)
	Upper Bhander Shales	
	Upper Bhander Limestones	
	Upper Bhander Sandstones	Maihar sandstone
Bhander Series	Sirbu Shales	Sirbu Shale
	Lower Bhander Sandstones	
	Lower Bhander Limestones	Bhander limestone
	Ganurgarh Shales	
	Upper Rewa Sandstones	Rewa sandstone
	Jhiri Shales	
Rewa Series	Lower Rewa Sandstones	Rewa shale
	Panna Shales	
	Upper Kaimur Sandstones (Dhandhraul Quartzites)	Kaimur sandstone
	Upper Kaimur Conglomerates (Scarp Sandstones)	
Kaimur Series	Bijaigarh Shales	
	Upper Quartzite	
	Silicified Shales	
	Lower Quartzites	

GEOLOGICAL SET UP OF THE AREA

The general lithostratigraphy of upper Vindhyan sediments and the lithostratigraphy of Satna-Maihar area is given in Table 1. In Satna-Maihar area, there are fewer lithostratigraphic units and the succession is somewhat reduced in thickness. The Vindhyan sediments of Satna-Maihar area show gentle dips (2-5°), and do not exhibit any structural disturbances. In Satna, upper part of Bhander limestone is extensively developed and exposed in various nalas of the area. Few low mounds in the region are made up of Sirbu shale. The surface topography is made up of Sirbu shale.

In Maihar, the complete succession of upper Vindhyan sediments is exposed. The area around Maihar township provides exposures of Sirbu Shale. In the SE of Maihar township in various nalas upper part of Bhander limestone is exposed. The top of hills in the West and North of Maihar township are made up of Maihar sandstone, while at the base Sirbu shale is exposed. South of Maihar, between Badanpur and Sanwari, Kaimur and Rewa sediments are exposed.

Chanda and Bhattacharyya (1974) give an account of the geology around Maihar. Lower Bhander sandstone of Chanda and Bhattacharyya (1974) is actually the topmost horizon of Bhander limestone. The sand/shale alterations exposed in the hills east of Thomas River belong to Sirbu shale, and contain the characteristic sedimentary structures of Sirbu shale, e.g., salt pseudomorph shale. In Pathna nala and Lilji nala the upper part of Bhander limestone is exposed, and not the Sirbu shale as claimed by Chanda and Bhattacharyya (1974). The cabbage-head stromatolitic limestone horizon is the topmost horizon of the Bhander limestone. Thus, it is suggested that in Maihar area Lower Bhander sandstone is not developed. The topmost horizon of the Bhander limestone is the cabbage head limestone horizon exposed in Lilji nala which also happens to be the topmost limestone horizon of the area.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

A depositional environment is defined as a geomorphic unit, characterized by a unique set of physical biological, and chemical processes operating at a specified rate and intensity (Reineck and Singh, 1973). Identification of depositional environment in ancient sediments requires identification of various parameters, which provide clues to the geomorphic unit. The physical processes leave behind their imprints in lithology, grain size, and sedimentary structures, and can be utilized in environmental interpretation. Study of primary sedimentary structures helps in assessment of the intensity and type of energy of the environment (Wave, current, or wind), which provide good frame-work for the interpretation of the geomorhpic unit.

In the last decade, considerable work has been done on the genesis of sedimentary structures. Moreover, today considerable information is available about the modern sedimentary environments. A comparison of ancient sediments with the present-day environments is very useful in the reconstruction of the environment. Recently, Reineck and Singh (1973) have given a detailed account of various environmental models, based on the studies in modern sediments. The Vindhyan sediments are deposits of a shallow tidal-sea (Singh, 1973), and the environments recognized are carbonate and terrigenous tidal flat, lagoon, shoal-sandbar complex.

Several good studies of modern tidal flat sediments are available: Häntzschel, 1936; Van Straaten, 1954a; Hülsemann, 1955, Evans, 1965; Thompson, 1968; Reineck, 1963, 1967, 1970; Klein, 1970. Good examples of ancient tidal flat deposits are described by Singh (1969), Wunderlich (1970), De Raaf (1970), De Raaf and Boersma (1971) Kuijpers (1972). The interpretation of tidal flat environment (terrigenous) of the Vindhyan sediments has been based on the above mentioned works and author's personal experience in the North Sea tidal flats.

The carbonate tidal flats are quite similar to the terrigenous tidal flats, and exhibit similar sedimentary structures and successions. Thus, studies of terrigenous tidal flats also helped in the interpretation of carbonate tidal flats. Moreover, there are also good studies of the modern carbonate tidal flats, which helped in the environmental reconstruction (Imbrie and Buchanan, 1965; Shinn *et al.*, 1969, Evans, 1966; Kinsman, 1964; Logan *et al.*, 1964; Davies, 1970 a, b; Lucia, 1972).

There are only few detailed studies of modern lagoons and their ancient analogues from the point of view of environmental reconstruction. These include Warme (1971), Stewart (1958) Van Straaten (1954b), Masters (1965).

Shoal-sand bar environment is extensively developed in the Southern North Sea and has been studied by Senckenberg Institute, Wilhelmshaven. Shoals of North sea are developed into two major types—sand tongues/channel, and sand bar/channel, and have been studied by Reineck (1963), and Reineck and Singh in Dörjes *et al.* (1970). Oertel and Howard (1972), and Howard and Reineck (1972) provide data on the shoals of the Georgia coastal region, U.S.A.

In the following, sedimentaological characteristics of various litho-units of upper Vindhyan sediments are described. In each case, detailed sedimentological profiles recording every possible primary sedimentary structure and their disposition in vertical succession is given. Description of individual sedimentary structures has been kept to a minimum. The terminology of sedimentary structures followed in this paper is based mainly on Reineck and Singh (1973). For each litho-unit a tentative environment of deposition has been suggested. Nevertheless, it may be pointed out that as only few sections have been observed, the environmental interpretation given herein may not be entirely true on the regional scale, because there may be lateral facies change within a given litho-unit. However, only such studies where environmental interpretation is done in detailed sections would help in the environmental reconstruction on a regional scale, including the study of the evolution of sedimentation basin. The important sedimentological characteristics and the depositional environment of different litho-units of the area are also given in a tabulated form (Table 2).

ROHTAS LIMESTONE

South of Badanpur Rohtas limestone is exposed. The limestone is rather thinly bedded giving a slate-like appearance. Few decimetre thick limestone bands alternate with few cm. thick shale bands. Limestone band shows commonly horizontal bedding. Ripple bedding and washed ripples are rather common, along with small scale contorted bedding and other penecontemporaneous deformation structures. Fig. 2 gives the succession of

Table 2

Sedimentary structures and environment of deposition of various litho-units of the Satna-Maihar area.

Lithologic Unit	Lithology and Sedimentary Structure	Depositional Environment
Maihar Sandstone	The upper part of Maihar Sandstone is reddish quartzite. Large-scale cross-bedding produced by shifting bars is common. Megaripple bedding, and small ripple bedding are also present. Shallow channels are visible. Mud layers are completely absent. Two opposing current directions are present, however, one of them dominates.	Shoals with rather high energy, and marked tidal influences.
	The lower part is mixed facies (both sand and mud contents in comparable proportions). It exhibits features characteristic of a tidal flat environment. Extensive channels represented by discontinuity planes, filled up by muddy sediments are common. 1-3 m thick sand-dominant mixed facies alternates with 3-5 m thick mud-dominant mixed facies.	Broad Sandy tidal flats.
	The sand-dominant mixed facies is commonly made up of horizontally bedded sand layers (upto 50 cm thick). Less commonly they show ripple bedding, lenticular and flaser bedding. Rarely few bands show large-scale cross-bedding. Surface markings are common, which include various types of wave and current ripples, and modified ripples, i.e., ripples with flat crests, bifurcated and trifurcated crests, wrinkle marks, current crescent, rill marks, mud cracks, small wave ripples (micro-ripples). Often 10-25 cm thick ripple bedded sand layers alternate with 5-30 cm thick flaser and lenticular bedded layers. The lower contact of sand layers are often erosional. Shallow channels represented by low-angle discordance-planes are common.	Sandy intertidal flat.
	The mud-dominant mixed facies shows mainly lenticular bedding and 2-3 cm thick shale layers, intercalated with 2-5 cm thick sandy layers. Sand layers mostly show small ripple bedding. Ripples are common as surface features: wave ripples, current ripples, isolated ripples, modified ripples. The lower surface of some sand layers show sole markings, i.e., load structnre, flute marks.	Muddy intertidal flat.
Sirbu Shale	The upper part is partly sandy. 20-25 cm thick sandy units are interbedded in reddish brown shale. The top of sandy units invariably show ripples, which are mostly of modified type, e.g., flat-topped ripple.	Protected low energy tidal flat associated with a lagoon.
	The middle part (main part) of the Sirbu shale is made up of thin, papery shales. When fresh, they are greenish in colour quickly changes to red-brown. Within the shale thin sand/silt layers are interbedded. Thin sand layers can be as thin as 0.5 cm with wave ripples on the top layer. Thick sand layers are 5-10 cm thick and show wave ripple cross bedding. Sand layers are mostly lenticular and pinch out laterally, and are present at 1-1.5 m interval. Base of the sand layers often show sole markings, i.e., load structure, minute moulds of scour and tool marks. Top surface shows various types of ripples: symmetrical and flat-topped ripples are most common.	Shallow lagoon with oxidizing milieu.
	The lower part of Sirbu shale is rather sandy and somewhat greenish in colour. Various ripple patterns typical of very shallow waters and areas of intermittent subaerial exposure are common. Mud cracks are commonly present. There are also few horizons of salt pseudomorphs.	Transition from protected mud flat to shallow lagoon, locally with hypersaline milieu.
Bhander limestone	The upper part of Bhander limestone shows variable facies in different areas. Two important facies are: (i) The topmost 1-2 m is algal limestone with well developed stromatolites. Sandy shale intercalations show ripple bedding, mudcracks, raindrop imprints, normal and reverse graded bedding in thin bands. (ii) Thinly laminated dolomite often with gypsum bands, bird's eye structure, wrinkle marks, wave ripples, raindrop imprints, and incepient algal mats.	Supratidal with different facies in different areas depending upon the influx of detrital, salinity, etc.
	The middle part of the Bhander limestone is dominated by pure limestone (SMS grade). 2-5 m thick units of pure limestone are interbedded with shaly limestone, conglomeratic limestone, algal limestone, thinly laminated dolomite. Pure limestone shows large-scale cross-bedding, often bipolar, scoured and channel surfaces. Few layers show small ripple bedding, climbing ripple lamination, and penecontemporaneous deformation structures.	High-energy tidal flat. Main part represents subtidal with cycles from subtidal to supraridal.
	The lower part of the Bhander limestone is reddish, arenaceous limestone, with intercalations of reddish shale (1-2 cm thick). Thick units show large-scale cross-bedding. Thinner units dominantly show small ripple bedding, current ripples, parallel bedding, rarely also lenticular—and flaser bedding. Various types of ripples with different orientations are present.	Moderate-energy tidal flat. Subtidal to low intertidal.

Table 2—(*Contd.*)

Lithologic Unit	Lithology and Sedimentary Structure	Depositional Environment
Rewa sandstone	Rewa sandstone is red coloured sandstone with rare shale intercalations. Large-scale cross-bedding (bar cross-bedding) is most abundant (1-2 m thick). Occasionally 50 cm-1 m thick horizontally bedded units are also present. Intercalated are mega-ripples. Rarely thin bands of wave ripples and wave ripple bedding are present. Other important features are: horizons of flat mud pebble conglomerate, broad rill marks, current lineation, current crescents, penecontemporaneous deformation structures.	Shoal-beach complex with medium to high wave energy and strong tidal current.
Rewa shale	Rewa shale is greenish in colour and rather silty. It is thinly laminated. Intercalated in the shale are thin and thick sandstone layers of light brown colour. Thick sand layers (30-50 cm thick) invariably show sole markings. Flute marks are most common along with minute scour and tool marks. Lower surface of sand layers may show channeling. Thin sand layers show ripples of shallow-water type, e.g., flat-topped ripples. Wrinkle marks are quite common.	Lagoon with occasional current activity.
Kaimur sandstone	Upper part of Kaimur sandstone is a thick succession of reddish sandstone. The topmost part is shaly grading into Rewa Shale. Sandstone shows mostly large-scale cross-bedding (bar cross-bedding). Irregular erosional channels, ripples with mud drapes, horizontal bedded units are present. Few horizons of coarse sand and granules are present.	Shoal-beach complex.
	At the base of Kaimur sandstone, a 5 m thick horizon of pebbly sandstone, arkose-like in appearance is present. Pebbly sandstone, sandstone, shale are complexly inter bedded. The lower contact of this arkose horizon with Rohtas shale is irregular, erosional.	Fluvial.
Rohtas limestone	Upper part is calcareous shale. Very thinly laminated. No other significant sedimentary structure.	Lagoon or lowenergy high tidal flat.
	Below the calcareous shales are thinly bedded limestone giving slate-like appearance. 10-15 cm thick limestone bands are interbedded with thin calcareous shales. Limestones are thinly laminated, occasionally showing, washed ripples, penecontemporaneous deformation structures.	Low-energy carbonate flat.

sedimentary structures in Rohtas limestone. The spectrum of sedimentary structures suggest that they are deposits of tidal environment, formed mostly under subtidal to intertidal conditions. High content of argillaceous material was continuously coming from the land. Rohtas limestone of Son Valley also reflects a similar environmental setting (see Singh, 1973).

Rohtas Shale

Rohtas shale is exposed in the flat area of Badanpur, and north of Badanpur. These are extremely fine-grained, white coloured, calcareous shales. They lack any coarse-grained horizons. The only recognizable bedding structure of these deposits are the fine lamination. These features point to the deposition of Rohtas shale under low-energy conditions without any significant wave and current activity. In coastal, shallow-water environment such conditions are available in lagoon or mud flats. Thus, it is believed that Rohtas shale is a product of deposition in a protected lagoon or mudflat of a carbonate producing environment, where there was almost no supply of terrigenous material.

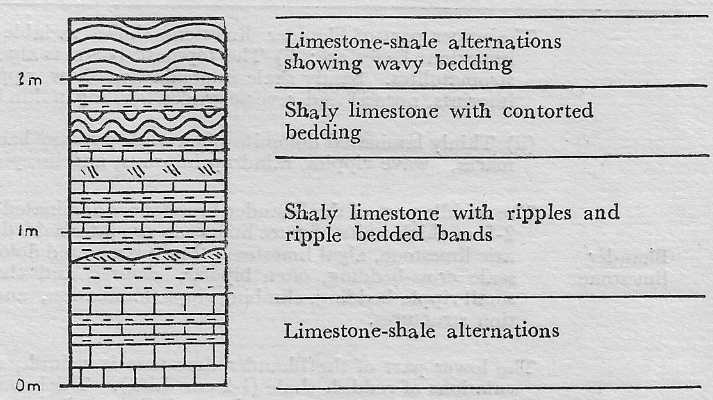

Fig. 2. Succession of sedimentary structures in Rohtas limestone, Badanpur, Maihar.

KAIMUR SANDSTONE

North of Badanpur the contact between Rohtas shale and Kaimur sandstone is exposed. The contact is irregular and erosional, exhibiting large-scale scours (Fig. 3). This basal part of Kaimur sandstone is made up of arkosic sandstone, pebble beds and shale bands. These sediments show complex interbedding. Sandstones show mainly large-scale cross-bedding, pebble beds show faint parallel bedding, shales are thinly laminated. The sandstones are arkose in composition and contain abundant kaolinitized felspar grains.

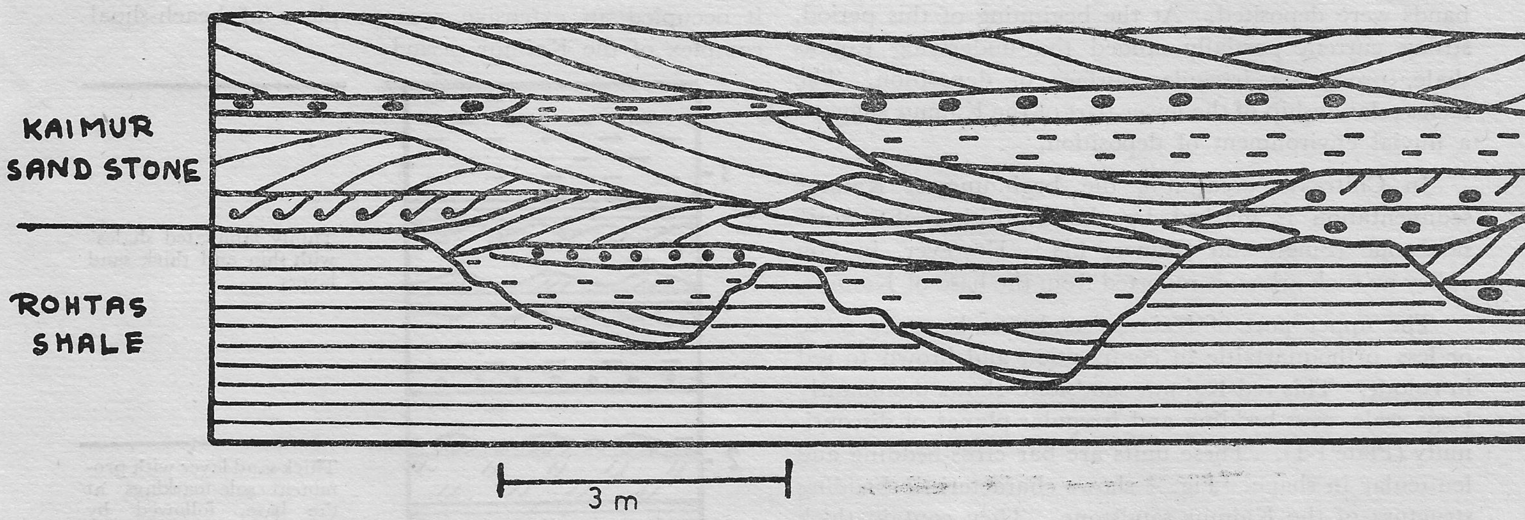

Fig. 3. Schematic diagram showing contact between Rohtas shale and overlying Kaimur sandstone (Arkose etc.), Badanpur, Maihar.

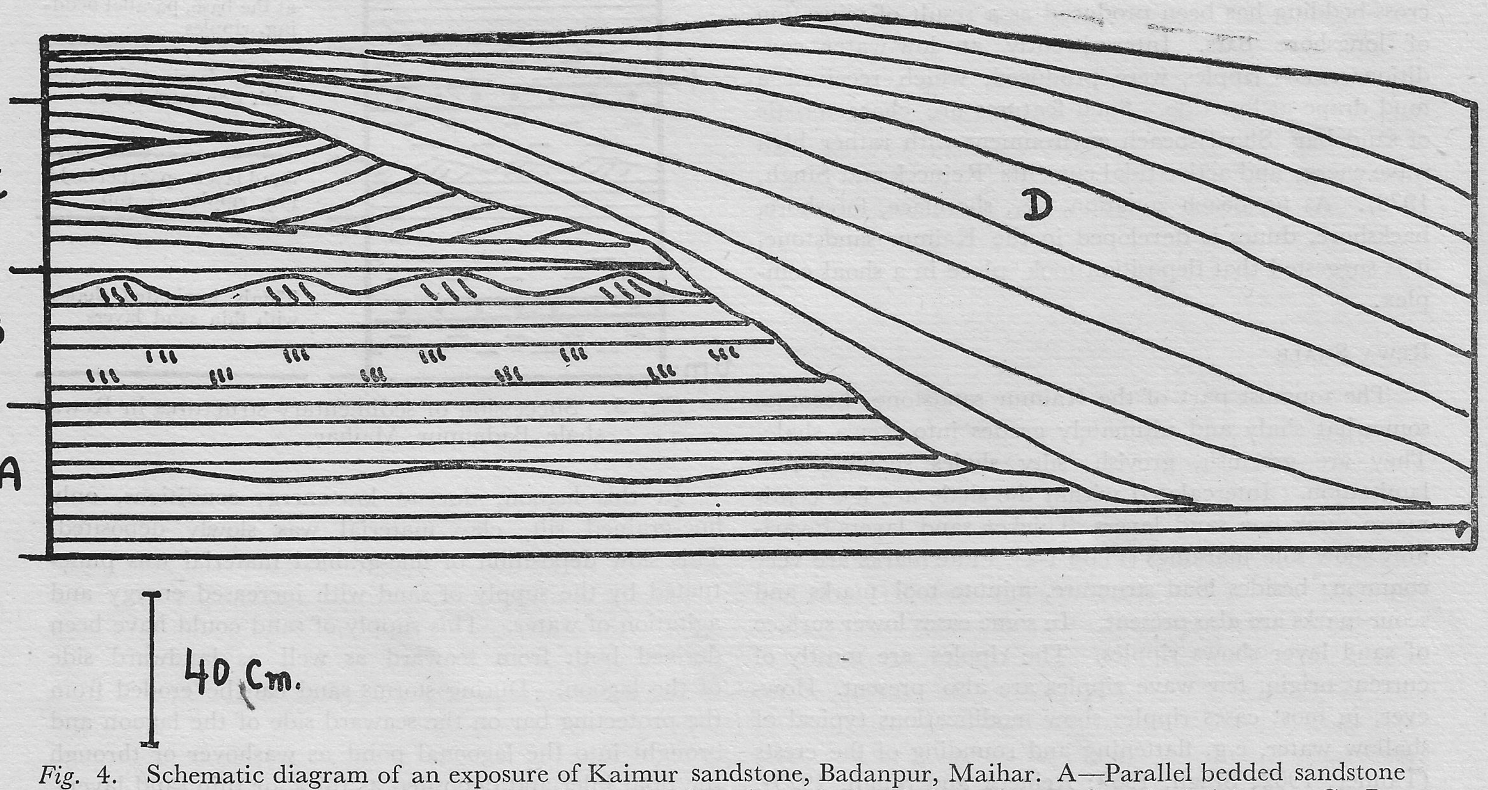

Fig. 4. Schematic diagram of an exposure of Kaimur sandstone, Badanpur, Maihar. A—Parallel bedded sandstone with minor discordances, B—Parallel bedded and ripple bedded sandstone, few rippled layers, C—Bar cross-bedding, sets of low-angle cross-beds with discordances, D—High-angle cross-beds of a bar with erosional lower contact. The unit is lenticular-shaped.

It is believed that after the deposition of Rohtas shale, there was a major change in the environmental conditions accompanied by a probable period of hiatus. Coarse-grained, undecomposed, terrigenous material was readily available and was deposited by moderately strong currents, interrupted with the periods of quiteness when shale bands were deposited. At the beginning of this period, strong current partially eroded the underlying Rohtas shale, producing irregular surface of deposition. The facies relationship of the lower part of the Kaimur suggests a fluvial environment of deposition.

In Chitrakut area also, the beginning of Kaimur sedimentation is marked by the deposition of arkosic sandstone (Singh and Kumar, Ms.) However, in Son valley no such arkose is reported from the base of Kaimur.

The upper part of Kaimur sandstone becomes more or less orthoquartzitic in composition and brown to red in colour. This red Kaimur sandstone shows dominantly large-scale cross-bedding and irregular planes of discontinuity (Plate I-1). These units are bar cross-bedding and lenticular in shape. Fig. 4 shows characteristic bedding structure of the Kaimur sandstone. They contain thick units of parallel bedded sandstone and beach-bar cross-bedding. Often 1-1.5 cm thick large-scale cross-bedded unit is overlain by a few cm thick ripple bedded unit with a thin mud drape. It is suggested that large-scale cross-bedding has been produced as a result of migration of longshore bars. Intermittently at low-water conditions small ripples were produced, which received a mud drape at low tide. Such features are characteristic of sand bar (Shoal)-beach environment with rather high wave energy and active tidal currents (Reineck and Singh, 1973). As no beach zonation, i.e., shoreface, foreshore, backshore, dunes is developed in the Kaimur sandstone, it is suggested that deposition took place in a shoal complex.

Rewa Shale

The topmost part of the Kaimur sandstone becomes somewhat shaly and ultimately grades into Rewa shale. They are greenish, greyish, silty shales showing thin lamination. Intercalated within the shale are few centimetre thick fine sand layers. Thicker sand layers invariably show sole markings (Plate I-2). Flute marks are very common; besides load structure, minute tool marks and scour marks are also present. In some cases lower surface of sand layer shows ripples. The ripples are mostly of current origin, few wave ripples are also present. However, in most cases ripples show modifications typical of shallow water, e.g. flattening and rounding of the crests (Tanner, 1962; Singh, 1969; Reineck and Singh, 1973). Thick sand layers exhibit a definite sequence of structure i.e., the lower surface shows sole markings, followed by parallel bedding in the lower part. The upper part shows ripple bedding, and ripples on the top surface. (Fig. 5.)

For the deposition of Rewa shale a lagoon is visualized. It is postulated that during deposition of Kaimur sandstone a shallow lagoon started developing and with time it occupied an extensive area in place of beach-shoal complex of the Kaimur period.

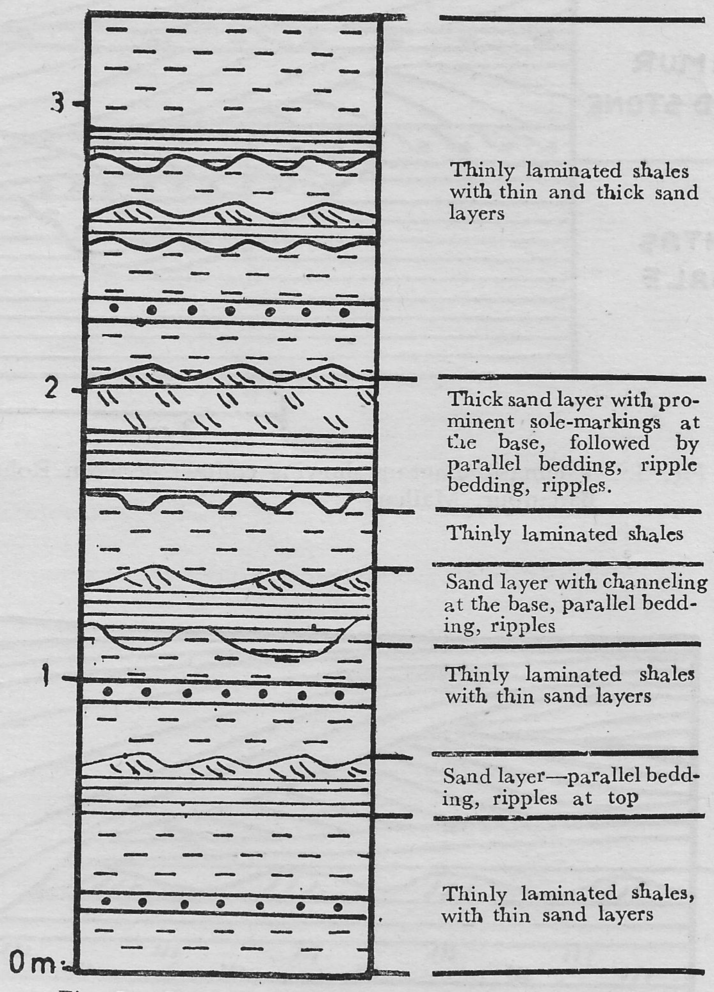

Fig. 5. Succession of sedimentary structures in Rewa shale, Badanpur, Maihar.

In this lagoon, due to low-energy conditions, only fine-grained silt, clay material was slowly deposited. This slow deposition of fine-grained material was punctuated by the supply of sand with increased energy and agitation of water. This supply of sand could have been derived both from seaward as well as landward side of the lagoon. During storms sand can be eroded from the protecting bar on the seaward side of the lagoon and brought into the lagoonal pond as washover or through the tidal inlet and deposited as thick or thin sand layers, depending upon the amount of sand available. Such processes are known in the present day lagoons (Warme, 1971). Similarly, small rivers of alluvial plain draining into the lagoon, periodically bring sandy material. The sequence of sedimentary structures observed in thick sand layers can be explained as follows:

As the sandy material is brought in by strong currents and waves, they cause slight erosion in the muddy sediments of the lagoon. Such scours are immediately filled by sand producing sole markings. In the beginning current or wave energy is high, producing parallel lamination. With time current energy is reduced and ripples are actively formed producing ripple bedding, and ultimately the ripples on the top surface. Similar sandy horizons also occur in shelf mud sediments and have been reported by Häntschel and Reineck (1968).

Sandy intercalations are rather common in the Rewa shale, thus it is believed that lagoon was never deep, at the most 1-2 m in depth, and was often subjected to the subaerial exposure. This is evidenced by the common occurrence of wrinkle marks (Plate I-3), and modified ripple patterns.

Rewa Sandstone

Rewa sandstone is extensively exposed on the northern slopes of the NE-SW running scarp, north of Badanpur. There are also few abandoned quarries in which good sections of Rewa sandstone are exposed. Rewa shale becomes more sandy in the upper part and eventually grades into red coloured Rewa sandstone. The most striking feature of the Rewa sandstone is the presence of 1-2 m thick sets of bar cross-bedding (Plate I-4), alternating with 50 cm-1 m thick units of megaripple bedding, made up of 10-20 thick cross-beds. sometimes, cross-bedding with overturned foresets is also visible (Plate I-6) Intercalated are few mud pebble horizons and thin mud layers.

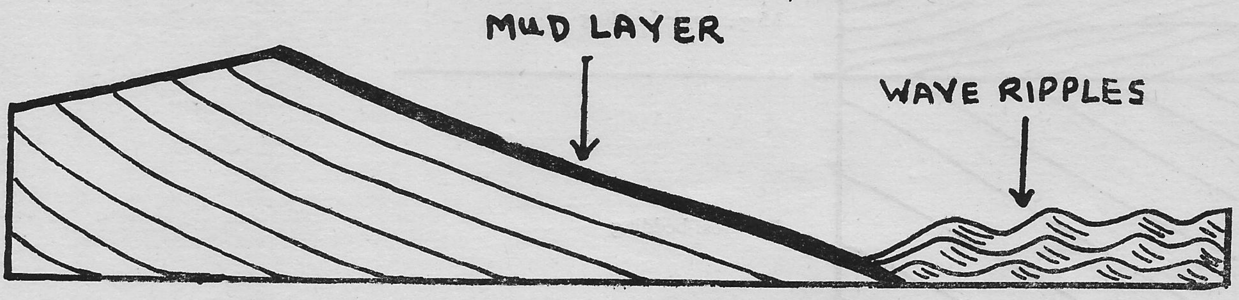

Fig. 6. Schematic diagram showing a megaripple, with wave ripples in its trough, Rewa sandstone, Badanpur, Maihar.

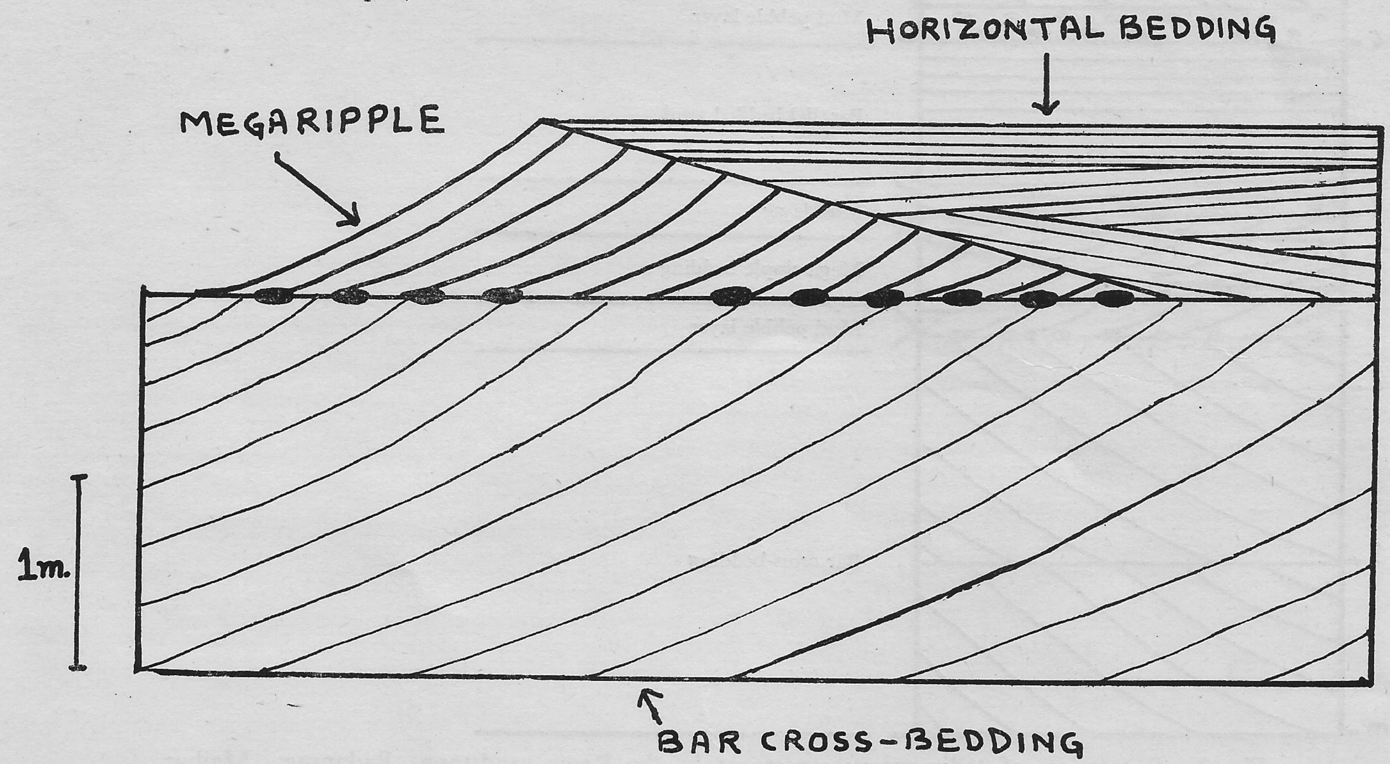

Fig. 7. Schematic diagram showing bedding structures in Rewa sandstone, Badanpur, Maihar.

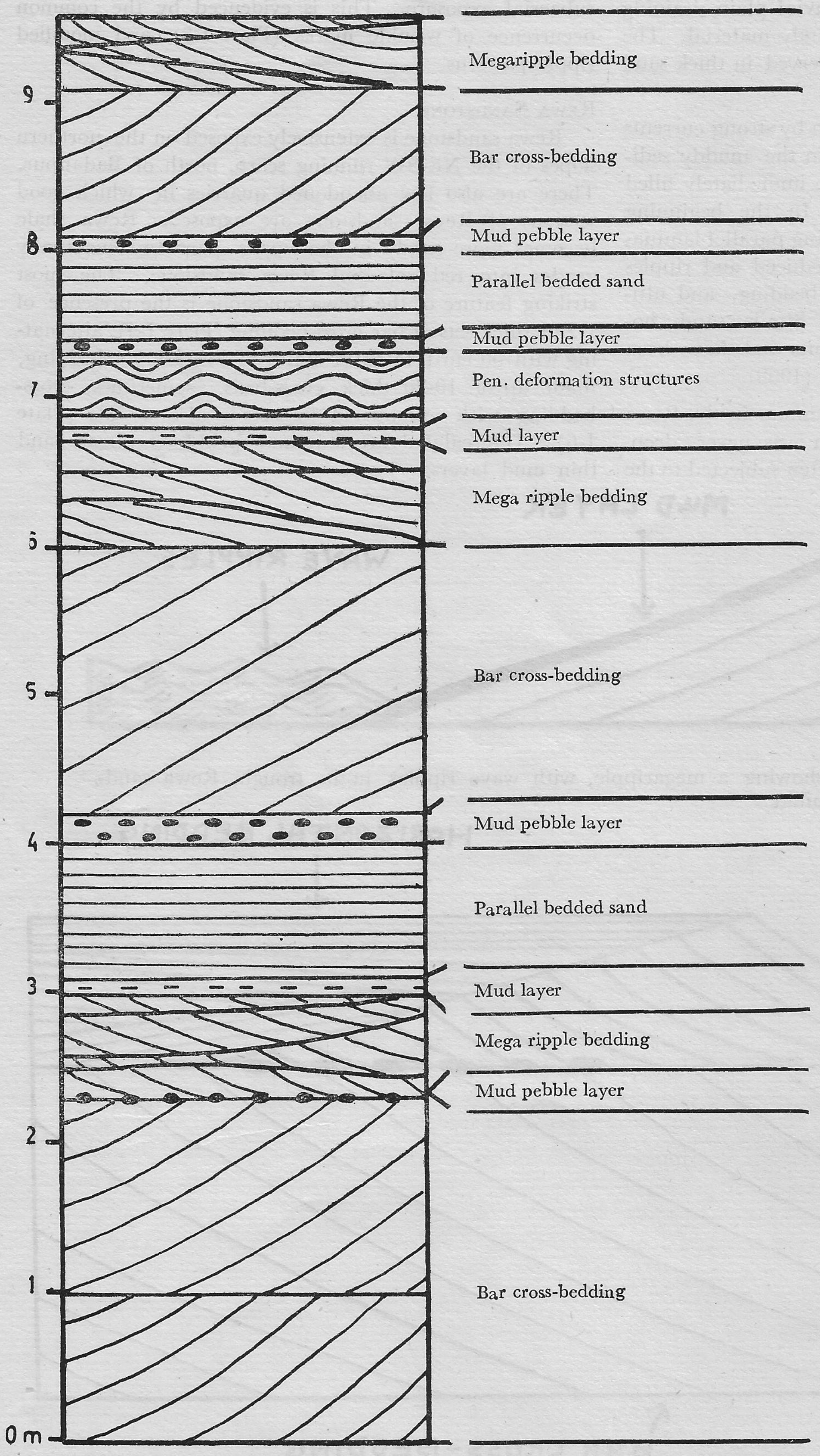

Fig. 8. Succession of sedimentary structures in the Rewa sandstone, Badanpur, Maihar.

Bar cross-bedding is made up of planar foresets inclined at 12-15°. The units are lenticular in shape and extend laterally up to 10-15 m. In rare cases the original morphology of the bar is visible. On the top of the bar megaripple is present, oriented at right angles to the orientation of the bar. Often, megaripple is covered by a thin drape of mud. In the trough of the megaripple, in few cases, 5-10 cm thick unit of wave ripples is present (Fig. 6), 50 cm-1 m thick units made up of parallel bedded sand (horizontal bedding) with low angle discordances are also intercalated (Beach type bedding) (Fig. 7, Plate I-5). Fig. 8 depicts the succession of sedimentary structures in the Rewa sandstone. On the extensive scarp-slope, the Rewa sandstone shwos extensive development of festoon cross-bedding, exposed in the surface view (Plate II-7). This large-scale festoon cross-bedding is related mainly to the undulatory megaripples.

Presence of large-scale bar cross-bedding suggests that the whole area was a sandy coastal region, where wave action was sufficiently strong to produce longshore bars, which actively migrated to make the bar cross-bedding. Longshore bars possess a steep landward side, and a gentle seaward side. On migration they make foresets on the steeper side. On the gentle seaward side, packets of horizontal bedding with or without low-angle discordances develop, alongwith current lineation. These units are produced by the wave action.

The common occurrence of megaripple bedding indicates that tidal currents were quite active in these coastal sands, producing abundantly undulatory megaripples on the top of the longshore bars. During periods of quiscence few cm thick mud layers can be easily deposited even in the high-energy environment of the coastal sand. During the next phase of wave or current action these mud layers can be partially or totally eroded into pieces, and rolled into mud pebbles. If these mud pebbles are deposited, concentrated in individual bands, the mud pebble conglomerate is formed.

In the trough of longshore bar and megaripples, wave ripples are produced during periods of low wave action, preferably during low-water stages. On the broad sandy surfaces, at low-water stage, features like broad rill marks, current crescent are produced in the intertidal zone.

As in the case of Kaimur sandstone, Rewa sandstone also lack any beach zonation, though beach type cross-bedding is present. It is suggested that the environment of deposition for Rewa sandstone was a shoal-beach complex, where real beach profile development did not take place. A modern analogue to these deposits are the shoal/sand bar/sand tongue complexes of North sea (Reineck and Singh 1973).

Basumallick (1962 a) made a petrographical study of Rewa sandstone and regards them to be platform blanket deposit of beach-continental shelf environment. They are mostly orthoquartzites with quartz grains showing double growth (sedimentary source).

Bhander Limestone

Bhander limestone is the only important calcareous horizon of the upper Vindhyan sediments, and is extensively developed. In Satna and Maihar areas it is quarried out for cement and metallurgical industry.

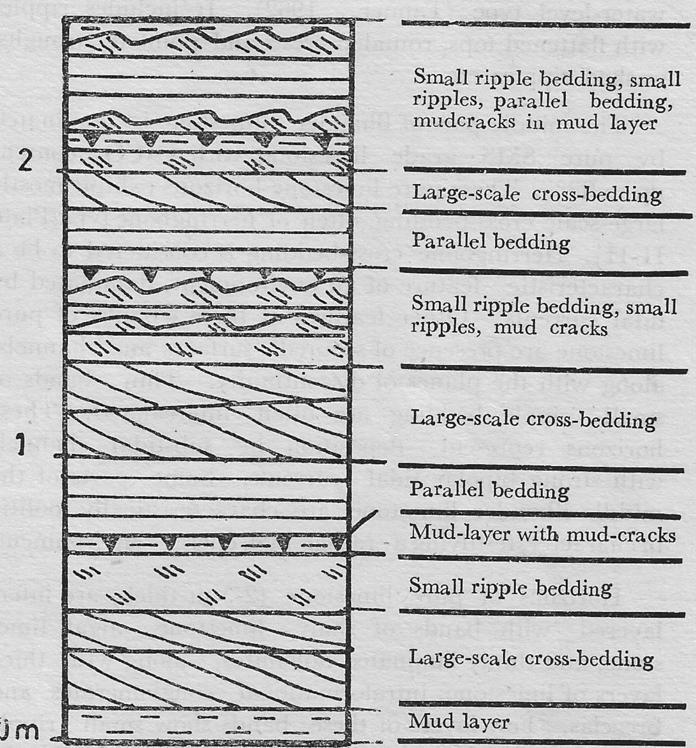

Fig. 9. Succession of sedimentary structures in lower part of Bhander limestone, Tons River, Maihar.

The basal part of the Bhander limestone is exposed in Tons river near the village Sanwari. The lower part of the Bhander limestone is rather sandy, more like a calcareous sandstone and light brown in colour. Though, the exact contact of Rewa sandstone and Bhander limestone is not exposed, it seems that the upper part of Rewa sandstone slowly grades into Bhander limestone. This transition is marked by a change from sandy facies to carbonate facies. This change in facies is marked by decrease in the supply of terrigenous material coupled with the increased precipitation of carbonate, and a significant decrease in the energy of the environment. The structures of the lower part of the Bhander limestone point to a tidal flat environment, the domain of deposition remaining mainly in subtidal to intertidal zone. Fig. 9 shows the succession of sedimentary structures in this horizon. The thicker units invariably show large-scale cross-bedding, probably of megaripple origin. The thinner units show small ripple bedding. Intercalated are thin (few cm) mud layers, which often show mud cracks, suggesting a frequent subaerial exposure of the sedimentation surface. Parallel bedding, lenticular and flaser bedding are present in minor amounts. Ripples are quite abundant and show much variation in their orientation. Ripples are mostly of shallow water type and falling water-level type (Tanner, 1962). It includes ripples with flattened tops, rounded crests and pointed troughs, washed ripples etc.

The middle part of Bhander limestone is dominated by pure SMS grade limestone with $CaCO_3$ content up to 98%. These pure limestone horizons exhibit mostly large-scale cross-bedding, often of herringbone type (Plate II-11). Herringbone cross-bedding is considered to be a characteristic feature of an environment, dominated by tidal currents. Other features of these bands of pure limestone are presence of scoured surfaces and channels, along with the planes of discontinuity. Thin bands of small ripple bedding are often intercalated. These horizons represent deposition in sub-tidal channels with strong bipolar tidal currents. Some parts of the middle Bhander limestone are characteristically oolitic in character, testifying a rather high energy environment.

Horizons of pure limestone (2-5 m thick) are interlayered with bands of shaly limestone, algal limestone, and thinly laminated dolomites, along with thick layers of limestone, intraformational conglomerates and breccias. Few layers of these bands show small ripple bedding, climbing ripple lamination (Plate II-8), and penecontemporaneous deformation structures. Herringbone cross-bedding and wave ripple-bedding are also common (Plate II-9). Locally, stromatolitic limestone becomes quite prominent, e.g., in Tons river section, Maihar (Fig. 10) These bands are mostly deposits of intertidal to supratidal region of a carbonate-tidal flat. Thinly laminated dolomite suggests partially hypersaline, evaporating environment in high intertidal-supratidal zone.

The upper part of Bhander limestone is extensively exposed in various nalas and quarries of Satna and Maihar areas. It is an interesting horizon and shows much facies variation from one section to the other. In Maihar area the upper part is rather sandy and shaly, suggesting an increased influx of terrigenous material. However, in Satna area the upper part of

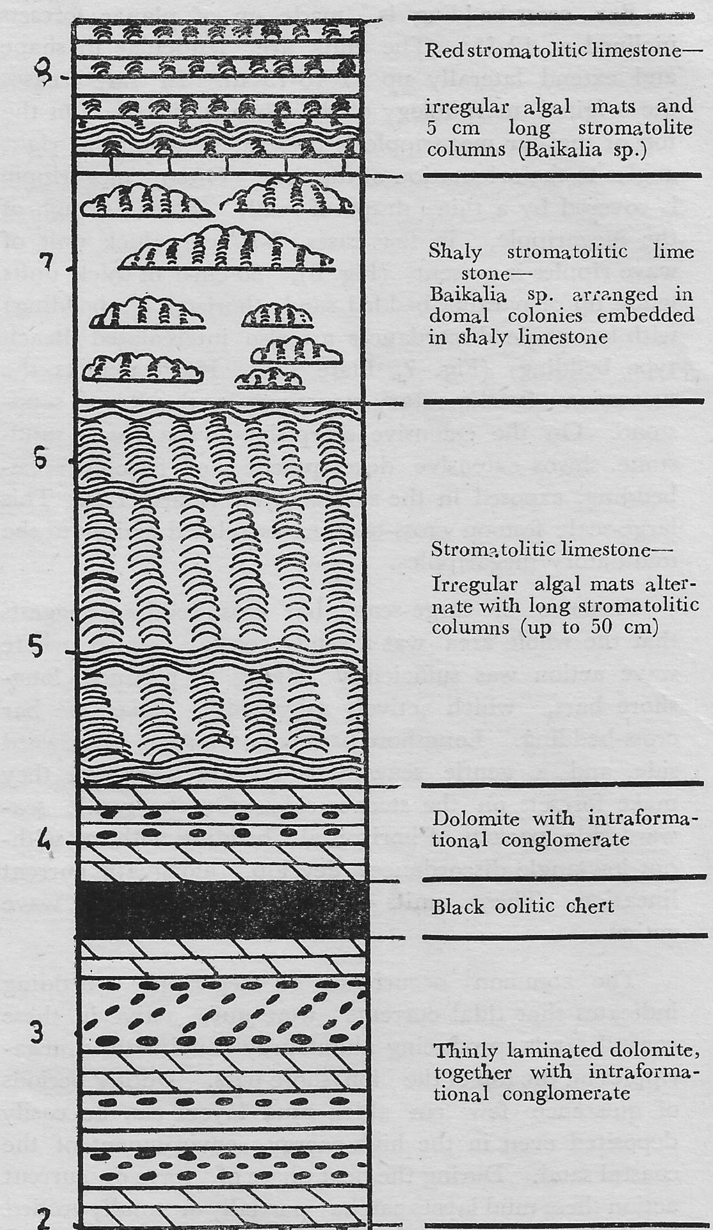

Fig. 10. Succession of sedimentary structures in Bhander limestone, Tons River near Emlia quarry, Maihar.

Bhander limestone does not show any increase in the terrigenous material. In general, four different types of facies can be recognized in the topmost horizon of the Bhander limestone (upper 3-4 metres).

(i) *Laminated dolomite facies:* This facies is encountered in Bamhore quarry, Satna. There is almost 2 m thick dolomite horizon which is thinly laminated and shows few scoured surfaces. Thin layers of penecontemporaneous deformation structures and ripple bedding are present, along with thin bands of ill-developed algal mats. Sometimes, this dolomitic horizon is overlain by ca. 1 m thick band of stromatolitic limestone, intraformational conglomerates (Figs. 11, 12, Plate III-13, 14). These dolomites have revealed raindrop imprints, micro-ripples (Plate III-16, Plate II-10). The environment of deposition is a supratidal zone with slightly increased salinity, resulting into direct precipitation of dolomite.

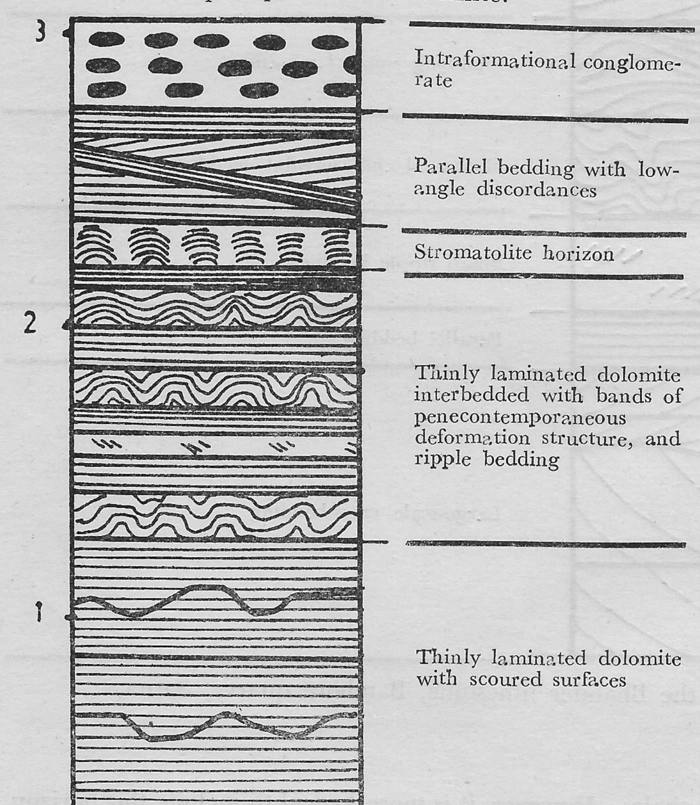

Fig 11. Succession of sedimentary structures in the upper part of the Bhander limestone, Bamhore quarry, Satna.

(ii) *Gypsiferous facies:* This facies is present in the Chaurasia limestone quarry, Satna. The topmost 2 m shows development of massive as well as finely laminated dolomite, which shows bird's eye structure. The cavities of bird's eye structure are lined with gypsum. The topmost 50 cm is made up of gypseferous dolomites, where gypsum and dolomite are intricately interbedded (Fig. 13). The environment of deposition is supratidal flat with moderate evaporitic conditions. Bird's eye structure is considered to be characteristic of the supratidal environment (Shinn, 1968).

(iii) *Algal limestone facies:* The topmost 1-2 m of Bhander limestone is always made up of algal limestone, except in cases of evaporitic conditions leading to development of laminated dolomite and gypsum. The algal limestone shows several horizons of well-developed stromatolites in various shapes. Interbedded are thin limestone bands showing various types of ripples and mud cracks. Valdiya (1969) has described the stromatolites from Bhander limestone. They also represent deposition in supratidal zone, but under conditions of normal salinity.

(iv) *Terrigenous facies:* This facies is well-exposed in Lilji nala, Maihar. Here, below the topmost 1 m thick algal limestone horizon almost 3 m thick succession is exposed made up of a sequence of shale, shaly limestone, and sandstone. It contains rippled units showing both wave and current ripples, and modified ripples. Thin bands of ill-developed algal mats are also present. Mud cracks are very prominent and well-developed (Fig. 14, Plate II-12). The environment of deposition is also supratidal zone. Ill-developed algal mats are due to increased supply of terrigenous material in the supratidal zone.

As discussed above, the topmost part of the Bhander limestone is a product of deposition of supratidal zone. Normally, it shows extensive development of algal mat facies with well-developed stromatolites. Depending upon the supply of terrigenous material, and salinity this horizon shows rapid facies changes from one section to the other.

Recently, Chanda and Bhattacharyya (1974) have discussed the depositional environment of the Bhander limestone in Maihar area. What they have named as lower Bhander sandstone (Alternation of sandstone and shale) is actually the upper part of Bhander limestone (Terrigenous facies), and are deposits of mainly supratidal zone (Few parts may have been deposited in high intertidal zone). The possibility of its deposition is mudflat (mixed flat) can be ruled out, because of the presence of well-developed mud cracks in this horizon. The horizons with climbing ripples have been most probably deposited in the gullies and channels of the intertidal zone (Fig. 15). The gullies and channels are the only suitable sites for the development of climbing ripples in an intertidal zone. The top of the Bhander limestone in Maihar area is taken at the topmost carbonate horizon, which is mostly

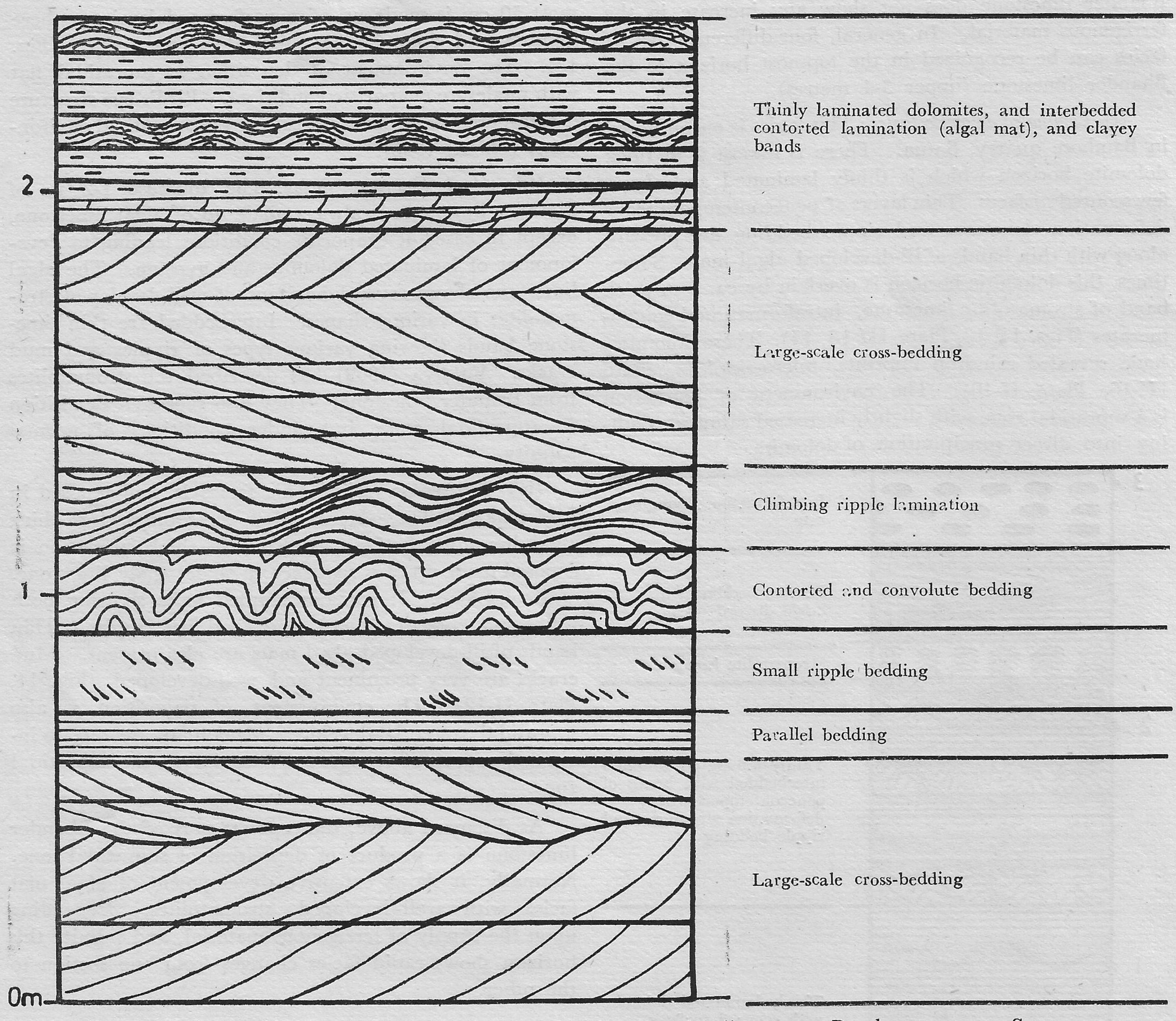

Fig. 12. Succession of sedimentary structures in the Bhander limestone, Bamhore quarry, Satna.

developed as stromatolitic limestone, e.g. Lilji Nala section (Fig. 14, Plate III-17). In Tons river section an interesting horizon of chert is present, which is made up of silicified oolites and shows development of ripples (Fig. 10, Plate III-15).

SIRBU SHALE

The change from Bhander limestone to Sirbu shale is best exposed in Lilji Nala, Maiher. The topmost horizon of Bhander limestone is 1 m thick horizon of stromatolitic limestone, exhibiting cabbage head stromatolites of *Baikalia* sp. Chanda and Bhattacharyya (1974) have included this limestone horizon in Sirbu shale. However, it is more logical to include this horizon in Bhander limestone.

The stromatolitic limestone is followed by a succession of argillaceous sediments. Fig. 16 gives the succession of Sirbu shale in Lilji nala, Maihar. The lower 3 m is represented by sandy shale with many thin (2-5 cm) fine sand layers, all showing ripple marks (Plate III-18). There are also several shale horizons exhibiting extensive mud cracks. Upwards, sediments become more shaly, and rippled sand layers become less frequent.

As discussed earlier, topmost part of the Bhander limestone in Maihar area becomes rich in terrigenous material. This tendency increases with time, and ultimately carbonate precipitation ceases and only terrigenous material is deposited. This change from carbonate to terrigenous facies is also accompanied by a decrease in the energy of environments, so that dominantly clayey sediments are deposited. In other words, the carbonate tidal flat gradually changes into a protected lagoon or a interdistributary bay.

Throughout the succession, shales contain thin sand layers showing ripples and horizontal bedding. Number and thickness of sand layers is highly variable. In some parts sand layers are quite abundant, in others the monotonous shale succession is interrupted only by few mm thin sand layers showing faint lamination. The thicker

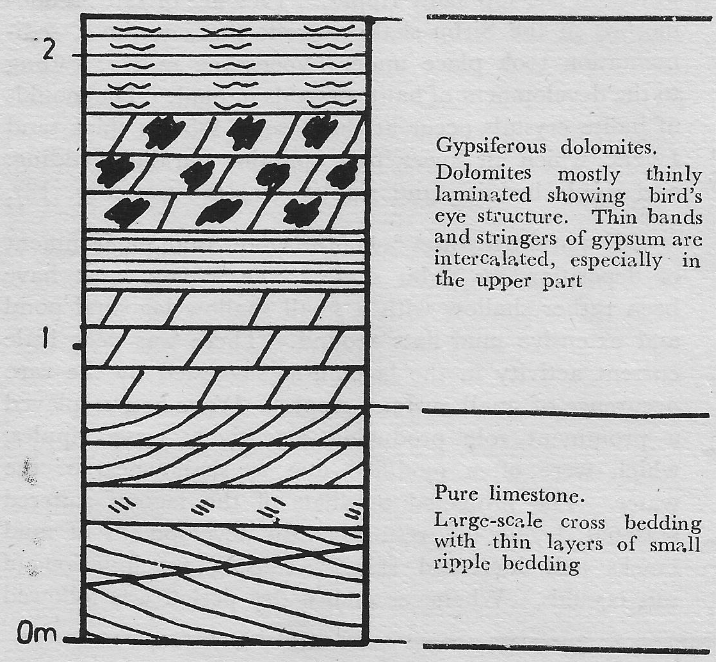

Fig. 13. Lithological succession in the upper part of the Bhander limestone, Chaurasia limestone quarry, Satna. In this succession instead of algal limestone evaporitic facies (thinly laminated dolomite, gypsum) is developed.

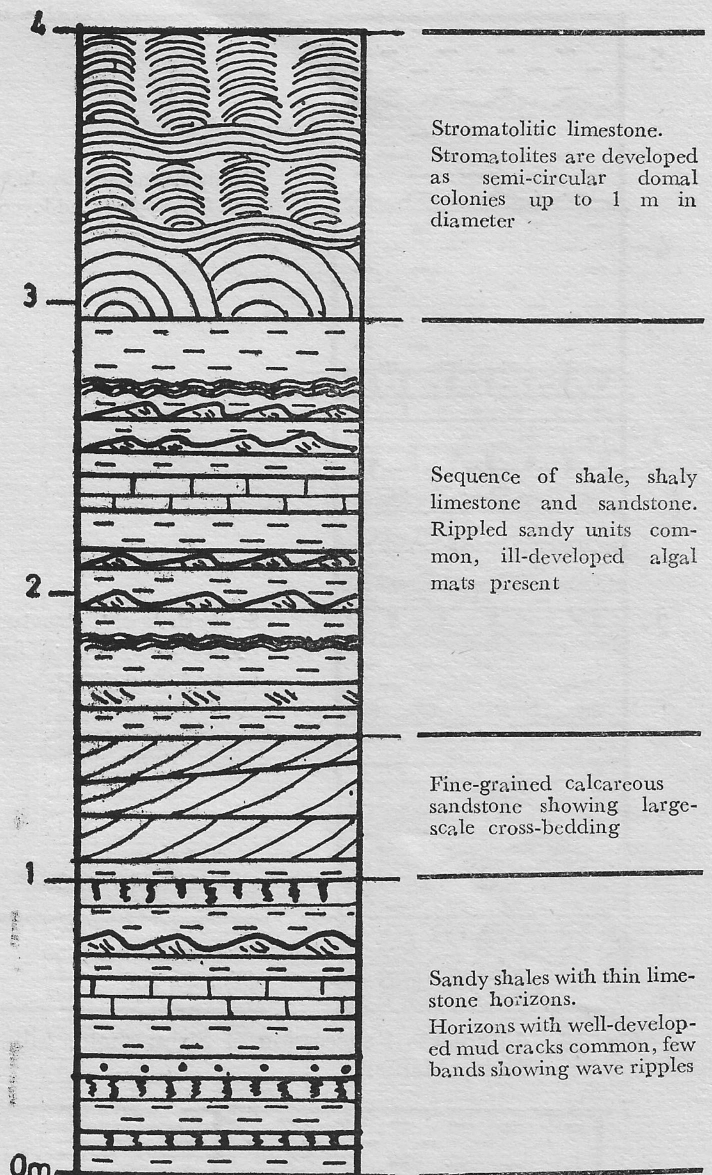

Fig. 14. Succession of sedimentary structures in the topmost part of Bhander limestone, Lilji Nala, Maihar.

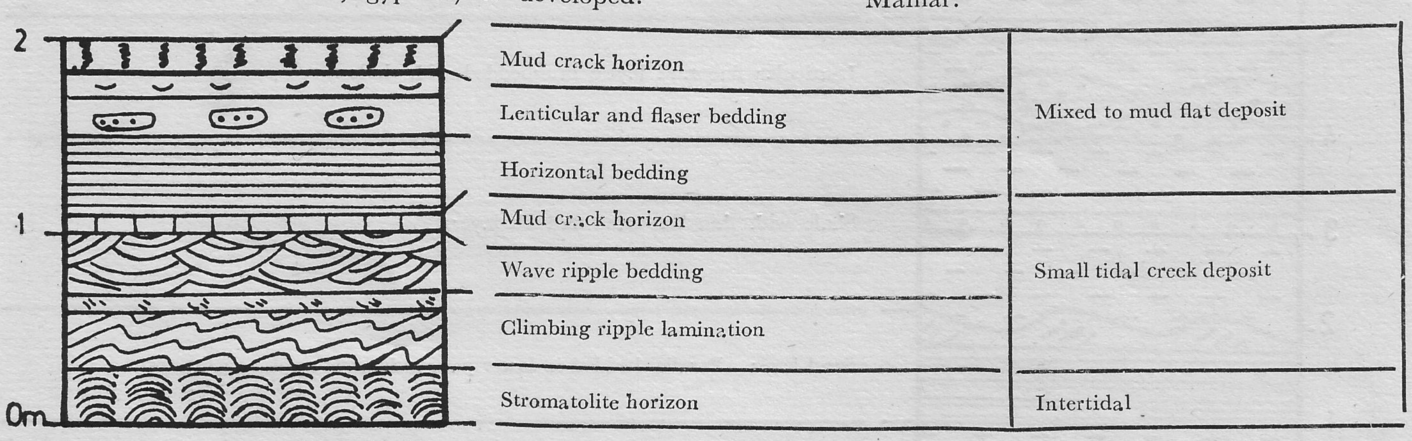

Fig. 15. Succession of sedimentary structures in the upper part of the Bhander limestone, Steel mine quarry, Satna. (Sagma Station)

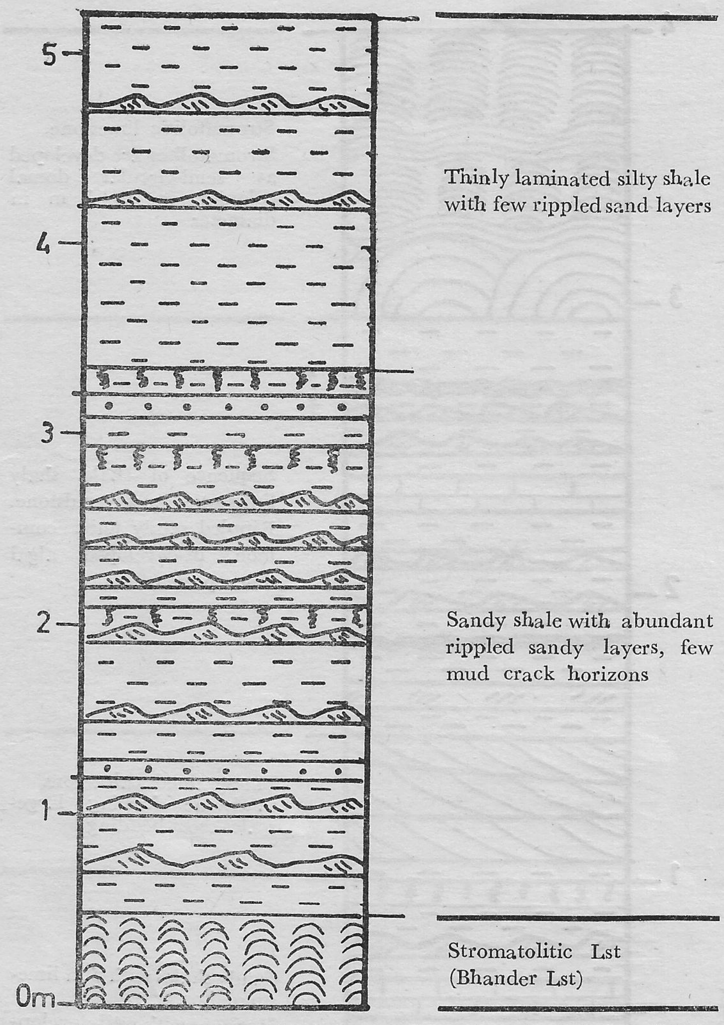

Fig. 16. Lithological succession of Sirbu shale, Lilji Nala, Maihar.

sand layers often show various types of tool marks, scour marks and load structure at the base. 3-5 cm thick sand layers show parallel bedding near the base, followed by ripple bedding, and the top surface invariably shows ripples (Fig. 17). The ripple bedding is, in most cases, of wave ripple origin. The ripples are mostly symmetrical wave ripples, asymmetrical wave ripples and rarely small current ripples. Often, the ripples show modified patterns, e.g., the small current ripples modified into a symmetrical wave ripples, flat topped-ripples (Plate IV-19), ripples with rounded crests.

Sirbu shale in Maihar area also contain salt pseudomorphs. They occur as moulds at the base of sand layers, which on the top show ripples. Presence of salt pseudomorphs in the Sirbu shale suggests that, at times, sedimentation took place under hypersaline milieu, leading to the development of halite crystals in mud. The moulds of halite crystals occur at the base of 3-5 cm thick sand layers, which in lower part contains parallel bedding, and ripple bedding and ripples near the top (Fig. 18).

Most of the features favour a lagoon as an environment of deposition for Sirbu shale. The lagoon must have been rather shallow with a small shallow lagoonal pond and extensive mud flats around. There was very little current activity in the lagoon, as suggested by the rare occurence of small current ripples. Wave action played a prominent role producing extensively wave ripples, which were often modified due to shallowness of the water. The protected mudflats of the lagoon suffered seasonal drying up, resulting into development of mud cracks and increased salinity causing precipitation of salt crystals. Whenever such a dry period was followed

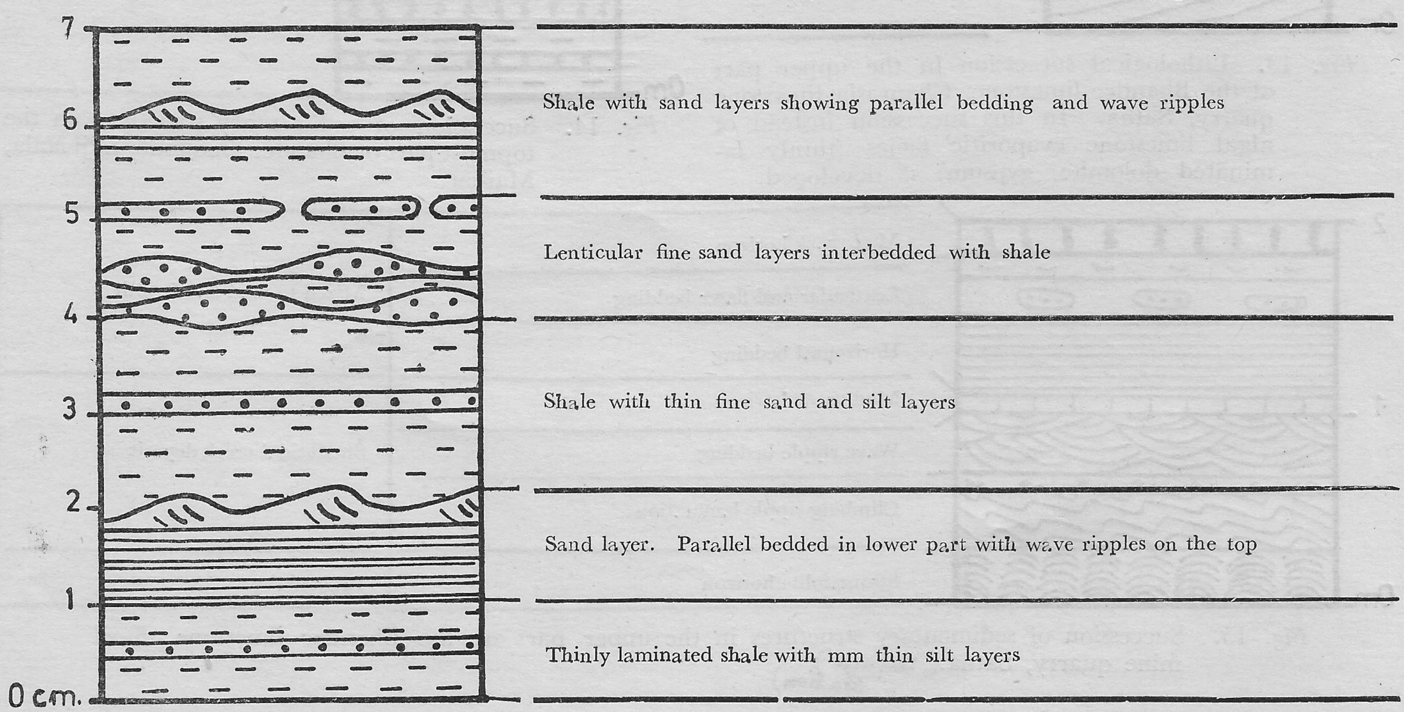

Fig. 17. Succession of sedimentary structures in Sirbu shale, Satna-Panna Road, Satna.

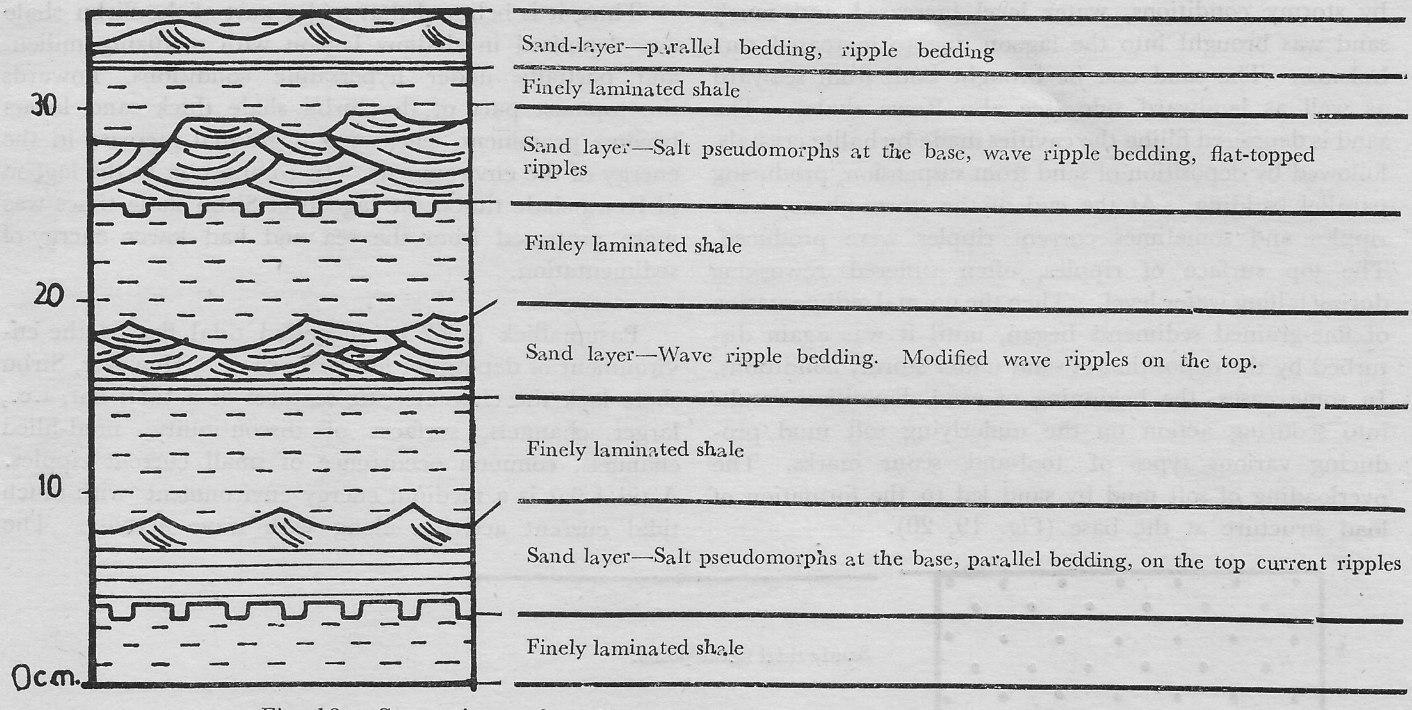

Fig. 18. Succession of sedimentary structures in Sirbu shale, Maihar.

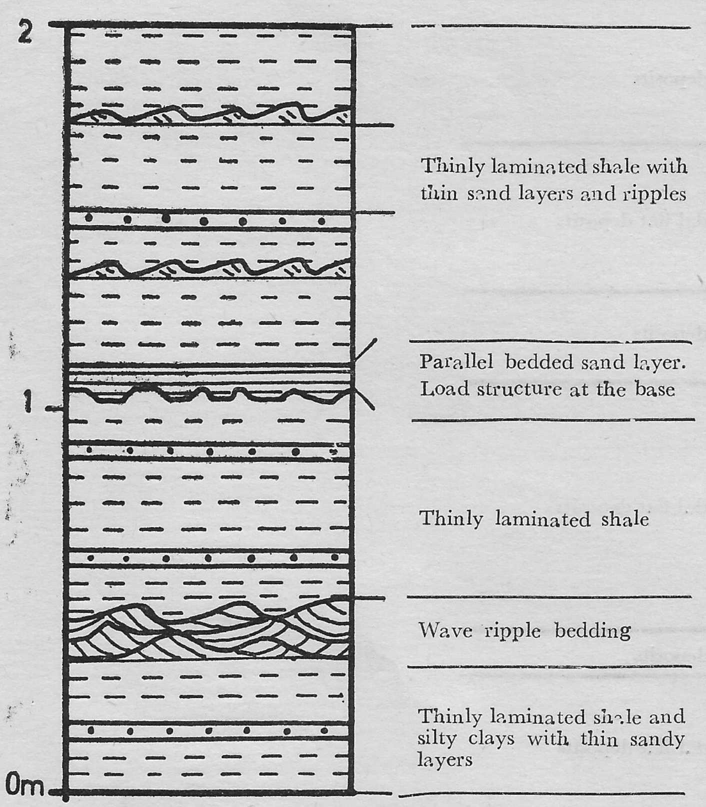

Fig. 19. Succession of sedimentary structures in Sirbu shale, Satna—Panna road, Satna.

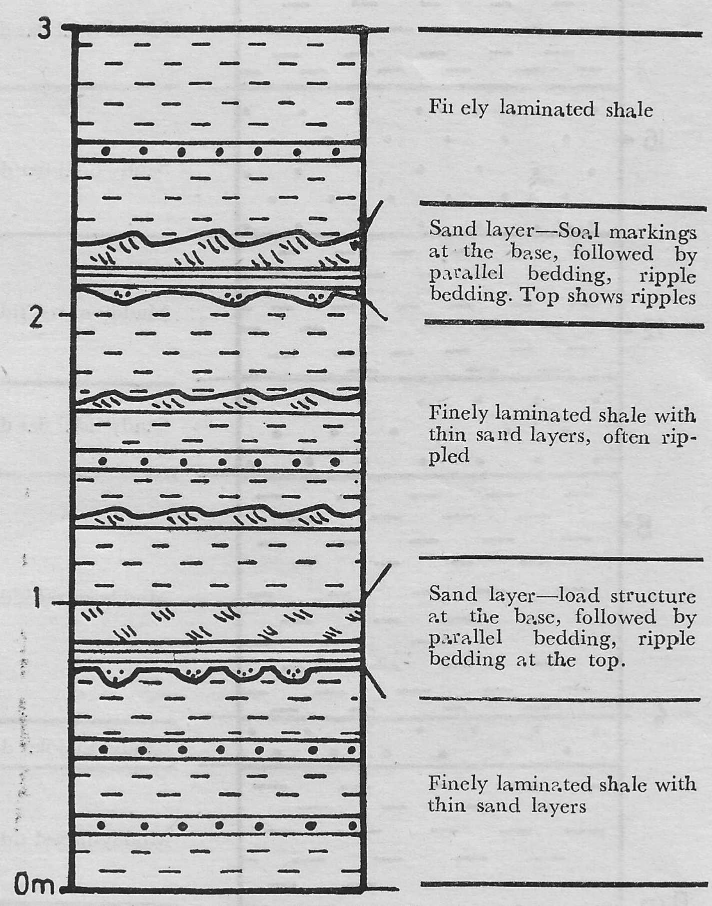

Fig. 20. Succession of sedimentary structures in Sirbu shale, Kasla hill, Maihar.

by stormy conditions, water level increased and much sand was brought into the lagoon due to increased turbulence. The sand can be brought both from seaward as well as landward side (see also Rewa shale). The sand is deposited filling the cavities made by halite crystals. followed by deposition of sand from suspension, producing parallel bedding. At the end of the storm-phase, wave ripples and sometimes current ripples were produced. The top surface of ripples, often suffered reworking during falling water level. Then the normal sedimentation of fine-grained sediments began, until it was again disturbed by the deposition of sand under stormy conditions. In some cases, the beginning of sand deposition results into scouring action on the underlying soft mud producing various types of tool-and scour marks. The overloading of soft mud by sand led to the formation of load structure at the base (Fig. 19, 20).

Thus, it is believed that major part of the Sirbu shale was deposited in shallow lagoon with oxidizing milieu. and partially under hypersaline conditions. Towards the topmost part of the Sirbu shale thick sand layers become prominent, suggesting a gradual increase in the energy of the environment. In comparison to the lagoon of Rewa shale times, the lagoon of Sirbu shale times was more protected from the sea and had lower energy of sedimentation.

Basumallick (1962 b) suggested tidal flat as the environment of deposition for Sirbu shale. However, Sirbu shale lack the characteristic features of a tidal flat, i.e., larger channels, surfaces of discontinuity, mud-filled channels, common occurrence of small current ripples. A tidal flat is a medium energy environment with much tidal current activity, along with wave activity. The

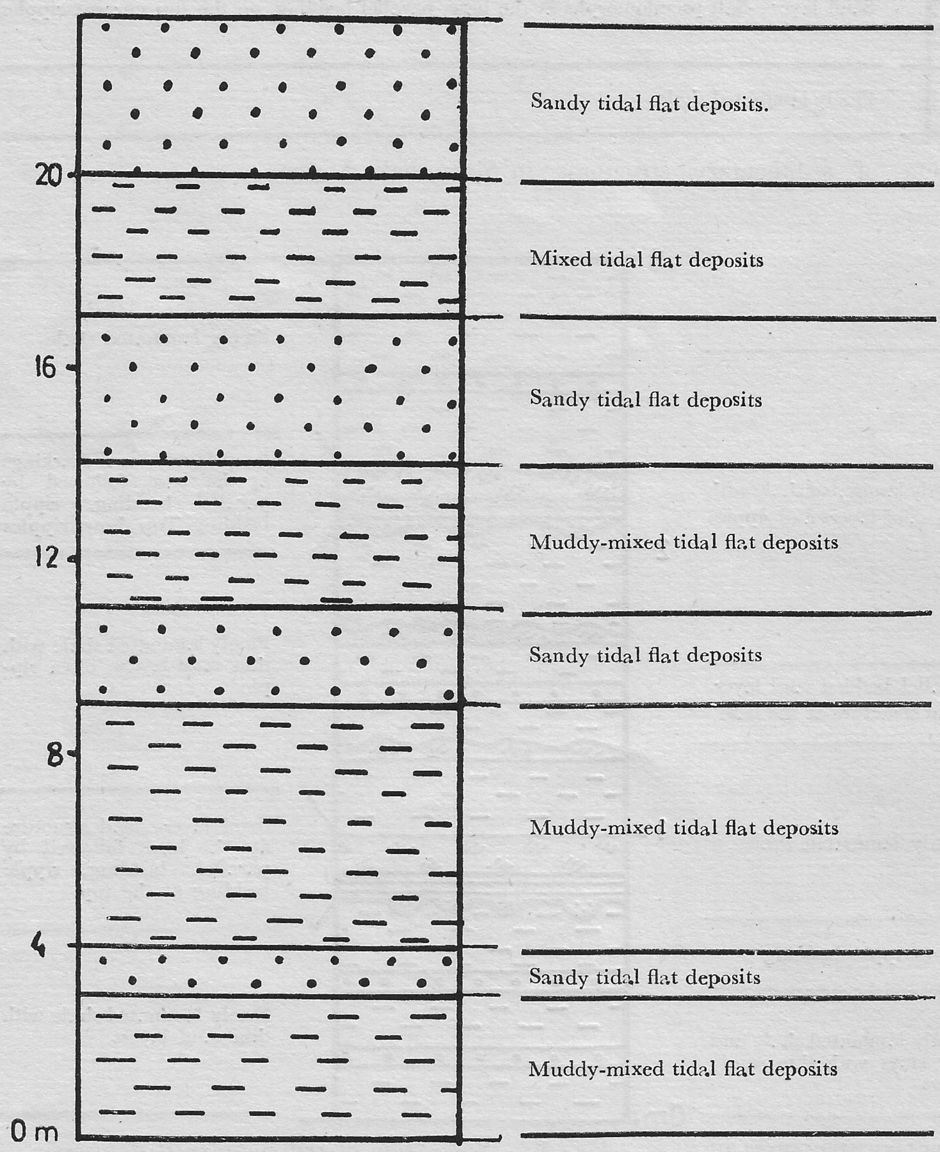

Fig. 21. Lithological succession of Maihar sandstone, 1990′ hill, Maihar.

features of Sirbu shale suggest a low energy environment with occasional wave activity, and only a subordinate current activity. Such an environment of deposition is a coastal lagoon.

MAIHAR SANDSTONE

In upper part, Sirbu shale gradually becomes more sandy, and finally grades into Maihar sandstone. It is made up of brown to red coloured sandstone and deep red coloured shale. This is well-exposed in the hills around Maihar.

The lower part of Maihar sandstone (ca. 25 m thick) is a mixed facies containing high proportions of shales along with sandstones. 1-3 m thick sand-dominant mixed facies alternates with 3-5 m thick mud-dominant mixed facies. In the 1990′ hill, located north of Sharda temple hill there are four such cycles (Fig. 21). These cycles are traceable up to considerable distance in this hill

The sand-dominant mixed facies is marked by the dominance of sandy beds over muddy beds. (Plate IV-21, The sandy beds are commonly made up of 30-50 cm thick horizontally bedded sand. 10-30 cm thick sandy units are often made up of small ripple bedding. Rarely few bands show large-scale cross bedding. The muddy layers are present as 5-30 cm thick units made up of lenticular and flaser bedding. These muddy sediments are often present in shallow channels, showing planes of discontinuity. The lower contact of sandy units with the muddy units is often erosional. The most important feature of the sandy facies is the abundance of surface markings, especially the ripple marks. Ripple marks are very common and show a wide spectrum of varieties, e.g., double and triple crested ripples, interference ripples, wave ripples, micro-ripples, flat-topped ripples, rhomboid small ripples (Plate IV-20), small current ripples of undulatory and lingoid type. Besides, rill marks, wrinkle marks, current crescent (Plate IV-24), and faint, minute mud cracks are quite common. These features point to deposition in sandy tidal flats. Presence of minute mud cracks and wide spectrum of ripples demand deposition in the intertidal zone. The dominance of thick parallel

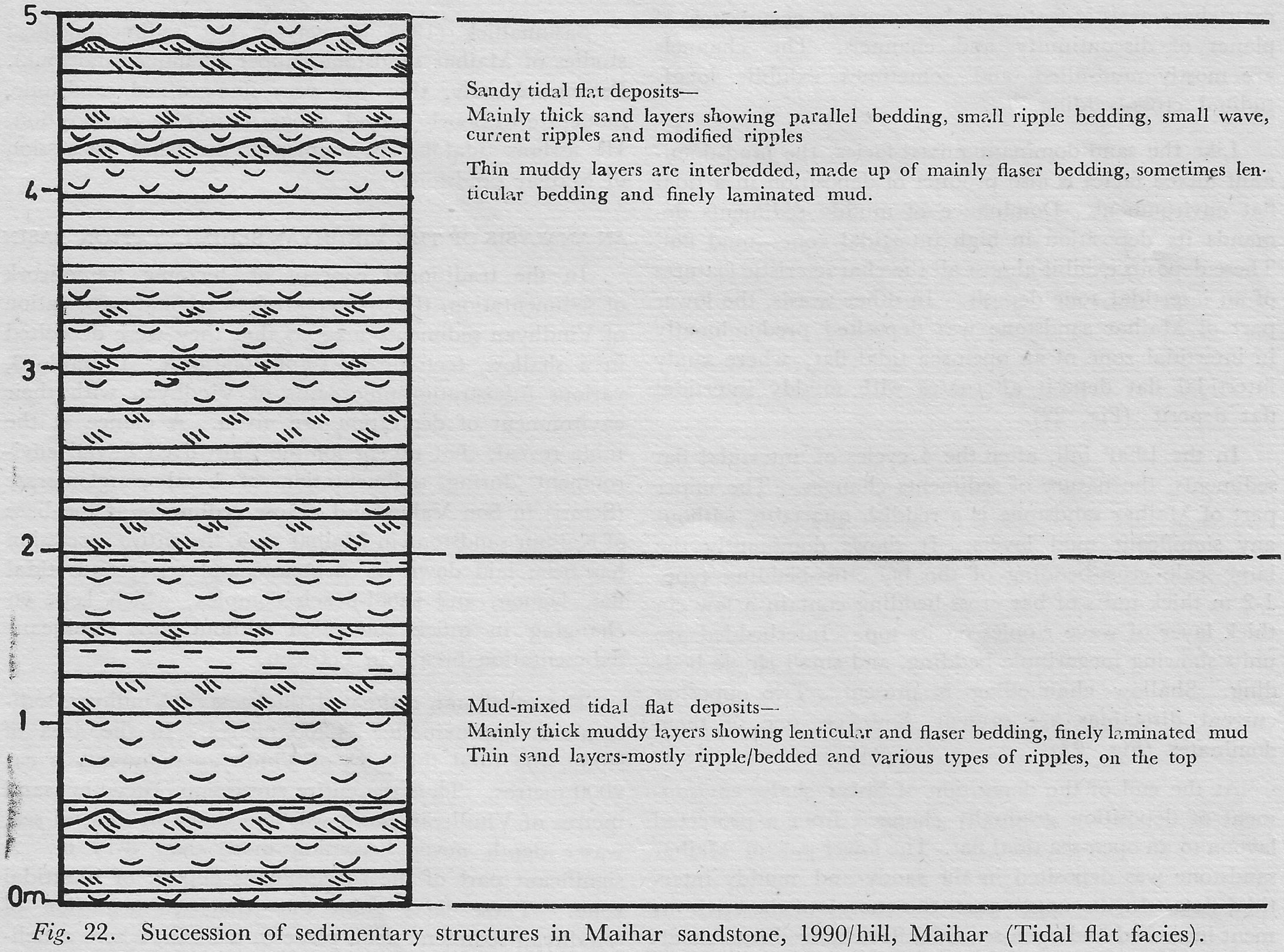

Fig. 22. Succession of sedimentary structures in Maihar sandstone, 1990/hill, Maihar (Tidal flat facies).

bedded sandy units suggests that the tidal flat was also subjected to considerable wave action. Most probably, the tidal flat was of open-sea type, where sandy parts were exposed to moderate wave action, especially under heavy weather conditions.

The mud-dominant mixed facies is marked by the dominance of muddy sediments over sandy sediments. The muddy units show mainly lenticular-and flaser bedding in all possible variations, however, the lenticular bedding dominates over the flaser bedding. Interbedded are few cm thick mud layers showing thin lamination. There are also few cm thick units made up of finely interbedded mud/sand (tidal bedding). Thin sandy horizons (3-5 cm thick) are present showing small ripple bedding.

Sand layers showing ripples are quite common. The ripples belong to the type of wave ripples with double or even triple crests (Plate IV-23), flat topped ripples, isolated ripples. Other surface features present are current crescent, minute rill marks, wrinkle marks. The lower surface of few sand layers shows sole markings, e.g., flute marks, load structure. etc. (Plate IV-22). The most characteristic feature is the common occurrence of planes of discontinuity and channels. The channels are mostly mud-filled and sometimes exhibits longitudinal cross-bedding.

Like the sand-dominant mixed-facies, the mud-dominant mixed facies is also product of deposition in a tidal flat environment. Dominance of muddy sediments demands its deposition in high intertidal zone—mud flat. These deposits exhibit almost all the characteristic features of an intertidal zone deposit. In other words, the lower part of Maihar sandstone was deposited predominently in intertidal zone of an open-sea tidal flat, where sandy intertidal flat deposit alternates with muddy intertidal flat deposit (Fig. 22).

In the 1990′ hill, after the 4 cycles of intertidal flat sediments, the nature of sediments changes. The upper part of Maihar sandstone is a reddish quartzite, without any significant mud layers. It shows dominantly the large-scale cross-bedding of the bar cross-bedding type. 1-2 m thick units of bar cross-bedding contain a few cm thick layer of wave ripples on its top. Interbedded are units showing megaripple bedding, and small ripple bedding. Shallow channelling is present. Two opposing current directions are present, however, one of them dominates (Fig. 23).

At the end of the deposition of Sirbu shale, environment of deposition gradually changed from a protected lagoon to an open-sea tidal flat. The lower part of Maihar sandstone was deposited in the sandy and muddy intertidal flats. In the upper part, the energy of the environment increased and open-sea tidal flat changed into shoal-

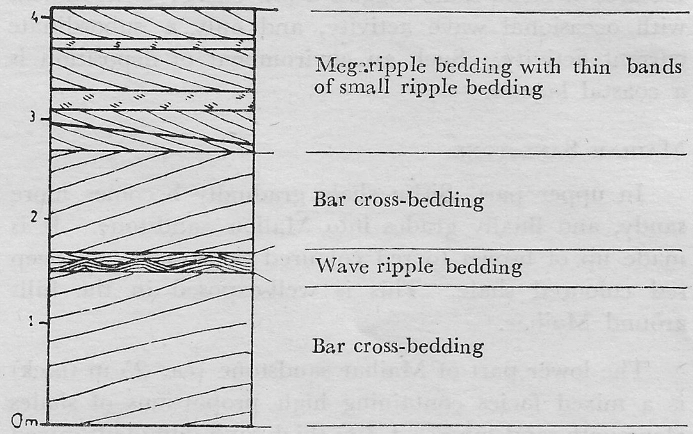

Fig. 23. Succession of sedimentary structures in the upper part of Maihar sandstone (shoal facies), 1990′ hill, Maihar.

sand bar complex with prominent wave action along with the strong tidal currents. The wave action is responsible for the development of lenticular-shaped bar cross-bedding. Tidal currents produced megaripple bedding.

Basumallick (1962 b) carried out sedimentological studies of Maihar sandstone (upper Bhander sandstone). Petrographically, they are very fine-grained sandstone, moderate to poorly sorted, subgraywacke in composition. He assigns tidal flat environment to the whole succession of Maihar sandstone.

AN ANALYSIS OF THE VINDHYAN SEDIMENTATION BASIN

In the traditional concept of tectonic frame-work of sedimentation, the orthoquartzite-carbonate association of Vindhyan sediments suggests that they were deposited in a shallow, tectonically stable platform. In table 3, various lithostratigraphic units of Vindhyan with their environment of deposition are given. A glance at the table reveals that except for the short-lived fluvial environment during sedimentation of basal conglomerate (Semri) in Son Valley and arkose sediments at the base of Kaimur sandstone in Maihar area, the entire succession has been laid down in carbonate and terrigenous tidal flat, lagoon, and shoal-beach complex, which kept on changing in quick succession without any significant sedimentation breaks in between.

The maximum estimated thickness of Vindhyan sediments is approximately 4,200 metres. In the area of study, the total thickness of Vindhyan sediments is ca. 2000 metres. Thus the entire succession of few thousand metres of Vindhyan basin was laid down in coastal sea, water depth never becoming more than 8-10 m. A significant part of the succession is deposit of intertidal zone. These facts point out that sedimentation of Vindhyan sediments took place in a basin, where a deli-

TABLE 3

Depositional environment of various lithological units of Vindhyan Sediments in Satna-Maihar area and Son Valley (Singh 1973)

	Lithological Units	Depositional Environment
Bhander	Maihar sandstone	.. Tidal flat-shoal complex
	Sirbu shale	.. Lagoon
	Bhander limestone	.. Carbonate tidal flat
Rewa	Rewa sandstone	.. Shoal-beach complex
	Rewa shale	.. Lagoon
Kaimur	Kaimur sandstone (Scarp sandstone and Dhandraul quartzite)	.. Shoal complex
	Bijaigarh shale	.. Lagoon
	Lower and Upper Quartzite	.. Tidal flat
Semri	Rohtas shale	.. Carbonate lagoon
	Rohtas limestone	.. Carbonate tidal flat
	Glauconitic sandstone	.. Tidal flat
	Fawn limestone	.. Carbonate tidal flat
	Olive shale	.. Lagoon
	Porcellanite	.. Lagoon
	Kajrahat limestone	.. Carbonate tidal flat
	Basal shale	.. Lagoon
	Basal sandstone	.. Tidal flat
	Basal stromatolitic imestone	Carbonate tidal flat
	Basal conglomerate	.. High gradient coastal rivers.

cate balance was maintained between subsidence and deposition, so that several hundred metre thick successions of single environment were formed. Even the change in environment like tidal flat into lagoon, or lagoon into shoal and vice versa does not need any significant transgressions and regressions. These environments are geographically related and occur in same water depths. They differ from each other only in the intensity of wave and current energy. Thus, a change from tidal flat into lagoon can be achieved due to developed of a sand bar (barrier island) towards the open sea. This development needs only an increased supply of sand from the land, i.e., only a minor sedimentary tectonical adjustment. Thick tidal flat deposits have also been described from other parts of the world. Singh (1969) describes extensive tidal flat deposits from Precambrian of Southern Norway, where several thousand feet thick sequence has been deposited exclusively in a tidal flat environment. Wunderlich (1970) describes a 60 m thick succession of Rheinian Devonian, W. Germany, laid down exclusively in a tidal flat environment, without any development of sequences. Kujpers (1972) describes a 840 m thick sequence of upper Devonian from Southern Irland, deposited in shallow lagoon and tidal flat environment.

Following are the few important aspects of the Vindhyan sedimentation basin:—

(i) Transgressions and regressions in a shallow-water marine environment normally lead to the development of sequences of coastal sand—shelf-mud (Reineck and Singh, 1973). However, such sequences has not been recorded in the area of study of the Vindhyan basin.

(ii) In the lower Vindhyan sediments (Semri) in Son Valley the environment of deposition oscillates between tidal flat and lagoon. There is no development of extensive coastal sand deposits of shoal complex. On the other hand, in upper Vindhyan sediments there are three shoal-type coastal sand deposits (Kaimur sandstone, Rewa sandstone, Maihar sandstone). It seems that during sedimentation of lower Vindhyan sediments, the basin behaved differently so that no high energy coastal sand could be deposited and preserved. Banerjee (1964) points out that tectonic instability during lower Vindhyan times produced strong relief in the floor of the basin.

(iii) In the upper Vindhyan, there are three few hundred metre thick coastal-sand sequences of high energy environment (Kaimur sandstone, Rewa sandstone, upper part of Maihar sandstone). None of them show characteristics of a beach (mainland beach or barrier island beach), and the beach zonation. They seem to have been deposited in extensive shoal/channel systems, without development of typical beach.

(iv) In the Vindhyan sediments it is not possible to reconstruct the palaeoslope from palaeocurrent measurements. Attempts have been made to reconstruct the Vindhyan basin based on palaeocurrent measurements (for example, Banerjee and Sengupta, 1963; Jafar *et al.*, 1966, Mishra, 1967, Misra, 1969). None of these studies have considered the nature of deposits and the environment of deposition while interpreting the palaeocurrent data. Some of them have even considered the palaeocurrent direction identical to the palaeoslope. This assumption holds true only in the case of fluvial sediments, where river flow follows the regional slope; but not in the case of shallow sea deposits. In the case of coastal sand, the net transport of sediment is from sea towards land (just opposite to the palaeoslope).

The current pattern in a tidal dominated shallow sea is extremely complicated. There are coastal current and longshore current running parallel to the coast; rip current flowing from beach towards sea. Moreover there are two directions of tidal currents (Ebb and flood currents), running mostly parallel to the coast, but are affected by the geomorphology. In tidal inlets and embayments tidal currents flow at right angles to the coast line. In the intertidal zone, the direction of tidal current changes depending upon the position of tide, and often shows rotational nature. Sometimes one direction of tidal current is much stronger than the other, which produces more or less unimodal cross-bedding in the sediments (Reineck and Singh in Dörjes *et al.*, 1969). Moreover, wave action further complicates the picture, as it produces longshore bars, shifting towards land; and dominantly landward pointing wave ripples. The orientation of ripples (wave and current) is highly variable in tidal flat environment and is also influenced by changes in the weather conditions.

Basumallick (1962b) determined plaeocurrent in Maihar sandstone. He interprets the ripples to be exclnsively of current origin. However, in Maihar sandstone wave ripples are most abundant, even the fig. 1 of Basumallick (1962 b) shows typical wave ripples showing tuning-fork like bifurcation.

Determination of sediment transport in modern tidal seas have shown that palaeocurrent patterns of tidal-sea sediments are extremely complicated (see fig. 403 in Reineck and Singh, 1973). In no case, palaeocurrents in shallow sea deposits can be regarded as an automatic indicator of palaeoslope. Much care is needed while interpreting the paleocurrent data of the Vindhyan sediments.

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EXPLANATION OF PLATES

Plate I

1. A succession showing horizontal bedding (lower part), followed by large scale cross-bedding. Kaimur sandstone, Badanpur, Maihar. Length of the hammer=37 cm.
2. Flute marks superimposed on the transverse ridges developed at the base fo a sandy unit of Rewa shale. Badanpur, Maihar. Length of the pencil=15 cm.
3. Wrinkle marks on the top of a sand layer. Rewa shale, Badanpur, Maihar.
4. Bar cross-bedding. Rewa sandstone, Badanpur, Maihar.
5. Low-angle discordances in horizontally bedded sandstone. Rewa sandstone, Badanpur, Maihar. Length of the hammer=30 cm.
6. Large-scale cross-bedding showing overturned foresets.

Plate II

7. Trough cross-bedding (festoon bedding) in the surface view. Direction of flow—towards lower-right corner. Rewa sandstone, Badanpur, Maihar. Length of the hammer=30 cm.
8. Climbing ripple lamination. Direction of flow towards right hand side. Bhander limestone, Steel mine quarry, Satna. One division of the scale=1 cm.
9. A succession of ripple bedding. Part of it shows wave ripple bedding; the other part shows herringbone cross-bedding. Bhander limestone, Steel mine quarry, Satna. Length of the hammer=37 cm.
10. 'Micro-ripples'. Distance between two adjacent troughs is less than 1 cm. They are wave ripples formed under very thin layer of water. Bhander limestone, Bamhore quarry, Satna. Length of the pencil=15 cm.
11. Large-scale cross-bedding. Note the two opposing directions of flow (Herringbone cross-bedding). Bhander limestone, Bamhore quarry, Satna. Length of the pencil=15 cm.
12. Mud cracks. Note the large polygons, which themselves show smaller polygons. Three generations of polygons are visible. Bhander limestone, Lilji Nala, Maihar. Length of pencil=15 cm.

Plate III

13. Penecontemporaneous limestone conglomerate showing cross-bedding. The limestone pieces are somewhat rounded. Bhander limestone, Tons river section, Satna. One division of the scale=1 cm.
14. Conglomerate horizon on the top of Bhander limestone in the dolomite facies. The pebbles are rounded and made up of dolomite derived within the basin of deposition. Bamhore quarry, Satna.
15. A chert horizon showing ripples. The chert is made up of silicified oolites. Tons river section, Maihar.
16. Raindrop imprints in thinly laminated dolomite. Bhander limestone, Bamhore quarry, Satna.
17. Cabbage-head stromatolite horizon marking the top of Bhander limestone in Maihar area. It is made up of Baikalia sp. Lilji Nala, Maihar.
18. Wavy bedding and wave ripple bedding in the lower part of Sirbu shale, Lilji Nala, Maihar.

Plate IV

19. Ripples with flattened tops. The flattening or capping off of the ripples takes place during subaerial emergence of rippled surface. Sirbu shale, Maihar. Length of the clip=2.6 cm.
20. Rhomboid ripple marks. Note minute striations on the top. These ripples are produced under extremely thin film of water (few cm). Direction of flow—towards bottom. Maihar sandstone, Maihar. Length of the pencil=14 cm.
21. Succession of sand-dominant tidal flat facies in Maihar sandstone. The sandy horizons are mainly made up ripple bedding. The muddy layers show dominantly lenticular and flaser bedding. Note the continuous nature of individual horizons. Maihar sandstone, Maihar.
22. Sole markings on a sandy layer of Maihar sandstone, Maihar. One division of the scale=1 cm.
23. Ripple marks showing triple crests. Such ripple marks are characteristic of a falling water-level environment. Maihar sandstone, Maihar. One division of the scale=1 cm.
24. Current crescent. Note the raised rim on the upstream side. Direction of flow towards right hand side. Maihar sandstone, Maihar, Length of the clip=2.6 cm.


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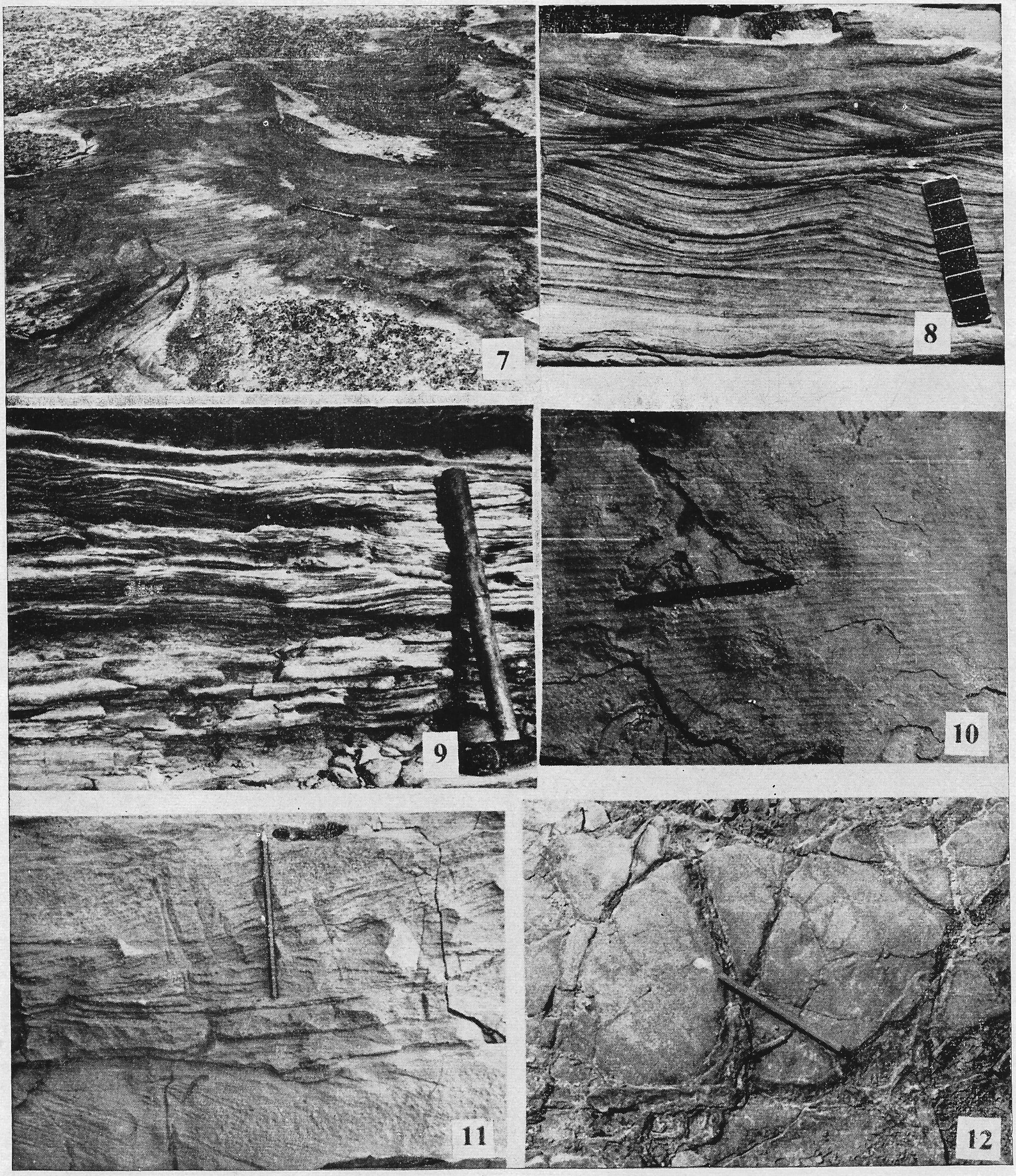
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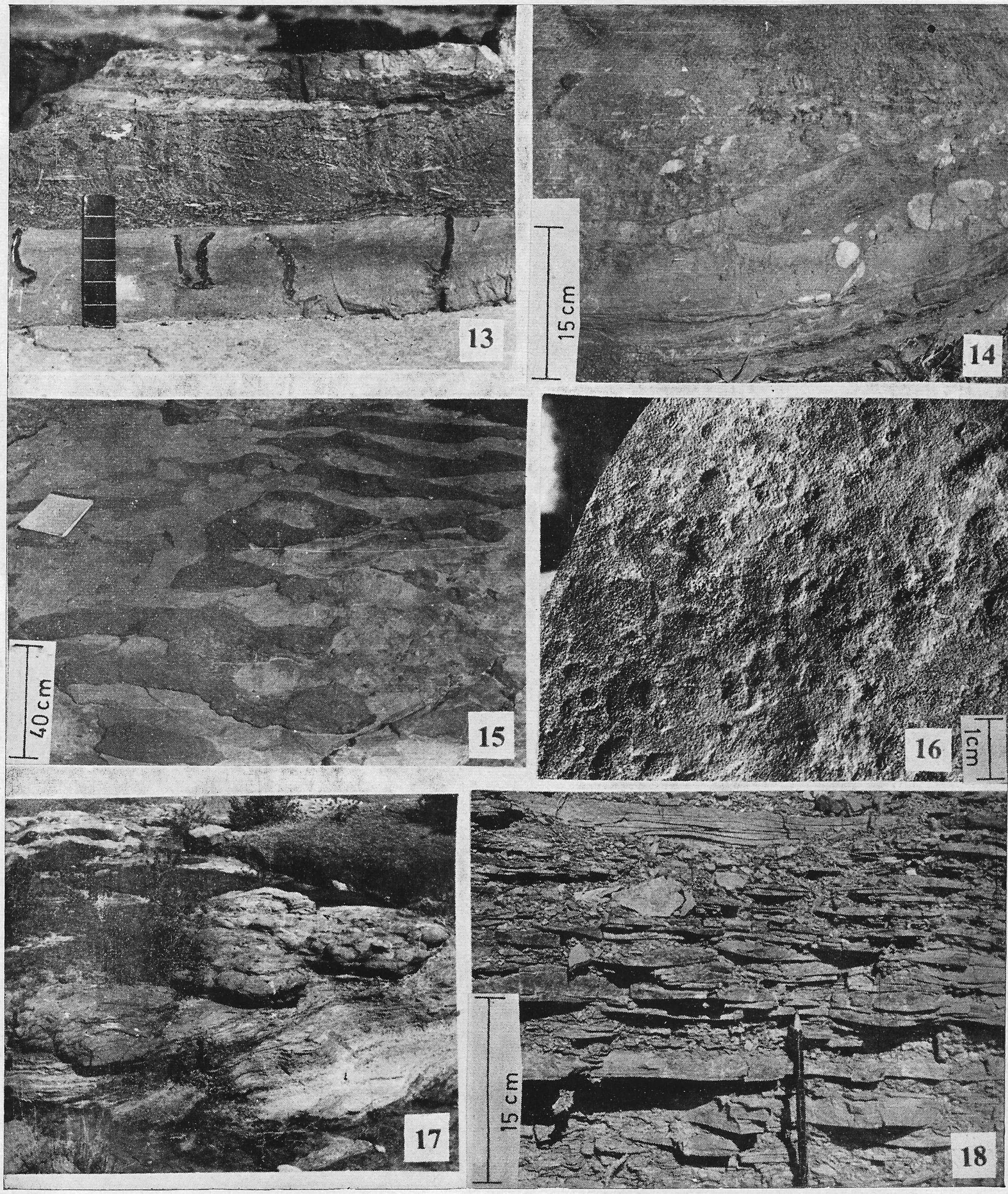
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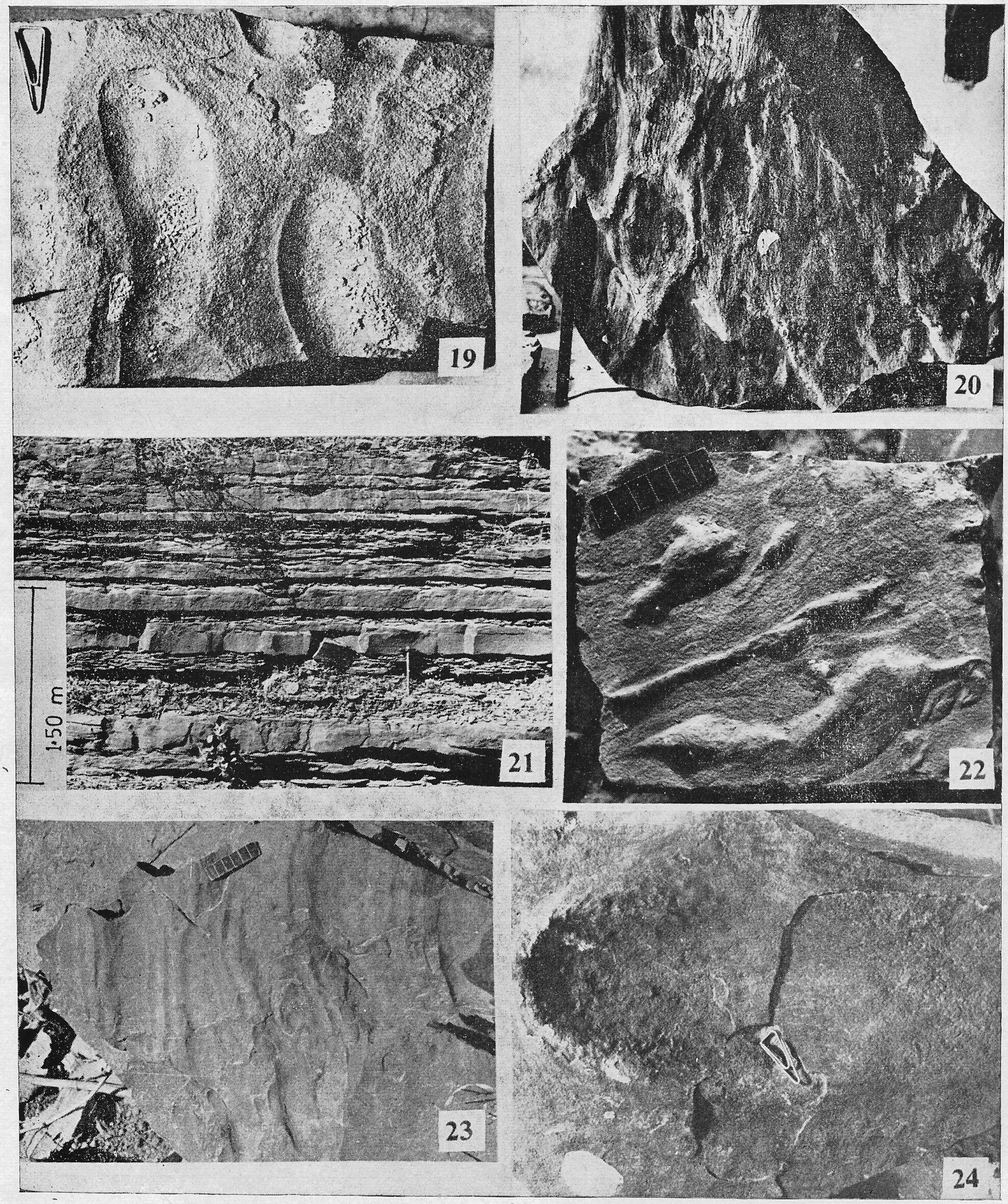

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