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Facies analysis and sequence development of Rampur and Sirbu Shale in Vindhyan Supergroup, Central India

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CERTIFICATE

This is to certify that Ms. **SUSMITA SARKAR** of M.Sc. Final Year, 2019, bearing examination Roll No **MGEO194013** and Registration No **128268 of 2014-15**, has worked under my guidance in the Department of Geological Sciences and completed her thesis entitled " **FACIES ANALYSIS AND SEQUENCE DEVELOPMENT OF RAMPUR AND SIRBU SHALE IN VINDHYAN SUPERGROUP, CENTRAL INDIA"** which is being submitted towards partial fulfilment of her M.Sc. Final Examination in Applied Geology of Jadavpur University in 2019.

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ABSTRACT

Black shales are important sink for organic carbon. It also indicates the anoxia of a basin. In the present work, detailed study of two black shales one from the Upper Vindhyan, namely Sirbu Shale and other from the Lower Vindhyan, namely Rampur Shale were carried out. Both the shales are well exposed within the Vindhyan Super Group at and around Maihar and Chorhat, M.P. Facies analysis of both the shale units reveal that the black parts of the shales were possibly deposited during the maximum transgression. The Rampur Shale shows an overall transgressive trend and black shale appears in the Maximum flooding zone. The Sirbu Shale on the other hand shows an initial transgressive trend, marked as TST and then an overall regressive trend. Signatures of the microbiota are abundantly present within the black shales. Different types of microbial mat geometry have been identified within the shales. SEM-EDS analysis shows the different forms are present which are similar to some cultured mat form and their carbon content are also significantly high. The microbial mats of Sirbu Shale are different from the Rampur Shale and only crinckly laminated mats are observed.

CHAPTER-1

INTRODUCTION

1.1. Introduction:

The Palaeo to Neo Proterozoic Vindhyan basin (area- 162,000 sq. Km and maximum thickness~ 4.5km) is the largest Proterozoic sedimentary basin of India and 2nd largest Proterozoic sedimentary basin in the world. The Vindhyan rocks are well exposed in Bihar, Uttarpradesh, and Madhhyapradesh while other parts are exposed in Rajasthan area (Chakaraborty, 2002). The vindhyansupergroup comprises a succession of sandstone, shale and limestone/ domomite with horizon of volcanoclastic sediment (porcellinite) particularly in lower part (Bose et al., 2001). The Son valley Vindhyan sediment succession has two distinct subdivision separated by an unconformity (Sarkar et al; 1996) i.e. lower Vindhyan/ Semri Group and upper Vindhyan. The lower Vindhyan consists of five formations while the upper one consists of three formations (Fig.1.1.) (Bose et al. 2001). Though the position of unconformity is well established but the exact stratigraphic position of the unconformity is still controversial.

The lower Vindhyan/ Semri Group which comprises of five formations like deoland , Kajrahat, Porcellanite, Khenjua, and Rohtas and upper Vindhyan contains three formations like Kaimur, Rewa and Bhander formation. All the formations are significantly different from each other by lithofacies, depositional environment, records of volcanism, lateral variation in facies thickness and scale of syndepositional deformation features between the two divisions (Chakraborty, 1995; Bose et al., 1997,2001, Sarkar et al., 2002).

My present dissertation topic is on the sedimentological and geochemical aspects of two black shale units from the Rampur shale member of the Rohtas formation and the Sirbu Shale Member of the Bhander Formation of the Vindhyan Supergroup, India. The Rampur Shale contains thick black shale unit which is part of a trangressive sequence, showing overall fining trend. Top part is dominated by black shale indicating MFS. Here black shale is not only representative of a reduced environment; petrography and geochemical analysis reveals an enrichment of microbial assemblage within it. The presence of different types of mats makes the Rampur shale unique from the other formations. The mat presents here are not only morphologically different but also chemically different from each other. On the other hand the Sirbu Shale also contain a black facies which was not properly reported earlier. Here microbial mat features are also abundantly present.

Supergroup	Group	Fm.	Member	Description	Paleogeography
VINDHYAN SUPERGROUP	UPPER VINDHYAN	BHANDER	Upper Bhander Sandstone	Well sorted Sst with wave features below and cross-strata translatent,and adhesion laminae above	Fluvio-eolian and marginally marine
			Sirbu Shale	Sst-Sh interbed with wave quadripolar sole features, carbonate patches in Sh with emergence features below	Shelf Lagoon
			Lower Bhander Sandstone	Sst-Mudstone interbed with wave and emergence feature	Coastal playa
			Bhander Limestone	Micrite, ooolite and stromatolitic Lst	Shallow marine
			Ganuragarh Shale	Mudstone-Sst interbed with wave and emergence feature	Chenier
		REWA	Rewa sandstone	Well-sorted Sst with thin mudstone below and large cross stratified coarser Sst with emergence features above	Tidal to fluvio-eolian
			Rewa Shale	Sh-Sst interbeds with wave and sole features	Shelf
		KAIMUR	Dhandraul Sst.	Well sorted Sst with thin mudstone below and large cross stratified coarser Sst with emergence features above	Shelf in fluvio-eolian
			Scarp Sst.		
			Bijaigarh Sh.	Pyrite rich black shale interbeded with sandstone and silt stone	Intertidal to Shelf
			Upper Quartzite	Well sorted Sst with dominance of mud deposition	
			Silicified Sh./Bhagwar Sh.	Alteration of thick-thin siltstone and black shale beds (siltstone are mainly reworked volcanoclastic sediments)	
			Sasaram Sst. (LQ)	Moderately sorted sub-arkosic sandstone unit with shale	
	LOWER VINDHYAN	ROHTAS	Rohtas Limestone	Lst,locally interclastic, wave rippled	Shelf
			Rampur Shale	Grey Sh. with sand filled gutters	Shelf
		KHE-INJUA	Chorhat Sandstone	Well sorted, wave features Sst often amalgamated	Shallow marine
			Koldaha Shale	Sh-Sst interbeds with wave and sole features, local coarser poorly sorted Sst intervals with emergence features	Dominantly shelf, deltatic fluvial
		PORCELLANITE		Volcanic ash, pyroclastic flow/surge deposits, locally bearing large bombs	Shallow marine
		KAJHR-AHAT	Kajhrahat Limestone	Dolomitized Lst with Stromatolitic and desication features towards top	Subtidal to peritidal
			Arangi Shale	Scarcely exposed grey Sh	Shelf
		DEO-LAND		Well sorted Sst, bimodal-bipolar cross stratification, localized basal diamictile	Shallow Shelf

Fig.1.1 Stratigraphy of Vindhyan Supergroup and it’s depositional environment (P.K Bose et.al., 2001)

1.2. AREA OF STUDY:

The investigated area is in and around Maihar in the district of Satna of Madhya Pradesh provides good sections where sedimentary features are very well preserved. Maihar is situated about 1000km away from Kolkata and is well connected by rail from Allahabad and Katni through broadgauge. National Highway no. 7 passes through Maihar. Bihara Kola is another section of Rampur shale studied during this dissertation work which was situated around 74 km S-W form Rampur Village. The studied section of Sirbu shale was found near a place named as Katar which is 10 km northward fron the Maihar town.

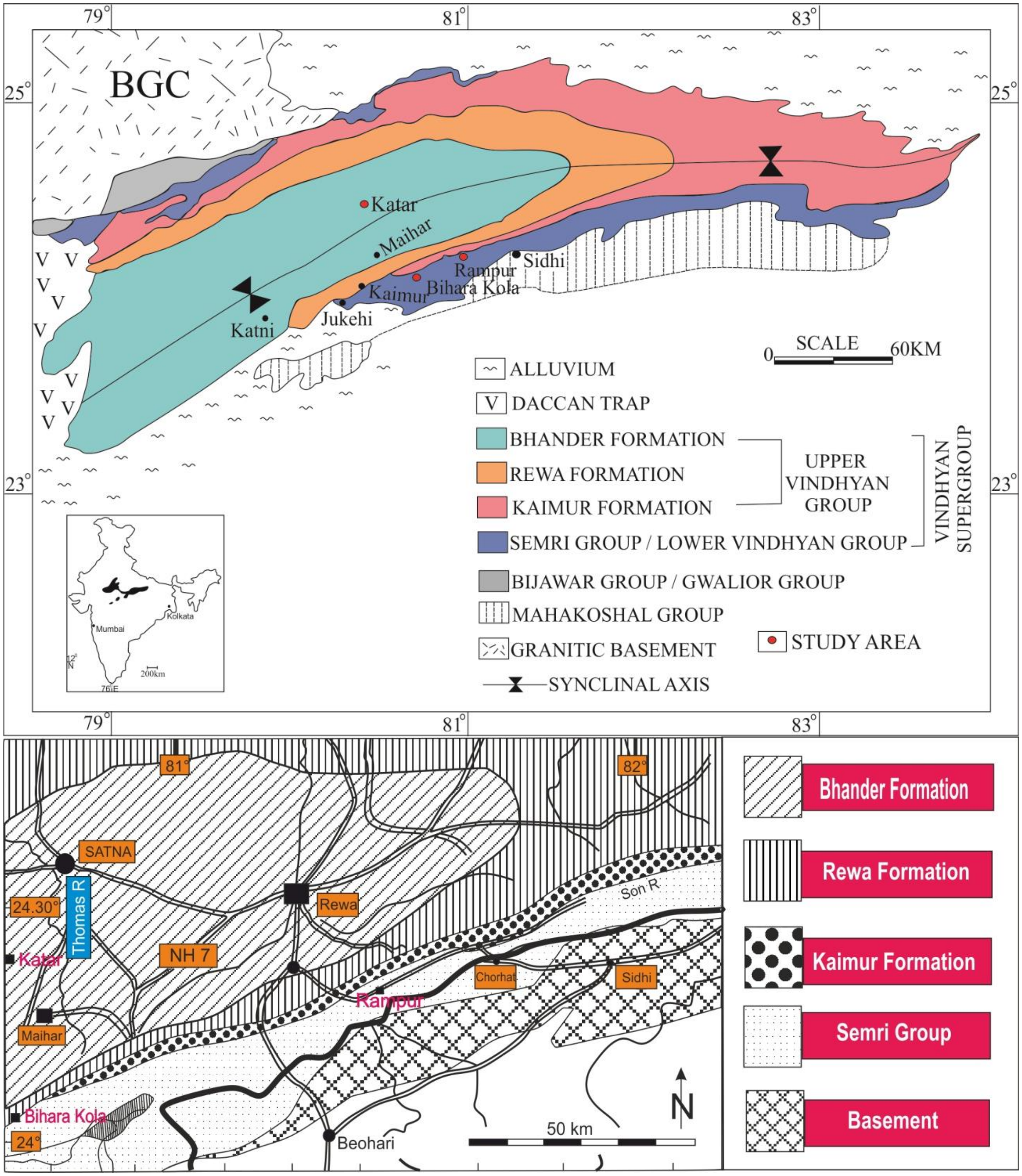


Fig.1.2. Geological map of VIndhyan Supergroup in Son Valley sector (modified after Auden, 1993) and Location map of the studied area

1.3. GEOLOGICAL BACKGROUND:

1.3.1. GENERAL GEOLOGY AND STRUCTURAL DISPOSITION:

The Vindhyan Supergroup is the thickest Precambrian sedimentary succession of India and the duration of its deposition is one of the longest in the world. The Basin overlies the stable Bundelkhand craton of Archean-Early Proterozoic age (Tandon et al., 1991).The southern margin of vindhyan basin is marked by a major ENE-WSW trending lineament termed Narmada-son lineament.Vindhyan Supergroup has been broadly divided into four Groups- Semri, Kaimur, Rewa and Bhander, from the bottom to top. The Semri Group, also called Lower Vindhyan Group, is gently deformed and mildly metamorphosed and consists of carbonate-rich sediments. They are overlain by siliciclastics of later three Groups, i.e., the Upper Vindhyan Group. The Vindhyans are bordered by the Aravalli-Delhi orogenic belt (2500–900 Ma) (Roy, 1988) in the west and the Satpura orogenic belt (1600–850 Ma) (Verma, 1991) to the south and east. The Bundelkhand massif (3.3–2.5 Ga) (Crawford and Compston, 1970; Mondal et al., 2002) occurs at the centre of the basin and divides it into two sub-basins-Son Valley in the east and Aravalli-Vindhyan in the west.

1.3.2. TECTONIC FRAMEWORK:

Different ideas have been proposed about the tectonic setting for the Vindhyan sedimentation on the basis of piecemeal observations. Sedimentation in a foreland basin verging northward (Chakraborty & Bhattacharyya 1996) or southward (Chakrabarti et al. 2007) was suggested. Some workers envisaged the Vindhyan Basin as a strike-slip fault basin (Crawford &Compston 1970; Crawford 1978). However, the general fine grain size, and high textural and mineralogical maturity of sandstones, defy rapid sedimentation from supracrustal source and do not comply with these suggestions. Extensive studies on multiple fronts later reveal intracratonic north–south rifting with a dextral shear at the initial stage (Bose et al. 1997, 2001) and sag at a subsequent stage (Sarkar et al. 2002). Consequently the east–west-elongated main Vindhyan Basin had initially been divided into several sub-basins by a number of NW–SE-oriented ridges (Bose et al. 1997), but during the Upper Vindhyan sag stage this segmentation was largely removed (Bose et al. 2001). A strong opinion exists that the basin was east–west elongated, opening westward (Chanda & Bhattacharyya 1982; Sarkar et al. 2004).

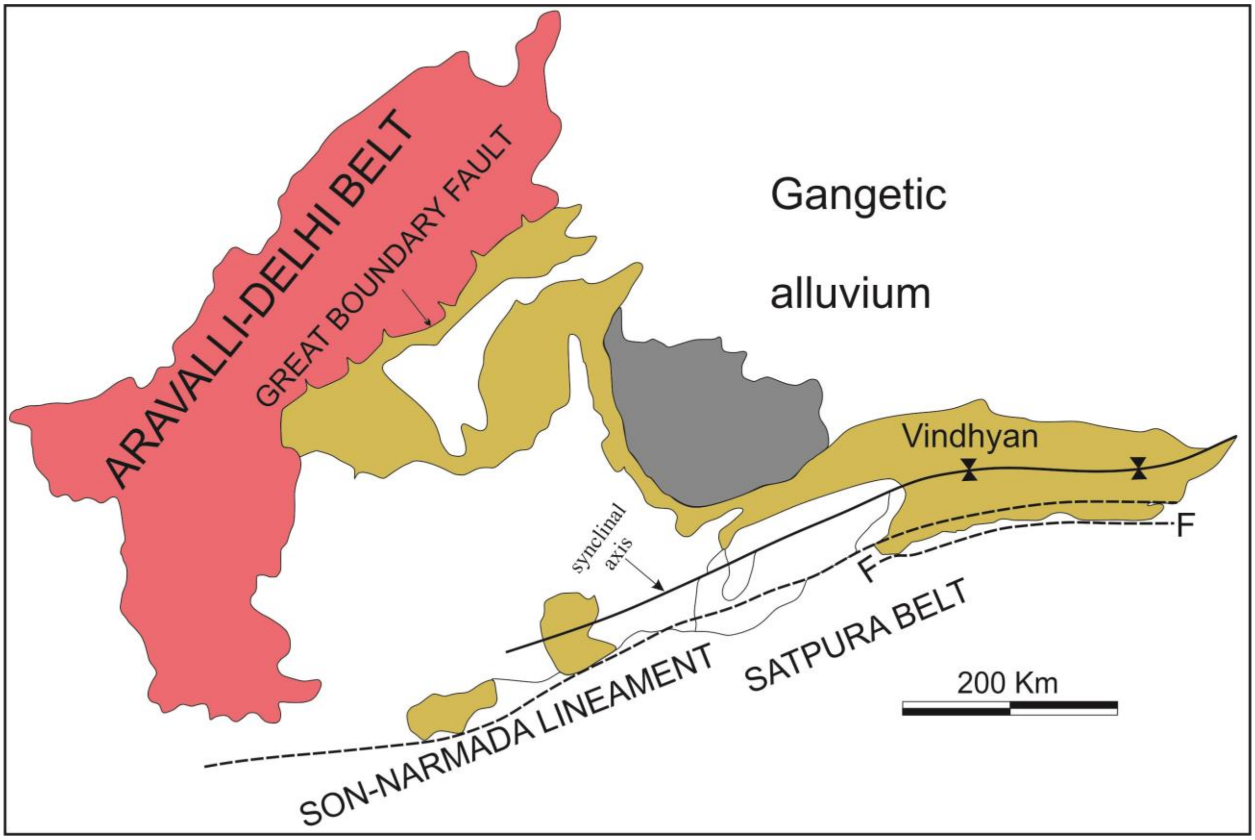


Fig 1.3.2. Tectonic framework of Vindhyan Basin

1.4. STRATIGRAPHY:

The stratigraphic work of the Vindhyan Supergroup was started by Medlicott, 1859 and evolved through the works of Mallet, 1869, Oldham et al., 1910, Vredenburg, 1910 and Auden, 1933. The Vindhyan succession overlies the granitic basement/Mahakoshal groups of rock and underlies the Gondwana and Deccan trap and recent sediments. The entire Vindhyan succession, maximum thickness estimated to be around 3 km, and comprising mainly sandstone, shale and limestone is assigned as the Vindhyan Supergroup. The Vindhyan have been separated into 2 divisions which, though of very unequal proportions, have been determined by important physical considerations. They are separable as much by an unconformable junction between the two divisions as by the sharp lithological contrast between them. The lower division consists of one group and upper divisions have three groups. Thus the Supergroup is divisible into two groups on the basis of an unconformity:

1. Semri Group or Lower Vindhyan Group

2. Upper Vindhyan Group

Each group is again subdivided into several formations. The Semri Group in the Son valley rests unconformably on a variety of pre-Vindhyan rocks such as granites and metamorphics. In the Bundelkhand area, the group overlies the Bundelkand Granite Gneisses and Bijawar Group of metamorphics, whereas in the southern Son valley, Mahakoshal is the basement in most places; however, in some localities (e.g., Deoland, M.P.) the basement is granite. The Semri succession of the Bundelkhand area has two detached outcrops around Chitrakut and Bijawar respectively, and is only a few tens of meters thick. The Vindhyan Supergroup is composed mostly of low dipping formations of sandstone, shale and carbonate, with a few conglomerate and volcanoclastic beds, separated by a major regional and several local unconformities. The regional unconformity occurs at the base of the Kaimur Formation and divides the sequence into two units: the Lower Vindhyans (Semri Group) and the Upper Vindhyans (Kaimur, Rewa and Bhander Formation). . On the basis of lithological distribution Lower Vindhyan/Semri Group and Upper Vindhyan have classified into several formations. Semri Group is divied into Deoland Fm., Kajrahat Fm., Porcellinite Fm., Khenjua Fm and Rohtas Fm. Kaimur Fm. Rewa Formation and Bhander Formation are within the Upper Vindhyan. Mathur, 1981; Rao et al., 1981; Sastry and Mitra, 1984; Bhattacharyya, A.K., 1996 , Chaudhuri et al. 1998 said that the unconformity between the Upper and Lower Vindhyan is overlain by Bhagwar Shale, upper most unit of Rohtas stage/ Formation and underlined by Kaimur Formation .

It is generally believed that the Vindhyan basin was a vast intra-cratonic basin formed in response to intraplate stresses. The different depositional systems recognized in the Vindhyan succession are: alluvial fan, fan delta, braid delta, braidplain, eolian sand sheet, tidal flat (carbonate as well as siliciclastic), shoreface (tide and storm dominated), storm dominated shelf, homoclinal carbonate ramp, distally steepened carbonate ramp and epeiric peritidal flat (siliciclastic). The overall paleocurrent directions of the depositional systems in the Son valley are northerly suggesting a source towards south.

The unconformities divide the Vindhyan succession of Son valley into five sequences. Each sequence consists of several systems tracts representing different paleogeographic settings and marking paleogeographic shifts. The different strata of the Vindhyan succession show evidences of soft-sediment deformation suggesting synsedimentary tectonic activity. The progressive and successive angular unconformities suggest that the deformation pattern shown by the Vindhyan strata is a reflection of synsedimentary tectonic activity. It is postulated that the individual sequences of the Vindhyan succession are related to discrete episodes of tectonism that induced the subsidence necessary for accumulation of sediments and resulted into deformation of the older strata. Angular unconformities resulted due to erosion of the uplifted crest of the anticlines on which the next sequence of strata was deposited with an angular discordance.

There are sediment packages at the northern part of the Vindhyan basin developed from a northerly source and thus representing different tracts and sequences from those of the southern part. These packages are represented intermittently in the succession and have been interpreted as representing periods of uplift of the Bundelkhand Granite and subsequent erosion in the north. The paleocurrents revealed by the Vindhyan strata are typically northerly suggesting that the evolving Satpura orogeny served as the source for the Vindhyan sediments. However, the source for the clastics occurring within the Semri and the lower parts of the Kaimur and Rewa Groups in the Bundelkhand sector was perhaps the Bundelkhand Granite Gneiss, Bijawar and Gwalior Group of rocks as manifested by the southerly paleocurrent direction.

Different authors have adopted different stratigraphic nomenclature for same litho-units of Vindhyan Supergroup of rocks, which have generated a lot of confusions when considered in regional scale, and for correlation. The stratigraphy of Vindhyan Supergroup, Son Valley has been compared in the fig 1.1.

1.5. CHRONOSTRATIGRAPHY:

The Vindhyan Supergroup is the thickest Pre- cambrian sedimentary succession of India and the duration of its deposition is one of the longest in the world. The age of the VindhyanSupergroup has been a matter of debate for over last hundred years. Venkatachala et al (1996) published a compre- hensive review of geochronological information on the Vindhyans. In spite of minor inconsisten- cies the available data supported the conventional belief that the Vindhyan strata were deposited between the earliest Mesoproterozoic and latest Neoproterozoic(1400–600 Ma). Barring some indi- rect information from carbonaceous mega fossils and stromatolites (e.g., Kumar and Srivastava 1997; Rai et al 1997), most of the pre 1998 chronological information came from a large number of K–Ar ages, mostly from the work of Vinogradov et al (1964). Seilacher et al. (1998) reported discovery of the oldest known trace fossils of multicellular animals (non Ediacaran) in Chorhat Sandstone (Semri Group), which was believed to be ~ 1100 Ma old based on K–Ar and F–T ages. Recently quite a good number of radiometric age (Fig 1.4) have been put forward for the Age of Vindhyan Supergroup.

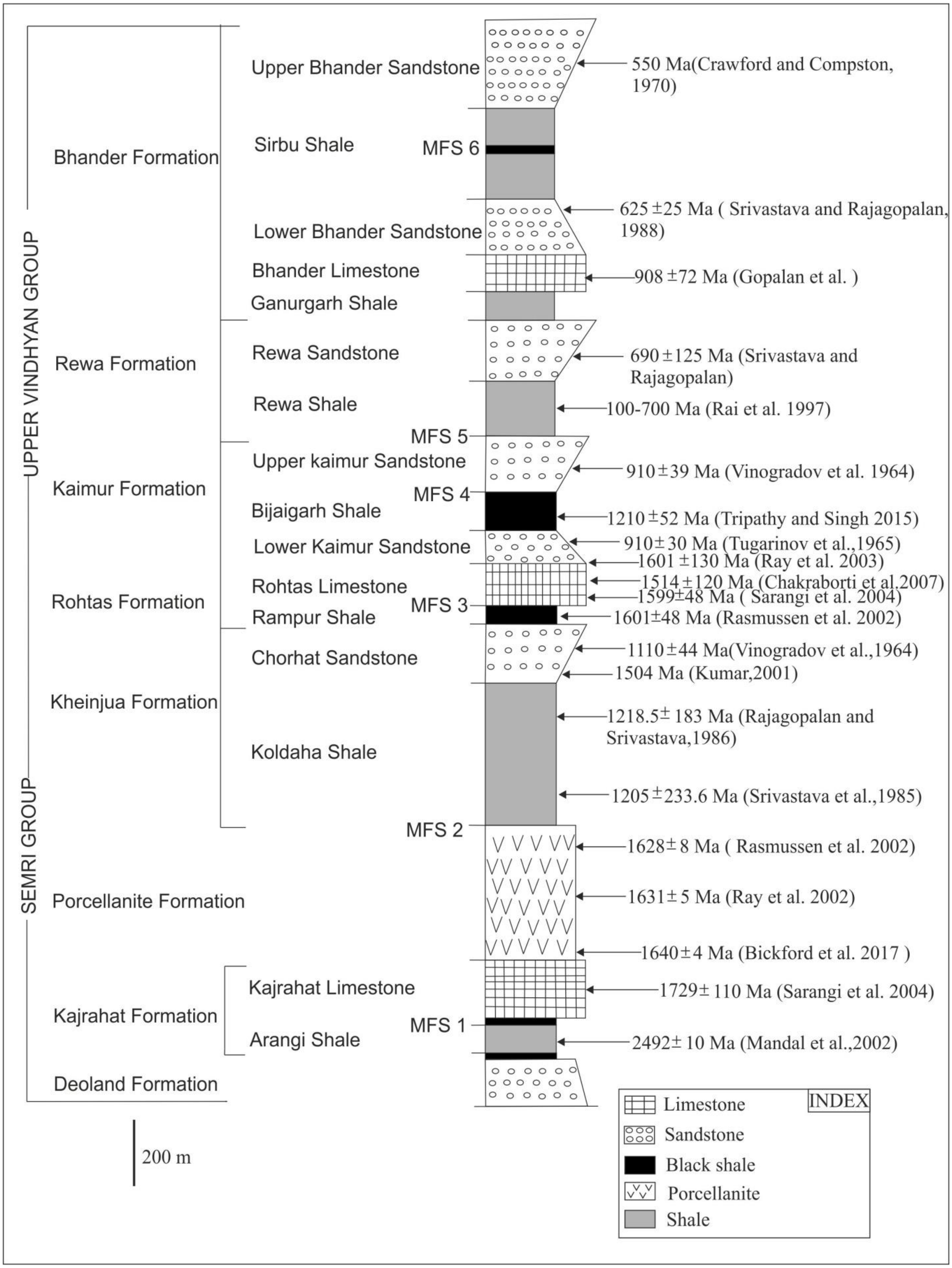


Fig.1.5. .General litholog and Chronostratigraphy of Vindhyan Supergroup (after Bose et al., 2001)

1.6. LITHOSTRATIGRAPHY, PALAEOGEOGRAPHY AND SEQUENCE STRATIGRAPHY:

The Vindhyan sedimentary rocks are generally interpreted as predominantly shallow marine in origin. Dominant lithologies of this Supergroup are sandstone, shale and carbonate. Conglomerate is rare and almost exclusively intraformational. Major felsic pyroclastic deposits are present in the lower part of the Stratigraphy. The depositional palaeoslope was presumably gentle throughout the basin history. Palaeocurrent direction was consistently northward and indicates terrigenous supply from relatively low relief southern source. Palaeoclimate was probably warm and humid to facilitate elimination of the labile minerals.

There have been several attempts to visualize the depositional environments and the palaeogeographic set ups of Vindhyan Basin. Vindhyan Supergroup is dominated by near shore marginal marine, such as barrier bar, lagoon, tidal flat & beach deposits within termittent subaerial exposure (Banerjee,1964; Singh, 1976, 1985; Rao & Neelakantam, 1978; Chanda & Bhattacharya, 1982; Prakash & Dalela, 1982; Soni et al., 1987; Prasad & Verma, 1991; Akhtar, 1996, Bose et al.,1999, 2001, Sarkar et al., 2002 a,b, 2004). Banerjee (1974) invoked a "paired barrier island sedimentation" model for the Vindhyan in Son valley. He interpreted linear sandstone ridges comprising cross bedded, mature quartzarenite as the product of barrier beach-dune complex, and limestone shales as lagoonal-tidal flat deposits on the landward side of the barrier island. Singh (1980, 1985) interpreted all the major Vindhyan sandstone units as shallow marine shoal complexes and fine grained clastics and carbonates as lagoonal tidal-flat deposits. Chanda and Bhattacharya (1982) argued that the whole Vindhyan was deposited in shallow marine environment, atleast within wind fetch. However shallow marine depositional framework appears to be very inadequately reconciled in terms of the mechanisms of crustal subsidence, basin development and sea level fluctuation. Bose and Chakrabarty (1994) identified fluvial and aeolian deposits in the Rewa formation delineating products of different flow stages and different sub-environments Aeolian longitudinal dunes, draas-interdraas complex, translatent strata can be recognized in the upper part of the Upper Bhander Sandstone in Rampur hill near Maihar(Boseetal.,1999). Process related study in marine segments were conducted by Bose and Chaudhury (1990); Chakrabarty and Bose (1990, 1992a, b); Chakrabarty (1995); Chakrabarty (1995); Sarkar et al.(1996,2002a,b) and Bose et al.(1997 a) and shelf deposits have been documented at many stratigraphic levels. The only disconcerting view was that of Bhattacharya (1996b) who suggested that Vindhyan sedimentation took place entirely in terrestrial environment such as lacustrine, flvial, aeolian, and refused his earlier emphasis on marine sedimentation. This view however did not receive favour from later workers. Only the rare patches of diamictite at the very base of the super group have been attributed to glaciation by some workers (Dubey and Chowdhury, 1952; Chaudhury,1953; Ahmad,1955, 1958). Besides some reddish mudstone sequences at the top of the Supergroup bear Pseudomorphs of gypsum, anhydrite and salt indicating arid climate last lap of Vindhyan sedimentation.

Lower Vindhyan/Semri group has been persistently interpreted as the product of sedimentation in shallow marine and coastal environments (Singh,1973; Banerjee,1974). However, Chakrabarty et al., 1996, argued that the sequence was laid down in deep marine setting below the storm wave base. But Bose et al. (2001) conclusively proved it to be dominanatly shelf deposit. Local patches of diamictite at the base of Deoland formation although has been attributed to glaciation, such hypothesis is questionable (Ahmad, 1958; Chaudhury, 1953; Dubey and Chaudhury, 1952; Mathur, 1954, 1960, 1981, 1989). There is no record of worldwide glaciation at that time. Chakrabarty and Bhattacharya (1996) have suggested that the conglomerates are mass flow products in a high gradient alluvial fan. The Deoland sandstone inferred as shelf sediment, fines upward and grades into the Arangi shale as of marine offshore origin (Boseetal.,2001). Kajrahat limestone with profuse development of stromatolites was considered by Singh (1973) and Banerjee (1974) as tidal flat deposits, whereas Banerjee et al., (2007) described as it a shallow marine product. Volcanic tuff, pyroclastics surge and flow deposits make the Porcellanite formation and imply intrabasinal volcanism. Srivastva (1997) recorded sub-aerial volcanism whereas Banerjee (1997) recorded frequent sub aerial to sub aquous transitions in the porcellanite formation. The Kheinjua formation was entirely considered as lagoon tidal flat deposition by Banerjee (1974) and Singh (1973). Sarkar et al,1996 a,b and Bose et al.,1997 recently indicated deposition in the shore face, fluvial and coastal aeolian environments. A tidal flat environment of deposition was suggested for the Rohtas formation. Chakrabarty et al.,1996 considered Rohtas limestone even as a slope deposit from the preserved conglomerate horizons. On the contrary Chatterjee and Sen, 1988 and Banerjee, 1997 regarded the succession as open shelf originated. Bose et al., 2001 however recorded the presence of wave ripple sand shelf storm bed sand lateral pinchout of those conglomerate horizons and established shoaly upward trend in the Rohtas limestone.

The Upper Vindhyan in contrast to the lower Vindhyan is well studied. The Lower Kaimur is shaley and lenticular in geometry. The basal sandstone incorporates tidal bars (Chakrabarty and Bose, 1990) and this interval passes up into a fining upward interbedded shale-sandstone succession ascribed to predominant storm deposition. The sand free organic rich and pyritic Bijaygarh Shale on the top of lower member is inferred as a deep offshore product (Chakraborty, 1993b). The entirely sandy upper Kaimur is now thought to be product of inner shelf to fluvial transition (Chakraborty, 1993a).

The Rewa Shale comprising the lower part of the formation is again a storm dominated shelf product (Chakrabarty et al., 1996, Chakraborty and Sarkar, 2005) resting on a thin granular lag blanket on top of the underlying Kaimurformation. The overlying Rewa sandstone like the Upper Kaimur shows an upward transition from inferred shallow marine-tidal to fluvial/aeolian deposits (Bose and Chakraborty, 1994). The younger Bhander formation is the only Upper Vindhyan that has a laterally persistent carbonate deposit of thickness more than 80 m known as the Bhander limestone (Sarkar et al. 1996a). It is bounded below and above by Ganurgarh Shale and Lower Bhander Sandstone, interbedded mudstone-sandstone sequence. Both these bounding formations are reddish in colour, bear emergence features and salt crystals pseudo morphs, and are of probable coastal origin (Bose and Chaudhury, 1990; Chakrabarty et al., 1998). Between them the micritic, stromatolitic, intraclastic and Oolitic Bhander limestone is of shallow shelf product (S arkar et al.,1996, 1998). The Sirbu Shale overlies the Lower Bhander Sandstone gradationally and its basal part, comprising stromatolitic and oolitic patches enclosed by grey shale and showing emergence features, is interpreted as lagoonal (Singh,1973). This lagoonal shale is overlain by dark-coloured sand free shale showing no emergence features and is designated of shelf origin (Sarkar et al., 2002). Eventually the Sirbu Shale shelf succession grades upward into the Upper Bhander Sandstone, the youngest member of the Vindhyan Supergroup. It is entirely terrestrial but there are thin coastal storm packages at certain levels (Bose et al., 1999; Sarkar et al., 2004). Depositional environment, Palaeogeography and the system tracts are given in after Bose et al. (2001)

1.7. OBJECTIVES OF THE PRESENT WORK:

The present work has been framed with the following specific objectives in order to fulfil the required task.

- Detailed fieldwork of the studied areas and to delineate its lithological variation through facies analysis.
- Detailed sample collection for geochemical analysis.
- Detailed Petrographic analysis of microfacies both within Rampur and Sirbu shale to understand the depositional environment.
- SEM-EDS study to know the chemical differences of morphologically different microbial mat of Rampur shale. Because of time constrain SEM-EDAX analysis of Sirbu Shale has not been completed during the present study.
- Study of Different types of ultramicroscopic elements induced by bacterial activity which are preserved within Rampur shale.

1.8. METHODOLOGY:

- Detailed field study has been done in exposed quarries of Rampur Shale in Rampur village and part of Sirbu Shale which are exposed. Due to error of locality we have studied siliciclastic quarries which cover 500m distance. Fresh sample was collected for petrography study. For field purpose toposheet no. 63D/15 Survey of India, traditional field equipment including GPS, clinometer-compass, measuring tape, geological hammer, Chisel, Shovels and trowels were used. Methodologies for gaining specific insight will be detailed or referred to when adopted. Field data were analyzed (Nikon 600 POL, Leica DM LP with Leica DC 300 FX) that facilitated the work enormously. Vertical log, profile maps were done using computer softwares like Photoshop CS2 and Corel DRAW 15. Detailed ultramicroscopic studies (SEM-EDS) have been done to confirm the influence of microbial mat on sedimentation. Au coated samples were observed under a zeiss EVO 40 (Oxford Inca Penta FETx 3, Model- 7636) at the Geological Survey of India (GSI), Kolkata Head Quarters, for SEM-EDS analysis. Samples were analysed under BSE mode with 20 KV voltage and 650 pA current.

CHAPTER-2

FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT OF RAMPUR SHALE AND SIRBU SHALE, VINDHYAN SUPERGROUP

2.1. Facies analysis and depositional environment of rampur shale and sirbu shale in Vindhyan Supergroup:

Eliciting the depositional modes of the ancient sedimentary rock is an essential pre- requisite for the study of sedimentary rock. To achieve the goal by which one can infer the environment of deposition is always helpful to a sedimentologist. A facies analysis with potential for working out the genetic differences between co-existing sedimentary body as adapted here, would thus be more beneficial (Miall, 1980; Hallam, 1981; Walker, 1984; Reading, 1986). The identification of various sedimentation processes from deposits, or sedimentary facies, is crucial to the recognition and paleo-geographic reconstruction of ancient sedimentary environments. Sedimentary facies are visually distinguishable descriptive varieties of sedimentary deposits, with different facies indicating different modes of sediment deposition. For this purpose, sedimentology combines knowledge derived from studies of modern environments and laboratory experiments, and uses this knowledge to understand the origin of sedimentary rocks. Stratigraphic analysis of facies succession gives insight into the depositional processes, paleo-environmental conditions and development history of sedimentary basins, and allows prediction of the geometry, lateral extent and spatial distribution of sedimentary rock bodies.

2.2. Facies analysis of Rampur Shale:

The 80 m thick shale succession, Rampur Shale is overlying on Chorhat Sandstone with a gradational boundary. The entire sedimentary succession has dominance of shale, though few sandstone and siltstone beds have appeared in the amalgamation with shale and the upper part is totally sand-free, also contain black shale at its top (fig 2.2). On the basis of primary sedimentary structures and different lithologic characters divide the Rampur Shale into ten facies. The descriptions and interpretation of each facies are as followes.

2.2.a. Cross stratified sandstone:

This facies comprises coarse to medium grained sandstone exhibiting unidirectional cross stratification (fig.2.3.1). It is present at the basal part of Rampur Shale. The average thickness of this facies is 30 cm. Cross stratifications are tabular in character. The cross stratas are oriented in south-east direction. Thickness of individual foreset varies between 0.7 cm to 1 cm. the dip of the foresets are ca. 4-5^0 . This facies is associated with shale and ripple laminated sandstone. Erosional and sharp boundary is present between planar laminated shale and ripples laminated sandstone and gradational boundary between cross laminated sandstone and ripple laminated sandstone.

2.2.b. Hummocky cross stratified sandstone:

This facies is characteristically medium to fine grained, moderately sorted sandstone with lenticular beds with convex up tops (fig.2.3.1& 2.3.2). It is overlained by ripple laminated sandstone with gradational contact. Hummocks and swales are frequently observed with average wavelength and amplitude 40 cm and 12 cm. Basal part of the hummocks are erosional, containing flute casts and different types of tool marks.

2.2.c. Gutter infested sandstone:

Gutter infested sandstone facies are mainly characterized by medium grained sandstone with gutter casts (fig.2.3.1). This facies is overlying on planar laminated shale with an erosional boundary. Sometimes groove cast, prod marks, brush marks are also observed at the sole of this gutter casts. Filling sediments in gutter casts have formed differential structures like planar laminations, low angle cross beddings. Also step gutters have been frequently observed in this facies. Gutter sandstones are overlain by ripple laminated siltstone and planar laminated shale.

2.2.d. Ripple laminated sandstone:

This facies is characterized by small scale ripple lamination with fine grained sandstone to siltstone. average thickness of this facies is 5 cm. this facies is mainly associated with planar laminated siltstone and shale. Ripples are mainly sigmoidal in nature and crests are bifurcated on the bedding surface. Sometimes few syneresis cracks are observed in the trough of these ripples (fig.2.3.1). At the lower part of Rampur Shale, this facies is associated with cross stratified sandstone facies.

2.2.e. Planar laminated siltstone:

This facies is characterized by planar laminations with silt sized grains. This facies is associated with planar laminated shale and ripple laminated siltstone (fig.2.3.2). The contact of this facies is very sharp, in the association of planar laminated shale whereas the contact of ripple laminated sandstone is not sharp. The average thickness of this facies is 4 cm.

2.2.f. Planar laminated grey shale:

This facies is mainly dominating in the middle part of studied section. They are mainly characterized by planar laminations with shale. Shales are mainly grey in colour (fig.2.3.3). They are associated with the facies described above. The shale thickness has increased vertically.

2.2.g. Gutter infested siltstone:

This facies is associated with planar laminated grey shale. It is characterized by fine grained silts (fig.2.3.2). Siltstone beds are devoid of any sedimentary structures and lenticular in geometry. Average thickness of this facies is 5 cm. Lower boundary of this facies is very sharp and erosional. Some gutters casts are preserve at the basal part of siltstone beds.

2.2.h. Planar laminated black shale:

The facies is mainly dominant in upper part of studied section. Shales are black in colour with planar laminations (fig.2.3.3). They are associated with grey shale and ripple laminated sandstone. Average thickness of this facies is 50 cm. under microscope, crinkled laminations are observed. Crinkled laminations show diverging and converging characters. A few pyrite grains are associated with these laminations.

2.2.i. Ripple laminated volcanic ash:

This facies is mainly characterized by fine grained ripple laminations alternating with planer laminated black shale. Ripples are sinuous in natures and bifurcated on bedding surface. Under microscope, several volcanic glasses are observed. Average thickness of this facies is 3 cm and they are associated with planar laminated black shale (fig 2.3.4).

2.2.j. Planar laminated limestone:

Limestone beds are associated with planar laminated black shale. Limestone beds are characterized by planar laminations. There is gradational contact between the planar laminated black shale and this planar laminated limestone beds. The average thickness of individual beds is 2 to 3 cm (fig.2.3.4).

2.3. Facies associations:

The entire sedimentary succession of Rampur Shale has been divided into four facies association depending on the sand: shale ratio and differential distribution of primary sedimentary structures.

2.3.1. Facies association I:

Facies association I is the lower most interval of studied section. This part is mainly consist of cross stratified sandstone, hummocky cross stratified sandstone, single lobe gutter infested sandstone, ripple laminated sandstone. Shale: Sand ratio is 2:8.

Interpretation:

Abundance of cross stratification and sharp, erosional contact with lower shale beds indicates sandstone was deposited in high energy condition. Presence of hummocky cross stratified sandstone with coarse grain sand and flute casts, groove marks; brash marks infer they were deposited in high flow regime storm. Presence of ripple laminations on top of cross stratified sandstone infers storm waning deposit. Bifurcation of ripple crests represents wave dominance in depositional site. Planar laminated shale on top of ripple laminations also infer waning of storm flow. Gutter infested sandstone beds with sharp, erosional contact with prod marks, brush, groove casts also interprets as high storm flow.

2.3.2. Facies association II:

Facies association II comprise of hummocky cross stratified sandstone, step gutter infested sandstone, ripple laminated sandstone, planar laminated siltstone and planar laminated shale. Hummocky cross stratified facies is only restricted in the lower part of this facies association.

Interpretation:

Abundance of shale deposit infers shale was deposited in an suspension fall. Dominance of gutter casts in association of shale with lenticular fashion and sharp, erosional contact infer they were deposited in high storm flow. Presences of different tool marks in the sole of these beds infer energy condition was very high. Step gutters infer gutters have formed by storm and depositional site was affected by different sets of storms. Massive filling of gutters infer quick deposition. Low angle cross stratifications in gutters convey side filling. Planar laminated normal grading in some gutter represent waning of storm current. Presence of planar laminated siltstone, ripple laminated sandstone of fine sand grained infer waning of storm energy deposit. Ripple lamination with bifurcating crest indicated wave dominated deposit as well.

2.3.3. Facies association III:

Facies association III consists of shale. Shale: Sand ratio is almost 9:1. Dominant facies of this facies association are planar laminated grey shale, planar laminated siltstone, gutter infested siltstone, planar laminated black shale.

Interpretation:

Huge thickness of shale deposition indicates shale was deposited in suspension condition. Presence of planar laminated siltstone also infer suspension fall. But the sharp contact of these facies indicates more high energy deposit compare to shale. Presence of gutter infested siltstone beds with siltstone beds infers storm deposit. Massive filling of these gutters indicates quick deposition from storm cloud. Presence of microbial laminates in black shale facies infer deposition site was within photic zone.

2.3.4. Facies association IV:

Facies association IV is totally different from other depending on the shale abundance. It is entirely sand free. It compares of planar laminated black shale, ripple laminated volcanic ash.

Interpretation:

Abundance of planar laminated black shale infers deposition took place at greater depth. It indicated the maximum flooding surface that is the maximum deepening of the basin. The energy was low.

Depositional environment:

All the facies and facies association in the depositional site convey deposition must have taken place in a marine condition. Facies association I infer depositional site was highly wave influence. The presence of hummocky cross stratification, gutter casts with sharp, erosional boundary and flute casts, groove casts, brush marks, prod marks convey wave deposition was interrupted by storm surge. Increment of shale in facies association II indicates depositional site was dominance of suspension fall out i.e. deposition was took place much greater depth compares to facies association I. Presence of abundance gutter infested sandstone beds infer depositional site was influence with storm surge as well. Minute preservation of ripple lamination on top of gutter sandstone convey it was wave influence as deposition of storm enforce the depositional site and fill up the accommodation space below fair weather wave base. Presence of black shale in facies association IV infers deposition was took place much greater depth compare to other facies association. Preservation of microbial mats in this facies association and presence of pyrite grains conveys deposition site was anoxic during facies association IV deposition.

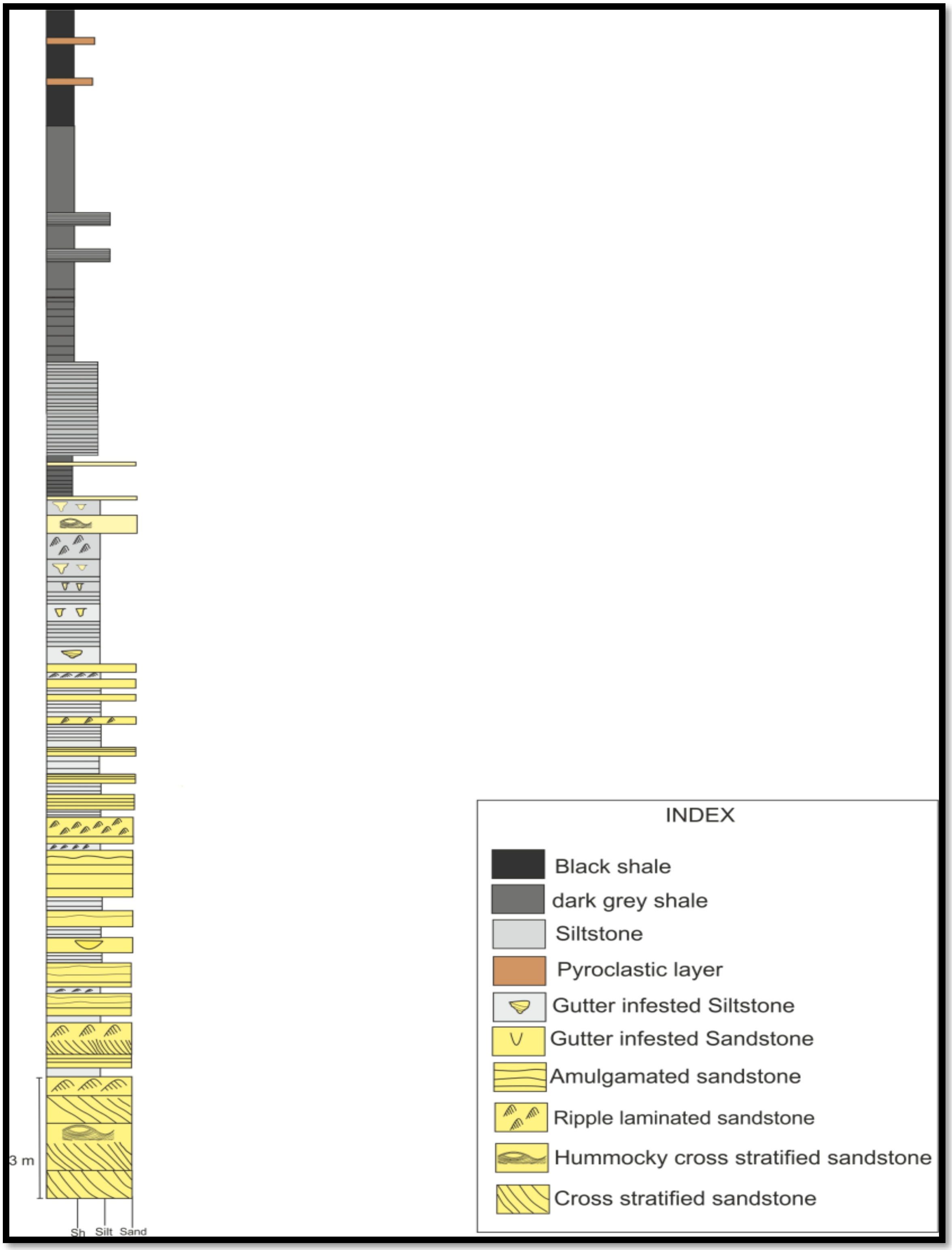


Fig. 2.2. Detailed litholog showing vertcical facies distribution within the Rampur Shale of Rohtas Formation.

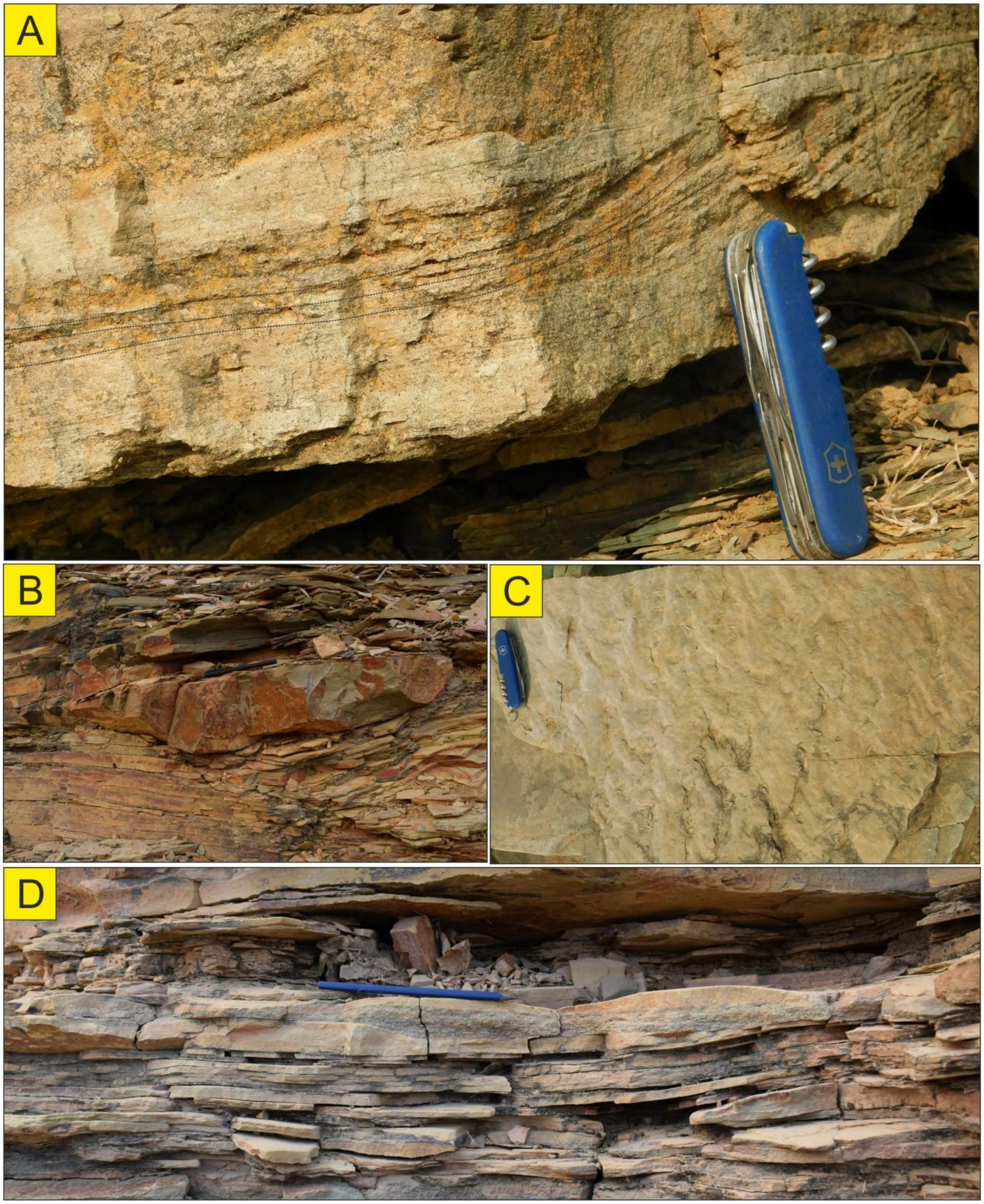


Fig 2.3.1. Facies association I represents sand dominated facies, A) Cross stratified sandstone, B) Single lobe gutter filled up with sandstone, C) Ripple laminated sandstone, D) hummocky cross stratified sandstone

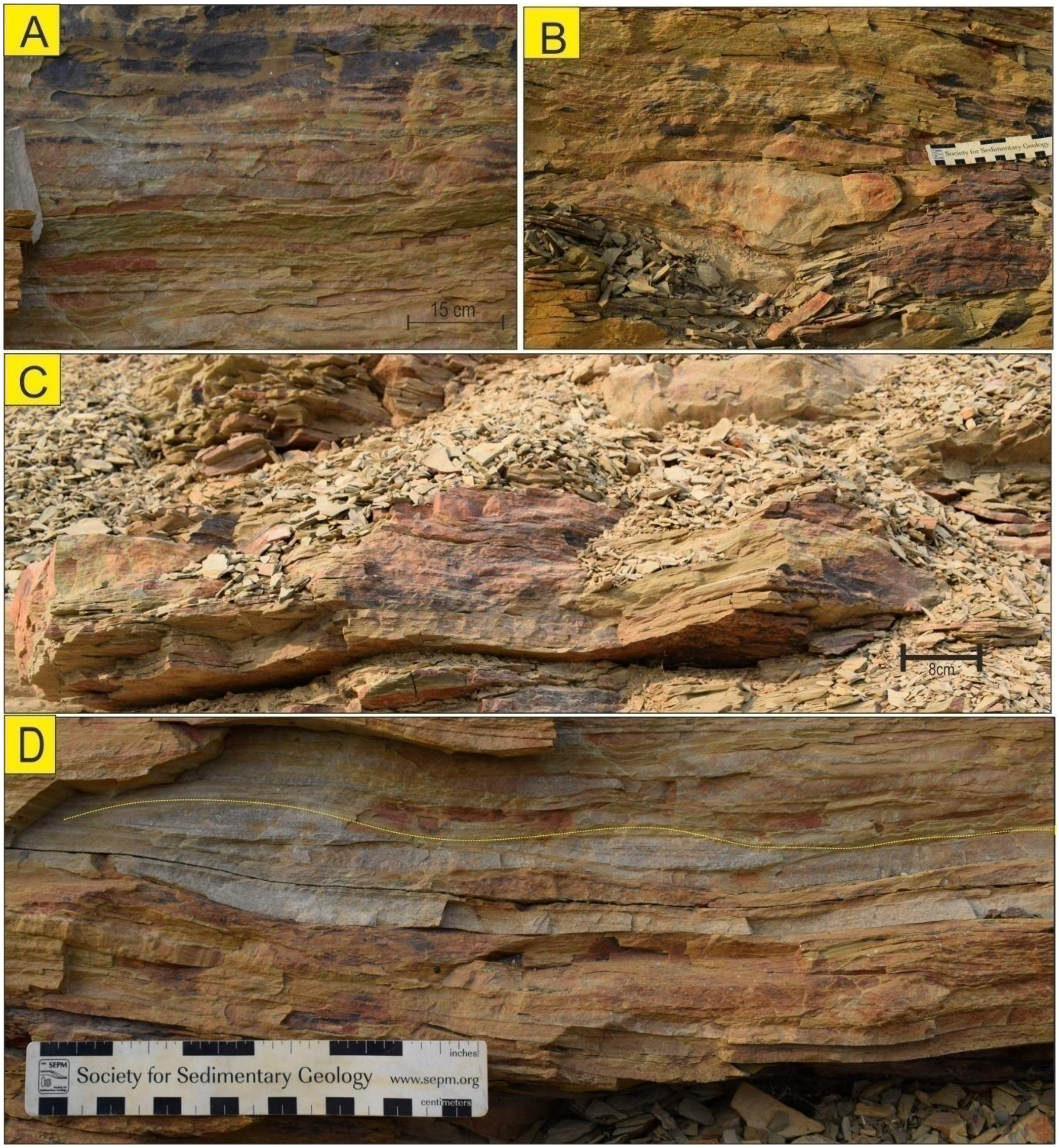


FIG 2.3.2. Facies association II represents silt dominated facies, A) Planar laminated siltstone, B) Step gutter infested sandstone, C) Planar laminated shale. D) Hummocky cross stratified sandstone

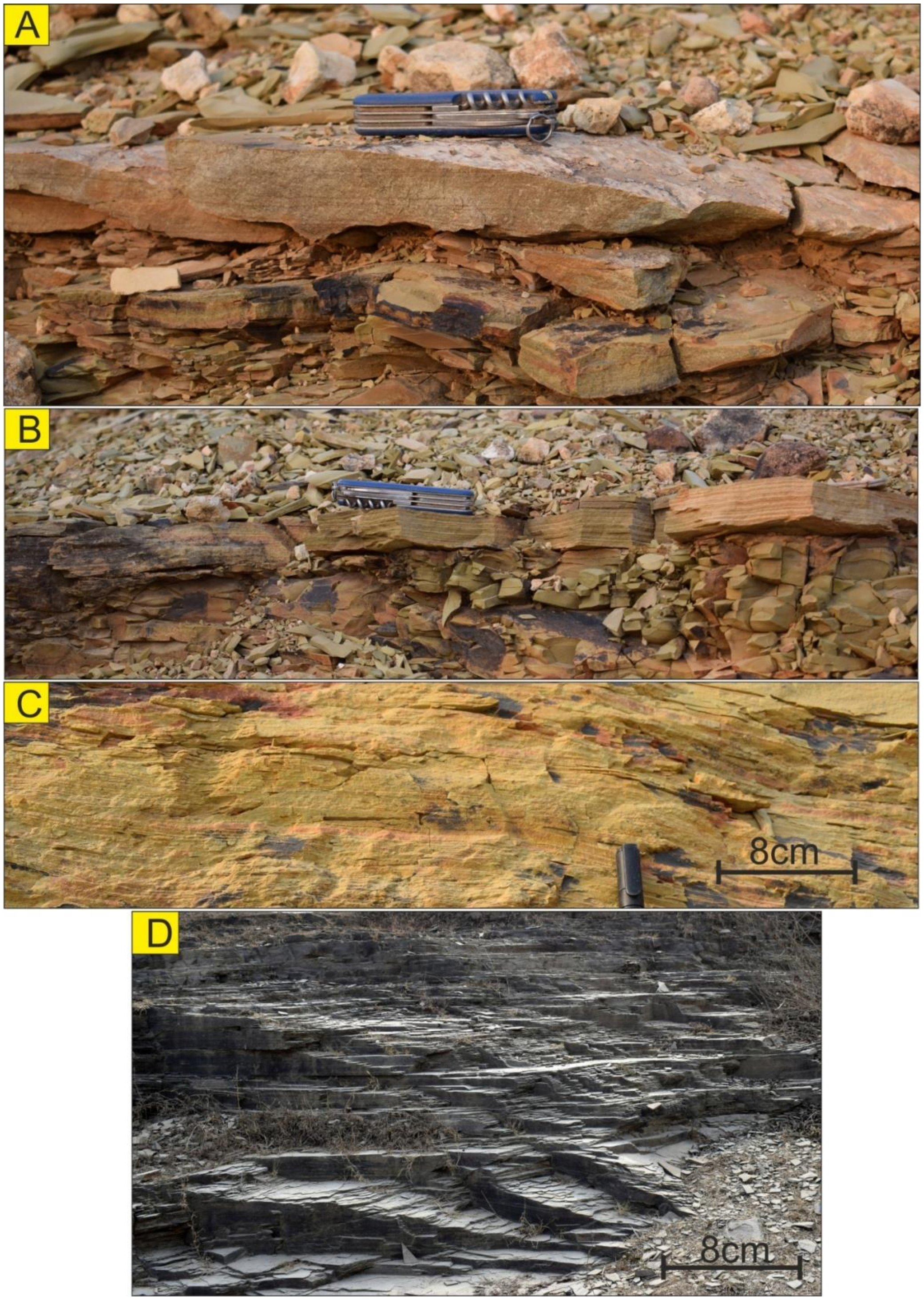


FIG 2.3.3. Facies association III represents gradual deepening of the basin A) Gutter infested siltstone, B) Planar laminated siltstone, C) Planar laminated grey shale, D) Planar laminated black shale.

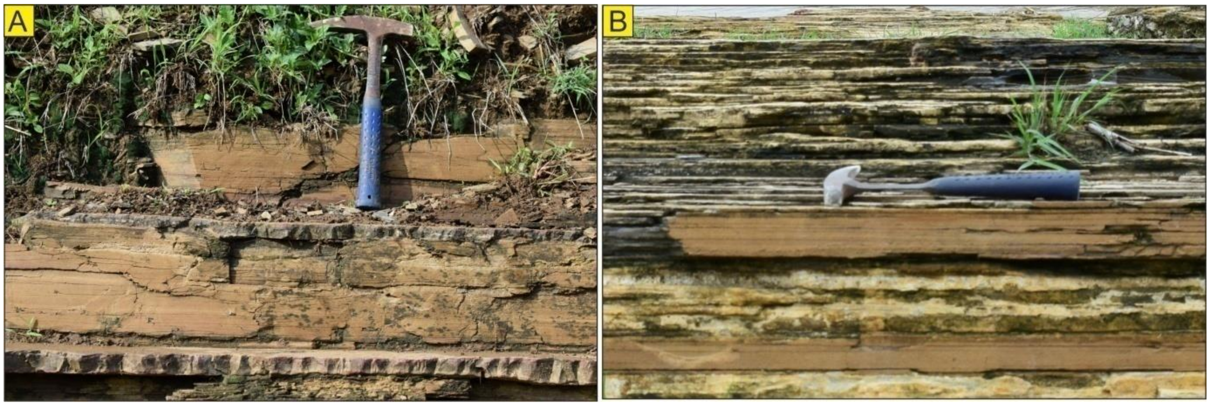


FIG 2.3.4. Facies association VI, A) Ripple laminated volcanic ash, B) Planar laminated black shale

2.4. FACIES ANALYSIS OF SIRBU SHALE:

The 200 m thick shale succession, Sirbu Shale is overlying on lower Bhander Sandstone with a gradational boundary. The entire sedimentary succession has dominance of shale, though few sandstone and siltstone beds have appeared alternate with shale (fig.2.4.1). On the basis of primary sedimentary structures and different lithologic characters divide the Sirbu Shale into eight facies (fig.2.4.2). The descriptions and interpretation of each facies are as followes

2.4.2.a. Gutter cast bearing sandstone:

In this facies distinctive sole features are observed. Numerous numbers of isolated, elongated ridges at the base that is gutter cast is observed. The gutters are filled with fine grained sandstone. The facies is associated with ripple laminated siltstone. Some ripple laminated and planar laminated shale layers are also present. The gutters are formed by the truncation of silt shale unit. The gutter bearing sandstone is draping on the scouring surface. Then gradually it turns into planar lamination. The length-width ratio of the gutters gradually increases as we move upward and subsequently it get jointed.

Interpretation:

Presence of gutter casts infer that the scouring at the base is formed by a high energy flow. Draping of sandstone on this scouring surface infer that deposition occur by suspension fall out. coarse, poorly sorted sandstone. The base of the basis unit is very sharp, but undulated due to the presence of alternate scours and mounds, resembling hummocks and swales. Bed tops show multiple sets of sinuous crested, asymmetric mega ripples

2.4.2.b. Massive siltstone:

Massive siltstone bed is characterised by coarse grained silt and massive in character. They are associated with planar laminated black shale and planar laminated siltstone. Basal parts of these beds are very sharp, erosional. Sometimes few sole marks, tool marks are present in these beds. Planar laminated siltstone beds are gradationally pass from this massive siltstone beds.

Interpretation:

deposition of massive siltstone beds in a shale depositional environment infer siltstone beds were deposited in high energy condition. Quick deposition from high suspension cloud destroys to build any sedimentary structures. The presence of sharp erosional contact with sole marks, tool marks infer these beds were deposited during storm surge.

2.4.2.c. Tabular Cross stratified siltstone:

This facies is chracterised by cross stratification with silty grain size. Thickness of this varies from 15 cm to 9 cm. This facies has sudden appearance with planar laminated black shale. Cross stratification are tabular in nature. Dip of the cross stratification is very low and its maximum dip is 15^0.

Interpretation:

Cross stratification bearing siltstone bed infer it has formed by some tractive current. Association with black shale indicates black shale deposition was disrupted by high energy flow. This high energy flow may be storm surge.

2.4.2.d. Ripple laminated siltstone:

This facies is also associated with planar laminated black shale. Ripple are sinuous in nature with sharp crests. On the bedding surface ripple are bifurcated in nature. Ripple index varies from 8 cm to 10 cm. Very small scale cross laminations are observed in transverse section. But interestingly siltstone beds have appeared in lenticular shaped at lower part in an alternation with black shale. Syneresis cracks are also observed on this bedding surface.

Interpretation:

Ripple laminated siltstone is a production of tractive flow. Bifurcated ripple crests with high ripple index infer ripple was produced by wave action. Sinuous crest infer energy condition was not so high. Lenticular geometry of ripples infers sedimentation rate was not sufficient to continue deposit.

2.4.2.e.Planar laminated black shale:

This facies is characterized by very fine grained sediments which is black in colour. Black shale bears planar laminations. Maximum thickness of this facies ca. 50 cm. Laminations are very fine and its maximum thickness 0.2cm. This facies is alternating with ripple laminated siltstone, massive siltstone, gutter cast bearing sandstone and hummocky cross stratified sandstone. Crinkly laminated and lenticular shaped microbial mats are associated with this facies.

Interpretation:

Planar laminated shale deposition infers shale was deposited in suspension fall. The depositional regime was very calm and quite. Shale was deposited below storm wave base though it was intervened by storm action sometimes. Presence of crinkly lamination and lenticular shaped mat infer it was highly organic rich. Pyrite grains in an association of microbial mat infer it was deposited in anoxic condition.

2.4.2.f. Planar laminated siltstone:

This facies is characterized by planar laminated siltstone. This facies has appeared numerously with planar laminated black shale facies. Basal part of this facies is sharp and top part is gradation with planar laminated black shale. Thickness of this facies varies from 1cm to 15 cm. Thickness of this facies gradually increased as we move upward. Top part of this succession it is associated with grey shale.

Interpretation:

Planar laminated siltstone also indicates this facies was deposited by suspension fall out as well. But presence of sharp base infers silt size grain was carried out by high energy event and gradually energy condition was minimized and again shale deposition was continued.

2.4.2.g. Planar laminated grey shale:

This facies is dominance of fine grain shale. Shale is mainly grey in colour and planar in character (fig). It is mainly associated with ripple laminated and planar laminated siltstone with the gradational contact. Average thickness of this facies is 40 cm.

Interpretation:

Fine grained shale deposition infers depositional site is dominance of suspension fall out sedimentation. Abundance of shale deposit infers convey deposition was taken place in a deeper shelf.

2.4.2.h. Hummocky cross stratified sandstone:

This facies is characterized by Hummocky cross stratified sandstone which is upwardly bulging/ warping sand unit. The laminations above it drape the hummocks. This facies is associated with planar and ripple laminated siltstone. Some shale unit is also present occasionally.

Interpretation:

The presence of hummocky cross stratified sandstone strata infers that the deposition is associated with some storm activity. It is formed at a depth of water below fair weather wave base and above storm weather wave base. This facies indicate shallow marine environment.

Depositional Environment:

Minute observation of all the facies present in the studied section convey deposition was took place in a marine depositional setting. Abundance of shale in the depositional infer suspension fall out is the main deposition which was flow prevailing in depositional site. Presence of microbialites with black shale facies infer deposition must have taken place within photic zone. Abundance of pyrite grains in this association also infers depositional site was highly anoxic. Presences of ripple lamination in the association convey depositional site was wave agited with time. Presence of massive beds with sharp contact of black shale facies infers storm surge deposit in depositional site. Increasing of grey shale in vertical shifting convey swallowing the basin. Associations of ripple lamination, cross stratification infer entrance of wave agited deposit. Presence of hummocky cros stratifications, gutter infested sandstone convey depositional site was frequently interrupted by storm flow.

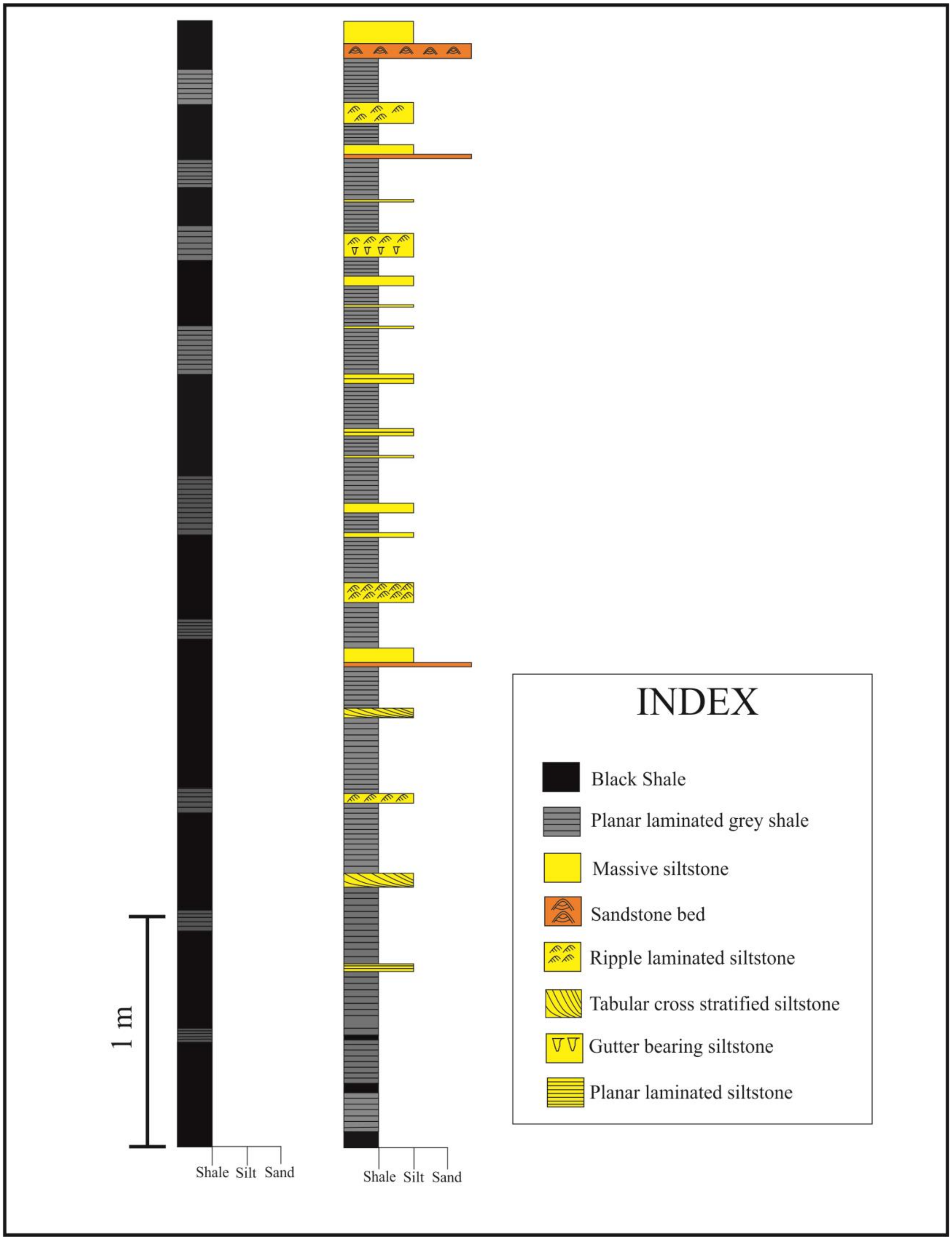


Fig 2.4.1. Detailed log showing vertical distribution of black shale part of Sirbu Shale of Bhander Formation

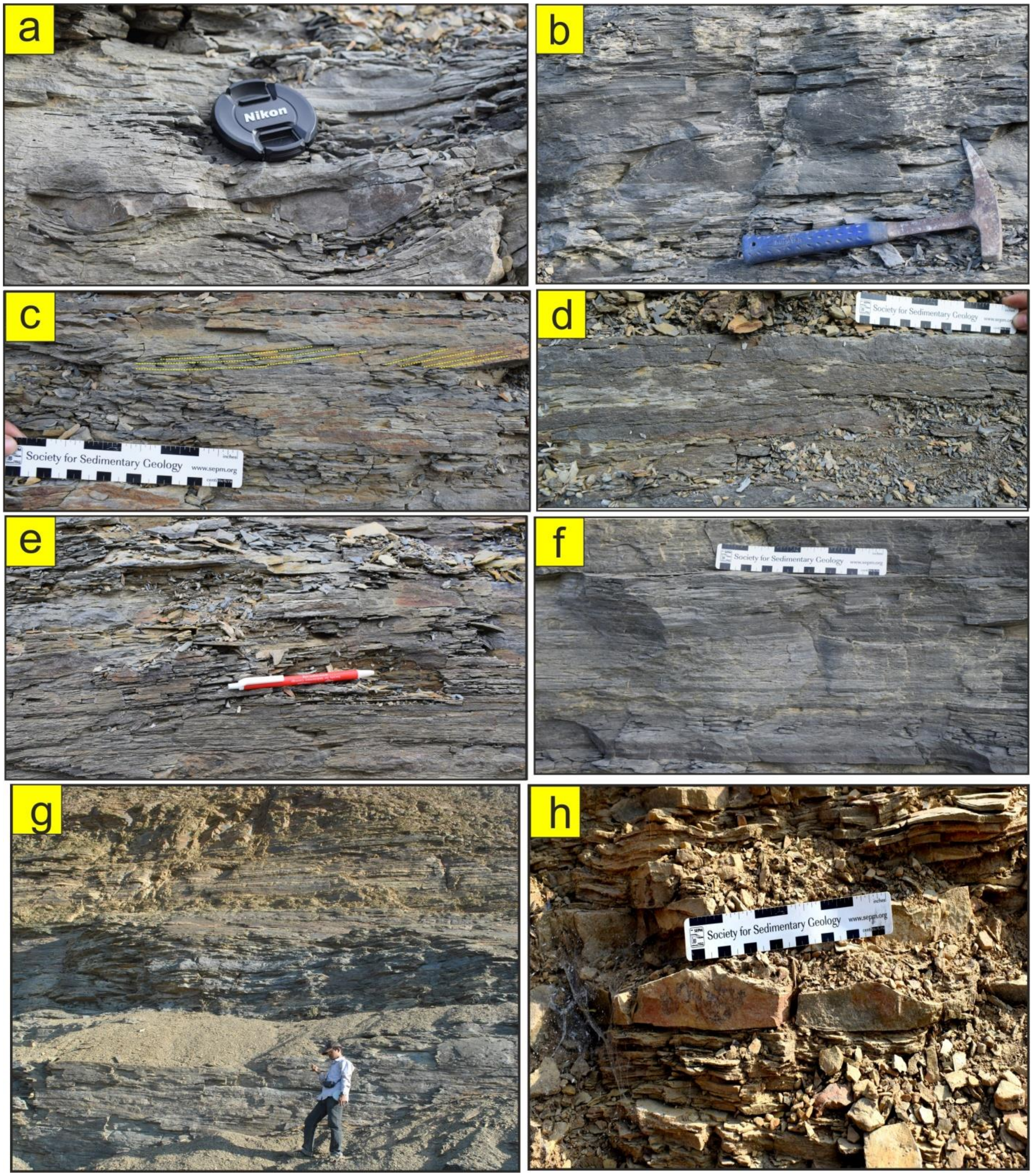


Fig.2.4.2 represents facies of Sirbu Shale, a) Gutter infested sandstone, b) Massive Siltstone, c) Cross stratified siltstone, d) Ripple laminated siltdtone, e) Planar laminated black shale, f) planar laminated siltstone, g) Planar laminated grey shale, h) Hummocky cross stratified sanstone

CHAPTER- 3

SEQUENCE DEVELOPMENT OF RAMPUR SHALE AND SIRBU SHALE

Sequence stratigraphy calls for a new outlook in stratigraphic successions. It aims for dividing a succession in genetically related stratal packages in chronologic terms, absolute or relative. Sequence stratigraphy is considered as one of the latest conceptual revolutions in the field of sedimentology revamping the methodology of stratigraphic analysis (Miall, 1995, Catuneanu et.al.,2009). The process requires prior understanding of the facies constituents. When applied to a specific depositional system, sequence stratigraphy helps to understand processes of facies formation, facies relationships, and facies cyclicity in response to base-level changes. Sequence stratigraphy is also focused on identification of key surfaces to determine the chronological order of basin filling and erosional events. Stratal stacking patterns respond to the interplay of changes in rates of sedimentation and sea level/base level, and reflect combinations of depositional trends that include progradation, retrogradation, aggradation and downcutting. Each stratal stacking pattern defines a particular genetic type of deposit (i.e., 'transgressive', 'normal regressive' and 'forced regressive'), with a distinct geometry and facies associations. From the environmental perspective these deposits are genetic (i.e., they can be identified in different depositional settings), and may include tracts of several age-equivalent depositional systems (i.e., systems tracts). Identification of the system tract in a depositional setting convey the sedimentation rate, sea level fluctuation and tectonic influence of the depositional setting. The change of sea level is only recorded by the change of sedimentation pattern during the deposition.

3.1. Sequence development framework of Rampur Shale:

Rampur shale, the bottom most member of Rohtas Formation overlies on the Chorhat Sandstone of Kheinjua Formation with gradational contact. Deposition of Chorhat sandstone infers a shallow marine high stand system tract . Gradational contact with shale and gradual increasing of shale proportion in upward direction of Rampur Shale from Chorhat Sandstone infers sea level increasing during Rampur Shale sedimentation. The increasing shale **:** sand ration in vertical transition from facies association I (lower most part of Rampur Shale) to facies association IV i.e. 2:8 to 8:2 infers gradual increasing of sea level in vertical transition. The presence of gradational contact with Chorhat Sandstone and increasing of shale thickness i.e. shale **:** sand 2:8 infer early stage of transgression. Vertical transition from grey shale (abundant in lower part of

Rampur Shale) to black shale conveys great increment of sea level and maximum deepening of the basin. The thick black shale deposition at the top part of Rampur Shale infers the maximum flooding surface (MFS). The gradational contact between the black Rampur shale and the overlying Rohtas Limestone indicate possible lowering of sea level. The Rohtas Limestone above Rampur Shale conveys high stand system tract deposit.

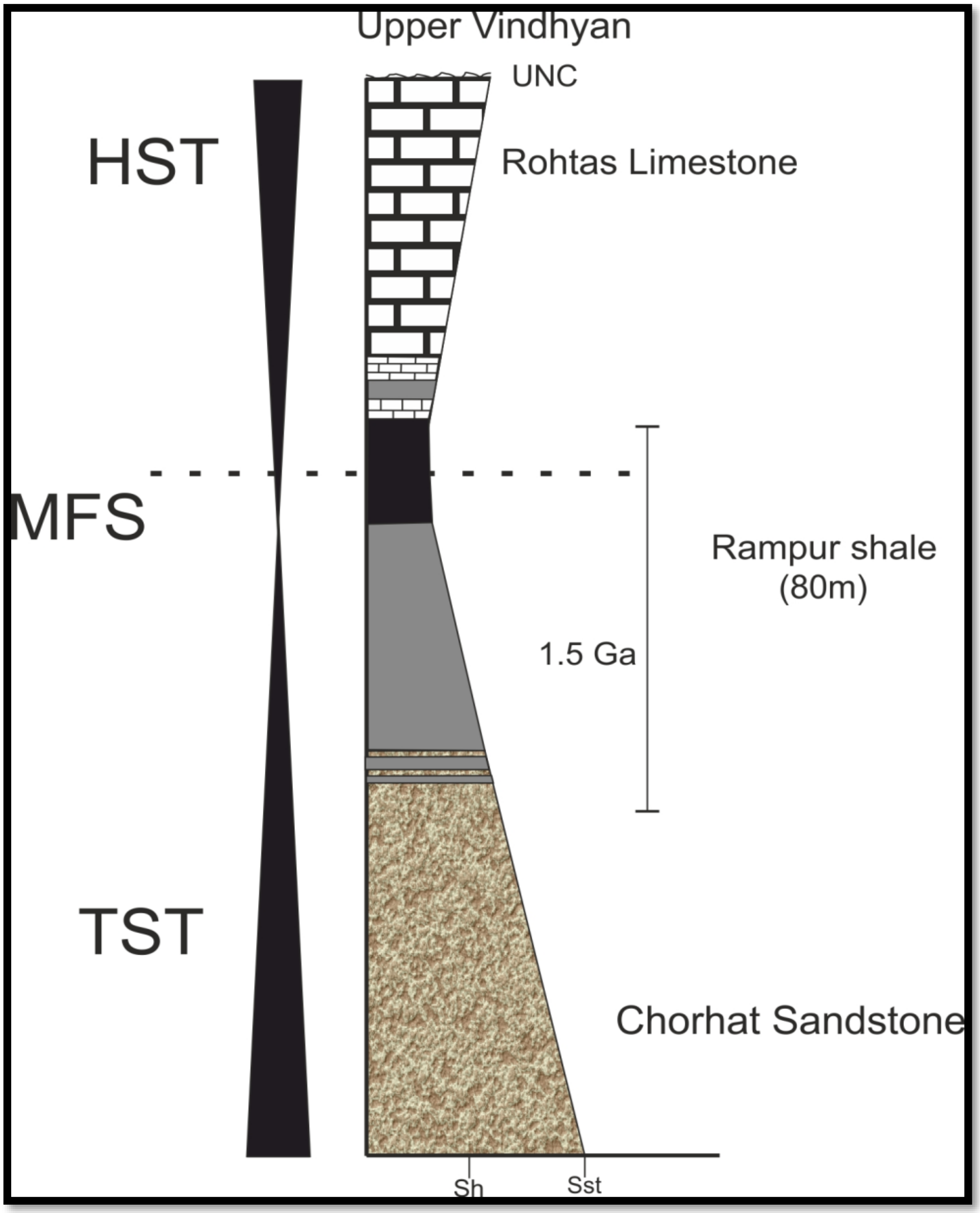


Fig 3.1. Sequence Stratigraphy of Rampur Shale

3.2. Sequence development framework of Sirbu Shale:

The upper vindhyan sequence comprises three formation. Kaimur, Rewa and Bhander Formation from bottom to top. The Bhander Formation is consists of five members. They are Ganurgarh Shale at the bottom followed by Bhander Limestone, Lower Bhander Sandstone, Sirbu Shale, Upper Bhander Sandstone. The Sirbu Shale overlies the lower Bhander sandstone. From sandstone to shale change is gradational and comprises stromatolitic and oolitic patches enclosed by grey shale replete with emergence feature at the lower part. The deposit is interpreted as lagoonal shale which is sharply overlain by dark coloured sand free shale, devoid of emergence feature. After that it shows a coarsening up sequence with alternating shale-silt and gradually it turns to silt and sandstone layer with occasionally interference of shale. So the Sirbu Shale shows gradual transition from shale to silt and finally coarser sand. The upper part of Bhander Formation shows some coarsening up parasequences. The transition from lower Bhander Sandstone to Sirbu Shale is a transgressive sequence which shows a fining upward sequence. The black shale unit in Sirbu Shale demarcates the maximum flooding surface (MFS). The shelfal Sirbu shale and the dominantly terrestrial upper Bhander sandstone together constitute a HST with the MFS at the base.

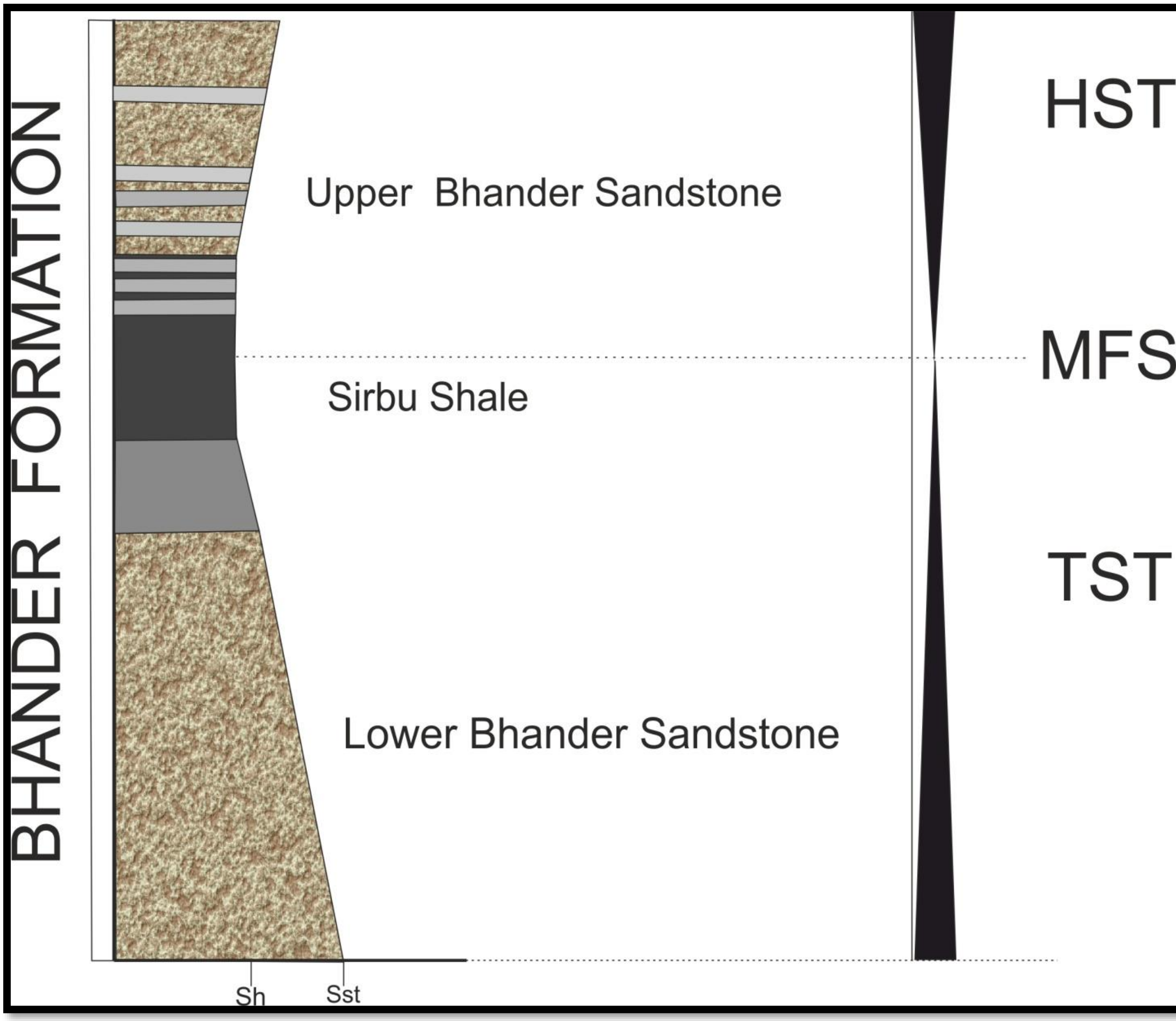


Fig.3.2. Sequence Stratigraphy of Sirbu Shale

CHAPTER- 4

MICROFACIES ANALYSIS OF BLACK SHALE OF RAMPUR SHALE AND SIRBU SHALE

4.1. Microfacies analysis of black shale in Rampur Shale:

Petrographic observations:

Different type of microscopic features in Rampur Shale are observed under microscope. Details of these features are given below:

- **4.1.1. Wavy and Crinkly laminated Carbonaceous shale facies:**

Thin section studies of the Rampur Shale show wavy and crinkly lamination of clayey and carbonaceous shale facies. Carbonaceous films of clayey shale facies are very thin, continuous to discontinuous wavy crinkly laminae of variable thickness (~ 0.01 mm to 0.15 mm) and consist of organic matter, with embedded tiny pyrite cubes, whereas the carbonaceous films of the carbonaceous shale facies are thick (up to 0.1mm) and represent mostly continuous wavy crinkly laminae. The observed wavy-crinkly lamination closely resembles microbial mat laminae observed in both modern and ancient microbial mat deposits (Horodyski*et al* 1977; Krumbein and Cohen 1977; Schieber 1986; Gerdes and Krumbein 1987; O'Brien 1990), and suggests the presence of benthic microbial mats during the deposition of these shales. Along with the wavy crinkly lamina some shale lenses are also observed within the thin sections. Both the shale lenses and shale layers are composed with clay minerals.

The studied samples are dark carbonaceous shale sample of Rampur Shale.it is suspected that the black colouration is due to organic incorporation. Microbial mat present here in three different modes such as crinkly lamina, lense shaped and in purely circular form. all of the three varieties contain different carbon content which is discussed later.

Crinkly lamina shows different types of primary microstructure within it which satisfy its microbial mat induced origin. These are described as follows:

4.1.1.a. False Cross Lamina:

Cross laminae like structure was observed within the crinkly laminated mat layer-developed due lateral accretion of the mat layer. It is situated in between two mat layers. Internal drapes of the microbial mat ranges from 5-20 μm in thickness. The clearly visible thicker shale drapes from an angle of about 10-12^0 with the base of the dark mat layer.the feature is the interpreted as the result of the step-wise lateral expansion of a pioneer mat that was interrupted by deposition of mat drapes (Schieber, 1986). Stratigraphic up is to the right. (Fig 4.1.1.a)

4.1.1.b. Jagged Ends:

Microbial mat layers are sticky in nature so if they face any tensional force then it got torned and the edges show irregular or notched ends. It is another indication towards the confirmation of microbial mat. (Fig.4.1.1.b)

4.1.1.c. Joining, Branching and Lateral Accretion:

Microbial mats with in the dark carbonaceous shale showing numerous branching, joining. Somewhere the laminas are converging with one another and makes a single laminae. Somewhere one lamina diverge into two laminae. (Fig4.1.1.c)

4.1.1.d. Trapping:

Microbial mat is cohesive in nature. So the mineral(silt sized quartz grain) are got trapped in between the sticky mat. microbial mats are too cohesive in nature due to secretion of EPS(Extra Pollymeric substance) from their body. (Fig.4.1.1.d)

4.1.1.e. Fly Paper effect :

Incase of Shales , Clay minerals and mica flakes are generally try to orient along the bedding plane and so that thefissility plane developed with in shales, but if the shale is enriched with microbial mat layer then the siliciclastic shale behaves as cohesive material and the flaky minerals are stuck in between the mat and show haphazard orientation which are unable to align with the bedding plane in that case fissility plane are not developed in shale. This property is known as FLY PAPER EFFECT. (Fig.4.1.1.e)

4.1.1.f. Drappinng:

shale layers are contemporaneously dolomitised so somewhere microbial mat are just drapped over the growing dolomite grains or may be the dolomite grains are pushed the microbial mat lamina upwardly (Fig.4.1.1.f)

- **4.1.2. Pyrite Laminae:**

Pyrites are identified under petrographic and reflected microscope but the occurrence was identified under SEM. Pyrites are present both in framboidal and layerwise deposit. wavy pyrite (euhedral to subhedral in shape) laminae were present in the black shale. (Fig:4.1.2)

- **4.1.3. Dolomite enrichment in association with microbial mat:**

Dolomites are selectively present with the microbial mat layer. Generally they are scattered with the organic rich carbonaceous crinkly laminae and clustard in places in association with lense shape and circular shape mat. dolomites are syndepositional with the mat because mat laminaedrapped over the dolocrystals. It is noticed that dolocrystals are showing variation in size some where these are larger and some are tiny rhombic crystal presented here. (Fig:4.1.3)

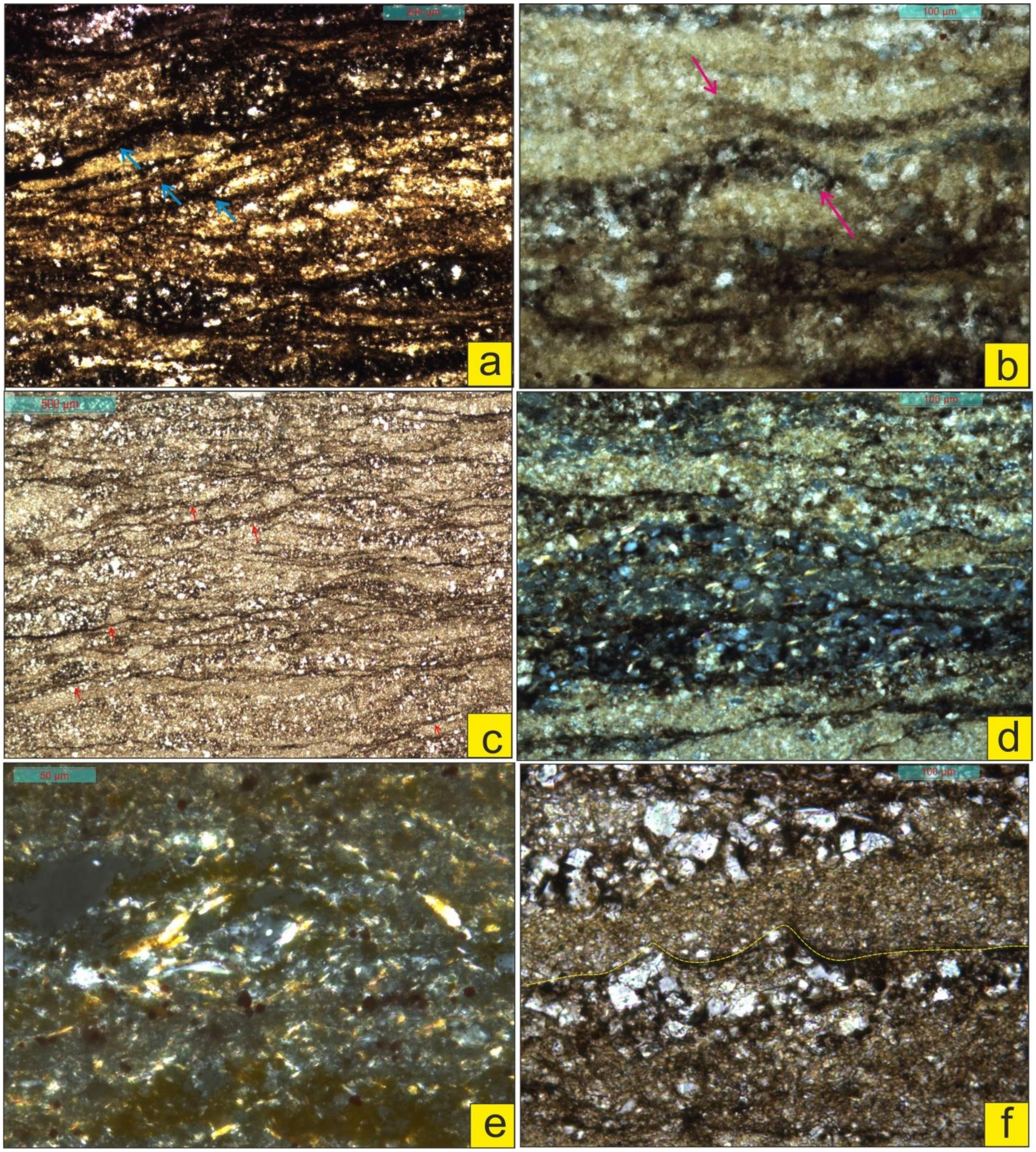


Fig.4.1.1 Represent the microfacies in Rampur Shale. a) False cross lamination is shown by microbial mat layer, b) Jagged ends, c)Joining, branching and lateral accretion of mats, d) Trapping of Quartz grains into mat layer, e) Fly paper effect, f) Drapping where the mat layer is following the dolomite layer

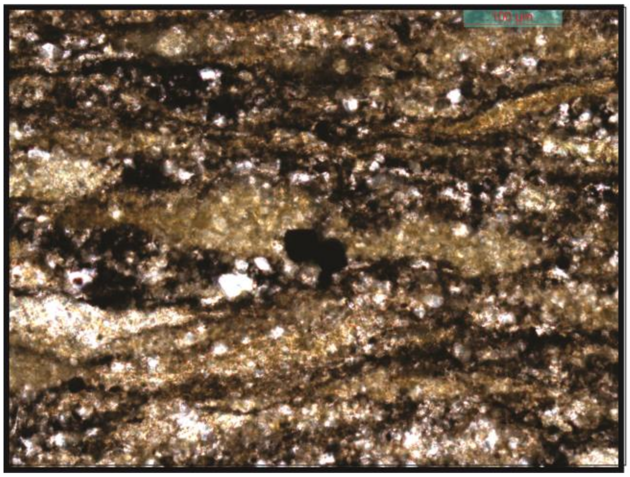


Fig.4.1.2. Pyrite grain in black shale

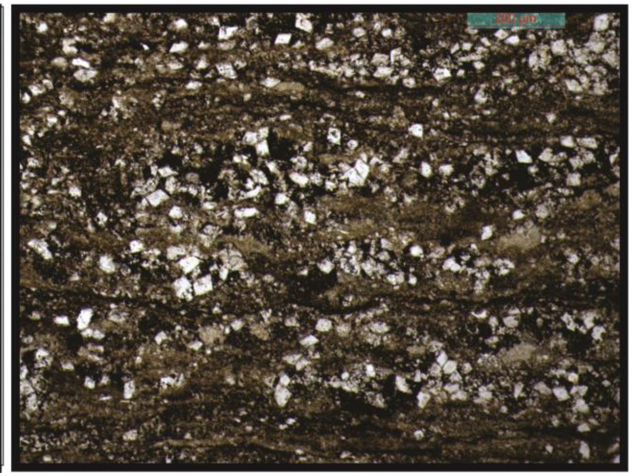


Fig.4.1.3. Dolomite enrichment with microbial mat

4.2. Microfacies analysis of black shale in Sirbu Shale:

Petrographic observations:

Some pertrographic features that are observed in thin sections are as follows:

4.2.1. Microfacies within microbial mat

4.2.1.A. False Cross Laminae:

Cross laminae like structure observed within the crinkly laminated mat layer-developed due lateral accretion of the mat layer. It is situated in between two mat layers. Internal drapes of the microbial mat ranges from 10-20 μm in thickness. The feature is the interpreted as the result of the step-wise lateral expansion of a pioneer mat that was interrupted by deposition of mat drapes (Schieber, 1986).

4.2.1.B. Jagged Ends:

Microbial mat layers are sticky in nature so if they face any tensional force then it got torned and the edges show irregular or notched ends. It is another indication towards the confirmation of microbial mat.

4.2.1.C.Alternate layers of carbonaceous shale and grey shale:

There are alternate layers of carbonaceous shale and grey shale. In thickness of the layers vary. In the grey shale layers flaky mica minerals are present which shows orientation parallel to the bedding plane.

4.2.1.D. Haphazardly oriented mica grains:

In case of Shales , Clay minerals and mica flakes are generally try to orient along the bedding plane and so that the fissility plane developed within shales, but if the shale is enriched with microbial mat layer then the siliciclastic shale behaves as cohesive material and the flaky minerals are stuck in between the mat and show haphazard orientation which are unable to align with the bedding plane in that case fissility plane are not developed in shale. This property is known as FLY PAPER EFFECT.

4.2.1.E.planar laminated carbonaceous shale:

Many Planar laminated carbonaceous shale layers are present which contain some microbial mat within it.

4.2.1.F. Joining, Branching and Lateral Accretion:

Microbial mats with in the dark carbonaceous shale showing numerous branching, joining. Somewhere the laminae are converging with one another and makes a single laminae. Somewhere one lamina diverge into two laminae.

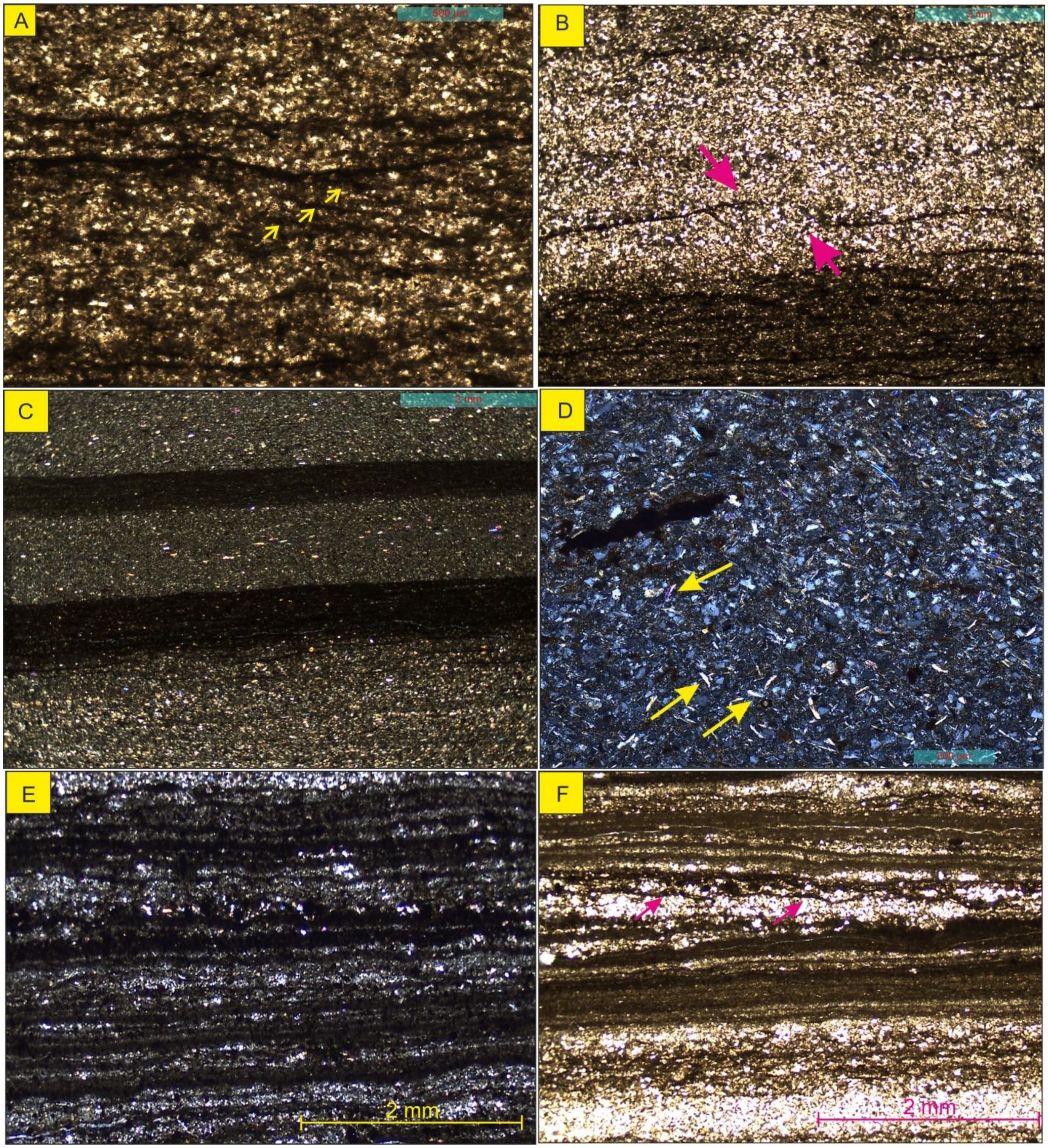


FIG 4.2.1. A) False Cross Lamina, B) Jagged Ends, C) Alternate layers of carbonaceous shale and grey shale, D) Fly paper effect, E) Planar laminated carbonaceous shale, F) Lateral Accretion of microbial mat

Comparison between the microfacies of Black Shale of Rampur Shale and black part of Sirbu Shale:

The depositional set up of these two formation are different. So the sediment that deposited within this two formations are also different from each other. In Rampur Shale black shale is associated with limestone in upper part of the formation, showing gradational contact wehereas in Sirbu Shale, black part is associated with siliciclastic sediments. this variation also reflects in microfacies. Rampur Shale contains some volcanic input whereas Sirbu shale does not.there are different types of verities of mats are present within Rampur Shale like crinkly laminated, lense shaped and pure circular shaped mat body along with some microbial mat chips but the Sirbu Shale contains only crinkly laminated mat. Rampur Shale contains both framboidal and layer wise pyrite deposit but Sirbu shale contain only framboidal pyrite. Rampur Shale is enriched with dolomite crystal associated with different types of mat bodies but in contrast Sirbu Shale does not contain any dolomite. Both the Rampur and Sirbu shale contain mica flakes which are showing haphazard orientation. As a whole it may be said that, both the shale are the product of MFS but the depositional scenario was quite different from one another which makes the difference in between two shales.

CHAPTER- 5

SEM-EDS STUDY OF BLACK SHALE OF RAMPUR SHALE

SEM-EDS DATA ANALYSIS OF THE BLACK SHALE IN RAMPUR SHALE:

Presence of shale in a succession calls for its geochemical analysis because of its fine grain size, which cannot be petrographically analyzed in a complete spectrum. Black shale which is rich in organic carbon as well as few of metallic constituents is deposited in the deep marine environments where the rate of sedimentation is quite low. This gives rise to a condensed zone which is called the maximum flooding zone.

Geochemical analysis of Rampur shale (1500Ma), which is also a carbonaceous black shale, has revealed various forms of Mat structure which are morphologically different from each other. Due to time constraints, only SEM-EDS study was carried out.

SEM –EDS study:

Under petrographic microscope, three different types of mat has been distinguished. That is the crinkly laminated, lense shaped and purely circular mat. The SCANNING ELECTRON MICROSCOPIC (SEM) STUDY along with ELECTRON DISPERSIVE X-RAY SPECTROSCOPY (EDS) STUDY shows that not only morphologically but they are also chemically different from one another. Pyrite and dolomites associated with mat layers are also observed. They are described below:

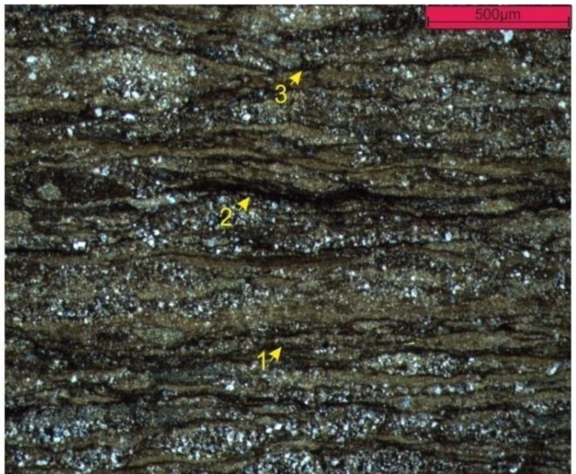
5.1. Four different types of mat has been identified under petrographic microscope.

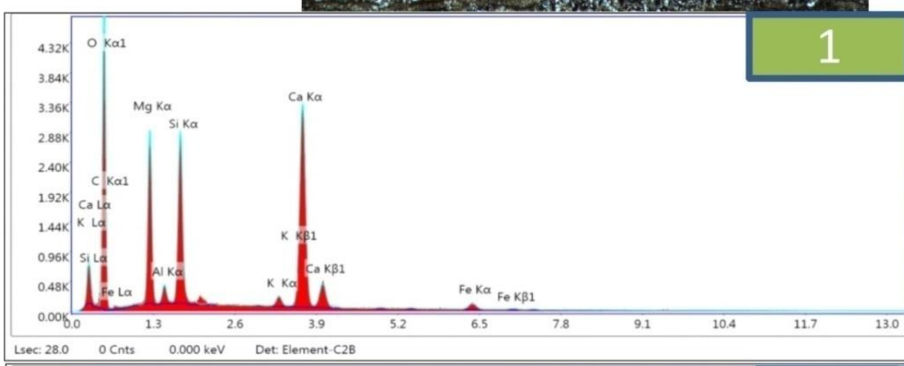
1. Crinkly laminated mat
2. Lens shaped mat
3. Pure circular mat
4. Dark carbonaceous chips

All the three verities of mat contain dolomites within it and the dolomites are slightly differ in composition in each type. But the dark carbonaceous chips do not contain any dolomites with it.

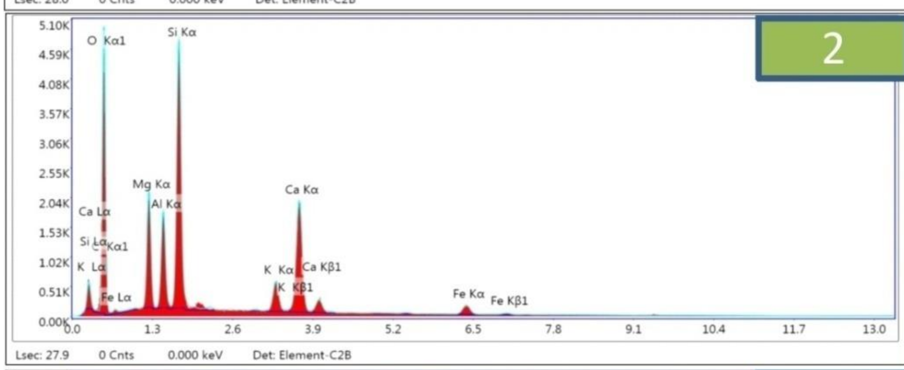
5.1.1. Carbon % in crinkled mat layer:

Here the crinkly laminated mat has been choosen for chemical analysis. Three points has taken over it and each point shows a good amount of carbon % which is near about 6-7%.

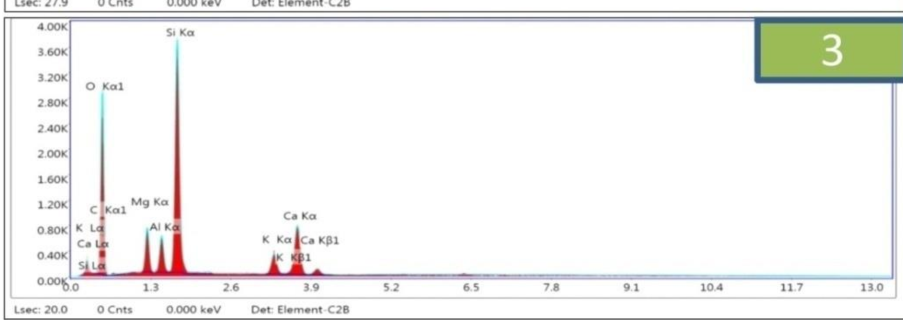




Element	Weight %
C K	6.62
O K	51.20
MgK	11.70
AlK	1.93
SiK	4.25
K K	1.02
CaK	21.85
FeK	1.42



Element	Weight %
C K	6.72
O K	48.23
MgK	11.00
AlK	1.11
SiK	8.86
K K	0.87
CaK	21.72
FeK	1.49

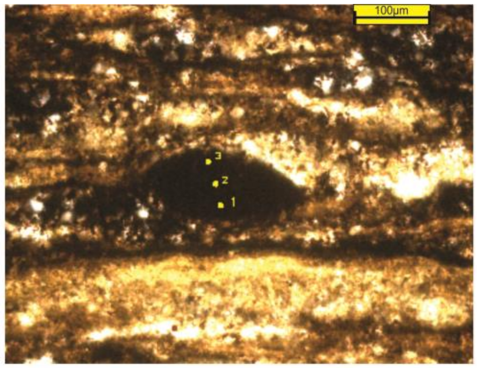


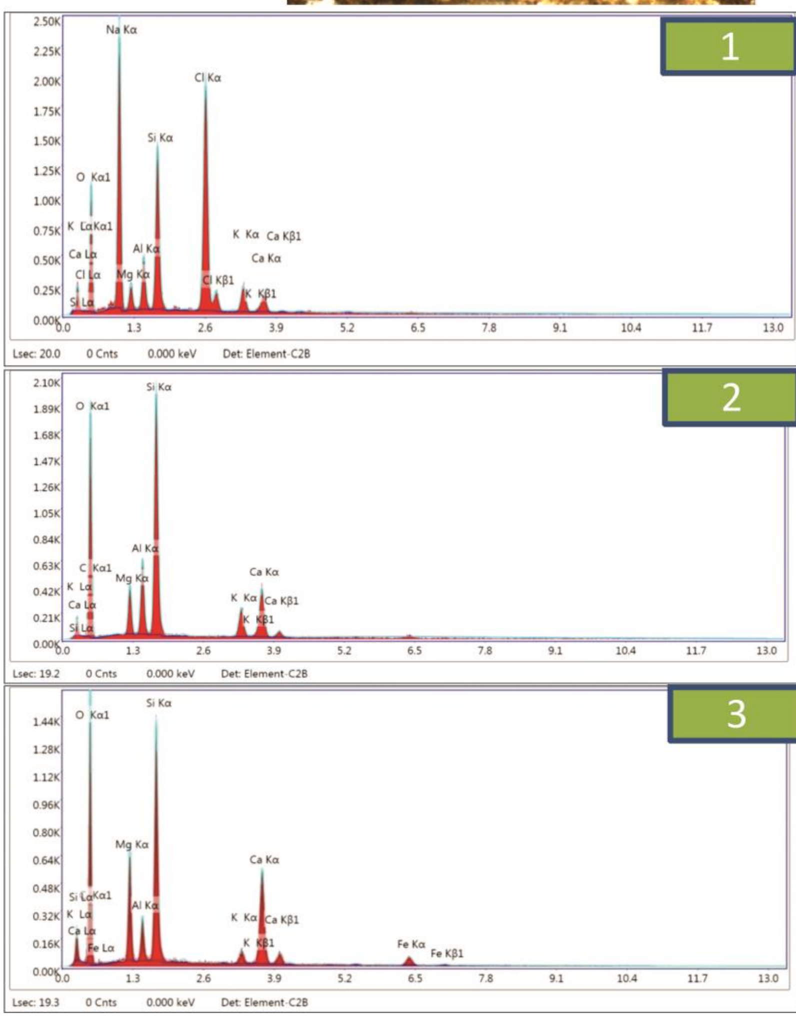
Element	Weight %
C K	7.09
O K	48.28
MgK	5.14
AlK	3.79
SiK	21.88
K K	3.50
CaK	10.32

Fig.5.1.1. SEM-EDS data for crinkled laminated mat showing 6-7% of

5.1.2. Carbon % in lense shaped mat body:

Here also three points have been choosen within lense shaped mat and the EDS data shows that the carbon % in it is near about 9%.





Element	Weight %
C K	8.31
O K	42.87
MgK	3.37
AlK	6.25
SiK	16.33
ClK	16.85
K K	5.51

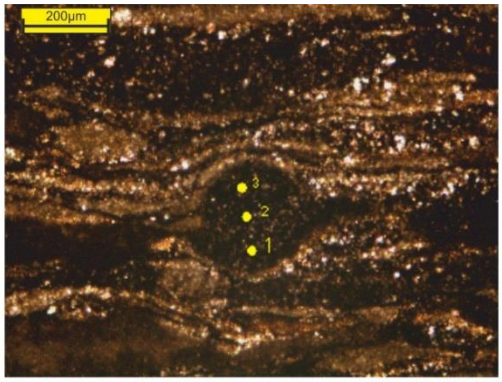
Element	Weight %
C K	8.94
O K	49.96
MgK	9.57
AlK	2.47
SiK	6.15
K K	2.07
CaK	20.83

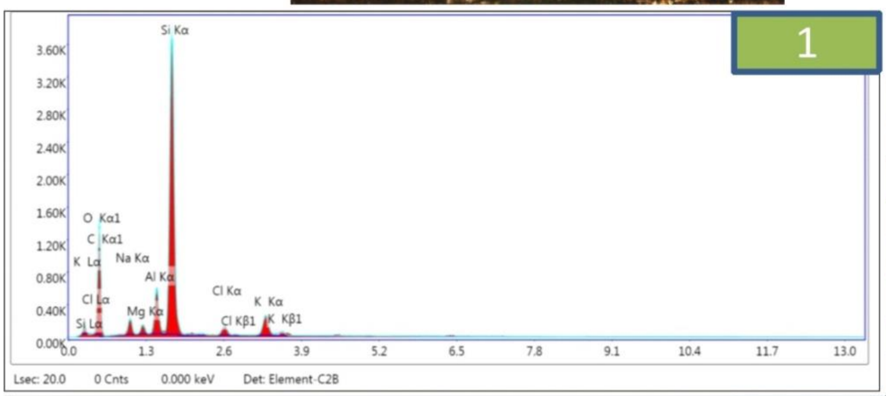
Element	Weight %
C K	8.68
O K	41.08
MgK	4.64
AlK	4.83
SiK	12.57
ClK	16.35
K K	2.53
CaK	6.40
FeK	2.61

Fig.5.1.2. SEM-EDS data for lense shaped mat showing 8-9% of Carbon

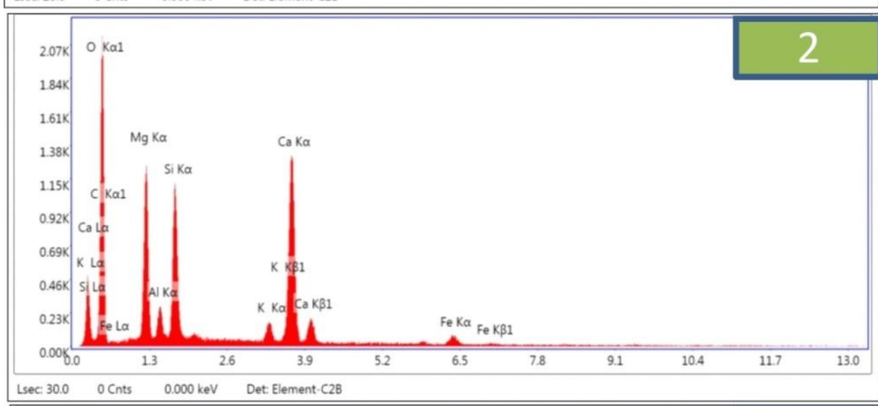
5.1.3. Carbon % in pure circular mat body:

Three point is choosen here for chemical analysis. And the EDS data shows that the mat within pure circular shape contain 9-10% carbon.

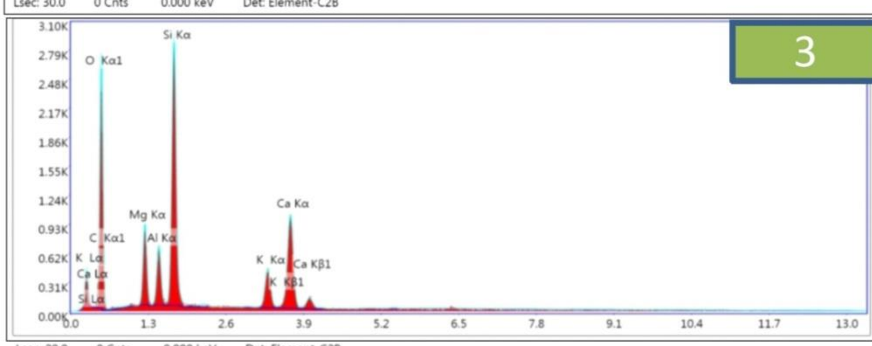




Element	Weight %
C K	10.24
O K	37.41
NaK	3.38
MgK	1.26
AlK	5.52
SiK	35.44
ClK	2.00
K K	4.75



Element	Weight %
C K	9.90
O K	47.41
MgK	10.84
AlK	1.82
SiK	7.56
K K	1.55
CaK	18.69
FeK	2.22



Element	Weight %
C K	9.76
O K	46.98
MgK	6.03
AlK	4.02
SiK	16.40
K K	4.21
CaK	12.60

Fig.5.1.3. SEM-EDS data for circular shaped mat body showing 9-10% of Carbon

Interpretation:

On the basis of carbon % it can be arranged in descending order like pure circular> lense shape > crinkly lamina.

5.1.4. Dark carbonaceous chips:

It is actually mat fragments from another mat layer , may be deposited at the same time. These are enrichd in carbon near about 50% . they have no shape and any preferred orientation. These are haphazardly present within the mat rich layer.

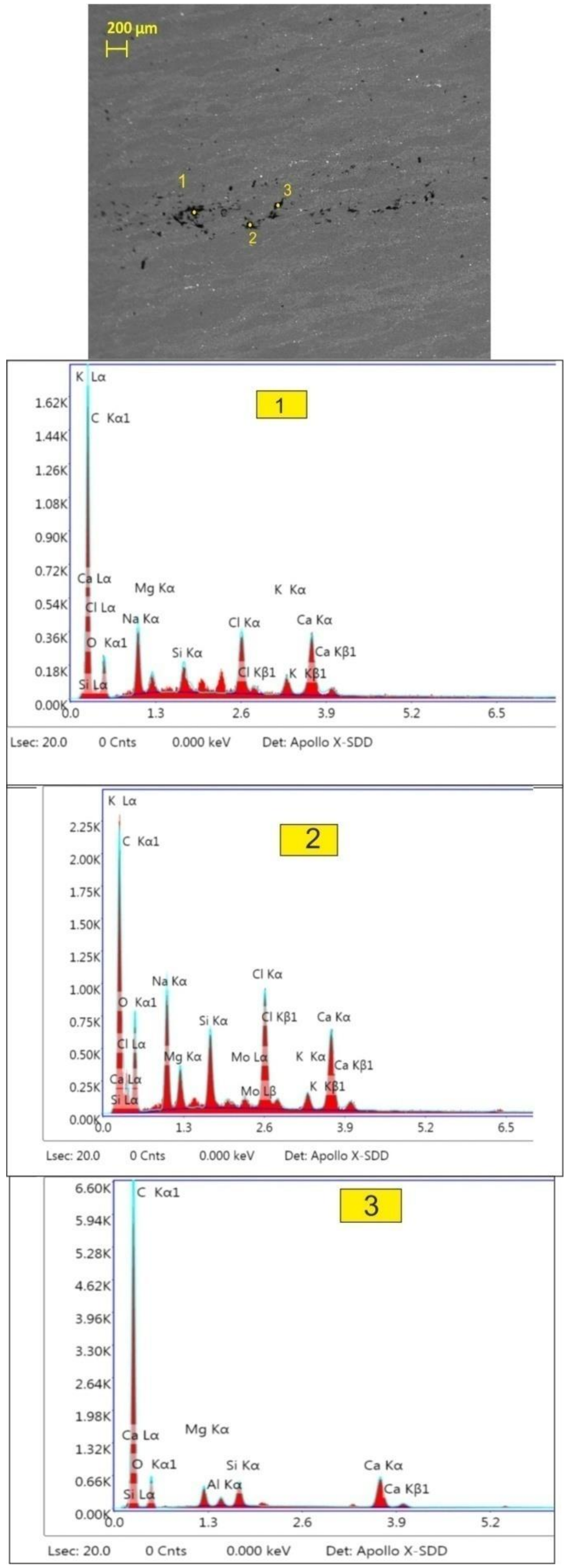


Fig.5.1.4. Carbonaceous chips withim black shale showing very high amount of carbon %

5.2. Confirmation of the Pyrite by EDS:

Pyrite is frequently present and associated with the mat layer. It was present with mat both as framboidal pyrite and layer wise pyrite deposit. Composition is confirmed by EDS data.

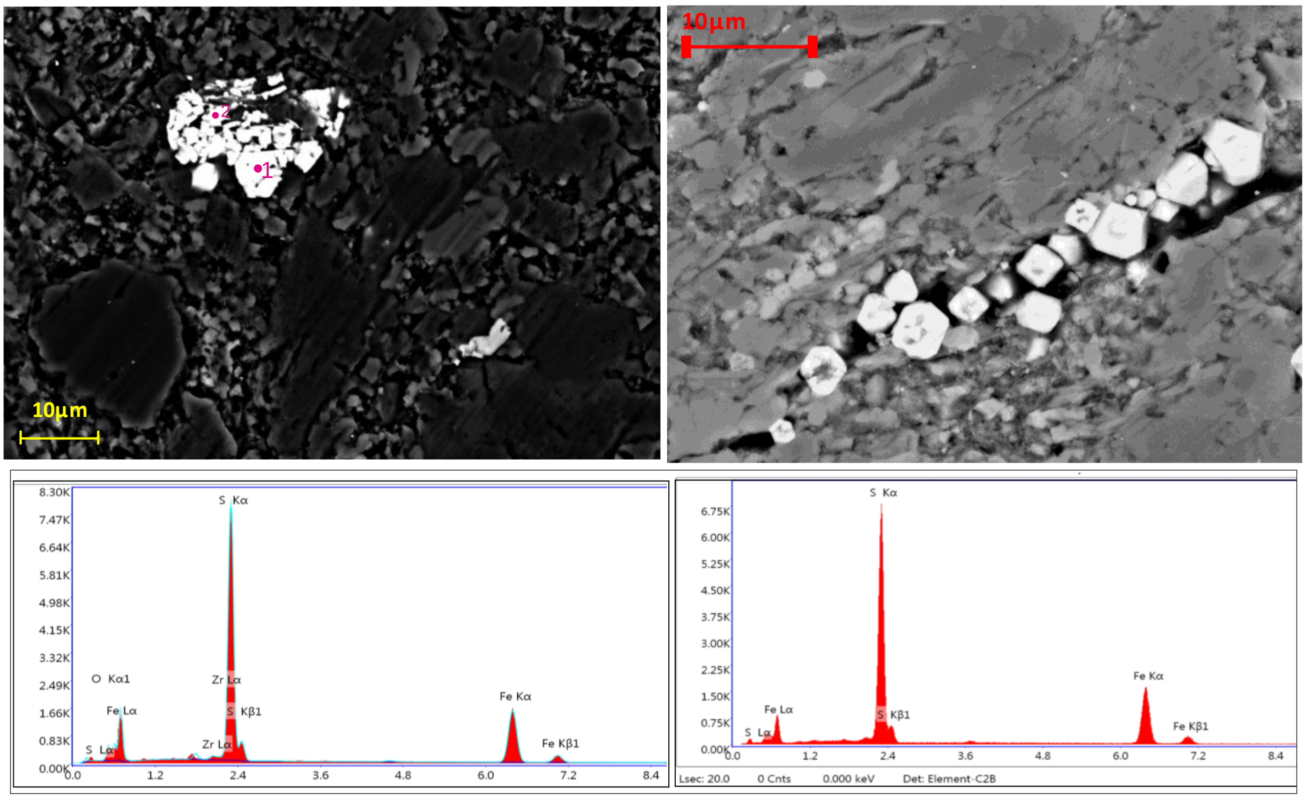
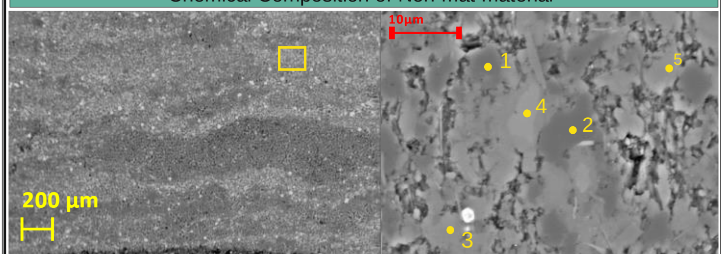


Fig.5.2. SEM-EDS data confirms presence of pyrite garins within mat layer

5.3. Chemical analysis of the non-mat layer:

Other than mat layer some non mat layers are present within the black shale. Which is less dark compare to the mat rich part. EDS data shows that these portions of the shale are nothing but the clay minerals, the data also supports the composition of clay.

Chemical Composition of Non-mat material

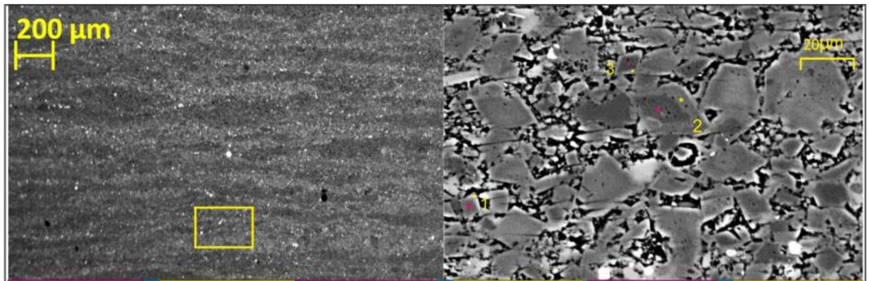


1		2		3		4		5	
Element	Weight %	Element	Weight %	Element	Weight %	Element	Weight %	Element	Weight %
O K	51.28	O K	44.90	OK	50.45	O K	42.48	O K	43.92
Al K	8.66	Na K	1.40	Al K	10.82	Al K	8.89	Na K	1.71
Si K	32.39	Al K	10.82	Si K	30.55	Si K	18.26	Al K	11.18
K K	6.11	Si K	30.97	KK	13.72	K K	12.43	Si K	31.12
Ca K	1.56	K K	11.91			Sr K	17.94	KK	12.08

Fig.5.3. Chemical analysis of non-mat layer showing similar composition of clay mineral

5.4. Characteristic dolomitisation within microbial mat :

It is observed that dolomites are present within the three different types of mat. All the dolomites are different from each other by chemical composition. In case of crinkly lamina carbon % is near about 6-7%, for lense shaped, it is 14-15% and for pure circular shape it is 8-9%. Dolomites are zoned and the Mg % is slightly higher than the core part.



1

Element	Weight %
C K	6.69
O K	51.58
MgK	13.66
Al K	1.24
SiK	1.83
CaK	25.00

Element	Weight %
C K	6.82
O K	51.33
MgK	12.86
CaK	28.99

2

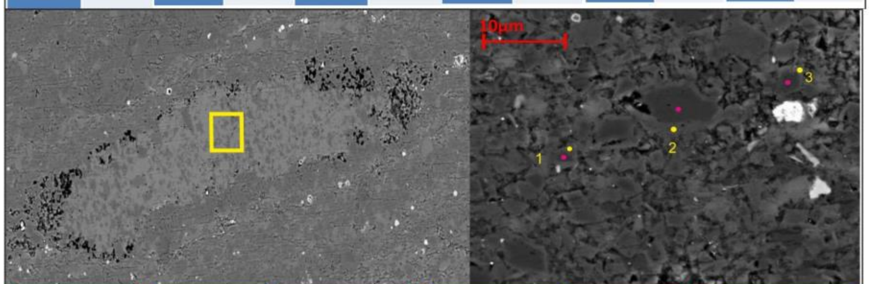
Element	Weight %
C K	6.85
O K	51.16
MgK	13.78
CaK	28.21

Element	Weight %
C K	6.11
O K	50.53
MgK	14.33
CaK	29.03

3

Element	Weight %
C K	6.14
O K	53.45
MgK	12.07
CaK	28.34

Element	Weight %
C K	6.81
O K	50.74
MgK	12.91
CaK	29.55



1

Element	Weight %
C K	7.27
O K	51.52
MgK	14.82
CaK	26.39

Element	Weight %
C K	7.91
O K	52.03
MgK	13.49
CaK	26.57

2

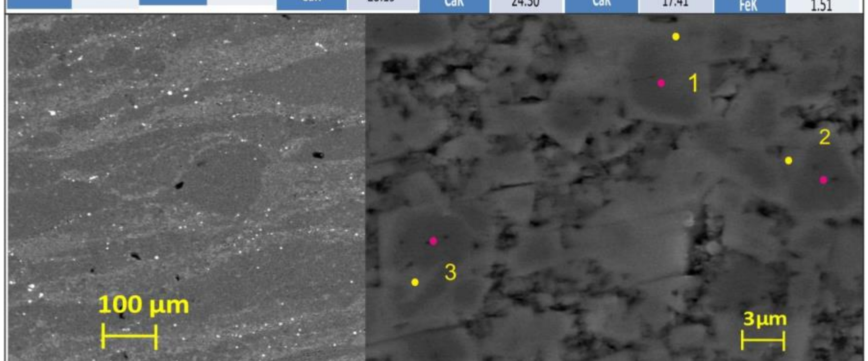
Element	Weight %
C K	9.05
O K	50.84
MgK	13.08
SiK	3.84
CaK	23.19

Element	Weight %
C K	14.97
O K	47.34
MgK	11.44
SiK	1.94
CaK	24.30

3

Element	Weight %
C K	15.56
O K	55.81
MgK	10.48
ZrL	0.75
CaK	17.41

Element	Weight %
C K	13.42
O K	49.09
MgK	7.50
SiK	13.00
CaK	15.48
FeK	1.51



1

Element	Weight %
C K	9.33
O K	53.14
MgK	13.03
Si K	0.63
CaK	23.72
Zn K	0.15

Element	Weight %
C K	9.74
O K	51.00
MgK	12.02
Si K	0.58
CaK	25.01
Fe K	1.65

2

Element	Weight %
C K	9.82
O K	51.69
MgK	12.30
CaK	25.19
RbK	1.00

Element	Weight %
C K	10.82
O K	52.00
MgK	13.30
CaK	22.19
RbK	1.69

3

Element	Weight %
C K	9.96
O K	50.34
MgK	11.89
CaK	25.19
K	1.87

Element	Weight %
C K	9.78
O K	51.25
MgK	13.03
CaK	24.57
Fe K	1.38

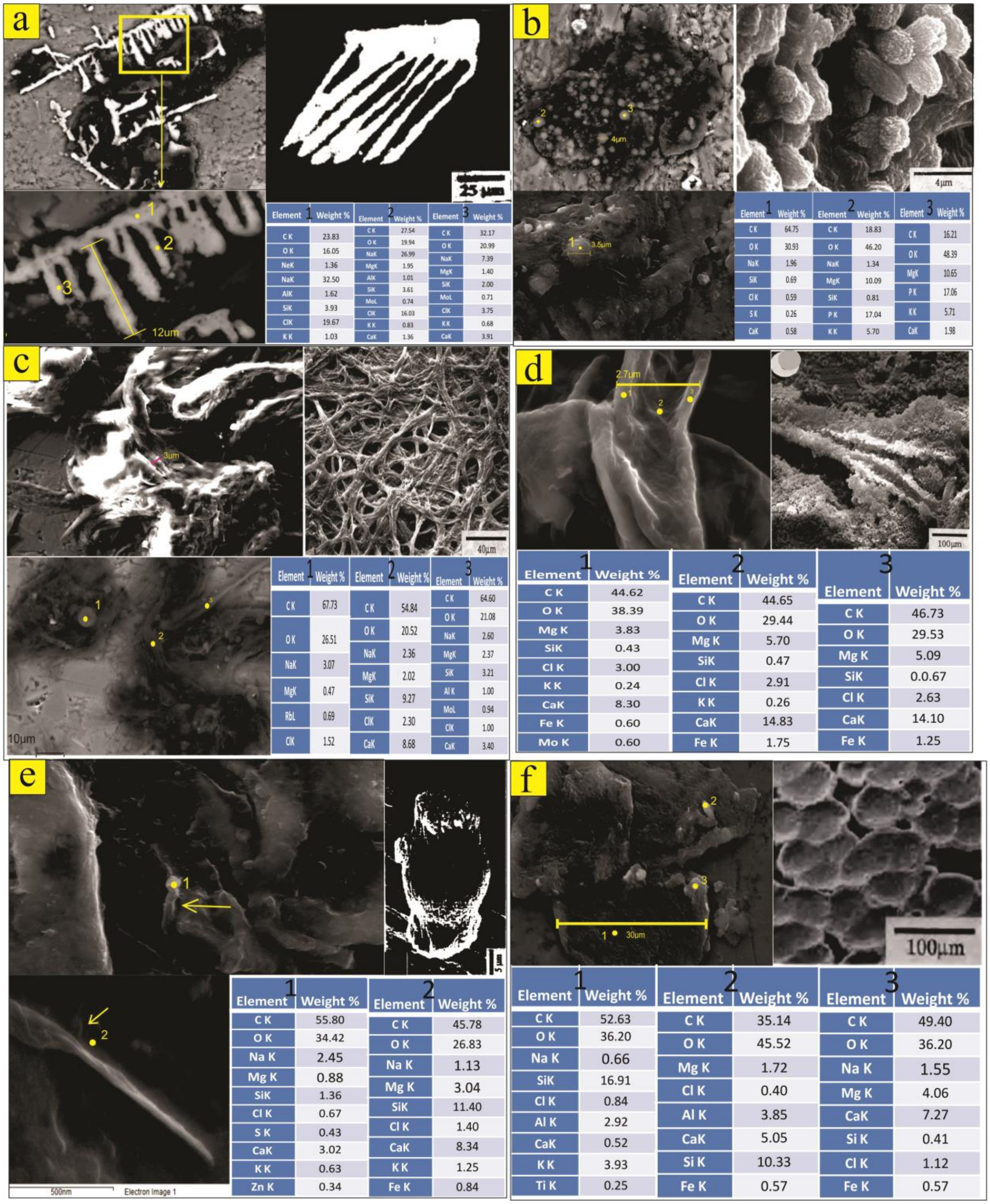
Fig.5.4. represents different carbon % of dolomites within different type of microbial mat. The upper one is for dolomites within crinkled laminae, middle one for lense shaped and below most is for circular shape

5.5. Ultramicroscopic elements within the different types of mat and dark carbonaceous chips:

Calcium carbonate precipitation may be induced by marine bacteria both in laboratory and nature, which results in single crystal and aggregate of crystals (crystal bundles). The crystal bundles are observed as formed like rods and spheres with numerous variations in between these forms. The most common of which is the bulbous, filamentous, brush-like, saucer shaped, half cylinder type appears to be unique to bacterially induced precipitates and consequently, may serve to identify bacterially induced precipitates in the rock record. There are some inducing factors which control this precipitation (Buczynski and Chafetz; 1990).

- Viscosity: viscosity of the growth medium is the most important controlling factor for the mineral precipitation. If the viscosity is medium then the ion diffusion rate varies and thus the precipitation rate also varies and consequenty, the mineral precipitated. For the liquid medium, circulation and ion diffusion rate are both high, which results in rapid precipitation and thus aragonite forms. In a gelatineous medium little circulation occurs, the ion diffusion rate is also slow and as a result calcite is precipitated (Buczynski and Chafetz; 1990).

Here some spectacular morphology of microbiota has been represented which are uniquely reported from the black part of the Rampur shale, along with their lab cultutre equivalent.



a)

Element (1)	Weight %	Element (2)	Weight %	Element (3)	Weight %
C K	23.83	C K	27.54	C K	32.17
O K	16.05	O K	19.94	O K	20.99
NeK	1.36	NaK	26.99	NaK	7.39
NaK	32.50	MgK	1.95	MgK	1.40
AlK	1.62	AlK	1.01	SiK	2.00
SiK	3.93	SiK	3.61	MoL	0.71
ClK	19.67	MoL	0.74	ClK	3.75
K K	1.03	ClK	16.03	K K	0.68
		K K	0.83	CaK	3.91
		CaK	1.36		

b)

Element (1)	Weight %	Element (2)	Weight %	Element (3)	Weight %
C K	64.75	C K	18.83	C K	16.21
O K	30.93	O K	46.20	O K	48.39
NaK	1.96	NaK	1.34	MgK	10.65
SiK	0.69	MgK	10.09	P K	17.06
ClK	0.59	SiK	0.81	K K	5.71
S K	0.26	P K	17.04	CaK	1.98
CaK	0.58	K K	5.70		

c)

Element (1)	Weight %	Element (2)	Weight %	Element (3)	Weight %
C K	67.73	C K	54.84	C K	64.60
O K	26.51	O K	20.52	O K	21.08
NaK	3.07	NaK	2.36	NaK	2.60
MgK	0.47	MgK	2.02	MgK	2.37
RbL	0.69	SiK	9.27	SiK	3.21
ClK	1.52	ClK	2.30	Al K	1.00
		CaK	8.68	MoL	0.94
				ClK	1.00
				CaK	3.40

d)

Element (1)	Weight %	Element (2)	Weight %	Element (3)	Weight %
C K	44.62	C K	44.65	C K	46.73
O K	38.39	O K	29.44	O K	29.53
Mg K	3.83	Mg K	5.70	Mg K	5.09
SiK	0.43	SiK	0.47	SiK	0.0.67
Cl K	3.00	Cl K	2.91	Cl K	2.63
K K	0.24	K K	0.26	CaK	14.10
CaK	8.30	CaK	14.83	Fe K	1.25
Fe K	0.60	Fe K	1.75		
Mo K	0.60				

e)

Element (1)	Weight %	Element (2)	Weight %
C K	55.80	C K	45.78
O K	34.42	O K	26.83
Na K	2.45	Na K	1.13
Mg K	0.88	Mg K	3.04
SiK	1.36	SiK	11.40
Cl K	0.67	Cl K	1.40
S K	0.43	CaK	8.34
CaK	3.02	K K	1.25
K K	0.63	Fe K	0.84
Zn K	0.34		

f)

Element (1)	Weight %	Element (2)	Weight %	Element (3)	Weight %
C K	52.63	C K	35.14	C K	49.40
O K	36.20	O K	45.52	O K	36.20
Na K	0.66	Mg K	1.72	Na K	1.55
SiK	16.91	Cl K	0.40	Mg K	4.06
Cl K	0.84	Al K	3.85	CaK	7.27
Al K	2.92	CaK	5.05	Si K	0.41
CaK	0.52	Si K	10.33	Cl K	1.12
K K	3.93	Fe K	0.57	Fe K	0.57
Ti K	0.25				

Fig.5.5. represents some ultramicroscopic elements in microbial mat layers which are found in Rampur Shale, a) Degenerated and fragmented hair brush-like form within an uprooted and older microbial mat chip. Note high carbon content on the right, a form equivalent in a lab culture, b) Bulbous forms on microbial mat fragments. Note highly variable carbon content on right close form equivalent in lab culture, c) Filamentous forms within microbial mat-chips. Note very high carbon content. Note close form equivalent from lab culture, d) Cylindrical form in half. Note intermittently placed cross walls. Note that carbon content is indeed high in the cylinder walls and on the cross walls on the right mould of such a form in lab culture, e) Partially covered rod like form. On right a rough form- equivalent in lab culture, f) Saucer-shaped form. Note very high enrichment in c. on right is an assemblage of form equivalent from lab culture

Interpretation:

Frequent preservation of microbial mats, microbial mat fragments and individual microbial elements In the Rampur shale appears unusual. it is imperative that the Rampur marine shelf sediment pile acted as a sink for organic carbon. It is likely that during the deposition of Rampur Shale the sea was less agitated and an anoxic environment was prevailed.

CHAPTER- 6

DISCUSSION

DISCUSSION:

The Rampur Shale member of Rohtas Formation, is underlain by Chorhat Sandstone in the study area. The transition from Chorhat sandstone to shale shows a fining upward sequence. The Rampur shale is not entirely black. The top part of this member is black which infers the maximum deepening of the basin, indicated by maximum flooding surface (MFS). The lowermost part of Rampur Shale is sand dominated. Presence of hummocky cross stratified sandstone, gutter infested sandstone indicate storm dominated environment. Then it gradually becomes silt dominated and in upper part shale is found. In silt dominated portion, cross laminated siltstone, planar laminated siltstone indicates deposition at distal part compare to the sand dominated facies association. Presence of some hummocks and gutters indicate intercalation of storm. The upper part is dominantly planar laminated grey shale and planar lamintated black shale which is indicative of deepening of the basin. It is likely that the Rampur shale is part of a TST which starts from underlying Chorhat Sandstone. Some volcanic ash layers are also associated with the planar laminated black shale at the upper part. These layers may be derived from nearby source. The gradational contact between the black Rampur shale and the overlying Rohtas Limestone indicate possible lowering sea level. The shallow water Rohtas Limestone above the Rampur Shale conveys high stand system tract deposit (HST).

The Sirbu shale, on the other hand, belongs to the Bhander formation which is underlain by the lower Bhander Sandstone and overlain by the Upper Bhander Sandstone. From the lithological sequences it has been observed that in the lower part of the shale there is a gradual transition from lower Bhander sandstone to Sirbu shale showing fining upward trend of the sequence and then again a gradual coarsening occurs from the Sirbu Shale to Upper Bhander sandstone. The lower part of the Sirbu shale is grey in color and contain some oolitic , stromatolitic and some emergence feature within it. The black shale within the Sirbu Shale possibly is the indicator of the Maximum Flooding Surface. This part of the Sirbu Shale is sand free but while moving gradually upward along the succession the silt sized grains start to increase and the black shale is also became lesser in amount. Some cross lamination and ripple lamination is present within the siltstone. As one move up the succession the silt-sized grains are replaced by sand populations. Thus the Sirbu shale gradually passes to sandstone, the Upper Bhander Sandstone Member. The whole succession is showing a general coarsening upward trend except the lower part of the Shale where it shows a transgressive trend.

Coming to the microfacies part of Rampur Shale, some excellent mat features are preserved within the black shale like false cross lamination, jagged ends, lateral accreation, diverging and converging characters which is the natural character of microbial mats, fly paper effect, trapping of grains etc. The presence of microbial mat indicates that during the formation of Rampur Shale, the Rampur marine shelf sediment pile acted as a sink for organic carbon and there was prolific growth of different types of microbiota. Frequent preservation of microbial mats, microbial mat fragments and individual microbial elements in the Rampur shale appears unusual. It is likely that during the deposition of Rampur Shale the sea was less agitated and an anoxic environment prevailed at that time. Presence of pyrite also supports the anoxic condition. SEM-EDS data also reveal the presence of morphologically and chemically different mat forms. Some ultramicroscopic elements which show very high carbon% are also found in the black shale which confirms the presence of microbiota. So we can infer that the Rampur Shale is rich in carbon.

In black part of Sirbu shale the mats are different from Rampur Shale. Pyrite grains are in layers whereas in Rampur Shale both framboidal and layer wise occurrence are present. Here also lateral accretion, false cross laminations are present. Further studies are required to analysis all the features and ultramicroscopic elements.

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