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Shallow to deep-water deposition in a Cratonic basin: an example from the Proterozoic Penganga Group, Pranhita–Godavari Valley, India

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Abstract

The unmetamorphosed Proterozoic succession dominated by deep-water lithographic limestone and shale in the western flank of the Pranhita–Godavari Valley is designated as the Penganga Group. The succession in different parts of the Valley includes the Pranhita Sandstone (25–400 m), the Chanda Limestone (300 m), and the Sat Nala Shale (>2000 m) in ascending order. The Pranhita Sandstone and the Chanda Limestone reveal considerable variations in the character of the stratal packages and depositional settings from Mancherial in the south to Adilabad in the north. The Sat Nala Shale in both southern and northern outcrop belts is completely devoid of sand. It is brown to purple in colour and resembles present-day deep-water mud deposits. In the Mancherial area, the Pranhita Sandstone consists of 25–400 m thick conglomerate, pebbly red arkose and quartzose sandstone succession of coastal alluvial fan to shallow shelf origin. The Chanda Limestone is micritic and locally includes interbedded lenses of cross-stratified quartzose sandstone in the lower part. The depositional milieu varies from shallow shelf to below wave base outer ramp carbonate platform.

Around Adilabad, the Pranhita Sandstone (25 m) lacks the conglomerate–pebbly arkose association at the base and comprises only quartzose sandstone and shale of shoreface to muddy shelf settings. The Chanda Limestone is essentially micritic but, in contrast to the Mancherial area, includes several interbedded intervals of slope-related, autoclastic debris flow limestone conglomerates and calciturbidites, and represents deep, outer ramp to slope and basinal settings.

A predominantly deep-water micritic limestone and deep-water shale succession suggests that the Penganga basin evolved to a vast, deep epicratonic sea connected to an open ocean. The absence of a coastal alluvial fan association at the lower part of the Pranhita Sandstone and presence of a slope to basinal association in the Chanda Limestone in the northern outcrop belts around Adilabad indicates a northward transition from coastal to deep shelf, slope and basinal conditions and a northerly paleoslope of the basin.

Keywords: Penganga Group; Chanda Limestone; Intracratonic basin; Deep-water ramp; Debris flow lime-clast conglomerate; Slope-basin environment; Palaeogeography

1. Introduction

The Proterozoic sedimentary succession in the Pranhita–Godavari Valley, South India, is designated as the Godavari Supergroup (Chaudhuri and Chanda, 1991). It occurs as two northwest-southeast trending belts separated by a medial strip of Gondwana rocks (Fig. 1). The western outcrop belt of the Godavari Supergroup includes the Pakhal (1330 ± 53 Ma), the Penganga (775 ± 30 Ma/790 ± 30 Ma) and the Sullavai Groups. The Sullavai Group overlies both the Pakhal and the Penganga Groups with an angular unconformity. The Pakhal Group is essentially a shallow marine mixed siliclastic–carbonate deposit whereas the Penganga Group records predominantly a lithographic limestone–shale succession deposited in a deep-water cratonic basin. The overlying Sullavai Group is a fluvio-aeolian deposit. Several workers have carried out stratigraphic analysis of the Penganga Group from different parts of the Penganga outcrop belts, e.g. Heron (1949), Johnson (1965) and Sreenivasa Rao (1987) from the southern part around Mancherial (Fig. 1), and Chaudhuri et al. (1989), Bandyopadhyay (1996) and Mukhopadhyay (1997) and others from the northern part around Adilabad (Fig. 1). The successions in the northern and southern parts of the Penganga outcrop belts reveal significant variations in

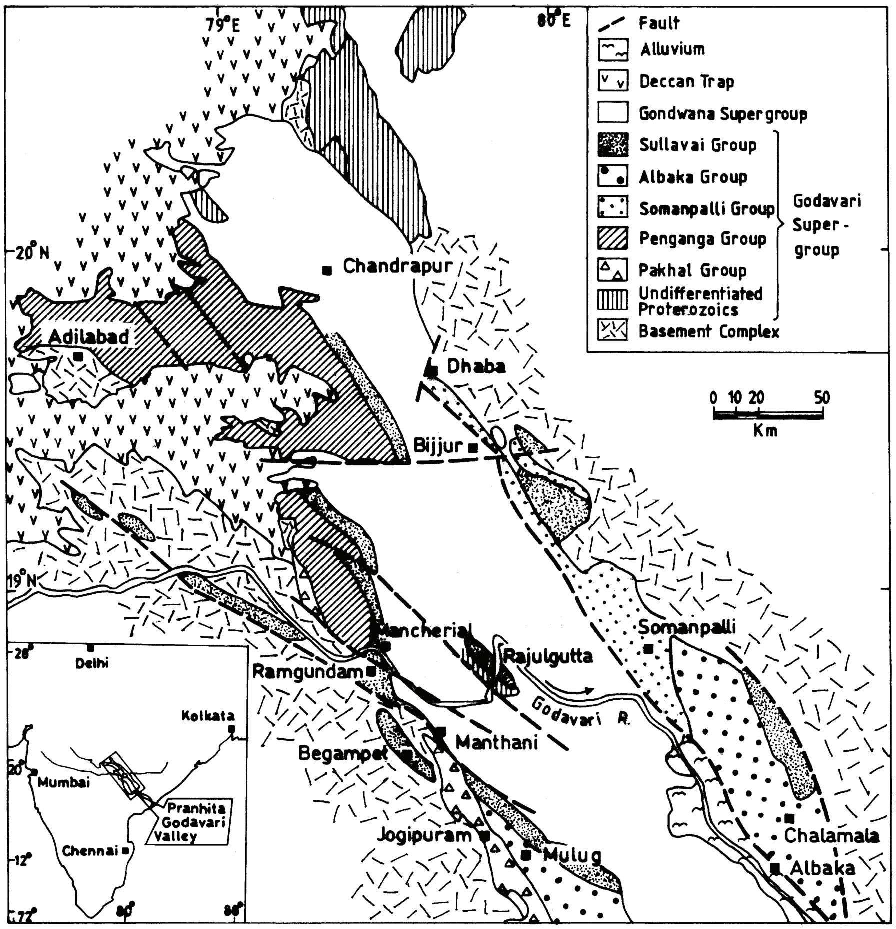

Fig. 1. Geological map of the northwestern part of the PG Valley showing the distribution of the Penganga Group.

stratal packages and depositional settings between Adilabad to the north and Mancherial in the south (Fig. 1). Sedimentologic analysis in order to constrain the depositional environment has only been attempted from the Adilabad area in the north (Chaudhuri et al., 1989; Bose and Sarkar, 1991; Bandyopadhyay, 1996; Mukhopadhyay et al., 1997). In this paper, we provide a comparison of successions mainly around Adilabad and Mancherial, correlate them and reconstruct the depositional setting and paleogeography of the Penganga basin by integrating the sedimentologic and stratigraphic information.

2. Distribution of the Penganga Group

The Penganga succession mainly occurs in the northwestern part of the PG Valley between Adilabad and Mancherial, to the north of the Godavari river (Fig. 1). The only known Penganga succession from south of the Godavari river was described by Sreenivasa Rao (1987) from a fault-bound outcrop belt around Taklapalli near Ramgundam. The southern boundary of the Penganga succession is delimited by the northwest–southeast trending Kaddam fault (Fig. 1), a major lineament in the valley. So far, the Penganga rocks are not properly documented from the northeastern outcrop belts of the PG Valley. King (1881) reported 'Pem Shale' ('Penganga Shale' of Heron (1949)) from this belt in the vicinity of Bijjur (Fig. 1). Recently, we encountered around Dhaba (Fig. 1) a small fault-bound exposure of micritic limestone very similar to the Penganga limestones around Adilabad and Mancherial. We consider this limestone as an extension of the Penganga Group in the northeastern part of the Valley.

3. Stratigraphy of the Penganga Group

The Penganga Group is most studied at Adilabad (Fig. 1). Chaudhuri et al. (1989) classified the Group into the Pranhita Sandstone (25 m), the Chanda Limestone (250 m) and the Sat Nala Shale (>2000 m) in the vicinity of Adilabad town. Other workers, e.g. Heron (1949) and Johnson (1965), also proposed tripartite classification of the Penganga succession into a sandstone, a limestone and a shale unit. Heron (1949) designated the succession as the Penganga series, and classified the series into the Pranhita sandstone (after Blanford, in King (1881)), Penganga limestone (the Chanda Limestone) and Penganga shale (Sat Nala Shale), in ascending order. Sreenivasa Rao (1987) subdivided the Penganga Group into the Taklapalli Arkose and Putnur Limestone around the Ramgundam area (Fig. 1).

Around Adilabad, the Pranhita Sandstone unconformably overlies the Archean–Paleoproterozoic gneissic Basement Complex and includes a lower sandstone member and an upper shale member. The sandstone is a cross-stratified mature quartzose sandstone (15 m) that grades upward to greenish to khaki brown siltstone and shale (10 m). The shale grades upward to the Chanda Limestone through a brown limestone–brown shale heterolithic zone. The Chanda Limestone is dominated by micritic limestone and is characterized by laterally persistent medium- to thick-bedding. The limestone contains several intervals of autoclastic limestone mass flow deposits, a glauconitic sandstone lentil of mass flow origin, and at least two intervals of 70 cm–1 m thick interstratified bedded chert-manganese oxide/carbonate ore bodies in its lower half. The upper half, by contrast, consists only of micrite with a subordinate amount of clay. The limestone grades upward to the Sat Nala Shale through a limestone–shale heterolithic interval. The limestone is devoid of any shallow-water carbonate component. It reveals stratigraphically controlled variation in colour, clay content, composition, and pressure solution features such as stylolites, solution seams and styloflaser. Based on these criteria, the limestone has been classified into a number of mappable (1:25,000) units, namely, brown, pink, light-grey, siliceous grey, steel-grey, black limestones, and heterolithic brown limestone–shale (Mukhopadhyay, 1997; Mukhopadhyay and Chaudhuri, in press). Mukhopadhyay and Chaudhuri (in press) grouped the mappable units into three formal members, namely, the Bhimsari, Ramai and Bilari Members and an informal brown limestone–shale upper heterolithic member. The Bhimsari Member comprises the lower brown, pink and light-grey limestone intervals. The brown and pink limestones are locally dolomitic (Mukhopadhyay et al., 1996). The siliceous grey limestone represents the Ramai Member, whereas the Bilari Member consists of steel-grey and black limestones. The glauconitic (*ferric illitie*, Patranabis Deb and Fukuoka, 1998) sandstone occurs as lenses (25 m thick and 250 m wide) within the brown limestone of the Bhimsari Member. The Bhimsari and Ramai Members constitute the lower half of the Chanda Limestone whereas the Bilari Member represents the upper half. The latter grades upward to the Sat Nala Shale through the upper heterolithic member. The Bhimsari and Ramai Members include several intervals of sheet to lenticular autoclastic debris flow limestone conglomerates and calcarenites of turbidity current origin (Chaudhuri et al., 1989; Bose and Sarkar, 1991; Bandyopadhyay, 1996; Mukhopadhyay et al., 1997). The interstratified bedded chert-manganese ore beds are restricted to the Ramai Member (Mukhopadhyay et al., 1999).

A detailed mapping of different units of the Chanda Limestone revealed a number of major thrusts at low-angles to regional bedding strike. The thrusts have repeated the Penganga succession several times in strike-parallel belts (Mukhopadhyay, 1997). The small-scale deformation structures associated with the thrusts and the stratal truncation relationships suggested a southerly propagation of the thrust-sheets (Mukhopadhyay, 1997; Mukhopadhyay and Chaudhuri, in press). The stratigraphic correlation within and between thrust-sheets indicates that the light-grey and siliceous grey limestones are down-slope equivalents of the brown and pink limestones. The Sat Nala Shale is a reddish brown shale with well-developed laterally persistent thin lamination, and is conspicuously devoid of any siliciclastic or carbonate components coarser than mud. The shale is either truncated by thrusts or capped by the Deccan Trap. In some profiles, the shale is more than 2000 m thick.

Heron (1949) studied the succession from the central and southern parts of the outcrop belt around Moinda and Mancherial (Fig. 1). The sandstone unconformably overlies granitic basement and grades upward to the limestone through thin impersistant khaki/brown shale. The sandstone is about 30–50 m thick and includes a basal conglomeratic to pebbly red arkose (20–25 m), and an upper, mature well-sorted buff coloured subarkose along the Kaddam fault outcrop belts, and in the Rali and Tilani valley around Mancherial (Fig. 1). The Penganga limestone is about 300 m thick and is micritic, brown/pink, grey to dark-grey in colour. The limestone beds are characterized by laterally persistent medium- to-thick-bedding. The limestone grades upward to the Sat Nala Shale, which is a red to purple shale without any siliciclastic and carbonate component coarser than mud. Heron (1949) noted local development of major faults and associated strong folding in the limestones.

Johnson (1965) reported a similar sandstone–limestone–shale succession near Mancherial (Fig. 1). He considered the sequence as Pakhals, a succession that primarily occurs in the area south of the Godavari river. Chaudhuri and Chanda (1991), however, identified the succession as the Penganga Group based on lithological characteristics of the sequence. This sandstone is very similar to that described by Heron (1949). The limestones are locally dolomitic and include small lenses of cross-stratified medium- to coarse-grained sandstone in the lower part. The upper part of the limestone is completely devoid of any sand-size clastics. The topmost shale is similar to the Penganga shale and was termed as Rali Shale.

Sreenivasa Rao (1987) described a fault-bound Penganga succession around the Ramgundam area from south of the Godavari river (Fig. 1) that includes a lower conglomerate and arkose unit, the Taklapalli Arkose (400 m), and an upper lithographic limestone interval, the Putnur Limestone (100 m). The limestone varies from pure to argillaceous varieties of brown, grey to steel-grey colour. Chaudhuri (1985) reported a siliceous limestone from this area. The limestones are locally dolomitic (Chaudhuri, 1985) and include intervals of manganiferous bedded chert (Sreenivasa Rao, 1987) and manganiferous siliceous limestone (Chaudhuri, A.K. and Deb, G., personal observation). The succession is in fault contact with the basement complex.

In order to obviate the problem of multiple nomenclature of the same lithostratigraphic unit in different parts of the Valley, we propose to extend the tripartite classification and nomenclature of the Penganga succession (Table 1) proposed in the Adilabad area (Chaudhuri et al., 1989). In this paper, we would refer to the conglomerate–arkose–quatzose sandstone–shale below the limestone as the Pranhita Sandstone. The limestone unit has been designated as the Chanda Limestone instead of the Penganga limestone of Heron (1949) and the Putnur Limestone of Sreenivasa Rao (1987), and the topmost shale as the Sat Nala Shale instead of the Penganga shale (Heron, 1949) or the Rali Shale (Johnson, 1965).

4. Depositional setting

The Penganga succession reveals considerable variation in stratal packages both vertically and laterally. Depositional setting can be visualized by considering the succession in terms of the following five associations.

4.1. Association A: red conglomerate–pebbly red arkose

The conglomerate and pebbly arkose association is characterized by clast-supported to matrix-supported massive conglomerates interbedded with cross-stratified pebbly red arkose. The proportion of pebbly arkose increases upwards. The conglomerates predominantly consist of quartz pebbles along with a subordinate proportion of BIF pebbles within an arkosic matrix. The association is developed in the basal part of the Pranhita Sandstone in outcrop belts along the Kaddam fault and around Mancherial. It shows a strong thickness variation from 30 to 400 m in different profiles. A maximum thickness of 400 m is reported from the Taklapalli area (Fig. 1) (Sreenivasa Rao, 1987).

Interpretation: The massive conglomerates are likely to be products of debris flows along steep slopes. The cross-stratified pebbly arkose deposits are of stream flow origin. The debris flow conglomerate and interbedded cross-stratified, red arkose deposits are typical of a gravely alluvial fan to braid plain at tectonically active semi-arid basin margins (Collinson, 1996, p. 59). Their distribution along a linear belt of more than 100 km and the arkosic composition of the sandstone as well as the matrix of the conglomerates suggest that these deposits were developed along major fault-controlled slopes. Similar conglomerate–arkose alternations are especially characteristic of piedmont zones along the margins of fault-bound intracratonic rifts (e.g. the basal part of the Devonian Old Red Sandstone, Bluck, 1967; Selley, 2000, p. 192).

4.2. Association B: quartzose sandstone, shale and limestone with lenses of sandstone

The association is characterized by cross-stratified quartzose sandstone which grades upward to brown shale or brown limestone with small lenses of sandstone. The association around Adilabad includes sandstone and shale, whereas around Mancherial it includes sandstone and limestone without the intervening shale.

The sandstone is planar, trough cross-stratified, and commonly forms asymmetric, linear, plano-convex bodies with positive relief and sharp basal surfaces (Fig. 2). The sandstone bodies are 1–3 m thick. The positive relief sandstone bodies interfinger with poorly sorted matrix rich, fine-to-medium grained, ripple-laminated sandstone and siltstone. The two types of sandstones exhibit complementary thickness variations. The latter becomes thicker over the thinned out margins of the positive relief sandstone bodies, and thins out at their crestal parts.

The set thickness of cross-strata in the positive relief sand bodies varies between 20 and 50 cm. The ripple marks are symmetrical, with straight to slightly sinuous and locally bifurcating crest lines. Interfering ripples and slightly asymmetric ripples are also present. Desiccation cracks occur locally.

The limestone is medium-to thick-bedded micritic limestone and is locally dolomitic. The shale is ca. 10 m thick, thinly laminated, brittle, and khaki to brown in colour. Millimetre to sub-millimetre-scale, persistent plane parallel lamination characterizes the shale. The shale includes a few cm-thick laterally persistent beds of plane-laminated siltstone and fine-grained sandstone.

Interpretation: The quartzose sandstone as well as the limestone with sandstone lenses are likely to represent above wave base marine deposits. The positive relief morphology and the internal structures of the sandstones indicate that they developed as linear bars and were formed by vertical aggradation and lateral accretion of 3D and/or 2D ripples and dunes (cf. Johnson, 1977; Chaudhuri and Howard, 1985). The desiccation cracks and small-scale interfering ripples indicate temporary emergence and a shallow depth of water over the bars. The predominance of symmetrical, locally bifurcating straight crested ripples on the surface of the sand bodies identify them as marine bars deposited within wave-dominated foreshore–shoreface zones. The medium- to fine-grained, poorly sorted sandstones formed in a quieter environment behind or between the vertically aggrading bars. The lenses of sandstone within limestone indicate deposition within fair-weather wave base. The sandstones are likely to represent small shoreface to foreshore sandbars in a shallow mixed siliciclastic–carbonate shelf.

The lamination character and absence of wave-generated structures in the shale suggest deposition in a quiet water environment below wave base. The interbeds of plane laminated, fine-grained sandstone and siltstone are likely to

Table 1
Stratigraphic classification of the Penganga Group

Formation	Adilabad		Mancherial	
	Facies	Depositional setting	Facies	Depositional setting
	Deccan trap/Sullavai Group		Sullavai Group	
	Unconformity	Unconformity	Unconformity	Unconformity
Sat Nala Shale (>2000 m)	Thinly laminated red to brown shale	Deep basin	Thinly laminated red to brown shale	Deep basin
Chanda Limestone (300 m)	Mostly micritic limestone with laterally persistent medium to thick bedding. Colour varies from brown, pink, grey, steel-grey and black. Locally, dolomitic. One thick interval of siliceous grey limestone that hosts interstratified bedded chert-manganese ores. A number of intervals with limestone conglomerates and calcarenites of mass flow origin	Distally steepened ramp to deep-water homoclinal ramp	Mostly micritic limestone and siliceous limestone with laterally persistent medium to thick bedding. Colour varies from brown, grey, steel-grey and black. Locally includes lenses of cross-stratified sandstone in the lower parts	Shallow to deep ramp
Pranhita Sandstone (25–400 m)	Cross-stratified, well-sorted quartzose sandstone grading upwards to thin-laminated khaki mudstone to brown shale	Foreshore–shoreface to muddy shelf	Conglomerate, pebbly-gritty red arkose. Cross-stratified, well-sorted subarkose grading upwards to thin-laminated khaki mudstone to brown shale	Alluvial fan-braid plain to foreshore–shoreface and muddy shelf
	Unconformity			
	Basement complex			

Fig. 2. Low-height sandstone bar in the Pranhita Sandstone. Note asymmetric nature of the body.

represent distal storm deposits. The shale is likely to indicate a transition zone between shoreface to inner shelf or outer shelf, below storm wave base (Potter et al., 1980, p. 62). The transition from a wave-agitated shoreface–foreshore setting to below wave base mud depositional setting indicates that the association was deposited within a transgressive systems tract during basin expansion (cf. Mukhopadhyay, 1997).

4.3. Association C: limestone with interbedded siliciclastic and carbonate mass flow deposits

The association is characterized by medium to thick bedded, micritic limestone with intercalated mass flow deposits. The mass flow deposits include clast- and matrix-supported lime-clast conglomerates (Fig. 3) and pebbly lime-mudstones of debris flow origin and calcarenites of turbidity current origin. It also comprises a lenticular body of glauconitic sandstone of mass flow origin. Interstratified bedded chert-manganese ore beds occur in this association in Adilabad (Mukhopadhyay et al., 1997). The maturation sequence of these bedded cherts closely resembles Phanerozoic biogenic bedded cherts (Mukhopadhyay et al., 1999). Interstratified manganese ore beds contain todorokite, birnessite, bixbyite, etc. (Roy et al., 1990; Bandyopadhyay,

Fig. 3. Matrix-supported debris-flow conglomerate in the Chanda Limestone. Note clast at a high angle to the bounding surface.

1996) and carbonates like rhodocrosite, kutnahorite, ankerite and Mn-calcite (Gutzmer and Beukes, 1998).

The glauconitic sandstone occurs as a 25 m thick and 250 m wide lenticular body within brown limestone in the Adilabad area. The sandstone consists of a fine- to medium-grained, ripple laminated to weakly developed plane laminated facies of turbidity current origin, and massive to weakly laminated, ungraded medium- to coarse-grained channellized debris flow sandstone bodies (Chaudhuri et al., 1989; Mukhopadhyay, 1997; Patranabis Deb and Fukuoka, 1998), incised into the finer ripple-laminated sandstone.

Slumps, lime-clast conglomerate as well as calciturbidite beds occur in the brown and pink limestones and in the lower and middle parts of the siliceous grey limestone. The conglomerates are autoclastic and consist of clasts and matrix of micritic limestone. A few conglomerates contain clasts of bedded chert–jaspillite and granite. Siliciclastic sand grains occur in the matrix of a few bodies. The conglomerates and calcarenites occur as tabular beds or as sheet-like shallow lenticular bodies with concave-up bases. The calciturbidites consist of normally graded calcarenites and climbing-ripple laminated lime-mudstone. Both coarse- and fine-grained mass flow beds are closely juxtaposed in the mass flow bearing intervals.

Interpretation: Micritic limestone interbedded with mass flow conglomerates are characteristics of carbonate platform margin successions (Cook, 1979; Cook and Mullins, 1983). The sheet-like conglomerate and calcarenite beds closely match deposits of base-of-slope carbonate aprons (Mukhopadhyay et al., 1997). The channellized, sheet-lenticular mass flow beds suggest deposition within gullied parts of the slope environments, whereas tabular beds of conglomerates and calcarenites are likely to represent base of slope, outer apron to basinal environments (Read, 1985; Mullins and Cook, 1986). The autoclastic nature of the limestone mass flow deposits suggests that the slopes were probably fault-controlled and developed in the below wave base part of the carbonate platform. The interstratified, bedded chert manganese ores in the base-of-slope association (Mukhopadhyay et al., 1997) have been related to upwelling circulation during a high sea level stand (Gutzmer and Beukes, 1998).

4.4. Association D: limestone and limestone–shale heterolithics

The association constitutes the bulk of the Chanda Limestone. It comprises laterally persistent, medium to thick bedded (10–30 cm) micritic limestone (Fig. 4) separated by 1–2 cm thick shale laminae. The beds characteristically contain bedding parallel stylolites, solution seams as well as randomly dispersed, discontinuous, concave-up, argillaceous laminae of insoluble residue that morphologically resemble mud flasers in the muddy sandstones of the tidal flats.

The limestone–shale heterolithic facies is a subordinate constituent of this association. The heterolithic facies is either defined by an alternation between brown limestone–brown shale or by black limestone–black argillaceous limestone. The brown heterolithic unit occurs at two stratigraphic positions, at the base of the Chanda Limestone in the transition zone with the overlying shale member of the Pranhita Sandstone and at its upper part in the transition zone with the overlying Sat Nala Shale. Thin to medium (2–10 cm) bedded micritic limestone alternating with shale beds of subequal thickness characterize the facies. Both limestone and shale beds are plane and parallel-sided and maintain uniform thickness for a considerable distance (exposure limit). The black heterolithic unit occurs at the middle part of the carbonate succession. It comprises laterally persistent beds of black micritic limestone alternating with steel-gray argillaceous limestone (Fig. 5). Nodular to idiotopic pyrite grains are common in this black heterolithic facies. Organic carbon (C_{org}) analyzed in four samples from Adilabad yielded a range from 0.3 to 1.1% (Gutzmer and Beukes, 1998).

Interpretation: Laterally persistent, thin to medium bedded micritic limestone interleaved with shale characterize periplatform ooze and occur in variable depositional settings ranging from deeper parts of the carbonate platform, slope, base-of-slope to basin environments (Bertrand-Sarfati and Moussine-Pouchkine, 1983; Cook and Mullins, 1983; Mullins and Cook, 1986). The absence of interbedded resedimented deposits or slump/slide suggests a deep-water, gently dipping homoclinal platformal depositional setting (cf. Ahr, 1973; Read, 1985; Gawthorpe, 1986; Grotzinger, 1989; Burchette and Wright, 1992). The depositional site was evidently beyond the zone of coarse clastic sedimentation and apparently represents the distal ramp and beyond. The black limestone with $>0.2\%$ Corg resembles an anoxic black shale facies (Byers, 1977; Wetzel, 1991), and represents the most anoxic condition in the Penganga basin.

4.5. Association E: shale

The Sat Nala Shale represents the topmost siliciclastic association. The shale is more than 2000 m thick and is characterized by uniform colour and stratification characteristics throughout. It is reddish brown with mm-scale, laterally persistent plane lamination. Locally the shale includes slightly calcareous greenish layers. The shale is conspicuously devoid of any siliciclastic/carbonate components coarser than mud.

Interpretation: Shale deposits in marine environments can range from inner shelf to deep-sea abyssal plains through outer shelf and slope settings (Potter et al., 1980, p. 61–63). Inner shelf shales are characteristically interbedded with graded storm sand/silt beds, sand and silt beds with wave-generated structures as well as flaser and lenticular beds. Outer shelf shale deposits also include storm-generated silt and sand beds with plane laminations, and

Fig. 4. Medium- to thick-bedded lime-mudstones separated by thinner shale layers in the siliceous grey limestone interval of the Chanda Limestone. Note the laterally persistent bedding character.

locally developed wave-generated structures. Shales of the continental slope and rise are commonly interrupted by channels filled with mass flow deposits, slumps and slides. In contrast, extensive homogeneous shale with uniform lamination laterally persistent for 100s of metres is likely to indicate a deep-water mud depositional setting below storm wave base (e.g. Potter et al., 1980, p. 63; Schieber, 1990).

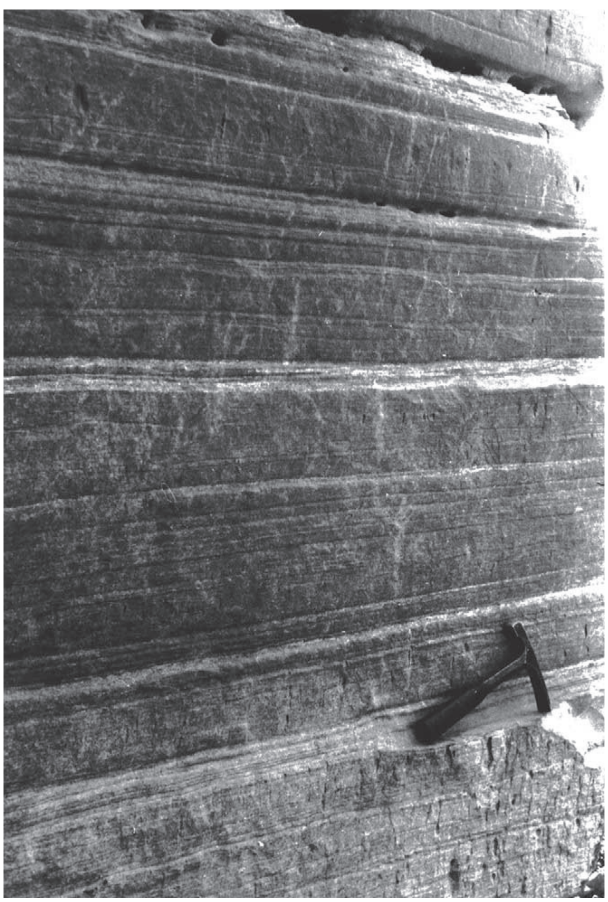

Fig. 5. Limestone–argillaceous limestone heterolithic facies in the black limestone interval of the Chanda Limestone.

The Sat Nala Shale is devoid of sand/silt-grade turbidities or any coarse-grained mass-flow deposits. The absence of mass flow deposits as well as slump/slide deposits indicate deposition over a gently sloping deep-water carbonate ramp. The shale thus may indicate a deep-water outer ramp and basinal environment.

5. Paleogeographic setting

A comparative study of successions in different parts of the valley reveals considerable variations in the associations in the lower part of the Penganga succession and provides clues for understanding the paleogeography. The conglomerate–arkose of Association A along the NW–SE trending Kaddam fault and around Mancherial (Fig. 6A) is an alluvial fan/braid-plain deposit related to basin-opening marginal fault-scarps during the active rifting stage. The Kaddam outcrop belt is likely to indicate a northwest–southeast trend of the coastline. This association is thickest along the Kaddam fault (ca. 400 m) and becomes thinner towards the north and northeast. It grades upward to quartzose sandstone–shale of Association B representing foreshore–shoreface settings. Around Adilabad, the Pranhita Sandstone unconformably overlies the gneissic basement, and only includes the foreshore to shoreface sandstone and inner to outer shelf shale of Association B (Fig. 6B) indicating basin deepening towards north–northeast.

The Chanda Limestone also shows considerable variations in depositional setting at its lower part. It comprises mixed sliciclastic–carbonate of shallow shelf association (Association B) around Mancherial, whereas around Adilabad its lower part is characterized by a well developed sequence of mass flow deposits (Association C) formed in slope to basinal environments (Fig. 6A and B). This indicates deepening of the basin towards the north–northeast (Fig. 7). The mass-flow deposit-bearing succession around Adilabad indicates the development of a slope to basinal setting towards the northern part of the Penganga basin and strongly supports a northerly paleoslope. The upper half of the Chanda Limestone consists only of micritic limestone and limestone–shale heterolithic sequence of Association D throughout the Penganga outcrops from Adilabad to Mancherial along the southwestern margin of the Valley, and also at Dhaba on its northeastern side. Development of a deep-water basinal facies association throughout the Penganga basin during the later part of carbonate sedimentation suggests a major transgression and formation of a very wide, deep marine basin. The black limestone interval occurring in both Adilabad and Mancherial indicates basin-wide anoxic conditions. Such basin-wide anoxic conditions are likely to indicate a high sea-level stand during which an oxygen deficient layer at depths ranging from 100 to 1000 m impinged upon wide areas of

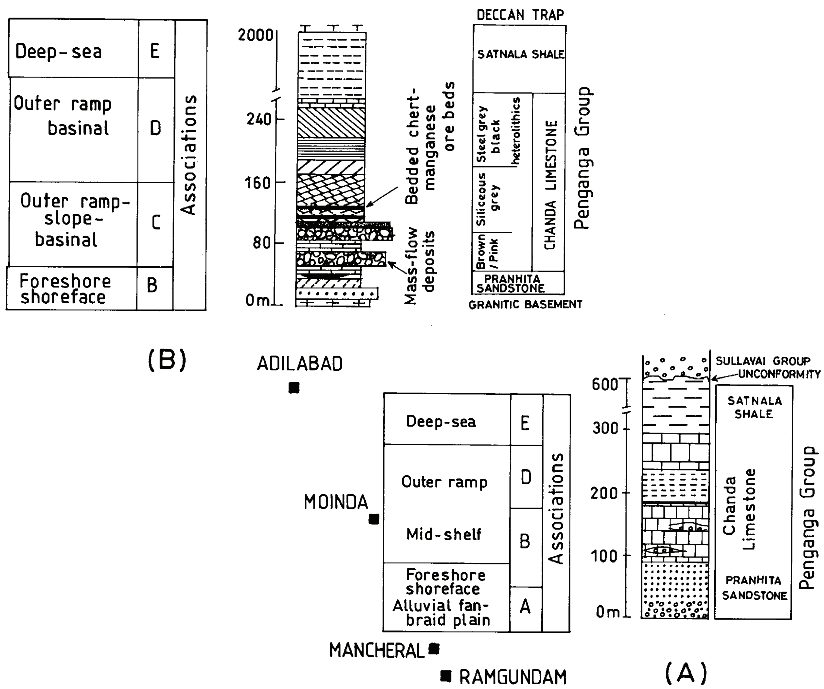

Fig. 6. Composite lithologic logs of the Penganga Group around (A) Mancherial (compiled from Heron 1949; Johnson, 1965), and (B) Adilabad. Note the decreasing thickness of the Pranhita Sandstone and increase in the thickness of the Sat Nala Shale towards the north.

continental shelves (Demaison and Moore, 1980; Allen and Allen, 1990, p. 315). This suggests that vast areas of the epieric seas (cf. Stow et al., 1996) were connected to the open sea.

The Sat Nala Shale of Association E occurs throughout the outcrop belt from Adilabad to Mancherial. The shale

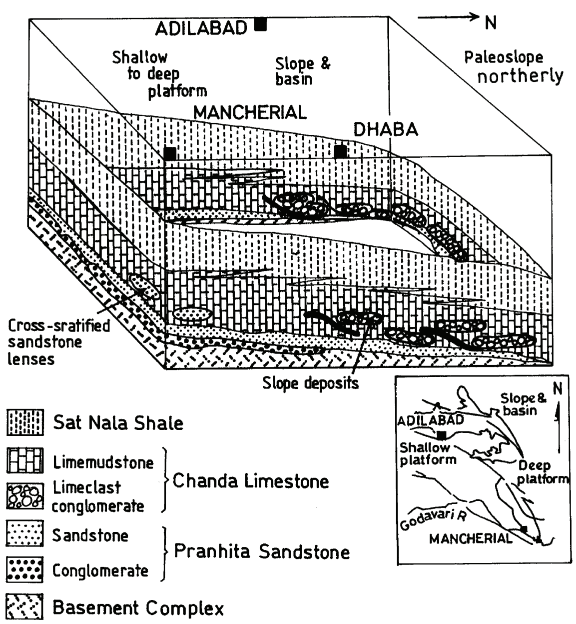

Fig. 7. Schematic model showing the depositional settings of the Penganga Group. Note basin opening towards the north.

gradationally overlies the deep basinal facies association (Association D) of the Chanda Limestone, and is either truncated by thrusts or capped by the Deccan Traps. It is thickest around Adilabad where it attains a thickness of more than 2000 m. Development of deep-water shale 100s to 1000s of metres thick towards the end of Penganga deposition suggests that a deep basinal mud depositional setting replaced carbonate sedimentation throughout almost the entire present day Penganga outcrop belt. In contrast to many Proterozoic epicontinental shales that exhibit a characteristic graded silt–mud couplet, e.g. shale-dominated formations of the Belt Supergroup, Nonesuch Shale of North America, and Gunpowder Creek Formation of Australia (Elmore, 1981; Schieber, 1990), the Sat Nala Shale is conspicuously devoid of any fine sandstone or siltstone beds. It is instead similar to modern deep-sea mud. Development of such extensive and thick deep-water shale in a cratonic basin would indicate that the Penganga basin developed into a 100s to 1000s of km wide, deep epieric sea. Examples of wide spread shales have been reported from many ancient deep basins such as during late Mesozoic opening of the North Atlantic basin (Ryan and Cita, 1977), the rift-related Triassic of the eastern United States where shale is the principal lithology (Van Houten, 1969), and thick Precambrian mudstone within an aulacogen in the Coronation geosyncline, Canada (Hoffman, 1973). Thick basinal mud accumulation in a cratonic basin suggests a major sea-level rise when transgressions can cover vast portions of continents (e.g. Sirte Basin, North Africa, Selley, 2000, p. 483).

6. Conclusions

The Penganga Group includes the Pranhita Sandstone, the Chanda Limestone and the Sat Nala Shale in ascending order. The Pranhita Sandstone records a transition from alluvial fan/braid plain to offshore mud through foreshore and shoreface settings. The Chanda Limestone is predominantly a below storm wave base, deep-water ramp deposit formed during a transgression. The limestone records a shallow wave-agitated shelf, deep-water ramp and fault-controlled slope to basinal settings. The spatial distribution of different facies belts in the limestone indicates a northerly paleoslope. The black limestone interval in the middle part of the Chanda Limestone suggests basin-wide anoxic conditions during a major transgression. The Sat Nala Shale is an extensive and thick basinal shale deposited during the transgression when the basin was converted to a deep, open epicratonic sea connected to an ocean. The spatial distribution of shelf, slope and basinal associations along with thickness variations of the Pranhita Sandstone collectively suggest that the Penganga sea was deepening and opening towards the north–northeast.

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