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Sequence evolution in the eastern Chhattisgarh Basin: constraints on correlation and stratigraphic analysis

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ABSTRACT

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The Proterozoic succession in the eastern part of the Mesoproterozoic Chhattisgarh Basin comprises two unconformity-bounded sequences. Sequence I represents the Chhattisgarh Supergroup of earlier workers. It overlies rocks of the basement complex with a profound unconformity. Sequence II unconformably overlies Sequnce I, and represents the closing phase of basin evolution during the early Neoproterozoic time. It is unconformably overlain by rocks of the Gondwana Supergroup.

The Lohardi and Gomarda formations at the lower part of the Chandarpur Group of Sequence I comprise an immature succession of conglomerate, sandstone and shale deposited in fan-delta - pro-delta environments, marked by rapid facies changes, variable rates of sediment influx, and uneven rates of subsidence and creation of accommodation space. The Kansapathar Sandstone in the upper part of the Chandarpur Group, by contrast, comprises a sheet of mature arenite deposited in a macrotidal shelf. The immature assemblage is best developed in the eastern part of the basin, and rapidly thins out towards west, where the Kansapathar arenite directly overlies the basement. The Raipur Group provides an excellent example of cyclic sedimentation of red shale and limestone. It comprises three shale-dominated intervals and two carbonate-dominated intervals, organized into multiple shallowing-up cycles. The lower carbonate succession, the Sarangarh Limestone, developed as a shallow water un-rimmed platform and evolved into a deep water ramp, with an extensive thin sheet of black limestone facies. Stromatolites are conspicuously absent in the Sarangarh Limestone. Small stromatolite bioherms appear in the Gunderdehi Shale which overlies the ramp succession, and abundant growth of stromatolite is noted in the upper carbonate succession which evolved as a rimmed platform. A thick ignimbrite horizon in the Churtela Shale attests to major felsic volcanism and termination of the Sequence at ~1000 Ma.

The Kansapathar Sandstone, the black limestone facies of the Sarangarh Limestone, and the Gunderdehi Shale embedded with small stromatolite bioherms can be used as key marker horizons to overcome the problem of intrabasinal correlation. The marker horizons can be traced from the western part to the eastern part of the basin. The stromatolites in the Gunderdehi Shale and in the Saradih Limestone further provide a biostratigraphic frame, subject to detailed morphologic and microstructural analysis, for possible chronostratigraphic classification.

Key-words—Chhattisgarh Basin, Mesoproterozoic, Lithostratigraphy, Controls on correlation, Stromatolites, Biostratigraphy.

पूर्वी छत्तीसगढ़ द्रोणी में अनुक्रम विकासः सहसंबंध एवं स्तरिक विश्लेषण पर व्यवरोध

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मीसोप्रोटेरोज़ोइक छत्तीसगढ़ द्रोणी के पूर्वी भाग में प्रोटीरोजोइक अनुक्रमण दो विषम विन्यास-परिबद्ध अनुक्रमों का है। अनुक्रम प्रथम प्रारंभिक कार्यकर्त्तों के छत्तीसगढ़ महासमूह को रूपायित करता है। यह गंभीर विषम विन्यास सहित आधार जटिलसंध के शैवाल पर अतिशयन करता है। अनुक्रम द्वितीय विषम विन्यास रूप से अनुक्रम प्रथम पर अधिशयन करता है, तथा प्रारंभिक नियोप्रोटेरोज़ोइक काल के दौरान द्रोणी विकास की समापन प्रावस्था रूपायित करता है। यह विषम विन्यस्त रूप से गोंडवाना महासमूह की चट्टानों से ऊपरी आवरित है।

अनुक्रम प्रथम के चंद्रपुर समूह के निम्न भाग पर लोहार्दी एवं गोमर्दा शैलसमूह संगुटिका, बालूपत्थर एवं शेल का अपरिपक्व अनुक्रमण खरित संलक्षणी परिवर्तन द्वारा चिह्नित, अवसाद अंतर्वाह की परिवर्तनीय दर और अवतलन की असमतल दर एवं वास स्थान की सृष्टि पंख-डेल्टा एवं पुरःडेल्टा वातावरण में निक्षेपित हो गई। चंद्रपुर समूह के ऊपरी भाग में काँसापत्थर-बालूपत्थर, विपयसि से परिपक्व एरेनाइट की चादर सन्निहित एक दर्घा ज्वारीय उपतट में निक्षेपित हो गई। द्रोणी के पूर्वी भाग में अपरिपक्व समुच्चय सबसे ज्यादा विकसित हुई है तथा तेजी से पश्चिम की ओर पतली हो गई है जहां काँसापत्थर-एरेनाइट आधार पर सीधे अतिशयन काता है। रायपुर समूह लाल रोल एवं चूना पत्थर के चक्रीय अवसादन का अत्युत्तम उदाहरण पेश करता है। यह तीन शेल-प्रभुत्वी अंतराल एवं दो कार्बोनेट-प्रभुत्वी, बहु उथले चक्रों में संघटित है। निम्न कार्बोनेट अनुक्रमण, सरनगढ़-चूनापत्थर, काली चूनापत्थर संलजक्षण की गहन पतली चादर सहित उथले जल बिन नेमि प्लेटफार्म के रूप में विकसित हुई तथा गहरे जल रैम्प में विस्तृत हो गई। सरनगढ़ चूनापत्थर में स्ट्रोमेटोलाइट्स स्पष्टतः नहीं हैं। गुडेरदेही शेल में सूक्ष्म स्ट्रोमेटोलाइट्स जेवहर्रा दिखते हैं जो कि रैम्प अनुक्रमण पर उपरिशायी हैं, तथा स्ट्रोमेटोलाइट्स की प्रचुर वृद्धि ऊपरी कार्बोनेट अनुक्रमण में नोट की गई हैं जो कि नेमि प्लेटफार्म की भाँति विकसित हुई। चुरटेला शेल में एक मोटी इग्निम्ब्राइट क्षितिज प्रधान फेल्सिक ज्वालामुखी एवं १०० करोड़ वर्ष पर अनुक्रम का अंतस्थ साक्ष्यांकित करती है।

काँसापत्थर बालूपत्थर, सरनगढ़-चूनापत्थर की काली चूनापत्थर संलक्षणी और गुँडेरदेही शेल सूक्ष्म स्ट्रोमेटोलाइट्स के साथ अंतःस्थापित हो गई। अंतःद्रोणीय सहसंबंध की समस्या से छुटकारा पाने हेतु जैवहर्म को सूचक चिह्नक क्षितिज के रूप में प्रयुक्त किया जा सकता है। चिह्नक क्षितिज द्रोणी के पश्चिमी भाग से पूर्वी भाग तक अनवेषित किए जा सकते हैं। गुँडेरदेही शेल एवं सरदीह चूनापत्थर में स्ट्रोमेटोलाइट्स संभव कालस्तरिक वर्गीकरण हेतु विस्तृत आकारिकी एवं सूक्ष्मसंरचनात्मक विश्लेषण पर निर्भर आगे जैवस्तरिक ढ़ाँचा देते हैं।

संकेत-शब्द—छत्तीसगढ़ द्रोणी, मीसोप्रोटीरोज़ोइक, लियोस्तरिकी, सहसंबंध पर नियंत्रण, स्ट्रोमेटोलाइट्स, जैवस्तरिकी।

INTRODUCTION

THE stratigraphic reconstruction on a basin-wide scale is the most fundamental requirement in basin analysis. Lack of accurately constrained correlation of stratigraphic sections may lead to unrealistic or even misleading interpretation of major geologic events, such as sea-level changes, climatic shifts or tectonic perturbations. Stratigraphic correlation of unfossiliferous strata in physically discontinuous outcrops is fraught with many uncertainties, particularly where the succession is marked by highly heterogenous facies assemblages or facies variations, or where major lithologic units in a cyclic sequence are not embedded with characteristic physical attributes.

The problems are acutely manifested in the stratigraphic analysis of the Purana basins of Indian peninsula, where holistic basin analysis is still severely impeded. The Chhattisgarh Basin provides a classic example of such stratigraphic uncertainties, which is manifested by the disagreements between different schemes of stratigraphic classification proposed by different workers (Fig. 1). Comparison of existing schemes of classifications points to major differences between them which create uncertainties in developing a holistic stratigraphic history for the basin.

Stratigraphic classification of the lower part of the eastern Chhattisgarh succession and the implication of the stratigraphic architecture on basin evolution were discussed in our earlier papers (Patranabis-Deb & Chaudhuri, 2002; Patranabis-Deb, 2004). Summary of the stratigraphy was presented in Patranabis-Deb *et al.* (2007, Fig. 2). This paper presents the complete stratigraphic succession in the eastern part of the Chhattisgarh Basin bounded by the eparchaean unconformity at the base and the sub-Gondwana unconformity at the top, detailed characterization of different formations, and comparison of the proposed classification with generally accepted classification for the western part of the basin. Attempt has been made to identify and characterize key beds for correlating the successions in the western and eastern parts of the basin, as well as to facilitate future attempts to compare and correlate the Chhattisgarh succession with other Purana successions of the South Indian craton. The approach of intrabasinal correlation of unconformity- bounded sequences has been adopted in view of the successful application of the method in correlating major unconformity-bounded cratonic sequences across the continents (Sloss, 1972; Soares, 1978). Biostratigraphic significance of the occurrence of stromatolites in different lithostratigraphic units, and its bearing in recognition of sea-level change and correlation has been evaluated.

	Dutt (1964) (southern part)	Schnitzer (1969) (northern part)		Murti (1987) (south central part)	Moitra (1990)		Das *et al.* (1992) (western part	eastern part)		Patranabis Deb (present classification)
							Maniari Formation (70 m)			Nandeli Shale
		Maniari Shale (100 m)					Hirri Formation (70 m)	Saradih dolomite, limestone and black shale	Kharsiya Group	Sarnadih Sandstone
	Raipur shale-limestone (450 m)	Hirri-Kharkhena Dolomite (50-100 m)								~ Unconformity~
		Belha Limestone (80 m)		Tarenga Shale (180 m)	Tarenga Shale (180 m)		Tarenga Formation (180 m?)			
		Patharia-Umaria Shale (50 m)								Curtela Shale (with Sapos and Sarnadih Tuffs) ~300 m
		~ Unconformity~								
		Nandini Limestone (80-100 m)			Khairagarh (Deodengar) sandstone (variable thickness)					
		Bhatapara Limestone/Dolomite (50 m)								
Kurnool Series	Khairagarh Sandstone (variable thickness)	Lilagarh Shale (50 m)	Chhattisgarh Supergroup; Raipur Group	Chandi Limestone (670 m)	Raipur Limestone (670 m)	Raipur Group	Chandi Formation (670 m)	Bamandihi purple calc-argillite with stromatolitic limestone as lenses and pockets		Saradih Limestone (~100 m)
		Akaltara Dolomite/Siliceous Limestone and Arenite (40 m)								
		~ Unconformity ~								
	Gunderdehi Shale (180 m)	Karuid II Shale (100-150 m)								
		Karuid I Bituminous/ Siliceous Limestone (50 m)		Gunderdehi Shale (430 m)	Gunderdehi Shale (430 m)	Chhattisgarh Supergroup	Gunderdehi Formation	Raigarh purple calc-argillite with limestone, chert and arenite intercalations		Gunderdehi Shale (>400 m)
	Charmuria Limestone (300 m)	Seorinarayan Shale (100 m)					Charmuria Limestone (490 m)		Chhattisgarh Supergroup; Raipur Group	Sarangarh Limestone (150 m)
		Sarangarh Bituminous/ Siliceous Limestone (30-50 m)		Charmuria Formation (Limestone dominated) (490 m)	Charmuria Limestone (490 m)					Bijepur Shale (100 m)
		~ Unconformity ~		~ Unconformity ~	? ? ?					
	Chandarpur Sandstone (300 m)	Chandarpur Quartzite (200 m)		Kansapathar/ Kondkera Formation (+125 m)	Chandarpur Sandstone (400 m)		Kansapathar Formation (20-200 m)	Kansapathar Formation		Kansapathar Formation (60 m)
			Chandarpur Group	Chaporadih Formation (15 m)		Chandarpur Group	Chaporadih Formation (20-200 m)	Chaporadih Formation	Chandarpur Group	Gomarda Formation (650 m)
		Conglomerate (300 m)		Lohardih Formation (240 m)			Lohardih Formation (20 m)	Lohardih Formation		Lohardih Formation (150 m)
	~ Unconformity~	~ Unconformity~		~ Unconformity~	~ Unconformity~		~ Unconformity ~			~ Unconformity ~
	Archaean Granite	Crystalline Complex		Archaean Basement	Precambrian Granite		Chhuipali Formation (~300 m)	Chhuipali Formation (~300 m)		Archaean Greenstone Belt and Granite Gneiss
						Singhora Group	Bhalukona Formation (20 m ±)	Bhalukona Formation (20 m ±)		
							Saraipali Formation (60 m)	Saraipali Formation (60 m)		
							Rehatikhol Formation (20 m +)	Rehatikhol Formation (20 m +)		
							~~ Unconformity ~~~			
							Archaean and Lower Proterozoic Basement			

Fig. 1—Stratigraphic classification of the Chhattisgarh succession by different authors. The column 5 from the left hand side represents the succession slightly modified from Das *et al.* 1992.

CHHATTISGARH BASIN

The Chhattisgarh is a large Purana basin, with the basin-filling succession covering about 36,000 sq. km of the Bastar cratonic block (Fig. 1). South of the main Chhattisgarh outcrops, there are several smaller occurrences of Proterozoic sedimentaries, lithologically similar to the Chhattisgarh succession. These outcrops are often referred to as deposits of separate basins, such as, Khariar Basin, Ampani Basin, Indravati Basin and Sukma Basin (Fig. 2). However, there is a prevailing view (Ahmad, 1958; Dutt, 1964; Ramakrishnan, 1987; Chaudhuri *et al.*, 2002) that the isolated outcrops are parts of a larger basin that was fragmented and separated by post-lithification faulting or doming up of the basement and erosion of structural highs.

The Chhattisgarh succession unconformably overlies the Archaean crystalline basement including the Sonakhan granite-greenstone belt and the Dongargarh-Kotri volcanics with a strong N-S trending structural grain. The K/Ar dates of glauconitic minerals from the lower part of the sequence yield an age of 700-750 Ma (Kruezer *et al.*, 1977). Murti (1987, 1996), however, places the sequence at 1250 to 1300 Ma on the basis of palaeomagnetic studies, whereas assemblage of algal stromatolites points to middle to upper Riphean age (Moitra, 1999). Recent SHRIMP zircon dates of a pyroclastic horizon at the upper part of the Raipur Group constrain an age of ~1000 Ma (Patranabis-Deb *et al.*, 2007) suggesting that the Chhattisgarh succession is primarily Mesoproterozoic, extending a little into the early Neoproterozoic.

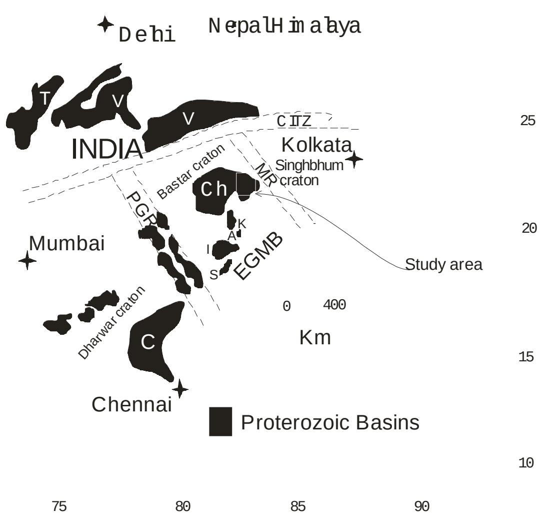

Fig. 2—Purana /Proterozoic basins and mobile belts of peninsular India; Ch, Chhattisgarh; K, Khariar; I, Indravati; A, Ampani; S, Sukma, PGR, Pranhita-Godavari Rift; C, Cuddapah; V, Vindhyan; T, Trans-Aravalli; MR, Mahanadi Rift; CITZ, Central Indian Tectonic Zone; EGMB, Eastern Ghats Belt. The Chhattisgarh Basin within the Bastar craton is bounded by rift basins and mobile belts.

The Chhattisgarh outcrop belt has been delimited on the north and north-east by a major WNW-ESE trending fault zone (Fig. 3). The fault has brought up a thin slice of sandstone from the lower part of the Chhattisgarh succession. The siliciclastic outcrops along the south-east margin contains wedges of conglomerates and pebbly sandstones at multiple points, which were deposited as alluvial fans and fan-deltas (Patranabis-Deb and Chaudhuri, 2007) suggesting that the present day south-eastern margin of the outcrop belt represents the basin margin during the early stage of basin opening. The western margin of the outcrop belt is fault bounded. Small outcrops of conglomerates, pebbly sandstones and coarse sandstones, designated as Khairagarh Sandstone (Dutt, 1964; Moitra, 1995), intertongue or intercalate with shale and limestones of the Raipur Group near the western margin, suggesting that the depositional basin margin was not far off from the present day fault margin.

The Chhattisgarh succession attracted the attention of geologists for more than hundred years (Ball, 1877; King, 1885; Dutt, 1964; Schnitzer, 1971; Murti, 1987; Das *et al.*, 1992; Moitra, 1995; Patranabis-Deb, 2001, 2004, 2005; Patranabis-Deb & Chaudhuri, 2007; Patranabis-Deb *et al.*, 2007; Chakraborty & Paul, 2008). Most of the earlier studies were focused on the stratigraphic classification, mainly in the western and south-central part of the basin (Dutt, 1964; Murti, 1987) where the succession is characterized by prolific development of stromatolites and mature sandstones, a characteristic stable platformal association. The eastern part, by contrast, comprises a wide range of lithologies deposited in widely varying conditions of sediment input, reworking, transport, and bathymetry of depositional interface (Das *et al.*, 1992; Patranabis-Deb, 2004; Patranabis-Deb & Chaudhuri, 2007). The succession is marked by remarkable facies variation, and a regionally variable lithostratigraphy, resulting from uneven rates of subsidence and creation of accommodation space in different parts of the basin, and a complex stratigraphic architecture.

LITHOSTRATIGRAPHY

The stratigraphic succession in the eastern part of the Chhattisgarh Basin and broad depositional environments of the deposits at formation level are shown in Fig. 4. Three major unconformities divide the succession into two unconformity-bounded sequences. The maximum preserved thickness of Sequence I is ~1900 m, and it is bounded by the sub-Lohardih unconformity at the base, and by the sub-Sarnadih unconformity at the top. The Sequence II has a preserved thickness of ~300 m, and is bounded by the sub-Sarnadih

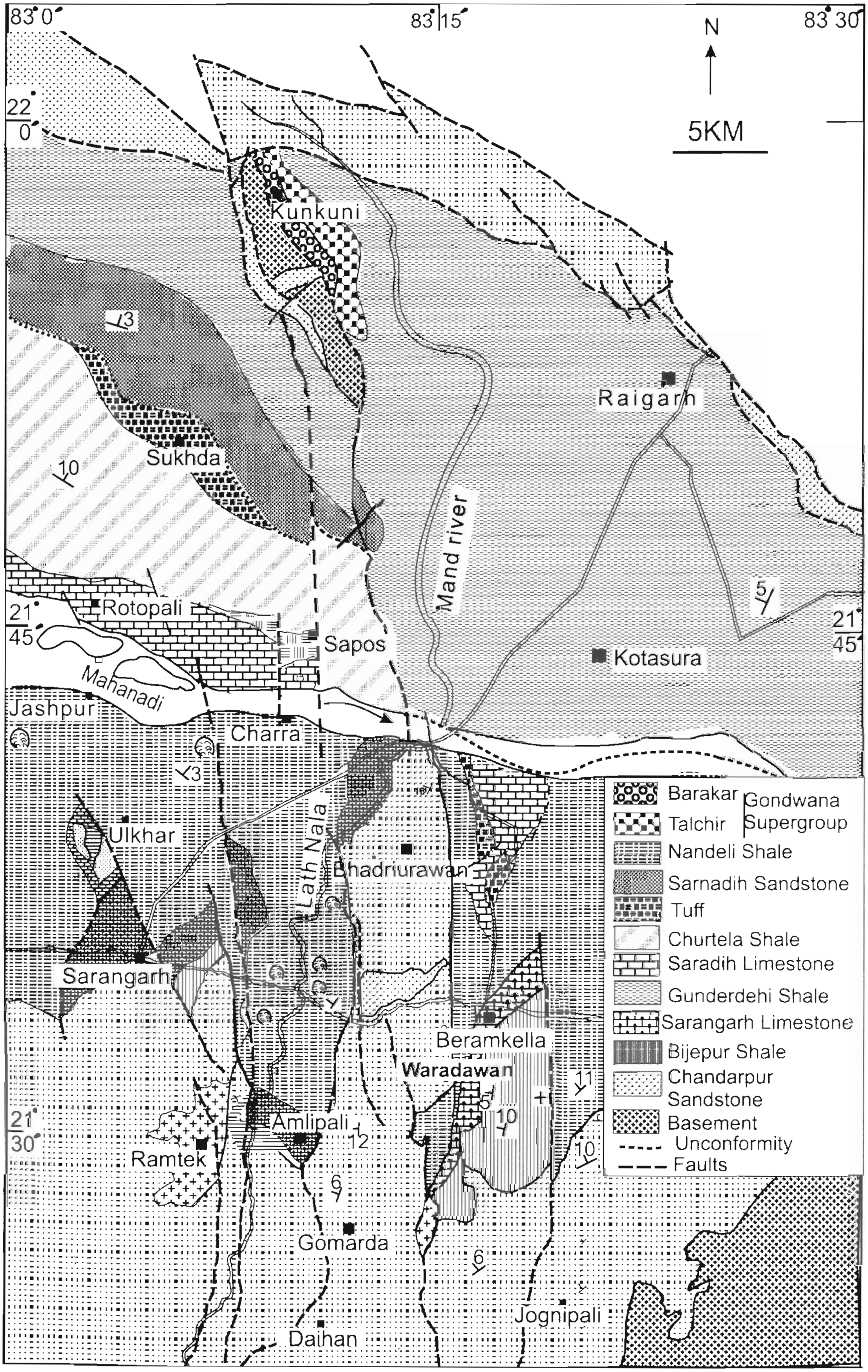

Fig. 3—Geological map of the eastern Chhattisgarh

unconformity at the base and the sub-Gondwana unconformity at the top.

The Sequence I corresponds to the Chhattisgarh Supergroup of earlier workers, and comprises a lower, sandstone-shale dominated Chandarpur Group, and an upper, limestone-red shale dominated Raipur Group. The Sukhda tuff, dated to be ~ 1000 Ma in age by U-Pb SHRIMP analysis of zircon (Patranabis-Deb *et al.*, 2007), occurs just below the sub-Sarnadih unconformity and defines the top of the Raipur Group. The sub-Sarnadih unconformity and Sequence II have been recognized for the first time. The Sequence II has been designated as the Kharsiya Group, and has been divided into two formations, the Sarnadih Sandstone and Nandeli Shale, in ascending order. It is directly overlain by Gondwana rocks, viz. Talchir and Barakar sandstones, across the sub-Gondwana unconformity.

CHARACTERIZATION OF FORMATIONS

A comparison of different stratigraphic columns (Fig. 1) points to a highly variable stratigraphic architectures. The differences are marked by local development of a number of formations, and disconformities in different sections, or by significant thickness variation between different sections. A new scheme of stratigraphic nomenclature, so, has been used for the units whose stratigraphic equivalents in central or western parts of the basin are not well established, or which shows major facies variations across the outcrop belt.

CHANDARPUR GROUP

The Chandarpur Group has been divided into three formations, Lohardih, Gomarda and Kansapathar formations, in an ascending order (Fig. 1). The siliciclastics exhibit remarkable facies variation from west to east. The details of lithological attributes of these formations are given in Patranabis-Deb (2004).

The Lohardih Formation has a maximum preserved thickness of 150 m, and is characterized by a heterogenous assemblage of conglomerate, sandstone and shale. The sequence shows strong lateral facies variations between different lithologies, and is inferred as a tectonically controlled fan-delta–pro-delta succession which developed at the initial stage of basin opening (Patranabis-Deb & Chaudhuri, 2007). The basal part of the Formation is dominated by conglomerates, pebbly sandstones and coarse sandstones, whereas its upper part is shale-dominated, characterized by lenticular bodies of coarse clastics enclosed within shale and mudstone.

The Lohardih Formation grades upward into the Gomarda Formation which is also marked by strong facies variation, and comprises alternation of sandstone and shale on different scales. The Gomarda sandstones are, in general, much finer grained and better sorted than Lohardih sandstones. However, the transition from mud-dominated upper part of the Lohardih Formation to the mud-dominated basal part of the Gomarda Formation is too gradational to delineate a well defined contact. A pebbly to gritty sandstone at the uppermost stratigraphic level within the zone of transition has been taken to mark the contact between them. The Gomarda Formation has a thickness of ~650 m.

The Gomarda Formation passes upward to the Kansapathar Sandstone through a narrow zone of transition. The Kansapathar Sandstone is characterized by high facies constancy, and is dominated by mature to supermature subarkose to quartzarenite. Shale and mudstones occur as subordinate components. The arenites formed as large shoaling-up tidal bars in a macrotidal shelf (Patranabis-Deb, 2005), and the bars coalesced into extensive sand sheets. The Sandstone has a maximum thickness of ~60 m. Its lower and middle parts are characterized by profuse development of symmetrical to slightly asymmetrical ripple marks mantling the bar surfaces, whereas its uppermost part exhibits well developed beach-stratification, desiccation cracks and adhesion warts (see Fig. 8, 12 of Patranabis-Deb, 2005). The assemblage of structures indicates that the Kansapathar Sandstone developed as an overall shallowing- and fining-up sequence, with its uppermost part having been deposited at the upper intertidal to supratidal environments.

RAIPUR GROUP

The Raipur Group has been classified into five formations, 3 intervals of reddish brown to red shale alternating with 2 intervals of carbonate rocks.

Bijepur Shale

The Bijepur Shale overlies the bar sandstones of the Kansapathar Formation (Fig. 4) and grades upwards to the basal brown interval of the Sarangarh Limestone through a narrow zone of shale-limestone alternation. The preserved thickness of the shale is highly variable at different sections, and its maximum preserved thickness is about 100 m. The shale is absent at a few sections where limestone directly overlies the Kansapathar Sandstone. The shale is dominantly brown; green shale occurs as a subordinate component at the basal part of the Formation. The beds are in general 2-5 cm thick, and often exhibit millimetre thick internal lamination. Fine sands and silts occur locally, and coarser clastics are conspicuously absent. The fine sandy/silty beds exhibit either normal grading or Ta - b or Ta - c divisions of the Bouma sequence, and successive beds occasionally exhibit very low angle discordance between them. Well preserved outcrops the Shale are locally found, such as in the Putka Nala section near Bijepur Village (21º34'53''N; 83º6'24''E).

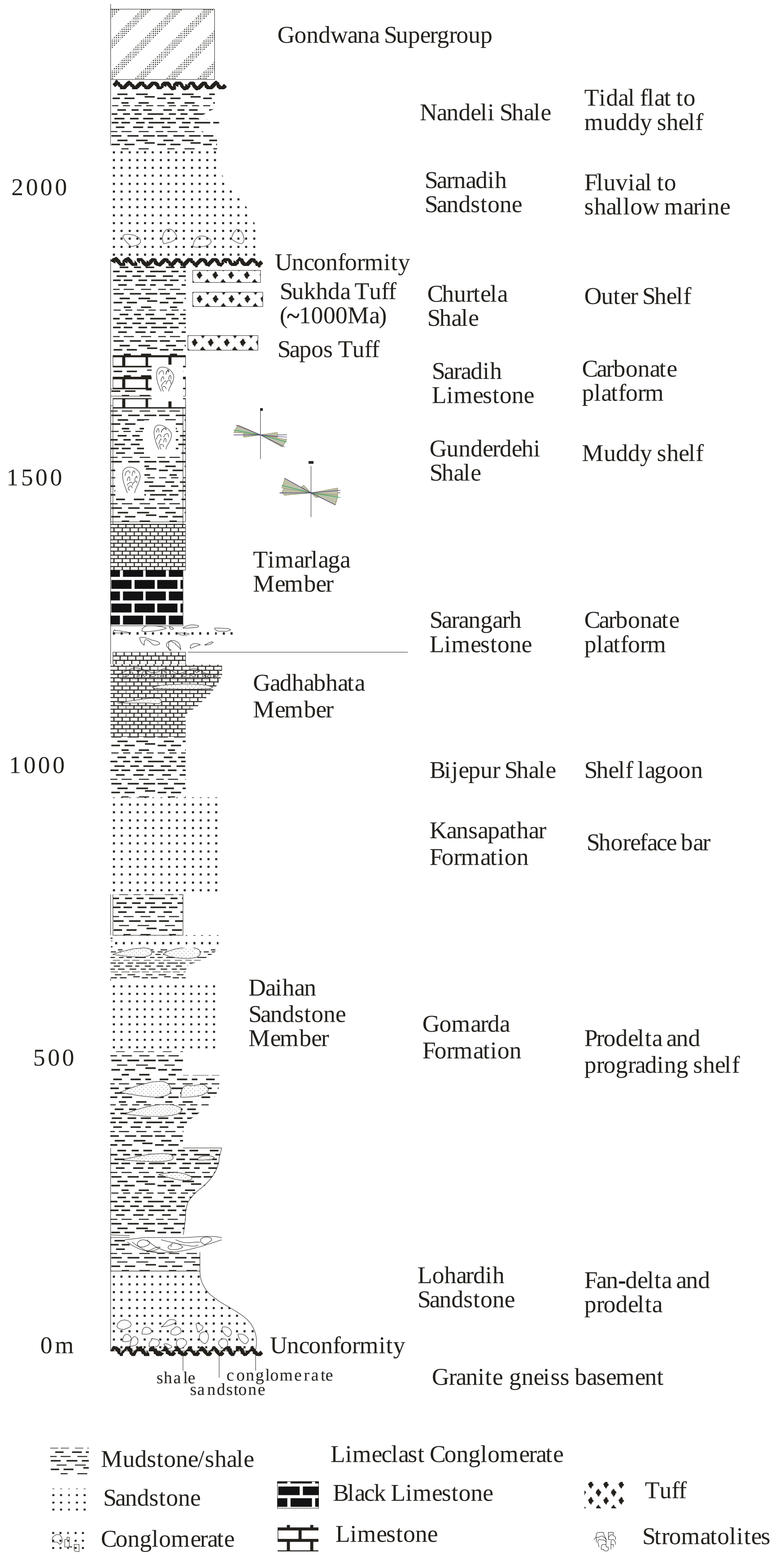

Fig. 4—Generalized stratigraphic succession in the eastern part of the Chhattisgarh Basin. Inferred depositional environments are shown in the right hand column.

The relation between Chandarpur Group and the Raipur Group had previously been interpreted as unconformity, doubtful unconformity or conformity. The controversy seems to stem from poor exposure condition. The Kansapathar Sandstone and the Bijepur Shale occur within a few metre of each other though, direct contact between them has not been observed anywhere. Despite assiduous search, we failed to identify any evidence which can speak for an unconformity between the two. The superposition of the Bijepur Shale on the fining-up Kansapathar Sandstone without any discernible zone of transition appears to us as a most likely indication of rapid sea-level rise, expansion of the basin and retrogression of the shore line. The supply of sand was restricted to episodic influx of fine sands and silts, either by sand-laden underflows or by storm-flows, depositing thin Bouma sequences in distal shelf areas.

Fig. 5—Medium to fine grained sandstone body within gray limestone.

Sarangarh Limestone

The Sarangarh Limestone gradationally overlies the Bijepur Shale and locally, as mentioned earlier, overlies the Kansapathar Sandstone with a sharp contact. It grades upward into the Gunderdehi Shale. The maximum thickness of the Formation is ~150 m. The Limestone contains several colour-defined stratigraphic intervals, e.g. brown, gray, black and mauve in an ascending order, which has been classified into two members, the *Gadhabhata Member* and the *Timarlaga Member*.

Fig. 6—Gadhabhata limestone with intercalated glauconitic sandstone. Note the sharp erosional contact.

Gadhabhata Member—The Member is best described as a mixed carbonate-siliciclastic succession, and comprises brown and gray limestone with high amount of intercalated sands. The sands occur as thin stringers, discrete layers, thick beds or small positive-relief bars of medium- to fine-grained subarkosic glauconitic sandstone at different levels (Fig. 5). Coarse to very coarse and gritty, well-rounded sands also occur locally at the uppermost level of gray limestone (Fig. 6) with sharp or erosional lower contacts. The sandstones are characterized by planar lamination, hummocky cross-stratification and combined-flow ripples. The interval also contains small pockets or thin sheets of limeclast conglomerates at places (Fig. 7). The lime-clasts are platy, and are either brown or gray, depending on the color of the host carbonate rocks, and range in size from a few cm to 1m. The maximum thickness of the Member is 100 m, and thickness of the thickest interval of glauconitic sandstone intercalated with limestone at village Gadhabhata is about 10 m.

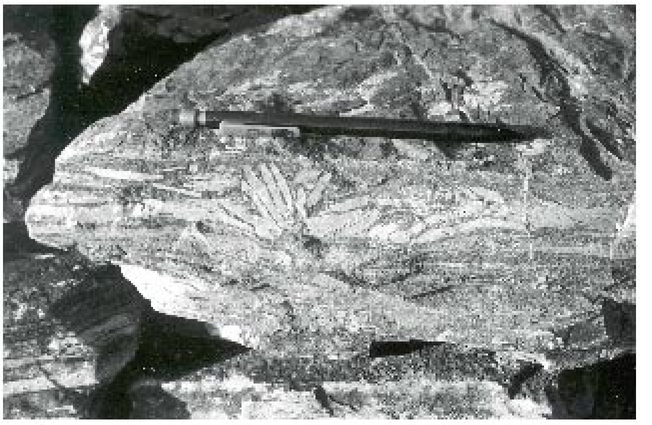

Fig. 7—Mixed siliciclastic-micrite bed with small pocket of autoclastic lime-clast conglomerate.

Timarlaga Member—It comprises a channel-fill body incised into the gray limestone of the Gadhabhata Member, and extensive sheets of black and mauve limestones. The channel-fill body is about 90 m wide, and has a maximum thickness of 50 m. It consists of intensely folded and contorted thin beds of gray limestone, and conglomerate with floating lime-clasts within a matrix of micrite and very well-rounded coarse sands (Fig. 8). It also consists of a few boulder-sized clasts of black chert. The conglomerate is best exposed along a nala just to the north of Gadhabhata Village (21º3'16''N; 83º7'16''E).

The black limestone overlies the channel-fill conglomerate body and the gray limestone with a sharp contact. It is jade black on fresh surface and weathers to a dull earthy residue. Siliciclastics coarser than mud are conspicuously absent in the black limestone and in the overlying mauve limestone. The black limestone is characterized by 5-30 cm thick, laterally persistent beds (Fig. 9), and there are several intervals of well developed rythmite of black limestone and gray/steel gray marly beds or dark calcareous mudstone engendering a heterolithic character. Pressure solution seams are well developed, and many of the bedding contacts are marked by thick concentrations of insoluble residues. The limestone and marly beds are commonly planar-tabular, though thickening and thinning of beds, wavy bedding, and hummocky cross-stratification are well developed at several intervals. Pyrite occurs profusely in this unit, either as isolated framboids or as well developed crystals along bedding planes. The black limestone is ~ 35 m thick, and grades upward to the mauve limestone, and finally to the brown shale of the Gunderdehi Shale. The Member is marked by remarkable facies constancy, and by conspicuous absence of sand size clastics. It is the best exposed in the Timarlaga quarry, near the confluence of the Lat Nala and the Mahanadi River where it attains a thickness of ~ 40 m.

The colour-defined intervals and the entire gamut of facies in the carbonate sequence very well developed in several exposures around Sarangarh, and it has been designated as the Sarangarh Limestone (also see Schnitzer, 1971). The Sarangarh Limestone, occurring between Kansapathar Sandstone–Bijepur Shale and the Gunderdehi Shale, corresponds to the Charmuria Limestone, described from the central and western part of the basin by Dutta (1964) and Murti (1987, 1996).

Gunderdehi Shale

The Formation is dominated by brown shale. Green shale occurs as a subordinate constituent. Dolomite, stromatolitic limestone, sandstone and tuff occur in minor quantities. The brown shale overlies the mauve limestone of the Timarlaga Member through a narrow transition zone of shale-limestone heterolithic. It is characterized by 2-10 cm thick very persistent beds. Several 10-25 cm thick mud-clast conglomerate beds occur at places. At certain levels, nodules of authigenic barite occur along a narrow zone within the shale.

Dolomite occurs at several intervals as lenticular beds which coalesce together to form positive relief feature, and also as thin planar beds alternating with shale and calcarenites forming up to 0.5-5 m thick packages. Thick green ash-tuff occurs at different levels within the brown shale. They are characterized by 2-10 cm thick beds with incomplete Bouma sequences, and well-preserved sole marks.

Stromatolites occur in small isolate bioherms, enclosed within red shale (Fig. 10), mostly at the basal part of the Formation. The occurrence of the bioherms distinguishes the Gunderdehi Shale from other red shale dominated intervals of the Raipur Group.

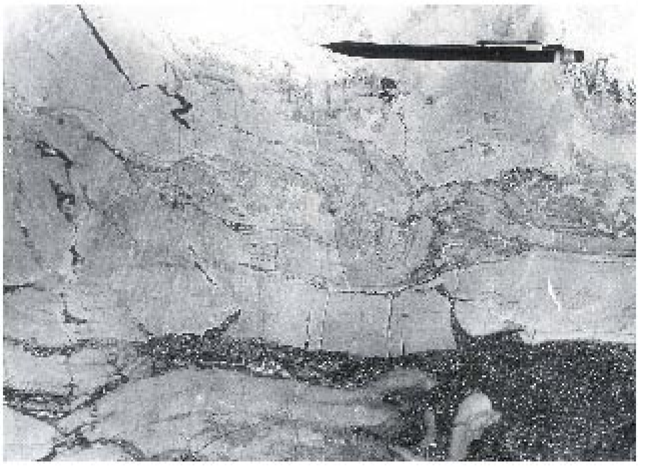

Fig. 8—Folded and contorted thin beds of gray limestone, and debris-flow conglomerate of auto-limeclasts floating within matrix of micrite and very well-rounded coarse sands.

Fig. 9—Black limestone (weathered) showing laterally persistent beds.

Fig. 10—The stromatolite mounds which occur in small bioherms, enclosed within red shale.

Saradih Limestone

The Saradih Limestone overlies the Gunderdehi Shale with a gradational contact, and, by turn, grades up to the Churtela Shale. The Limestone is characterized by rapid variations between major facies including dolomite, limestone-marl rythmite, tidal bars of sandy micrite, lime-clast conglomerates, and stromatolite bioherms. A thick unit of bedded dolomite occurs at the basal part of the formation, well exposed at the northern bank of the Mahanadi River, south of Rotopali Village (N21º46'21"; E 83º07'43") and Saradih Village (N21º43'31"; E 83º02'43"). The dolomites grade upward to a rythmite facies, very well exposed in a few quarries near Rotopali Village. The rythmite facies closely resembles the black limestone rythmites in the Sarangarh Limestone, though unlike in the latter, the Saradih rythmite rapidly grades upward into a tidal bar sequence of sandy micrite. Tabular beds of lime-clast conglomerate and small stromatolite bioherms occur in isolated patches. Profusion of stromatolite increases westward. The facies heterogeneity, absence of black limestone and the colour-defined stratigraphy, and profuse development of stromatolite distinguish the Saradih Limestone from the Sarangarh Limestone. Stromatolites are conspicuously absent in the latter. The Saradih Limestone has a maximum thickness of ~100 m in the study area, and becomes thicker westward. Bounded by the Gunderdehi Shale below and the Churtela Shale at the top, it occupies a stratigraphic position similar to the Chandi Limestone, defined from the western and central part of the basin (Dutt, 1964; Murti, 1987). The stromatolites characterize the Limestone as a major biostratigraphic unit (Moitra, 1999).

Churtela Shale

The Churtela Shale is ~300 m thick, and comprises a heterogeneous succession of red shale, green tuffaceous shale-mudstone, two intervals of ignimbrites, and subordinate dolomites, hydrofractured chert and volcaniclastic sandstone (Patranabis-Deb *et al.*, 2007). Dolomites occur as small isolated bodies within red and green shale, whereas hydro fractured chert occurs within the lower ignimbrite horizon. The Formation has been designated after the name of Churtela Village (83°5'E; 21°51'N). The lateral persistence of different constituent lithologies within this zone could not be unambiguously ascertained in the field, though the interval appears to be characterized by strong lateral facies changes between different lithologies.

The lower ignimbrite horizon, the Sapos Tuff, is best exposed near Sapos Village (83°10'E; 21°45'N), and is dominated by green welded tuff with interbedded unwelded tuff, and closely associated patches of coarsely crystalline dolomite and hydrofactured chert. The upper one, the Sukhda Tuff, is best exposed near Sukhda Village (N21º51'59.1"; E 83º05'56.2"), and includes intercalated beds of volcaniclastic sandstones. The welded tuff beds are brownish red, black and greenish in colour, and are commonly 2-10 cm thick. The volcaniclastic sandstone beds are commonly 40-60 cm thick, medium grained with very uniform texture, and are massive ungraded. The shale-tuff assemblage is terminated by the sub-Sarnadih unconformity, which, by turn, is overlain by the Sarnadih Sandstone of Sequence II.

The Churtela Shale occupies a stratigraphic position similar to that of the Tarenga Shale which overlies the Chandi Limestone in the central and western part of the basin (Murti, 1987, 1996; Das *et al.*, 1992). The Tarenga Shale is tuffaceous (Das *et al.*, 1992), and is considered as a lateral equivalent of the Churtela Shale.

KHARSIYA GROUP

Sarnadih Sandstone

The Sarnadih Formation, named after the village Sarnadih (83°6'E; 21°54'N) is the basal formation of the Kharsiya Group. It overlies multiple formations of the Raipur Group with an erosional unconformity, and comprises an extensive interval of red sandstone, with a thin conglomerate horizon mantling the unconformity surface. The sandstone and the conglomerate occur mostly in subcrop, and have been exposed in the extensive network of irrigation channels that are being excavated north of the Mahanadi River. It has been identified for the first time as a major stratigraphic element.

The conglomerate contains pebbles of brown, green and black welded tuff, unwelded tuff, chert and dolomite, as well as pebbles of quartzite, sandstone and vein quartz. The clast size commonly varies from 2-20 cm. The pebbles of tuff, chert and dolomite are strongly indicative of intrabasinal derivation from underlying Churtela Shale during the hiatus and exposure of the Churtela Shale to the erosional level.

The conglomerate grades up to pebbly sandstone and very coarse grained arkosic sandstone. The sandstone beds at the basal part are commonly 10-20 cm thick, with several beds ranging up to 70-80 cm in thickness. The beds are cross-to planar stratified, and exhibit signatures of intense soft sediment deformation. The deformation is mostly by fluid escape, which often generates overturned cross-strata, ball and pillow structures, crumpled mass of strata, or fluidization obliterating bedding structures. The arkosic sandstones grades up to medium grained red quartzose sandstone with slightly wavy bounding surfaces, and pinch and swell morphology. The beds are wavy to planar laminated, or planar cross-stratified often with asymptotic foresets. A few beds have wave ripple, parting lineation, and current crescent on their upper surfaces. Several bedding surfaces are mantled by single grain thick layers of small pebbles, or thin mud laminae.

Nandeli Shale

The Nandeli Shale, named after the village Nandeli (83°15'E and 21°53'30"N), gradationally overlies the Sarnadih Sandstone. The lower part of the formation is sandstone-mudstone heterolithic, and is characterized by intense soft sediment deformation in several stratigraphic levels. The deformation is manifested by ball and pillow structures, detached sandstone balls enclosed within red shale, or small sand volcano type structures protruding through shale. Many undeformed thin sheets of sandstone exhibits straight crested ripples, interference ripples and rain prints covering large areas of sandstone- pavements. The upper part of the sequence is shale dominated. The common occurrences of isolated sandstone bodies, often with strong soft-sediment deformation, characterize the Shale, and discriminates it from the Gunderdehi Shale, which is virtually free of sand accumulations. Patranabis-Deb *et al.* (2007) designated the Shale as Kharsiya Shale. However, it is being redesignated here as the Nandeli Shale, and the Sequence II is being designated as the Kharsiya Sequence.

GONDWANA SUPERGROUP

The Kharsiya Sequence is unconformably overlain by greenish sandstone and green shale of the Talchir Formation, and coarse grained arkosic sandstone of the Barakar Formation of the Gondwana Supergroup. The Gondwana rocks occur in a small outcrop around Kunkuni, (83°10'E and 21° 59' N), and appears to be the extension of the adjoining Rewa Gondwana basin.

CONSTRAINS IN CORRELATION AND STRATIGRAPHIC MARKERS

Comparison of stratigraphy presented here with the successions erected by earlier workers succinctly brings out the constraints in correlating different sections of an unfossiliferous succession. Though a fairly uniform mode has been followed by different workers for classifying the Chandarpur siliciclastics, precise correlation of different units in different sections poses major problems. In the Sarangarh–Raigarh section, the upper part of the Lohardih Formation comprises irregular bodies of sandstones and conglomerates, representing multiple delta lobes enclosed within shale (Patranabis-Deb & Chaudhuri, 2007), which for all practical purpose of mapping can not be distinguished from the shale at the lower part of the Gomarda Formation. The contact between them, thus, is tentative. Furthermore, the Gomarda Formation as proposed here comprises about 650 m thick immature succession of shale and sandstone, whereas in more westerly sections, the Chaporadih Formation which occurs between the Lohardih Formation and the Kansapathar Sandstone (Murti, 1987) and occupies a stratigraphic position similar to that of the Gomarda Formation, consists of an ~15 m thick unit of fine grained argillaceous sandstone or sandy shale. The three–fold classification of the Chandarpur Group was first introduced by Murti (1987), though Dutta (1964) and Moitra (1995) defined the entire siliciclastic assemblage from the base of the succession to the top of the Kansapathar Formation as Chandarpur Sandstone. Schnitzner (1971), on the other hand, classified it into a basal conglomerate and an upper, Chandpur quartzite. It seems that the three–fold classification of the Chandrapur Group is valid only in the eastern part of the basin, rather than in the western part where Chaporadih Formation can easily be considered as a member of a formation. In the area of the present study, only the uppermost unit, the Kansapathar Sandstone, is endowed with uniform textural and structural characters over wide areas, and has well defined upper and lower contacts. About 40 km west of Sarangarh, beyond the area of the map presented here, the siliciclastics occurring between the granite-greenstones of the basement complex and the overlying Sarangarh Limestone is about 80-90 m thick, and is dominated by locally glauconitic sub-arkose and quartzarenite. Conglomerates and pebbly sandstones occur as minor constituents. The sandstone is not amenable to classification into multiple lithostratigraphic units of formation status, and is considered as a lateral extension of the Kansapathar Sandstone.

Stratigraphic classification of a cyclic sequence similar to the Raipur and Kharsiya groups also poses many problems, particularly if characteristic lithological attributes of major stratigraphic units are not appropriately recognized, for example, small stromatolite bioherms and barites in the Gunderdehi Shale, pyroclastics in the Churtela Shale or small build-ups of sandstones all with strong soft-sediment deformation structures in the Nandeli Shale. It would also be a daunting task to correlate red shale dominated units in different sections without any reference to their stratigraphic relation to the Sarangarh and/or Saradih Limestone.

The problem of correlation can be overcome with the help of major stratigraphic marker horizons. In the Chandarpur Group, the Kansapathar Sandstone with its high sandstone maturity and high facies constancy throughout the basin is the most important stratigraphic marker for the purpose of correlation. In the Raipur Group, the black limestone facies of the Timarlaga Member is a very distinctive key bed for stratigraphic correlation. The Gunderdehi Shale characterized by the occurrence of stromatolite bioherms can also be used as an excellent marker horizon.

STROMATOLITES IN THE RAIPUR GROUP AND BIOSTRATIGRAPHY

Stromatolites and bioherms in the Chandi Limestone (referred to as Raipur Limestone in several publications) have been described in details by several workers (Chatterjee *et al.*, 1990; Guhey & Wadhwa, 1993; Moitra, 1999). Moitra (1999) has further made a detailed evaluation of the biostratigraphic status of the stromatolite-bearing Chandi Formation. A brief description of the stromatolites and bioherms in the Gunderdehi Shale, excluding any attempt for morphology based taxonomic classification, is being made here.

The bioherms in the Gunderdehi Shale range in size from 3-5 m (Fig. 10) to more than 100 m in length. Small bioherms consisting of a single build-up or mound normally range from 60-80 cm in height. Larger bioherms, such as the one near Malda Village in the eastern bank of Lath Nala (83°10'E; 21°34'N), on the other hand, may be more than 4-5 m in height. The larger bioherms are composites of smaller mounds, each separated from the adjoining one by shale-mudstone (Figs 10 & 11). Small individual mounds or larger composite bodies are all elongate in shape, with a very persistent direction of elongation in each locality. The bioherms occur as isolated bodies enclosed within red shale, fine sandy mudstone, or rarely by mud-dominant heterolithics with intercalated layers of fine sandstone. Coarse sands are conspicuously absent in the system.

The bioherms contain mainly 3 types of stromatolites with minor variation among themselves: 1. columnar non-branching stromatolite; 2. columnar branching stromatolite; 3. elongate stromatolite. These three types may occur in close association with each other, particularly in the larger bioherms. In the bioherm near Malda many of the smaller elongate mounds are made up only of elongate stromatolites, whereas quite a few consist of a closely associated assemblage of elongate and columnar structures.

Fig. 11—The larger bioherms are composites of smaller mounds, each separated from the adjoining one by shale-mudstone.

Fig. 12—Non-branching columnar stromatolites with parallel to sub-parallel columns, with a fairly constant diameter from the base to the top of the structures.

Fig. 13—Plan view of the columnar stromatolites which are as circular to slightly elongate with concentric laminations.

Type 1: Non-branching columnar stromatolites

The structures occur as parallel to sub-parallel, circular to slightly elongate columns, with a fairly constant diameter from the base to the top of the structures (Fig. 12). In plan the structures appear as circular to slightly elongate with concentric laminations (Fig. 13). Size of the columns, both diameter as well as height, varies considerably between adjacent colonies, though within a single colony the column size remains fairly constant. Spacing of the columns also varies considerably in different colonies, and the inter-columnar areas are filled up with argillaceous limemud (Figs 12 & 14). Column margins are smooth, though not enveloped. The internal laminae may be nearly flat, though commonly these are upwardly growing and convex-upward. The colonies develop a bedded appearance where column height is constant, and successive 'stromatolite beds' are separated by mudstone (Fig. 14).

Type 2: Branching columnar stromatolites

Individual columns are very similar to the non-branching columnar structures, but a single column bifurcate into nearly parallel columns. Branching may take place at multiple points upward from the base of the structure (Fig. 15). Columns may continue from base to top, but may also end up midway.

Type 3: Elongate stromatolites

The stromatolites are unlinked to partially linked, with elongation aspect ratios > 6 : 1 (Fig. 16). Column heights may range from 40-60 cm, and they often stand in upright position making parallel ridge-like structures. In sections perpendicular to the long axis, the structures look like narrow columns with width ranging between 4-6 cm. The constituent laminae show slight upward curvature in transverse sections, whereas they appear as nearly flat in sections parallel to the long axis. The inter-areas are filled up with brown lime-mud. They exhibit very persistent direction of elongation (Fig. 16). In several mounds, elongate stromatolites occur in close association with non-branching columnar type (Figs 17 & 18).

PALAEOGEOGRAPHIC IMPLICATION OF GUNDERDEHI STROMATOLITES

The elongate stromatolite structures in the Gunderdehi bioherms show a very well defined E-W trend (Figs 4, 16). Degree of elongation and asymmetry of laminae are most likely related to the direction of water flow and sediment supply (cf. Hoffman, 1967; Gebelin, 1969; Chaudhuri, 1970; Semikhatov *et al.*, 1979). Strongly elongate stromatolites are typical of subtidal to intertidal settings of high to moderate energy ramps where elongation of the mounds as well as of the structures is dependent on relative amount of wave surge and/or tidal strength (Grotzinger, 1989; Playford & Cockbain, 1969, 1976; Hoffman, 1976; Beukes, 1987). Extreme elongation of unlinked stromatolites as well as of stromatolitic mounds, similar to that in Gunderdehi bioherms, suggests exposure to strong tidal currents oriented at high angle to the shore line. Unlinked columnar structures, on the other hand, may have been subjected more to wave action (Hoffman, 1976). Close association of unlinked elongate and columnar structures in several elongate mounds in a large bioherm appear to speak for combined tidal currents and storm surges in open headlands. Localized occurrence of elongate structures only in a few bioherms further suggests that such bioherms possibly developed in large tidal channels with amplified tidal velocities. The E-W orientation of elongate stromatolites points to a broadly N-S orientation of the shore line during deposition of the Raipur Group.

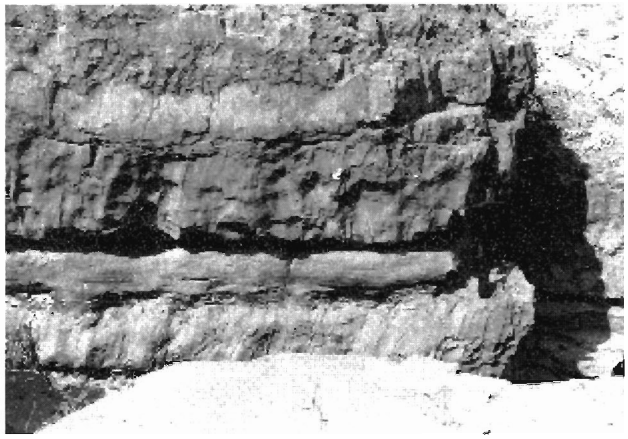

Fig. 14—Within a single mound the colonies develop a bedded appearance where column height is constant, and successive 'stromatolite beds' are separated by mudstone.

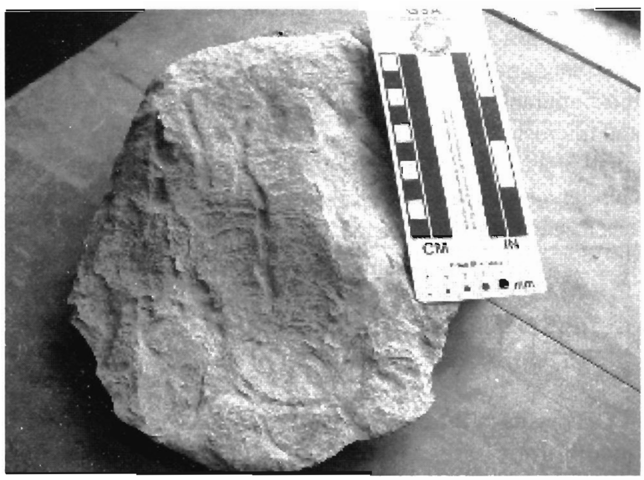

Fig. 15—A single column of branching type stromatolite showing bifurcation into nearly parallel columns. Branching may take place at multiple points upward from the base of the structure.

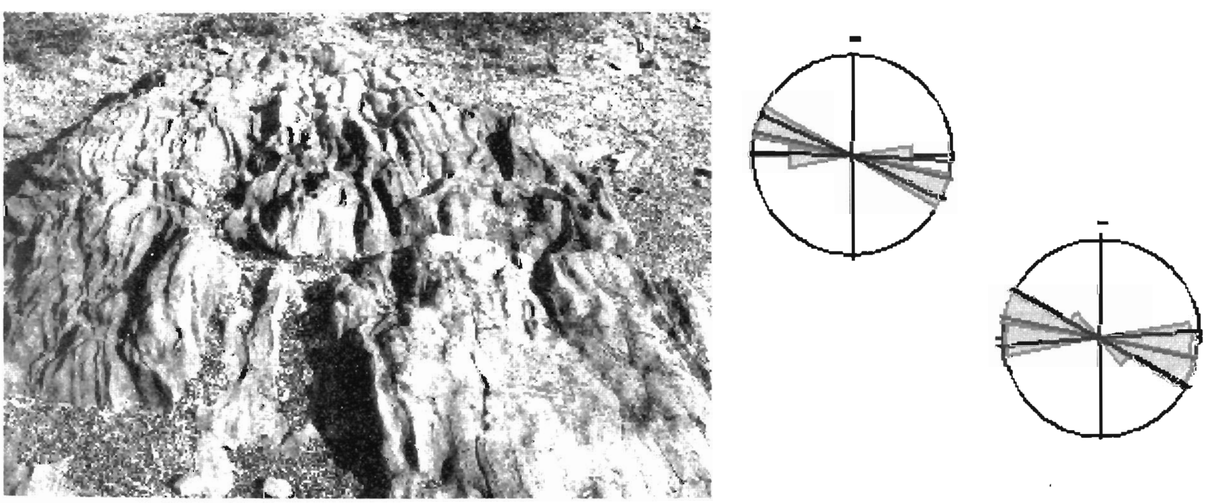

Fig. 16—Elongate columnar stromatolites. Direction of elongation shown by the rose diagram indicates palaeoflow direction within tidal channels.

BIOSTRATIGRAPHIC SIGNIFICANCE OF GUNDERDEHI STROMATOLITES

Despite protracted debate on the application of stromatolites in high resolution biostratigraphy, it is generally accepted that the morphological variability of stromatolites within an individual bioherm and between widely separated bioherms of the same type at an equivalent stratigraphic level is limited (Krylov, 1976). Krylov designates the combination of all principal morphological varieties that build up one or several bioherms of the same type as the 'bioherm series'. Although morphological varieties may be controlled to a large extent by environmental factors, the combination of morphologies at different stratigraphic levels are distinctive for each level and generally possess a distinctive, apparently time related microstructure (Serebryakov & Semikhatov, 1974; Bertrand-Sarfati & Walter, 1981; Wen-long &Walter, 1992; Hill, 2000). Detailed analysis of morphology and microstructure of stromatolites has established the biostratigraphic status of the Chandi/Saradih Limestone (Moitra, 1990, 1999). Though biostratigraphic correlation may require rigorous morphologic and microstructural analysis, occurrences of similar types of small bioherms within the limited stratigraphic interval of the Gunderdehi Shale speaks for its biostratigraphic status, and sets it out as a marker for intrabasinal correlation.

MAJOR EVENTS OF SEA-LEVEL CHANGES, DEPOSITIONAL CYCLES AND INTRABASINAL CORRELATION

Transits of the base level and the creation of surfaces of unconformity are related to changes in sea-level. Any succession of strata packaged between unconformities, and by default, the depositional cycles, specifically and unambiguously occupies some part of a chronostratigraphic time span that can be identified by refined biostratigraphy (Sloss, 1991). The application of the concept of depositional cycles, collectively with lithostratigraphic characterization of formations that speaks for depositional environments and changes therein, thus, provides the most sensitive tool for intrabasinal, and even interbasinal correlation of unfossiliferous successions.

An evaluation of the lithostratigraphic parameters of different formations suggests that the lithologic package or the sequence bounded between the sub-Lohardih and the sub-Sarnadih unconformities, i.e. the combined succession of the Chandarpur and Raipur groups is comprised of several coarsening-up and fining-up cycles (Fig. 4). The Lohardih and Gomarda formations exhibit several C-U/F-U cycles, related to active tectonics of the Chhattisgarh rift (Patranabis-Deb & Chaudhuri, 2002; 2007). The succession from the uppermost part of the Gomarda Formation to the top of the Churtela Shale, on the other hand, exhibits several well defined shallowing-up cycles.

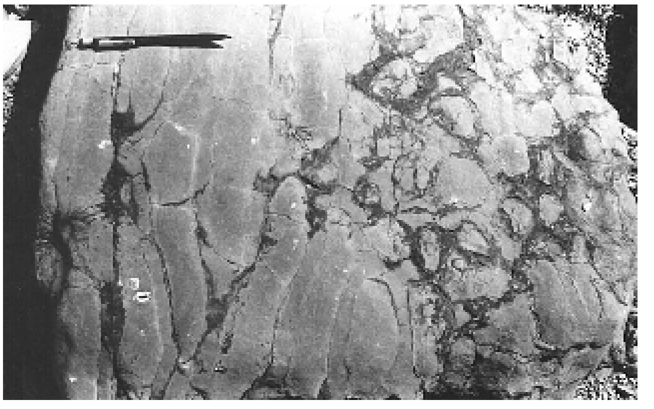

Fig. 17—Elongate stromatolites occur in close association with non-branching columnar type.

Fig. 18—Elongate stromatolites and elliptical non-branching columnar stromatolites in section. Note that the columns at the right hand side of the photo are inclined.

The first shallowing-up (S-U:I) cycle comprises the package from the uppermost part of the shale/shale-mud heterolithics to the top of the Kansapathar Sandstone, deposited between lower subtidal to upper intertidal/supratidal environments. The shallowing-up cycle II (S-U: II) is represented by the succession from the base of the Bijepur Shale to the top of the Ghadhabhata Member of the Sarangarh Limestone. As discussed earlier, the rapid superposition of the Bijepur Shale on the upper intertidal–supratidal facies of the Kansapathar Sandstone is the most likely indication of a rapid sea-level rise and retrogration of the coast line. Subsequent to the rapid rise, a gradual fall in the relative sea-level and progradation are indicated by influx of sands in the brown and gray limestones of the Gadhabhata Member, which peaked with the deposition of very coarse sands and granules at the uppermost part of the gray limestone. The granules and coarse sands were transported to the outer margin of the Ghadhabhata platform, and were transported down the channel forming the matrix of the limestone-clast conglomerates.

The succession from the base of the black limestone to the basal dolomite-bearing interval of the Saradih Limestone represents the shallowing-up cycle III (S-U: III). The cycle

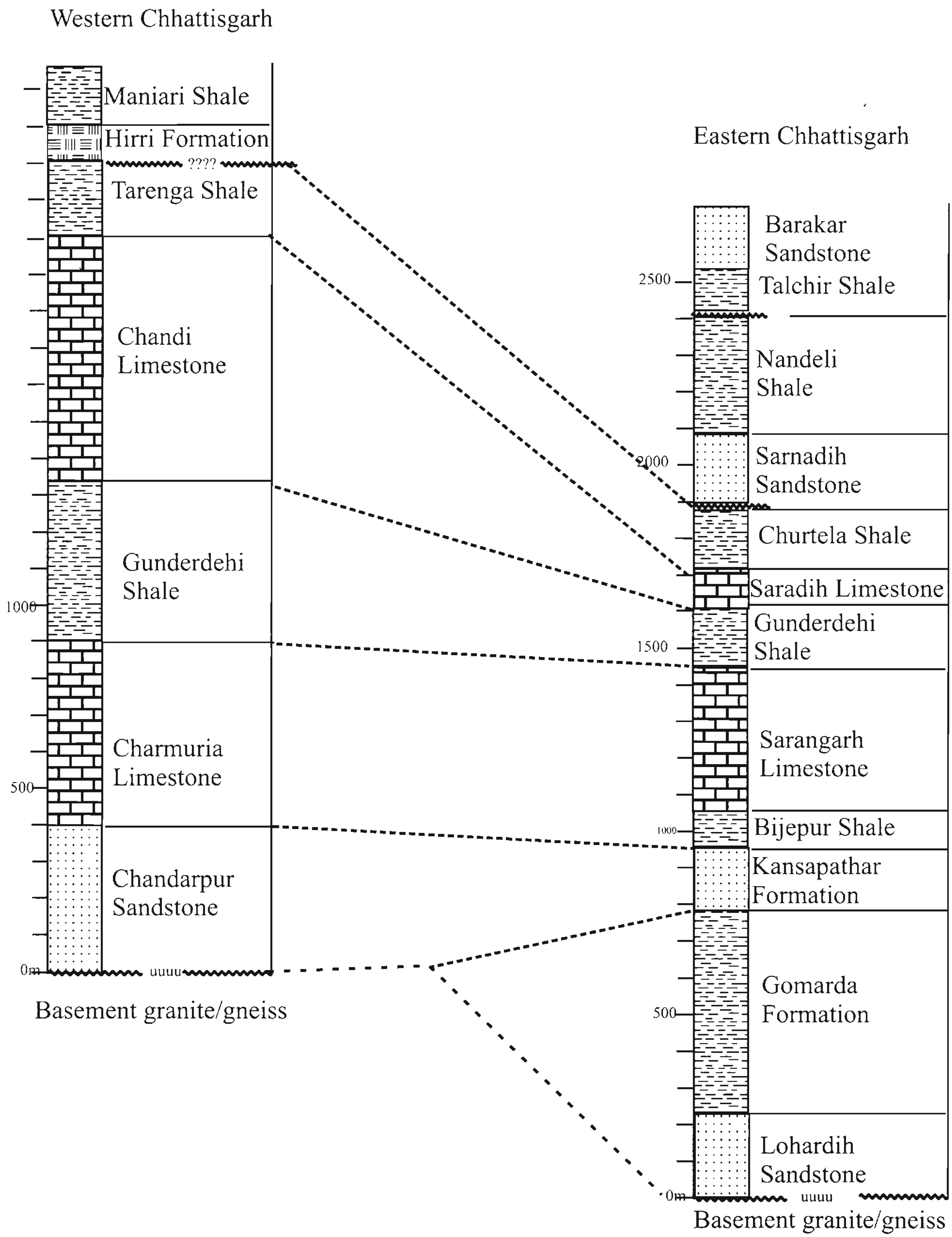

Fig. 19—Diagram showing possible lithostratigraphic correlation between the eastern and the western sectors of the Chhattisgarh Basin.

includes the Timarlaga Member of the Sarangarh Limestone, the Gunderdehi Shale and the basal part of the Saradih Limestone. The superposition of the black limestone on the mixed carbonate-siliciclastic deposits of the Gadhabhata Member along a sharp contact appears to us to represent an event of rapid rise in relative sea-level and retrogration. The stratigraphic relationship is similar to that between the Kansapathar Sandstone and the Bijepur Shale. Next shallowing-up cycle (S-U:IV) starts with the deposition of limestone-marl/shale rythmite of the Saradih Limestone, and terminated with the development of bioherms at the uppermost part of the Formation. Subsequent drowning of the Saradih platform and deposition of the S-U:V is represented by the Churtela Shale. The thick, massive ungraded beds of volcaniclastic sandstones intercalated with Sukhda tuff at the upper part of the preserved succession of the Churtela Shale point to deposition by sediment gravity flows, and preservation of the beds point to deposition below the storm wave base. The upper part of the cycle is truncated by the sub-Sarnadih unconformity.

The correlation of the formations developed in the western and eastern parts of the Chhattisgarh Basin, made on the basis of depositional cycles and key marker beds, is presented in Fig. 19. The correlation proposed here contradicts the concept of two sub-basins, the Hirri and Baradwar sub-basins, separated by a Sonakhan greenstone ridge and significant differences between lithofacies in western and eastern parts of the basin (Das *et al.*, 1992).

Recognition of the unconformity at the base of the Sarnadih Sandstone defines the Kharsiya Group as a major stratigraphic unit younger than the Raipur Group. The recognition of this unconformity further contradicts the geological maps of the Chhattisgarh area published by the Geological Survey of India. In the GSI maps, the large sandstone body enclosed within shale near Sukhda Village, has been designated as the Chandarpur Sandstone (GSI, 2005a) or as 'Lohardih Formation'(GSI, 2005b), which occurs at a much lower stratigraphic level, at the lower part of the Sequence I.

Correlation of the Kharsiya formations with the formations younger than the Tarenga Shale in the western part of the basin can not be attempted at this stage, and would require further evaluation of the relation of the Tarenga Shale with the overlying Hirri Formation and Maniari Shale. The probability that the Kharsiya Group may be younger than the Hirri and Maniari formations can also not be ruled out at this stage.

CONCLUDING REMARKS

The Chhattisgarh succession in the eastern part of the basin comprises two unconformity bounded sequences. The lower sequence (Sequence I) corresponds to the Chhattisgarh Supergroup of earlier workers and comprises the combined succession of the Chandarpur and Raipur groups. It overlies the rocks of the basement complex with a profound unconformity. The Sequence II has been identified for the first time, and has been designated as the Kharsiya Group. It overlies different formations of the Raipur Group, and is, in turn, unconformably overlain by rocks of the Gondwana Supergroup.

The Chandarpur Group constitutes the basal part of Sequence I, and consists of a siliciclastic assemblage comprising an immature succession of conglomerate, sandstone and shale, the Lohardih and Gomarda formations, which grades up into a mature sandstone, the Kansapathar Sandstone. The Lohardih and Gomarda succession is characterized by rapidly changing depositional systems indicating variable rates of subsidence and creation of accommodation space, and was deposited in alluvial-fan–fandelta–prodelta environments. It is best developed (about 800 m) in the eastern part of the basin, and rapidly thins out towards west. Near Bilaigarh and further west, the Kansapathar Sandstone directly overlies the basement. Welded tuffs at the upper most part of the Churtela Shale attest to intrabasinal volcanism at ~1000 Ma, leading to the basin closure and generation of a sequence-bounding unconformity. The upper sequence, Sequence II, comprises a sandstone-dominated and a shale-dominated formation. The formations show abundant soft sediment deformation structures, indicating unstable basin condition.

The Raipur Group includes two extensive carbonate platforms. The lower platform, the Sarangarh Limestone, is marked by the conspicuous absence of stromatolites, and developed as an un-rimmed shallow water platform which evolved into a deep water ramp. The upper platform, the Saradih Limestone (and its lateral correlative, the Chandi Limestone), had extensive growth of stromatolite bioherms and developed as a shallow water rimmed platform. The Raipur Group provides an excellent example of cyclic sedimentation between red/ brown shale and limestone. The cyclicity is manifested by three very well developed shallowing cycles. The preserved section of the Churtela Shale represents a deepening phase, though the general motif of sedimentation may indicate the development of a shallowing upper part, which was eroded out during the sub-Sarnadih unconformity. The dolomites of the Hirri Formation appears to represent the shallowing-up phase of the cycle, though a definitive interpretation would require further field checks.

The Kansapathar Sandstone, the black limestone facies of the Sarangarh Limestone, and Gunderdehi Shale characterized by development of small stromatolite bioherms enclosed within shale are key marker horizons for intrabasinal correlation of the formations. The most conspicuous lateral facies variation that can impede correlation is represented by the thick wedge of immature clastic succession of the Lohardih and Gomarda formations which had maximum development in the eastern part of the basin. The succession pinches out towards the western part where the minor facies variation within the sub-Raipur clastic succession can be accommodated within the definition and meaning of the Kansapathar Formation.

The formations of the Raipur Group can be traced laterally from the western to the eastern part of the basin indicating that the basin behaved as a monolithic unit during the subsidence stage of its evolution when accommodation space was created or destroyed at a fairly uniform rate throughout the basin. The proposition contradicts the concept of western and eastern sub-basins (cf. Das *et al.*, 1992), separated by a mountain of Sonakhan greenstone belt. The unconformity identified at the base of the Sarnadih Sandstone further contradicts couple of published maps where the sandstone around Sukhda Village has been shown as an inlier of Chandarpur Sandstone or Lohardih Sandstone.

The stromatolites in the Saradih Limestone and the Gunderdehi Shale impart a biostratigraphic significance to the formations, opening up the possibility for biostratigraphic correlation, both on intrabasinal and interbasinal scale.

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REFERENCES

Ahmad F 1958. Palaeogeograpy of central India. Geological Survey of India Records 87: 513-548.

Ball V 1877. On the geology of Mahanadi Basin and its vicinity. Geological Survey of India Records 10: 167-186.

Bertrand-Sarfati J & Walter MR 1981. Stromatolite Biostratigraphy. Precambrian Research 15: 353-371.

Beukes NJ 1987. Facies relations, depositional environments and diagenesis in a major early Proterozoic stromatolitic carbonate platform to basin sequence, Campbellrand Subgroup, Transvaal Subgroup, southern Africa. Sedimentary Geology 54: 1-46.

Chakraborty PP & Paul S 2008. Forced regressive wedges on a Neoproterozoic siliciclastic shelf: Chandarpur Group, central India. Precambrian Research 162: 227-242.

Chatterjee (Jha) N, Das N, Ganguly (Das) M & Chatterjee B 1990. Stromatolite based biostratigraphic zonation of Chandi Formation, Raipur Group, Chhattisgarh Supergroup, in and around Dhamdha-Nandini area, Durg District, Madhya Pradesh. Geological Survey of India Special Publication 28: 400-410.

Chaudhuri AK 1970. Precambrian stromatolites in the Pranhita-Godavari Valley (south India). Palaeogeography, Palaeoclimatology, Palaeoecology 7: 309-340.

Chaudhuri AK, Saha D, Deb GK, Patranabis-Deb S, Mukherjee MK & Ghosh G 2002. The Purana Basins of Southern Cratonic Province of India - A Case for Mesoproterozoic fossil rifts. Gondwana Research 5: 23-33.

Das DP, Kundu A, Das N, Dutta, DR, Kumaran K, Ramamurthy S, Thanavelu C & Rajaiya V 1992. Lithostratigraphy and sedimentation of Chhattisgarh Basin. Indian Minerals 46: 271-288.

Dutt NVBS 1964. A suggested succession of the Purana formations of the Southern part of Chhattisgarh, MP. Geological Survey of India Records 93: 143-148.

Gebelin CD 1969. Distribution, morphology and accretion rate of recent subtidal algal stromatolites, Bermuda. Journal of Sedimentary Petrology 39: 49-69.

Geological Survey of India 2005a. Geological and Mineral Map of Chhattisgarh.

Geological Survey of India 2005b. District Resource Map–Janjgir District, Chhattisgarh.

Grotzinger JP 1989. Facies and evolution of Precambrian carbonate depositional systems: emergence of modern platform archetype. *In*: Crevello PD, Wilson JL, Sarg, JR & Read JF (Editors)—Controls on carbonate platform and basin development: SEPM Special publication 44: 79-106.

Guhey R & Wadhwa 1993. Stromatolites from Raipur Limestone around Nandini, Durg District, Madhya Pradesh. Indian Journal of Earth Sciences 20: 42-49.

Hill AC, Cotter KL & Grey K 2000. Mid-Neoproterozoic biostratigraphy and isotope stratigraphy in Australia. Precambrian Research 100: 281-298.

Hoffman PF 1967. Algal stromatolites: use in stratigraphic correlation and paleocurrent determination. Science 157: 1043-1045.

Hoffman PF 1976. Environmental diversity of middle Precambrian stromatolites. *In*: Walter MR (Editor)—Stromatolites: 599-611. Elsevier, Amsterdam.

King W 1885. Sketch of the Progress of Geological Work in the Chhattisgarh Division of the Central Provinces. Geological Survey of India Records 18: 169-200.

Kruezer H, Harre W, Kürsten M, Schnitzer WA, Murti KS, & Srivastava NK 1977. K/Ar Dates of two glauconites from the Chandarpur-Series (Chhattisgarh/India): On the stratigraphic status of the Late Precambrian Basins in Central India. Geologisches Jahrbuch B28: 23-36.

Krylov IN 1976. Approaches to the classification of stromatolites in the USSR. *In*: Walter MR (Editor)—Stromatolites: 31-43. Elsevier, Amsterdam.

Moitra AK 1990. Chronologic implications of the stromatolites, microbiota and trace fossils of the Chhattisgarh Basin, Madhya Pradesh. Workshop on Precambrian of central India. Geological Survey of India, Special Publication 28: 384-399.

Moitra AK 1995. Depositional environmental history of the Chhattisgarh Basin, M.P., based on Stromatolites and Microbiota. Journal Geological Society of India 46: 359-368.

Moitra AK 1999. Biostratigraphic study of stromatolites and microbiota of the Chhattisgarh Basin, M.P., India. Palaentologia Indica, New Series: L1. GSI Kolkata, 1-95.

Murti KS 1987. Stratigraphy and sedimentation in Chhattisgarh Basin. *In*: Radhakrishna BP (Editor)—Purana Basins of Peninsular India (Middle to Late Proterozoic). Geological Society of India Memoir 6: 239-260.

Murti KS 1996. Geology, sedimentation and Economic mineral potential of the South-central part of Chhattisgarh Basin. Geological Society of India Memoir 125: 139p.

Patranabis-Deb S 2001. Purana (Proterozoic) Stratigraphy and Sedimentation in the eastern part of the Chhattisgarh Basin: A Fan Delta Motif. Unpublished Ph.D thesis, Jadavpur University, India. 169p.

Patranabis-Deb S 2004. Proterozoic stratigraphy of the area around Sarangarh in the eastern part of the Chhattisgarh Basin, Madhya Pradesh, India. Gondwana Research 7: 323-337.

Patranabis-Deb S 2005. Tidal shelf sedimentation in the Neoproterozoic Chhattisgarh succession of central India. Journal of Earth System Science 11: 211-226.

Patranabis-Deb S & Chaudhuri AK 2002. Stratigraphic architecture of the Proterozic succession in the eastern Chhattisgarh Basin: its tectonic implication. Sedimentary Geology 147: 105-125.

Patranabis-Deb S & Chaudhuri AK 2007. A retreating fan delta system in Proterozoic Chhattisgarh Basin, central India: facies analysis and palaeotectonic implications. American Association of Petroleum Geologists Bulletin 91: 1-24.

Patranabis-Deb S, Bickford ME, Barbara Hill, Chaudhuri AK & Basu A 2007. SHRIMP ages of zircon in the uppermost tuff in Chhattisgarh Basin in central India require ~500-Ma adjustment in Indian Proterozoic stratigraphy. Journal of Geology 115: 407-415.

Playford PE & Cockbain AE 1969. Algal stromatolites: deep-water forms in the Devonian of western Australia. Science 165: 1008-1010.

Playford PE & Cockbain AE 1976. Modern algal stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, western Australia. *In:* Walter MR (Editor)—Stromatolites. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands. pp. 389-411.

Ramakrishnan M 1987. Stratigraphy, sedimentary environment and evolution of the late Proterozoic Indravati Basin, central India. *In:* Radhakrishnan BP (Editor)—Purana Basins of Peninsular India. Geological Society of India Memoir 6: 139-160.

Schnitzer WA 1971. Das Jungpräkambrium Indiens ("Purana system"): Erlanger, Geologische 85: 44.

Semikhatov MA, Gebelin CD, Cloud P, Awramik SM & Benmore WC 1979. Stromatolite morphogenesis–progress and problems. Canadian Journal of Earth Science 16: 992-1015.

Serebryakov SN & Semikhatov MA 1974. Riphean and Recent stromatolites: a comparison. American Journal of Science 274: 556-574.

Sloss LL 1972. Synchrony of Phanerozoic sedimentary–tectonic events of the North American craton and the Russian platform. 24th International Geological Congress Reports, Section 6, p. 24-32.

Sloss LL 1991. Epilog. *In:* Interior Cratonic Basins. American Association of Petroleum Geologists Memoir 51: 799-805.

Soares PC, Ladnim PMBL & Fulfaro VJ 1978. Tectonic cycles and sedimentary sequences in the Brazilian intracratonic basins. Geological Society of America Bulletin 89: 181-191.

Wen-long Zang & Walter MR 1992. Late Proterozoic and Early Cambrian microfossils and biostratigraphy, northern Anhui and Jiangsu, central-eastern China. Precambrian Research 57: 243-323.