To Prof. S. M. Sengupta
With best regards.
Basudeb Datta.

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Stratigraphic and Sedimentologic Evolution of the Proterozoic Siliciclastics in the Southern part of Chhattisgarh and Khariar, Central India

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Abstract: The Proterozoic siliciclastic successions in the southern part of Chhattisgarh around Panduka village, Raipur dt., Madhya Pradesh and in the northern part of Khariar plateau around Nawapara, Nawapara (North Kalahandi) dt., Orissa consist of three comparable formations namely, the Lohardih, the Chaporadih and the Kansapathar Formations of the Chandarpur Group of the Chhattisgarh Supergroup. The evolution of the sedimentary successions in both the areas follows identical succession of events, i.e., an initial progradation and a subsequent transgression-regression phase. Palaeoslope of both the areas was towards south/southeast and the palaeo-shoreline trend was ENE-WSW to NNE-SSW. Marine transgression occurred from southeast. Environmental and palaeocurrent analyses suggest that the siliciclastic successions at Panduka and Khariar, separated by a wide stretch of crystallines, developed in different parts of the one and same basin, the Panduka area represents the proximal part whereas the Khariar plateau represents the distal part.

Keywords: Sedimentology, Siliciclastics, Proterozoic, Chhattisgarh, Khariar, Chandarpur Group, MP and Orissa.

INTRODUCTION

In the Precambrian Bhandara craton in central India Proterozoic sedimentary successions occur in two major and several minor detached outcrops (Naqvi and Rogers, 1987, p.130 and see insert map of Fig.1). The two major outcrops are represented by the Chhattisgarh Supergroup in Chhattisgarh and the Indravati Group in Bastar, respectively, and besides them minor detached outcrops include the Khariar plateau and several others. The relationship and the stratigraphy of these Proterozoic sedimentary successions in different outcrops have not yet been worked out in detail. The sedimentary rocks of Proterozoic age (1700-700 Ma) are unmetamorphosed and weakly deformed and are believed to have been deposited in several isolated Purana basins in Peninsular India (Kale, 1991). The Chhattisgarh basin is one of these Purana basins, but barring Murti (1987 & 1996) and Das, et al. (1992) few workers have paid attention to the Chhattisgarh succession.

The present study is focused on the stratigraphic succession of the siliciclastics of the lower part of the Chhattisgarh succession in the area around Panduka village (20°48' N, 81°56' E), Raipur Dt., Madhya Pradesh (study area 'A' in Fig.1) along the southern margin of the main Chhattisgarh outcrop, for evaluating the relationship between different lithounits and to trace the history of evolution of the succession.

A small area has also been studied around Nawapara (20°48'30"N, 82°32'08"E), Nawapara (North Kalahandi) dt., Orissa (study area 'B' in Fig.1), in the northern part of the Khariar plateau which is separated from the Panduka area on the main Chhattisgarh outcrop belt by a 20 to 40 km expanse of granitic and granite-gneissic Archaean basement rocks. It is intended to build up the stratigraphy of the sedimentary succession in the northern part of Khariar outcrop in order to evaluate its relationship with that around Panduka.

PREVIOUS WORK

The Proterozoic sedimentary succession of the Chhattisgarh area was first studied by Ball,

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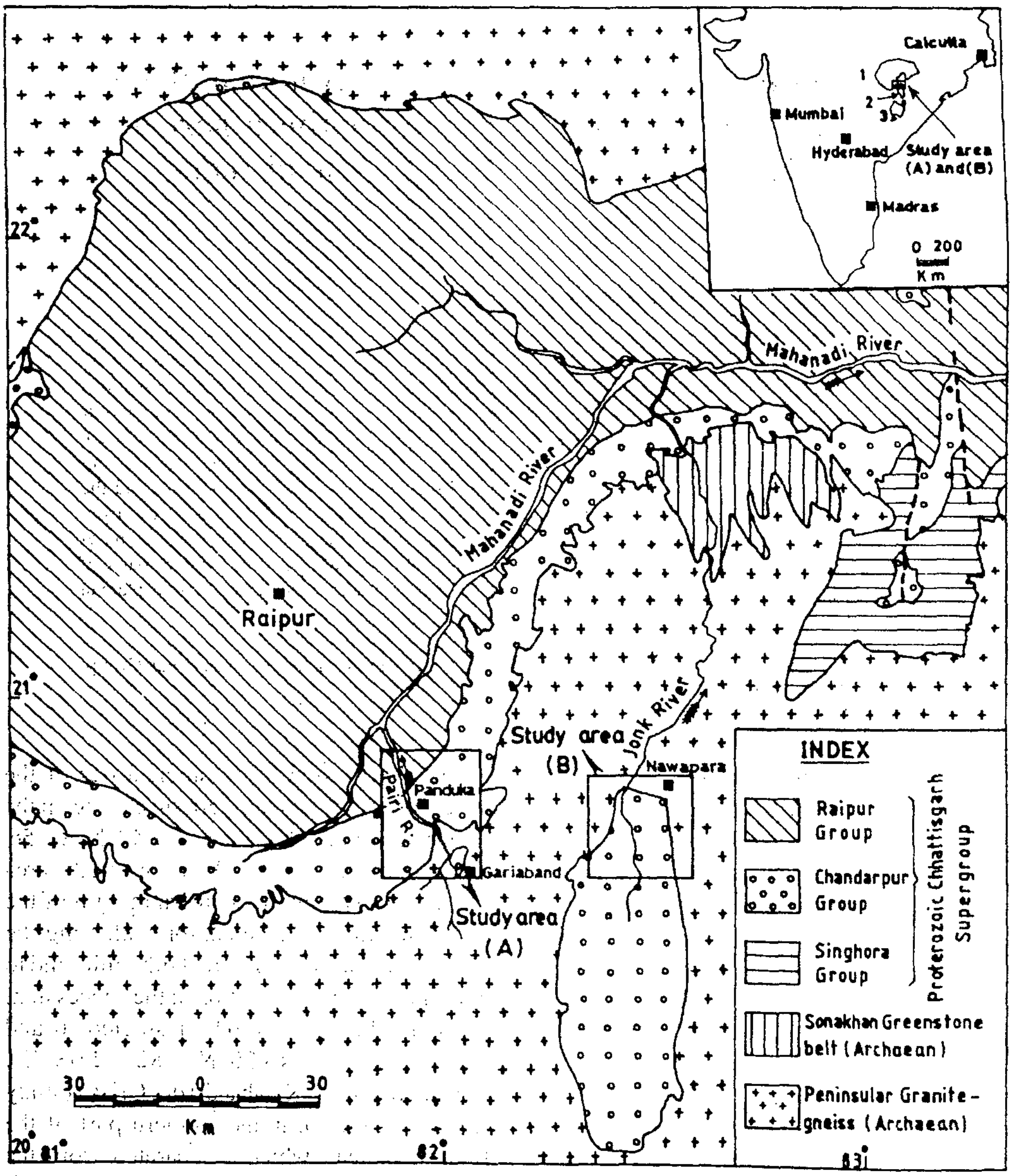

Fig.1. Generalised geological map of the Proterozoic Chhattisgarh and Khariar (after Das, et al. 1992 and Geological Survey of India, published map, Sheet No. 27, 1977); boxes mark the study areas. Inset map shows the Proterozoic sedimentary outcrops of Bhandara Craton of Peninsular India; 1-Chhattisgarh, 2-Khariar, 3-Bastar.

1877 and King, 1885 (quoted from Murti, 1987 and Das, et al. 1992), who described the succession to be the equivalent of the Vindhyans of Central India. Dutt (1964) first designated the succession as "Chhattisgarh Series" which was subsequently redesignated as Chhattisgarh Supergroup (Murti, 1987). Murti (1987 & 1996) studied the Chhattisgarh Supergroup in south-central part and divided the succession into a lower siliciclastic Chandarpur Group and an upper shale-carbonate-rich Raipur Group. The Chandarpur Group was further divided into three formations namely, lower Lohardih Formation, middle Chaporadih Formation and upper Kansapathar/Kondkera Formation (see

Table 1). Das, et al. (1992) basically followed Murti's (1987) classification but recognized an older siliciclastic-dominated Singhora Group underlying the Chandarpur Group in the eastern part of the basin (Table 1). The Singhora Group is however, absent in other parts of the basin (Fig.1).

STRATIGRAPHIC SUCCESSION AROUND PANDUKA

The succession around Panduka consists only of siliciclastics of the Chandarpur Group. The rocks are unmetamorphosed and undeformed, and occur as subhorizontal beds. The succession has been classified into four mappable units (Fig.2) on the basis of composition, texture and colour. The four units are conglomerate and pink feldspar bearing arkose (Unit-1), white feldspar bearing subarkose (Unit-2), mudstone (Unit-3) and purple quartzarenite (Unit-4) in the ascending order. The lowermost unit unconformably overlies the granitic and granite-gneissic Archaean basement in most of the sections, though in a few sections the second unit onlaps the unit-1 and rests directly over the basement. The basement-sediment contact occurs at different contour levels (with maximum contour difference of 20 m) which probably indicates the pre-depositional relief of the basement. The contact between the siliciclastics of the Chandarpur Group and the shale-carbonate succession of the Raipur Group, which occurs in the area north of Panduka, could not be established because of absence of suitable exposure.

Description of the Units

Unit 1: Conglomerate and pink feldspar bearing arkose

The conglomerate and pink feldspar bearing arkose unit has variable thickness and attains a maximum thickness of about 30 m (Fig.2). The unit comprises a fining-upward succession where conglomerate and pebbly sandstone occur in the lower part and pink feldspar bearing coarse-grained to granule-rich arkose in the upper part. The conglomerate is dominantly clast-supported though a few beds may be matrix-supported. The clasts are mostly of vein quartz and pink feldspar. The clasts are very angular to subrounded and the size varies from 11.0 to 86.0 mm. Most of the beds show crude plane stratification, whereas only a few beds are massive. Bed thickness of the conglomerate varies from 0.3 to 2.0 m. The pebbly sandstone is characterized by trough cross-stratification and few shallow concave-up erosional surfaces. The conglomerate and pebbly sandstone include lenses of planar and trough cross-stratified coarse-grained to granule-rich arkose. In the lower part of this unit 4 to 5 m thick interval of sheet-like beds (10 to 80 cm thick) of plane-stratified and shallow trough cross-stratified coarse-grained arkose occurs at many places. These sheet-like beds are interbedded with thin purple and green mudstones.

In general, the arkoses of this unit are coarse- to very coarse-grained, locally granule-rich and poorly sorted with angular grains. The arkoses are rich in ferruginous clay-matrix and iron-cement. The feldspar content ranges from 20.75 to 27.99%. The appearance of these arkoses immediately above the basement identifies them as granite-wash. In the upper part of the unit, the arkoses are dominated by small trough cross-strata, and are characterized by strong unidirectional, south-easterly palaeocurrent (Fig.3a).

Unit 2: White feldspar bearing subarkose

This unit (approximately 60 to 95 m thick) overlies gradationally the pink arkose in most of the sections (Fig.2). Frequency of pink feldspar gradually decreases upward with a concomitant increase in the frequency of white feldspar. In the lower part of the unit, the sandstones are in general coarse- to very coarse-grained and poorly to moderately sorted subarkoses. Undulatory sheet-like beds with composite internal structures, interbedded with thin ripple-laminated beds is the dominant organization in the lower part of this unit. The composite internal structures are characterized by small trough cross-stratification with south-easterly oriented strong unidirectional

Table.1. Stratigraphic Classification of Lower Part of Chhattisgarh Succession and Khariar Succession

	South-central part of Chhattisgarh (K.S. Murti, 1987)	Generalised Succession of Chhattisgarh (Das, et al. 1992)	Panduka, Southern part of Chhattisgarh (Present Study)	Nawapara, Northern part of Khariar Plateau (Present Study)
CHHATTISGARH SUPERGROUP	RAIPUR GROUP	RAIPUR GROUP		
	----Unconformity----	----Unconformity----	----?----	----?----
	CHANDARPUR: Kansapathar/ Kondkera Formation (+125 m) — White Sandstone	CHANDARPUR: Kansapathar Formation (20-200 m) — Glauconitic white to pinkish quartzarenite	CHANDARPUR: Kansapathar Formation (20-40 m) — Purple quartzarenite (Unit 4)	CHANDARPUR: Kansapathar Formation (220 m) — Upper sandstone
			----Gradational contact----	----Gradational contact----
	Chaporadih Formation (15 m) — Reddish brown and olive green sandstone	Chaporadih Formation (20-200 m) — Purple, green, grey and black shale with siltstone/quartzarenite intercalation	Chaporadih Formation (2-10 m) — Mudstone (Unit 3)	Chaporadih Formation (160m) — Shale
			----Gradational contact----	----Gradational contact----
	GROUP: Lohardih Formation (240 m) — White pebbly sandstone	GROUP: Lohardih Formation (200 m) — Ferruginous purple arkose and gritty wacke/arenite with shale partings; conglomerate at the base	GROUP: Lohardih Formation — Upper member (60-90 m): White feldspar bearing subarkose (Unit 2); ----gradational contact----; Lower member (0-30 m): Conglomerate and pink feldspar bearing arkose (Unit 1)	GROUP: Lohardih Formation (200 m) — Lower sandstone.
		----Unconformity----		
		SINGHORA GROUP: Chhuipali Formation (300 m ?) — Stromatolitic limestone and dolomite, variegated shale with minor bedded limestone, chert and siltstone intercalations. Bhalukona Formation (20 m ±) — Quartzarenite / siltstone and minor shale. Saraipali Formation (60 m) — Variegated shale with siltstone chert and minor limestone. Rehatikhol Formation (20 m+) — Feldspathic arenite. Arkose and conglomerate at the base		
	----Nonconformity----	----Unconformity----	----Unconformity----	----Unconformity----
	Archaeans Granite and basic dykes (Intrusive); B.M.Q., rhyolite, basalt, etc. (Chilpi and Sonakhan Groups)	Archaean and Lower Proterozoic basement	Granitic and granite - gneissic Archaean Basement rocks	Granitic and granite-gneissic Archaean basement rocks.

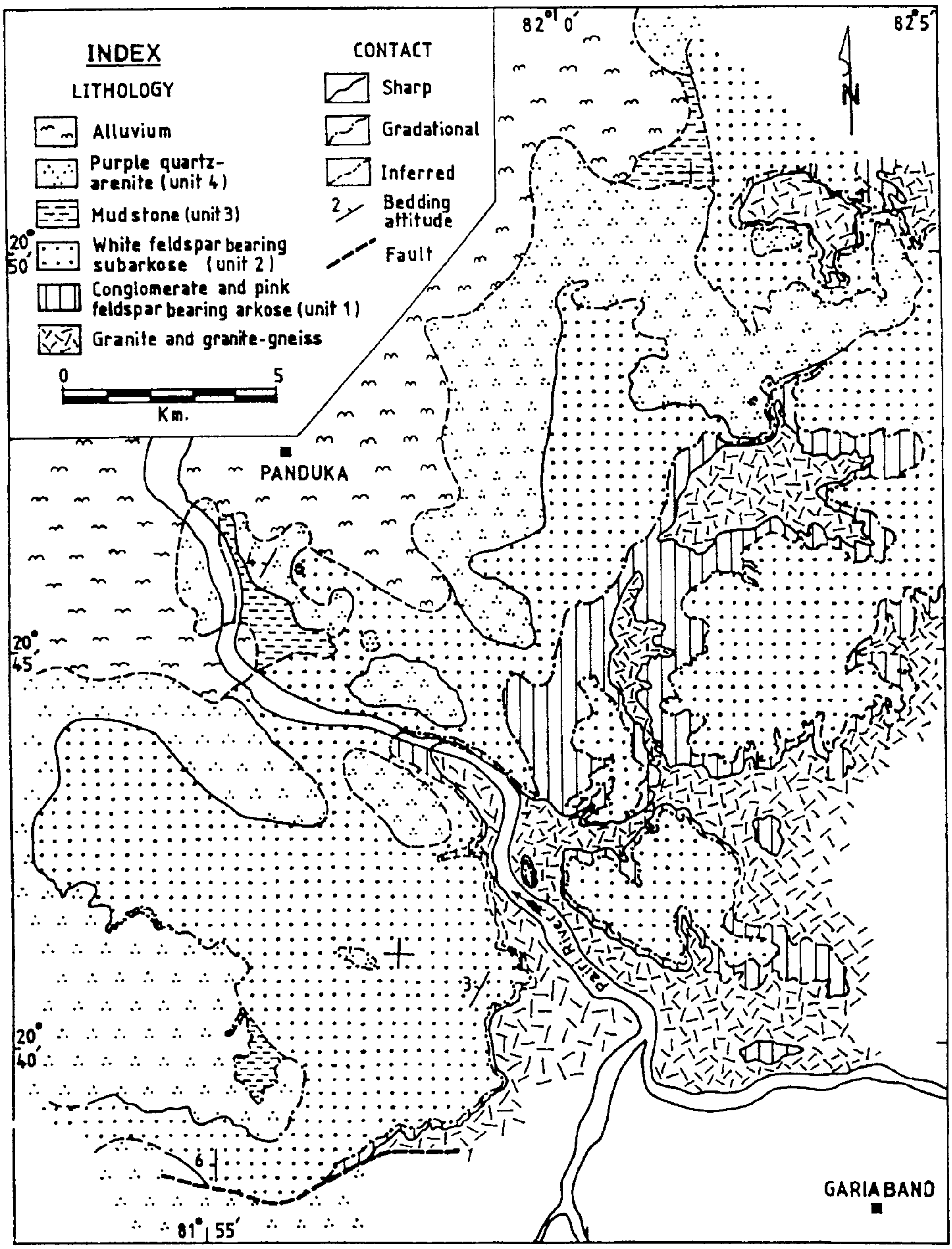

Fig.2. Geological map around Panduka (Study Area 'A' in Fig.1)

palaeocurrent (Fig.3b), and associated low-angle large planar compound cross-stratified sets with diverse orientations (Fig.3c).

The middle part of this unit is compositionally similar to the lower part, but is characterized by symmetrical megaripples, wave-generated internal structures (cf., de Raff, et al. 1977) and thick lenticular beds, mantled at

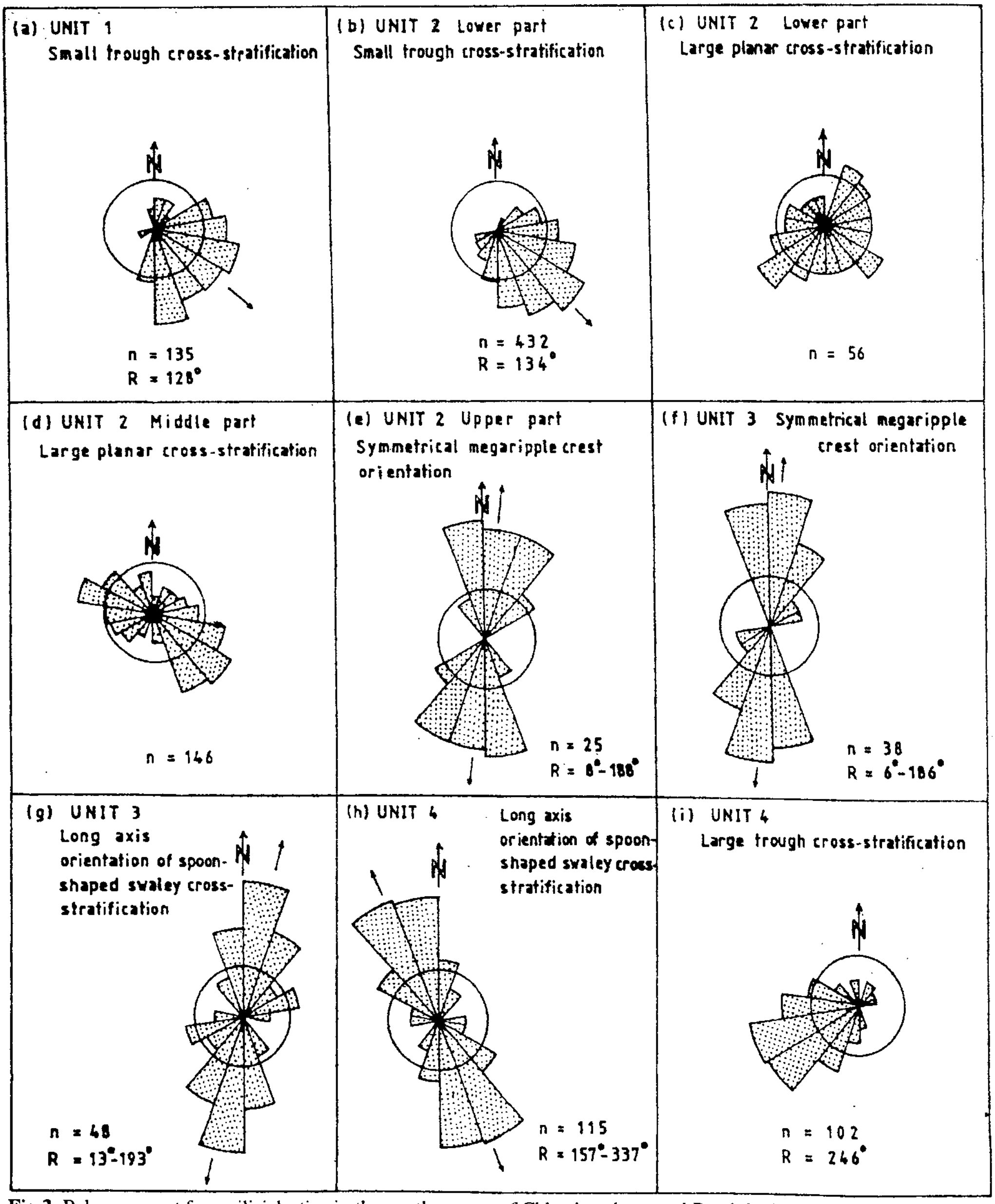

Fig.3. Palaeocurrent from siliciclastics in the southern part of Chhattisgarh around Panduka [n=number of observations, R = direction of resultant.]

places by thin layers of granule lags. The upper and lower bounding surfaces of these beds are wavy to undulatory and laterally these beds vary in thickness. Green mudstones and thin ripple-laminated beds are interbedded with thicker beds at places. Thick (0.5 to 2.0 m) beds with large planar simple to compound cross-stratifications with oppositely oriented (NW and SE) palaeocurrent modes (Fig.3d) also characterize the sandstones in the middle part of this unit.

In the upper part, the sandstones become quartzose, medium-grained, moderate to well sorted, matrix-free and are primarily silica-cemented. Variably oriented sets of small symmetrical and asymmetrical ripples, current lineations and sand-filled desiccation cracks are the notable sedimentary structures. Low positive relief wavy to undulatory beds with symmetrical megaripples and wave-generated internal structures (cf. de Raff et al. 1977) occur abundantly at places. The symmetrical megaripples are persistently oriented in a NNE-SSW direction (Fig.3c).

Unit 3 : Mudstone

The sandstones of unit-2 are gradationally overlain by a thick mudstone unit (approximate thickness is 2 to 10 m) with few isolated thick (0.5 to 1.0 m) lenticular sandbodies. The unit is thickest in the northeastern and northern part but pinches out in the southeastern part of the area (Fig.2). The mudstone is dominantly green on fresh surfaces but turns yellowish to brownish on weathered surfaces. It is characterized by millimetre-thin plane laminations and few intervening siltstone/fine sandstone layers with low-angle erosional surfaces and hummocky cross-stratifications (HCS). This unit is at places sand-dominated heterolithic where coarse-grained to granule-rich glauconitic sandstone lenses alternate with green mudstones. Starved ripples and wavy lenticular sandstone beds at places characterize the heterolithic part.

The isolated 0.5 to 1.0 m thick lenticular sandbodies are in general subarkosic, coarse-grained to granule-rich and they are rich in glauconite and rounded intraformational mudstone clasts. The sandstones are characterized by profuse symmetrical and flat-topped megaripples with wave-generated internal stratifications, swaley cross-stratifications, granule lags and granular conglomerate moulded into megaripples. The maximum crest-spacing and height of the symmetrical megaripples are 196.5 cm and 18.0 cm respectively. The symmetrical megaripple crests trend NNE-SSW (Fig.3f). The swaley cross-strata at places show spoon-shaped to elliptical pattern in plan, with a very consistent NNE-SSW trend of the long axis orientations of the spoons (Fig.3g).

Unit 4: Purple quartzarenite

The purple quartzarenite (approximately 20 to 40 m thick) is characterized by high textural as well as mineralogical maturity. The quartzarenite gradationally overlies the unit-2 and unit-3 in the northeastern and partly in the southwestern side of the area, whereas it overlies the unit-2 with a sharp contact in the central, west and southwestern part (Fig.2). In general, its contact with unit-3 is sharp but its contact with unit-2 is gradational. The sandstone is purple in colour, medium-grained, well sorted, matrix-free, quartzarenite with well rounded grains, abundant quartz overgrowth and iron-cement. The sandstones are glauconitic at places. The sandbodies are sheet-like, slightly pinching-swelling in character with wave-generated internal structures. They are characterized by profuse swaley cross-strata with spoon-shaped to elliptical pattern in plan, and large trough cross-strata at places, with opposite orientations. Long axis orientations of the spoons are fairly consistent throughout the area, and trend NNW-SSE to N-S (Fig.3h). The palaeocurrent indicated by the large trough cross-beds shows a strong westerly mode and a weak easterly mode (Fig.3i).

Stratigraphic Status of the Mappable Units

Unit-1 and -2 of Panduka area are gradational and lithologically very similar to the Lohardih Formation of Murti (1987) and Das, et al. (1992). Barring the difference in colour and the presence of conglomerate in unit-1, there is no other significant difference between the two units, and the two collectively constitute a fining-upward succession from conglomerate and pebbly sandstone to coarse arkosic to subarkosic sandstones. This succession may be considered as a single formation and the pink and white feldspar bearing units may be considered informally as two members, the lower and the upper member, respectively, (North American Commission on Stratigraphic Nomenclature, 1983, Article 30.e) of the Lohardih Formation (Table 1). The mudstone unit and the uppermost purple quartzarenite unit, are considered as two separate formations in view of their distinctive lithological associations. The former is lithologically comparable to the Chaporadih Formation, whereas the latter is comparable with the Kansapathar Formation (see Table 1).

Depositional Environments

Unit 1 : The overall unidirectional palaeocurrent of this unit (Fig. 3a), coarse sandy to pebbly grain size, poor sorting and angular grains indicate an alluvial condition. The dominant stratification type in this lower member of the Lohardih Formation, i.e., sheet-like beds with plane strata and persistently unidirectional small trough cross-strata, indicates that the environment was dominated by sheet flows or sheet floods (Hogg, 1982). The clast-supported to matrix-supported texture in crude plane-stratified or massive beds of conglomerate indicates that the conglomerate was deposited by mass flow-related processes in alluvial fan environment (Blair and Mc Pherson, 1994). The conglomerate and pebbly sandstone with trough cross-strata and shallow concave-up erosional surfaces, on the other hand, point to their deposition as gravelly braided streams. Collectively, the mass flow-related conglomerate, sheet flow/sheet flood generated sandstones and associated gravelly braided stream deposits point to an alluvial fan system (Bull, 1977; Nemec and Steel, 1984).

Unit 2: Profuse development of cross-stratifications, both planar and trough, persistent unidirectional flow (Fig. 3b), immature to submature nature of the sediments, coarse sand to granule grain size, sheet-like sandbodies and absence of thick clay beds collectively indicate that the lower part of the upper member of the Lohardih Formation was also deposited in braided fluvial streams (Eriksson, 1978). The association of unidirectional, small trough cross-stratified sets (Fig. 3b) and variably oriented low-angle large planar compound cross-strarta (Fig. 3c) appear to have developed as braided bar deposits, where the large planar compound sets are braid-bar accretion surfaces (Allen, 1983; Rust and Jones, 1987).

Symmetrical megaripples with wave-generated internal stratifications and the granule lags draping wavy to undulatory upper surface of the thick lenticular beds in the middle part of the upper member of the Lohardih Formation point to their origin as shallow marine wave-originated shoal-bar deposits (Levell, 1980; Cotter, 1985). Their overall compositional similarity with the underlying fluvial deposits suggests that the marine bars were developed by reworking the fluvially transported sediments. The muddy and thin, rippled beds intercalated with the bars are interpreted as intershoal deposits (Chaudhuri and Howard, 1985). The thick beds with large planar cross-stratification with nearly oppositely oriented palaeocurrent modes (Fig. 3d) point to a tidal setup.

Diversely oriented sets of small symmetrical and asymmetrical ripples, desiccation cracks and current lineations in the quartzose sandstones in the upper part collectively indicate shallowing of the marine environment, episodic emergence and high energy depositional regime. The associated sandstones with abundance of symmetrical megaripples with wave-generated internal structures and low positive relief wavy to undulatory bed geometry suggest that the sediments formed as shallow low-lying bars. Development of these bars, wave-generated stratifications and signatures of emergence point to tidal flat environment (Reineck and Singh, 1973, p. 355-372). The consistency of the crest orientations (NNE-SSW) of the symmetrical megaripples (Fig. 3e) indicates a possible NNE-SSW shoreline orientation (Levell, 1980).

Unit 3: Dominance of mud appears to suggest deposition in outer shelf area (Johnson and Baldwin, 1986) where coarse sands and granules were transported exclusively by storm surges. The low-angle erosional surfaces and hummocky cross-strata intervening the thinly laminated mudstones of this Chapordih Formation suggest storm deposition.The thick lenticular sandbodies with symmetrical megaripples of about 2 m crest-spacing, profuse wave-generated internal structures, granule lags and swaley cross-stratifications also point to deposition from strong storm surges and wave reworking (Leckie and Krystinik, 1989). The consistent NNE-SSW long axis orientation of the spoon-shaped outcrops of swaley cross-strata (Fig. 3g) and the NNE-SSW crest orientations of symmetrical megaripples (Fig. 3f), suggest possible NNE-SSW shoreline orientation.

Unit 4 : The supermature lithology and profuse wave-generated structures of the purple quartzarenite of the Kansaparthar Formation indicate prolonged high energy wave reworking. Swaley cross-stratifications forming spoon-shaped patterns are possible indicators of oscillatory storm waves whereas the large trough cross-stratifications with oppositely oriented modes indicate the influence of tidal currents. The association of structures suggests combined effect of storm-wave and tide (Johnson, 1975). Highly consistent NNW-SSE to N-S orientations of the long-axis of the spoons (Fig. 3h) indicate a possible NNW-SSE to N-S shoreline orientation. The westerly and easterly palaeocurrent modes of large trough cross-strata (Fig. 3i) also support this NNW-SSE to N-S shoreline orientation. Gradational relationship between this unit and the tidal flat deposits of the upper part of the upper member of the Lohardih Formation indicate that the purple quartzarenite was deposited in subtidal/shoreface environment.

Evolution of the Sedimentary Succession around Panduka

The succession at Panduka indicates that sedimentation was initiated by progradation of alluvial fan deposits comprising conglomerate and coarse-grained pink arkosic sandstones of the lower member of the Lohardih Formation. Progradation continued till the deposition of the braided fluvial interval which constitutes the lower part of the upper member of the Lohardih Formation. The transition between the fluvial and the overlying wave-tide dominated shallow marine shoal-bar deposits marks the earliest phase of marine transgression and the marine reworking of fluvially transported immature sediments during transgression. The medium-grained, moderately sorted quartzose sandstones of the tidal flat environment in the uppermost part of the Lohardih Formation strongly point to decreasing influence of fluvial processes and increasing intensity of marine reworking. The maximum limit of transgression is indicated by the mud-dominated Chaporadih Formation which was deposited in a relatively deeper outer shelf environment. This was followed by a marine regression when the shoreface/subtidal purple quartzarenite of the Kansapathar Formation was deposited. Thus the siliciclastic succession of the Chandarpur Group records the history of an initial progradation followed by a transgressive-regressive cycle (Fig. 6).

STRATIGRAPHIC SUCCESSION IN THE NORTHERN PART OF KHARIAR PLATEAU

In the northern part of the Khariar plateau, a detached outcrop of Proterozoic succession occurs in a very shallow N-S trending syncline (Fig. 4) with gently dipping beds. The succession essentially consists of three mappable units, two sandstones separated by a shale. The units have been mapped on 1:50,000 scale (Fig. 4). The sedimentary package unconformably overlies the granitic and granite-gneissic Archaean basement rocks.

Description of the Units

Lower sandstone : The lower sandstone of the Khariar plateau is exposed along the periphery of the elliptical tract of the plateau (Fig. 4). The maximum thickness of this unit is about 200 m. It unconformably overlies the basement rocks and the contact is marked by the presence of small lenticular pockets of conglomerate and pebbly sandstone at places. The conglomerate is mainly clast-supported but at places it is matrix-supported with large dispersed pebbles. Clasts are mainly of vein-quartz and range in diameter from 6 to 10 cm. The conglomerate and pebbly sandstone are interbedded with coarse-grained to granule-rich subarkosic sandstones.

In a few sections the basal ~1 m of the lower sandstone is very coarse-grained, poorly sorted arkose with abundant granite rock fragments, and is almost a granite-wash. It rapidly grades to a medium- to coarse-grained,

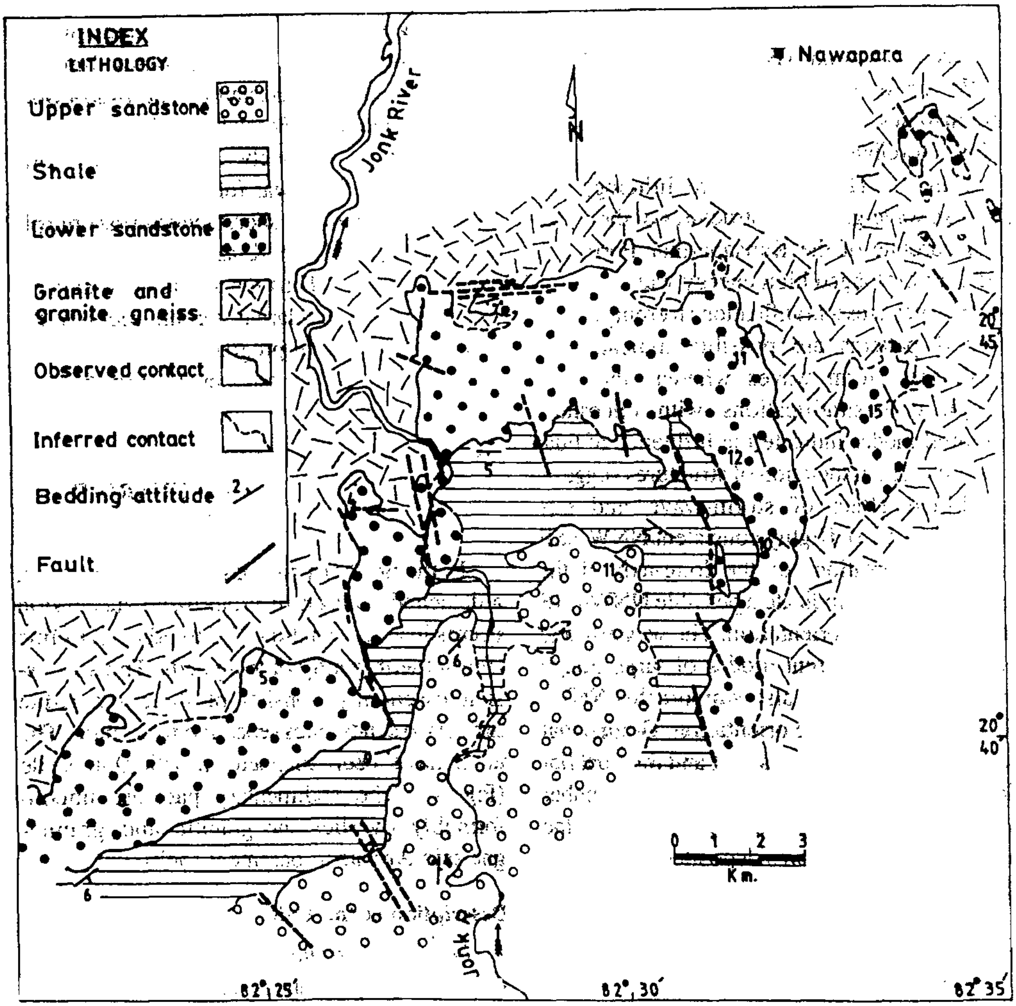

Fig.4. Geological map in the northern part of Khariar plateau (study area 'B' in Fig. 1).

well sorted, silica-cemented quartzarenite with well rounded grains. Many of the beds contain significant proportion of glauconite. The sandstone is characterized by profuse development of symmetrical, straight to slightly sinuous, round- to flat-crested megaripples. The megaripples, at places are developed on low amplitude large asymmetrical bedforms with crest-spacing of 25.0 to 68.5 m. Large trough cross-stratifications, bundles of thin low-angle laminations and wavy to even laminations are the dominant internal structures of the megarippled sandstones. Lenticularity and gradual pinching and swelling is the hallmark of most of the beds. Spindle-shaped, linear, small and sand-filled shrinkage cracks occur profusely on the bedding planes. The beds with shrinkage cracks are interlayered with thin, fine-grained silty or muddy layers. The overall crest orientation of the symmetrical megaripples is ENE-WSW (Fig. 5a) and the lee side orien-tations of the asymmetrical megaripples give a palaeocurrent vector mean of 161° (Fig. 5b), almost at right angle to the megaripple crest orientation. The palaeocurrent mean obtained from the large trough cross-stratifications is strongly unidirectional towards 210° (Fig. 5c). The sandstone fines upwards and grades to the overlying shale through a heterolithic zone.

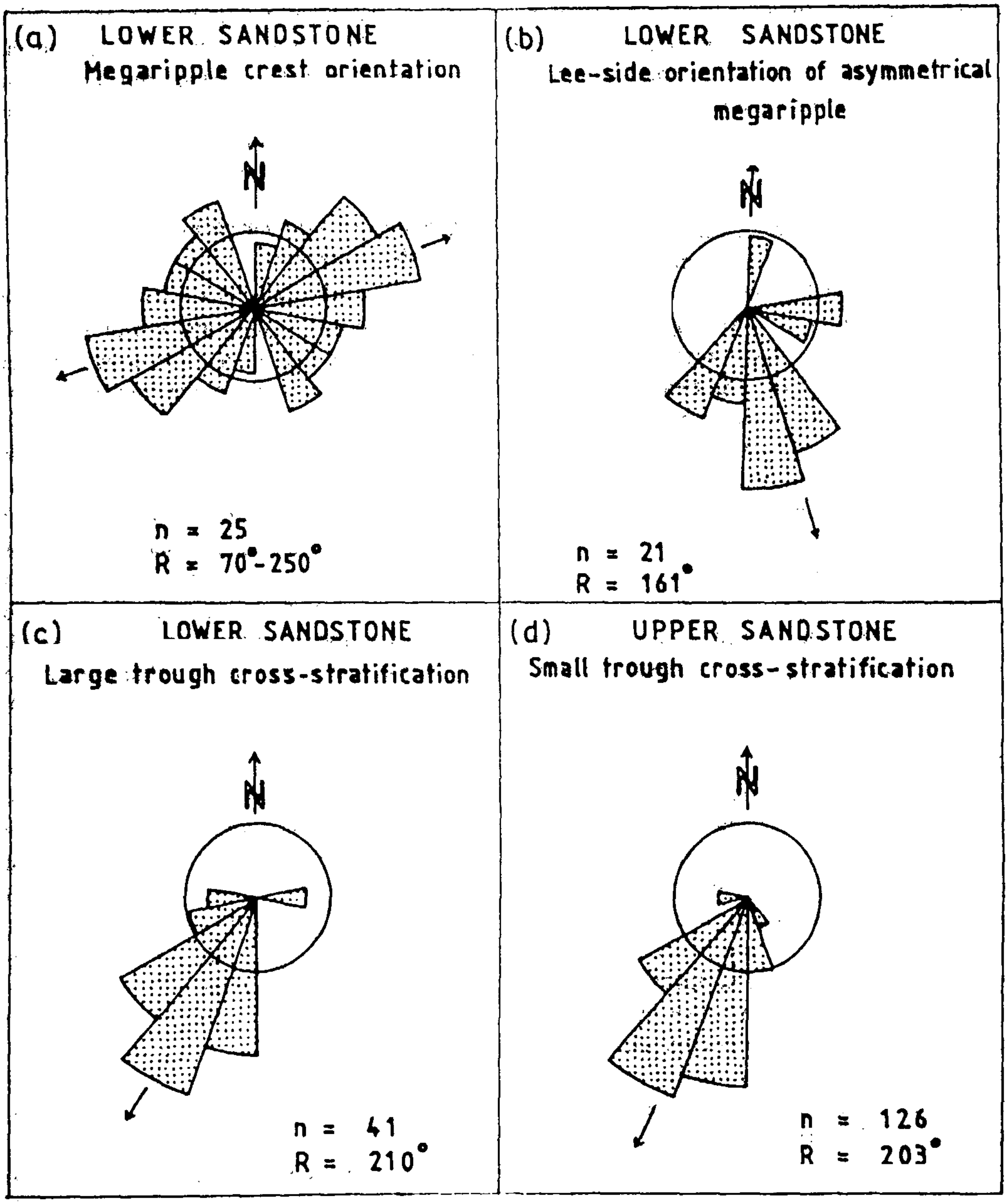

Fig.5. Palaecurrent from Khariar succession (n=number of observations, R=direction of resultant.)

Shale : The shale is about 160 m thick. In general, in the lower part, the shale is light green, yellow or grey on fresh surfaces and weathers to brownish black. The shale is characterized by very well developed centimetre- to millimetre-thick plane lamination. In the lower part, it is interbedded with a few beds of fine-grained sandstone, ranging in thickness from 1 to 15 cm. Some of these beds are characterized by normally graded bedding, thin plane lamination, small-scale ripple lamination and lenticular and wavy lamination, organized in Bouma sequence. In the upper part, the shale is ferruginous and is pink, reddish brown or maroon, thinly laminated and is splintery. In the upper part of the pink shale 1 to 2 m thick sandstone beds and sandstone-mudstone heterolithic unit occur at one/two interval(s) in a few sections. These sandstone beds are wavy with wave-generated internal structures. Thinly laminated or cm-thick massive beds of fine pyroclastics are at places interbedded with both green and pink shale at several stratigraphic intervals.

Upper sandstone : The upper sandstone overlies the pink shale with a gradational contact in most of the sections (Fig. 4). The maximum preserved thickness of the upper sandstone is approximately 220 m. The sandstone comprises mainly medium- to coarse-grained, moderate to well sorted, silica-cemented, quartzarenite with subrounded to well rounded grains. The sandstone is glauconitic at places. It is characterized by laterally persistent (~10 m), thick (10 to 56 cm), lenticular to pinching-swelling beds with trough cross-stratification and low-angle lamination. Straight-crested, symmetrical megaripples have developed profusely on many beds. Extensive (~5 m) planar erosional surfaces, surfaces with eroded mud clasts or clasts impressions, mud flasers and symmetrical small ripples occur at places. Sand-filled, spindle-shaped and linear shrinkage cracks profusely occur both on megarippled and rippled surfaces.

The mature sandstone grades upwards into a very coarse-grained to granule-rich, poorly sorted, trough cross-stratified subarkosic sandstone. This interval is characterized by unidirectional trough cross-stratification with palaeocurrent vector mean towards 203° (Fig.5d).

Stratigraphic Status of the Units

The three mappable lithounits can be identified as three formations (North American Commission on Stratigraphic Nomenclature, 1983). Despite minor differences, the succession is homotaxial with the succession of the Chandarpur Group at Panduka. The lower sandstone with pockets of conglomerate at the base can be equated with the Lohardih Formation at Panduka. Similarly the intervening shale can be considered as equivalent to the mudstone-dominated Chaporadih Formation whereas the upper sandstone can be the equivalent of the purple quartzarenite of the Kansapathar Formation (Table 1).

Depositional Environments and the Evolution of the Succession

Lower sandstone : The clast-supported to matrix-supported texture and the presence of outsized clasts indicate that the conglomerate and pebbly sandstone along the basement contact were deposited by mass flow-related processes, and are possibly the remnants of alluvial fan deposits (Nemec and Steel, 1984). Abundant symmetrical megaripples, lenticular to pinching-swelling bed geometry, bundles of thin low-angle lamination or wavy lamination and the presence of glauconite indicate that the major part of the lower sandstone (the Lohardih Formation) was deposited in a shallow marine wave-dominated environment (Elliott, 1986). The flat-topped megaripples, thin mud drapes and profuse shrinkage cracks indicate possible slack water conditions and extreme shallow depth of deposition with repeated emergence and current reversals, the hallmark of tidal flat environment. Trend of the symmetrical megaripples (Fig. 5a) indicate a possible ENE-WSW shoreline orientation. The larger asymmetrical bedforms with palaeocurrent vector mean towards SSE (Fig. 5b) and large trough cross-stratifications with unidirectional palaeocurrent towards SSW (Fig. 5c) indicate a strong southerly ebb flow (cf. Boersma, 1969).

Shale: Thinly-laminated green mudstone interbedded with few fine sandy beds with graded bedding, plane lamination and ripple lamination in the lower part of the shale (the Chaporadih Formation) indicate possible storm depositions in the shelf regions (Dott and Bourgeois, 1982). The ferruginous pink shale in the upper part of the Chaporadih Formation without any sand in the major part of it, on the other hand, is typical of quieter and deeper outer shelf environments (Johnson and Baldwin, 1986).

Upper sandstone : The medium- to coarse-grained mature sandstones of the Kansapathar Formation characterized by cross-stratified lenticular to wavy beds with symmetrical megaripples on the top and the presence of glauconite are typical of shallow marine wave-dominated environments (Levell, 1980; Elliott, 1986). The associated small ripples, mud flasers and shrinkage cracks indicate very shallow water depth and episodic aerial exposures. By contrast, in the uppermost trough cross-stratified part, the coarse grain size, poor sorting, submature lithology and strong south-southwesterly unidirectional palaeocurrent (Fig. 5d) vis-a-vis the absence of any signature of wave reworking indicate that the uppermost part of the Formation was deposited in braided fluvial environment. The overall coarsening-upward trend in the upper sandstone appears to be the signature of gradual replacement of the shallow marine regime by a fluvial regime.

The sedimentary succession in the northern part of the Khariar plateau was initiated by a progradational alluvial fan deposit represented by the remnants of the basal conglomerate and arkosic sandstones of the Lohardih Formation. This was followed by a prolonged phase of transgression during which the fluvial sediments were reworked by marine processes into the mature quartzose sandstones of the Lohardih Formation. The marine transgression continued through the overlying green shale of the Chaporadih Formation developed in inner- to outer-shelf environments. The pink shale of the outer-shelf association marks the maximum limit of transgression. The overlying coarsening-upward upper sandstone succession of the Kansapathar Formation representing shallow marine to fluvial depositional regimes marks the marine regression followed by a possible progradational phase of fluvial sedimentation. (Fig.6).

ANALYSIS OF PALAEOSLOPE AND PALAEOGEOGRAPHY

The fan and fluvial deposits in the lower part of the succession around Panduka show a strong unidirectional southeasterly palaeocurrent (Fig. 3a and 3b) indicating southeasterly palaeoslope. The detritus was transported from a provenance situated to the northwest. Orientation of the symmetrical megaripples (Fig. 3e) in the overlying shallow marine deposits of the Lohardih Formation suggests NNE-SSW trend of the shoreline. This type of orthogonal relationship was shown by Levell (1980) from the Late Precambrian shelf deposits of Norway and Leckie and Krystinik (1989) from several ancient deposits. The large planar cross-stratified sandstones with NW-SE bimodal-bipolar palaeocurrent pattern (Fig. 3d) within the shallow marine interval also support the NNE-SSW orientation of the shoreline and southeasterly palaeoslope. The bipolarity reflects flood and ebb tidal flows. The southeasterly directed mode closely parallels the unidirectional fluvial flows, and represents the down the slope ebb flows in the marine basin. The marine transgression from southeasterly direction is suggested.

Orientation of symmetrical megaripples (Fig. 5a) in the lower sandstone (the Lohardih Formation) of Khariar succession also indicates ENE-WSW orientation of the shoreline. Strong southerly sediment transport as obtained from lee side orientation of asymmetrical megaripples (Fig. 5b) and large trough cross-stratifications (Fig. 5c) in the lower sandstone possibly points to tidal ebb current. The coarse-grained to granule-rich trough cross-stratified fluvial interval in the upper most part of the upper sandstone (the Kansapathar Formation) also show a southerly palaeocurrent (Fig. 5d) and palaeoslope.

The palaeocurrent data from different stratigraphic intervals in the Panduka area and northern part of the Khariar plateau points to persistent palaeoslope towards south-southeast. Murti (1996) had studied the south-central part of Chhattisgarh, an area of about 40 km north-northeast of Panduka and observed an easterly palaeocurrent from the cross-stratification in the Lohardih Formation and suggested easterly palaeotransport. Thus in the south-central and southern part of the Chhattisgarh outcrop belt an easterly to south-easterly palaeoslope can be suggested. In the present study it is also observed that the possible shoreline orientation was ENE-WSW to NNE-SSW. The NNE-SSW orientation of the shoreline had also been suggested by Murti (1996) from the measurement of pebble alignment. Integration of the palaeocurrent data from different stratigraphic intervals in the Panduka area, in the northern part of Khariar and in the south-central part of Chhattisgarh (cf., Murti, 1996) points to regionally persistent palaeoslope towards east to southeast, and a stable basin configuration. The possible shoreline orientation during the sedimentation of the Lohardih Formation was ENE-WSW as observed in Khariar, and NNE-SSW as observed in Panduka and in the south-central part of Chhattisgarh. During the sedimentation of the Kansapathar Formation the possible shoreline orientation was NNW-SSE to N-S, as observed in Panduka. The slightly shifting shoreline trends may also be comparable with the variable shoreline orientation of the sea as

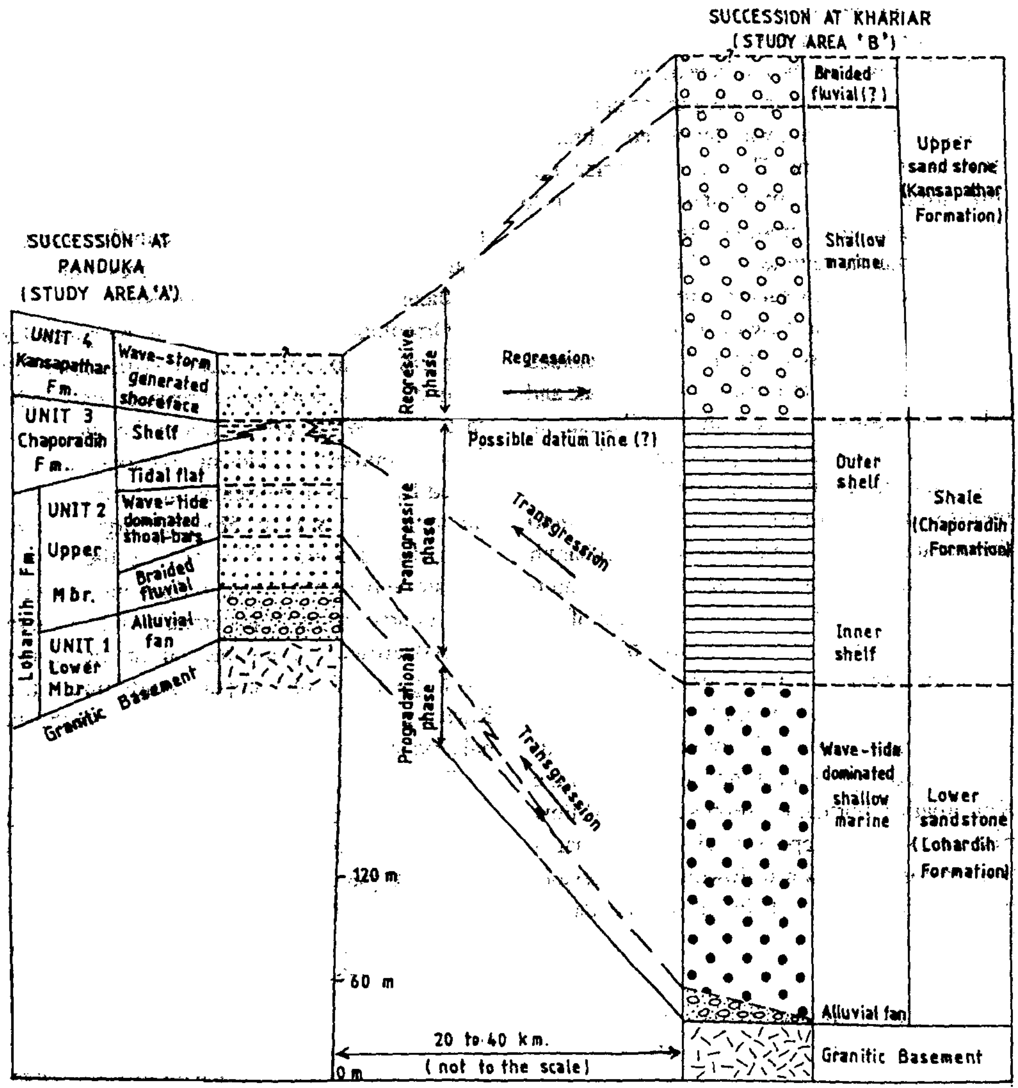

Fig.6. Schematic section along the regional palaeoslope showing the successions developed at Panduka and Khariar. Note the thickening and thinning of the litho-units and the correlation of the two successions, prepared on the basis of their progradation, transgression and regression phases.

exemplified by North Sea (Walker 1984; Elliott, 1986). The deeper part of the marine basin was towards east to southeast. The provenance was situated in a northwesterly direction, an area now being covered by the shale-carbonate succession of the Raipur Group (see Fig. 1).

SYNTHESIS

In the lower part of the sedimentary succession at Panduka the alluvial fan and braidplain deposit had developed as a progradational succession. The deposit pinched out towards southeast at Khariar in the downslope of Panduka, where it is represented by small remnants of conglomerate at the base of the lower sandstone (Fig. 6). This was followed by a marine transgression during which the fluvial detritus was reworked by coastal waves and tidal currents. The initiation of marine transgression was marked by the shallow marine megarippled quartzose sandstones of the lower sandstone (the Lohardih Formation) at Khariar and the wave-tide dominated middle to upper part of the upper member of the Lohardih Formation at Panduka (Fig. 6). During the peak of transgression deep shelf condition prevailed in the distal part of the basin, represented by the Khariar region where the thick shelf mud (of the Chaporadih Formation) was deposited above the shallow marine lower sandstone (Fig. 6). In the proximal part, represented by the Panduka region, the mudstone succession became thinner, and includes many storm deposited sandstone beds and lenses. The transgressive phase was followed by a regional marine regression when the lower part of the upper sandstone was deposited at Khariar and the uppermost purple quartzarenite of the Kansapathar Formation was deposited at Panduka (Fig. 6). With continued regression, the shallow marine regime was replaced by a fluvial regime when the upper part of the upper sandstone was deposited at Khariar. Thus the siliciclastic successions at Panduka (in the southern part of the Chhattisgarh outcrop belt) and in the northern part of Khariar have been developed through an initial progradation and subsequent marine transgression and regression phases. Initially the shoreline was ENE-WSW, as observed at Khariar and subsequently it had changed slightly to NNE-SSW to N-S, as observed at Panduka. The correlation between the sedimentary successions at Panduka and Khariar can be explained through their similar lithologic and stratigraphic makeup, similar palaeoslope, similar orientation of the palaeo-shoreline and similar depositional history (Fig. 6).

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