International Journal of New Technology and Research (IJNTR)
ISSN:2454-4116, Volume-3, Issue-2, February 2017 Pages 74-78

Wave-dominated Shoreline Sediments in Early Cretaceous Surajdeval Formation, Saurashtra Basin, Gujarat Western India

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Abstract— **The Early Cretaceous Surajdeval Formation of the Dhrangadhra group consists of the following three major facies: 1) a sand dominated facies (S), characterized by hummocky cross-stratification, planar and trough cross-bedding (Sp, St), and swaley cross stratification (SCS). 2) the hetro lithic facies (H) characterized by shatter red mudstone and fine-to very fine grained sandstone / red siltstone, exhibiting parallel and low-angle cross-laminations including symmetrical and interference ripples; 3) sand matrix-supported conglomerate/pebbly facies (Cg-S) displaying an alternation of coarse (50mm), medium to fine (<10-20 mm) pebbles in successive beds, and couplets of crudely graded conglomerate.**

The sedimentary facies and structures of the Surajdeval Formation reflect deposition by wave, and tide dominated events. Parallel-laminated and fine-grained sandstones are deposited in response to decrease incompetency and capacity of the flow.

The conglomerates and couplets with sandstone may be the product of longshore deposits. Mudstone may have accumulated in protected lagoonal environment. Paleocurrent indicators, such as cross-bedding and pebble fabric show orientation toward south-south-west, and north-north-west, and may be attributed to ebb tidal (onshore), and those exhibiting north-north-west orientation to flood tidal/ longshore (off-shore) currents. Thus, the sedimentological features of the Surajdeval Formation suggest that wave tides and storm processes were involved during its deposition.

Index Terms— **Early Cretaceous, Shoreline Sediments, Lithofacies, Surajdeval Formation, Saurashtra, Gujarat, India.**

I. Introduction

Studies of hetrolithic assemblages of shallow water origin have record the complex effects of both storm and fair-weather processes (Reineck and Singh , 1980 ; Cotter , 1975 ; Hamblin and Walker , 1979 ; Bourgeois , 1980 ; Dott and Bourgeois , 1982 ; Duke , 1985). In addition, numerous workers have suggested that the fine grained, plane or low angle cross-laminated sheet sands are often associated with either shallow-marine or shallow water wave-dominated environments.

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This features indicative of wave/storm related and tidally influenced depositional processes. The surajdeval Formation conformably overlie the Than Formation of the early cretaceous Saurashtra basin (Casshyap and Aslam, 1991, 1992) and crops out in the central and south-western part of the basin (Fig. 1A, 3). The formation comprises sandstone, mudstone (10 – 20 m), conglomerate of variable thickness (1 – 6 m), and interbedded mudstone/siltstone. Overall, the sequence is characterized by recurring fining-upward cycles of variable thickness (5 – 60 m). Casshyap and Aslam (1991 – 1992) suggested that the Surajdeval sequences of the Saurashtra basin show nearshore deltaic characteristics. This paper deals with detailed lithofacies studies of Saurajdeval Formation.

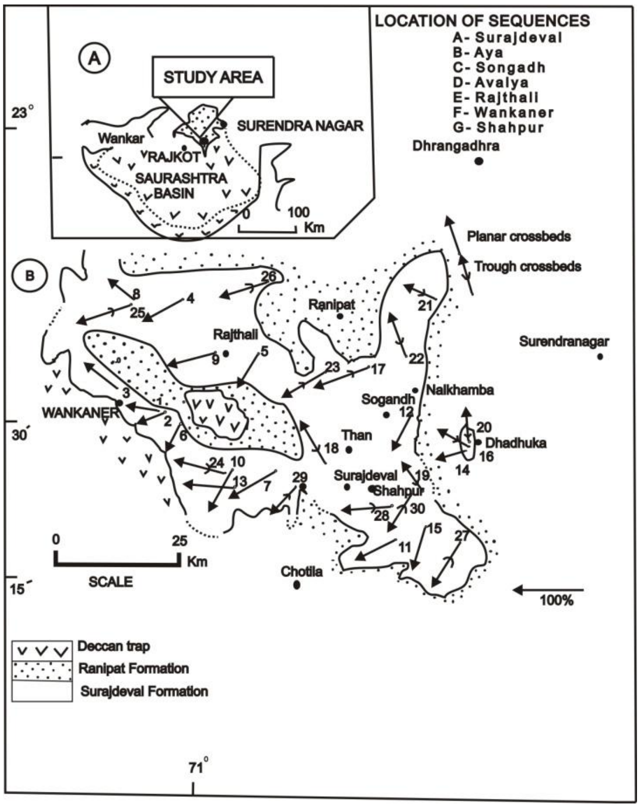

Fig.1A: Geological map of Saurashtra basin.
B: Paleocurrent map.

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Table 1: Lithostratigraphic subdivision, sedimentary characters, and depositional environment of the Mesozoic rocks of Saurashtra basin.

Group	Formation	Lithology	Depositional Environment
	Alluvium millolite limestone, Deccan traps with intertrappean beds (cherty limestone) Wadhwan (~50m)	Reddish, pebbly, coarse grained quartz arenite sandstone; mudstone, thin bands of limestone and coral banks.	Estuarines and shoals.
Dhrangdhra Group (Late Jurassic to early Cretaceous)	Ranipat (200m)	White to dirty white, coarse-medium and fine grained subarkosic sandstone; conglomerate and channel shaped cross-bedded are silvery white showing successive trains of intertidal flood ramp and reactivation surface.	Nearshore coastal, tidal, subtidal.
	Surajdeval (~175m)	Dirty white, coarse-medium and fine grained subarkosic sandstone; lenticular bodies of conglomerate, with thick interbeds of red mudstone and siltstone.	Storm effected shoreline deposits.
	Than (~125m)	Buff, grey, medium to fine grained subarkosic sandstone, carbonaceous shale and thin lenses of coal.	Backswamp of delta plain.

II. FACIES DESCRIPTION

The stratum of the Surajdeval Formation is assigned to three major facies based on their overall lithologic composition and bedding characters. These facies are: sand-dominated facies (S), a hetrolithic facies (H), and sand matrix-supported conglomerates/pebbles interbedded with sandstones facies (Cg – S).

The sand-dominated facies (S) consist of thick bedded units of laterally continuous sand sheets of planar and trough cross-bedded sandstone bodies. Three subfacies, however, are established: S-hcs, the thik bedded, hummocky cross-stratified subfacies and SCS, the parallel-laminated swaley cross-stratified subacies.

The hetrolithic facies (H), volumetrically, makes the second important unit. The H-facies represent the fine clastic component of the sediment assemblage. It consists of interbedded fine-grained sandstones, siltstone, and red mudstones. It is distinguished from the S-facies by its red colored mudstones, fine to thin-bedded nature and the low overall sand content (< 20%). two subfacies are recognized :Hf , the thinly bedded fine-grained sandstone and siltstone subfacies and Hm ,the thick-bedded mudstone subfacies.

The sandstone matrix–supported conglomerate/pebbly facies (Cg-S), volumetrically, least important. These conglomerates have scoured, and sometime flat bases. occasionally, there may be gravel lags at their bases.

A. The Hummocky cross-stratified subfacies (S-hcs)

The S-hcs is thick-bedded and sand dominated subfacies, from 2-5 meter thick, sheet-like sand bodies that persist over several hundred of meter in outcrop (Fig. 2). The lithological sequence of this subfacies is composed of medium to fine-grained quartzite which grade up into 15-25 cm thick fine-grained sandstone and siltstones. Bed thickness of this subfacies varies from 0.5-2m. The dominant sedimentary structure is the hummocky cross-stratification. The gentle undulating lamination has wave lengths of 0.5-3m. and heights from swale to adjacent hummocky of a few tens of centimeters. The upper surface of hummocky cross stratification beds show small scale symmetric ripples and, at places, the S-hcs overlies the swaley cross-stratified subfacies (SCS).

Fig. 2: hummocky cross-stratified bed.

Harms et al. (1975) suggested that the undulating hummocky cross stratification was produced either by storm wave base or by storm of hurricane flows (Hamblin and Walker, 1979; Bourgeois, 1980) or by hurricanes and intense winter storms (Duke, 1985) or can also produced by purely oscillatory flow (Southard et al. 1990).

B. The Cross-stratified subfacies

Extensively cross-stratified sandstone subfacies is characterized by planar (Sp) and trough (St) cross-bedding and forms the dominant lithology throughout the area. It occurs in successive sets and single sets. The sandstone beds are 0.5-1.5 m thick and are broadly lenticular or wedge shaped with sharp to uneven lower and upper contacts. Sets are 25-30 cm thick; between the sets are a few discontinuous lenses of conglomerate. Some of the superimposed planar sets form herringbone cross-bedded cosets with opposing transport directions.

The Sp-St subfacies display evidence of fining-upward cycles, with a progressive in scale of cross-bedding and corresponding grain size decrease in vertical sections of 3-6 m thickness. At places, the intervals appear to contain a random vertical arrangement of sedimentary structures, although well organized, fining upward depositional cycles containing the following sequence observed: trough cross-bedded coarse to medium grained sandstone resting on a gently curved surface at the base; small-scale trough cross-bedded, fine to medium-grained sandstone; and planar cross-bedded, coarse to medium grained sandstone.

The deposition of cross-stratified subfacies (Sp, St) may be attributed to migration of 3-dimentional medium subaqueous dunes (Ashley, 1990). Occasional presence of herringbone cross-bedding suggests deposition in tidally influenced channels.

C. The Swaley Cross-Stratified Subfacies (SCS)

This subfacies is about 5-10 m thick. The most common primary sedimentary structures within the SCS sand beds are parallel to low-angle cross-lamination, wavy and lenticular bedding, swaley cross-stratification (SCS), and penecontemporaneous deformation. The size of the swale in the structure increases with increasing bed thickness and sand content. The lower portion of the thicker bed show penecontemporaneous deformation structure (Fig. 3).

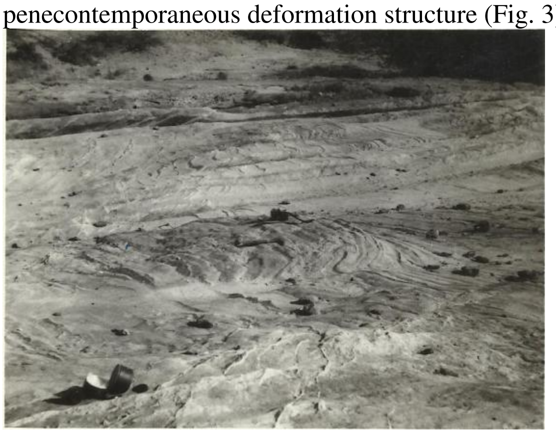

Fig.3: penecontemporaneous deformation structure with fluidized sediment. The laminae are folded.

Fig.4: thinly bedded fine-grained sandstone exhibiting parallel lamination and lateral continuity.

Fig.5: tidal channel sequences. Intrbedded with siltstone and shale.

The swaley cross-stratified subfacies (SCS), in water shallower than that for the S-hcs subfacies and probably above fair weather wave base. In the study area the swaley cross-stratification generally overlies the hummocky cross stratification, suggesting a close genetic link between SCS and S-hcs. In a prograding shoreline sequences, the SCS is directly overlain by shoreline deposits (Komar, 1976), which suggests that SCS may be a storm-dominated structure formed above fair-weather wave base.

D. The Thinly-bedded Fine-grained Sandstone and Siltstone Subfacies (Hf)

The thinly bedded fine-grained sandstone and siltstone subfacies are 3m thick and consist of a unique group of lithology. It is well exposed near Wankaner (Fig. 1B), and north-western part of the area. This subfacies can be distinguished by its grey color, and homogenous texture. In outcrop section the unit appears laterally continuous (Fig. 4), but when beds are traced over 100-150 m distances, they wedge out perhaps due to erosional truncations. The basal contacts of the beds are sharp and erosional. Channels up to 2 m deep and over 10-12 m across are present at the bases of some beds (Fig. 5).

Other internal sedimentary structures include parallel and low-angle cross-laminations and some large-scale convolute laminations. This subfacies, locally, contain symmetrical and interference ripples at the top of sedimentation units.

It is suggested that the Hf-subfacies may possibly represent tidal flat deposit with tidal crecks. The parallel and low angle cross-laminations represent continuous reworking by currents. The channels with sharp/erosional bases may be interpreted as the product of periodic, high-energy events, possibly related to wave or storm surges (swift et al., 1983).

Ripple scale bedforms may form due to oscillatory wave processes.

E. Thick-bedded Mudstone Subfacies (Hm)

Mudstones are well exposed in and around Surajdeval, Shahpur, and Dhadukaanddevelop in units of varying thickness from a few decimeters to about 10-20 meters, traceable in out-crops for tens of meters. They are mainly reddish in color but often contain purple tingers. Locally, individual units enclose thin, fine-very fine grained sandstone interbeds. Inter-bedded sandstones are flat-laminated and lenticular but may show wave ripples on their upper surfaces.

The accumulation of red-mudstone probably deposited in low energy aqueous environment by the settling of grains from suspension. The flat-bedded nature of this facies(Hm) reflect deposition in lagoonal environment (Reinson, 1984). However, this facies lack the typical structures commonly found in lagoonal sediments.

F. Sand matrix-supported Conglomerates Facies (Cg-S)

Sand matrix-supported conglomerates interbedded with sandstones (Fig. 6) are locally developed in the Surajdeval Formation. Individual beds seldom exceed 0.5-1.5m. Conglomerate may predominate throughout 5m thick succession. Clasts within conglomerates (50mm) are almost all quartzite, with the exception of small sandstones or sandy material (<10-20 mm). clasts are mostly subrounded to rounded and are set in a coarse sandy matrix. Pebbles and cobble are up to 20 cm in diameter have been observed, but 2-10 cm is typically the maximum size. Sandstons that are interbedded with this facies also contain conglomerate layers (Fig. 6).

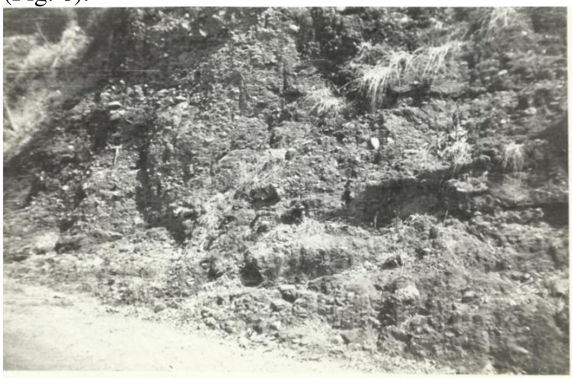

Fig.6: sand matrix supported conglomerate/pebbly sandstone (Cg-S) facies.

Generally, conglomerates fall into two types in terms of internal structures: 1) conglomerate showing flat bedding and crude cross bedding to a more or less similar nature to that seen in the interbedded sandstones. 2) conglomerate showing couplets of crudely graded conglomerate and well sorted sandstones. These couplets are commonly about 0.5-1m thick with sandstone forming the upper most 2-2.5m. There are no imbrications in these conglomerates. The associated sandstone appears massive in many cases, although this may be due partly to their good sorting.

The conglomerate-sandstone couplets appear to be the deposits of a single depositional event in that they show a crude grading. Similar conglomerates have been reported from Pleistocene deposits and have been interpreted as longshore deposits (Kumar and Sanders, 1976). Galloway (19676) has reported gravel banks in water depths of 15-20 m. on a wave-dominated shoreline.

III. PALEOFLOW ANALYSS

The paleoflow study is based on 643 reading of foreset dip azimuth of planar (396) and trough (185) cross bedding, long axis azimuth of elongated clasts (55), and ripple marks (7) as listed in Table 2. Computed value of vector mean and vector magnitude for directional attributes at each outcrop and formation level are listed in Table 2.

Table 2: Paleocurrent statistics of cross-bedding azimuth and other directional features at outcrop and formation level.

Facies	Directional structers	Outcrop No.	Number of readings (N)	Vector Mean (in degree) (θ_V)	Vector strength (L%)	Variance (S^2)	Standerd deviation (S)
SANDSTONE	Outcrop level						
	Planar cross-bedding.	1	7	300	87.25		
		2	12	249	91.44		
		3	9	340	97.64		
		4	10	245	96.72		
		5	20	210	93.80		
		6	26	221	65.36		
		7	39	241	93.78		
		8	24	340	65.36		
		9	16	265	92.43		
		10	6	215	92.14		
		11	9	240	88.17		
		12	11	185	88.19		
		13	13	330	94.00		
		14	10	261	78.11		
		15	21	213	78.87		
	Trough cross-bedding.	16	21	300	88.57		
		17	10	253	92.01		
		18	20	312	92.09		
		19	09	329	96.63		
		20	06	325	96.67		
		21	09	300	80.14		
		22	12	305	79.43		
		23	10	298	87.21		
		24	09	304	89.14		
		25	07	285	96.66		
		26	08	268	91.82		
		27	10	244	96.11		
		28	09	280	77.66		
		29	20	220	96.70		
		30	09	245	87.19		
	Formation level						
	Plana						

CONGLOMERATE	r cross-bedding		396	246	70.30	2315	48.11
	Trough cross-bedding		327	266	87.15	1596	39.20
	Pebble fabric		55	150-330	87.60	107	10.34
	Ripple marks		07	93-173	–	–	–

Walker, 1981). Conglomerate showing west-northwest orientations may suggest that they were transported by longshore currents or from oscillatory wave-generated flow.

ACKNOWLEDGEMENTS

The author is indebted to Prof. L.A.K. Rao, chairperson Department of Geology for providing necessary research facilities.

The research was supported by the CSIR, New Delhi, in the form of Research Associateship to one of the author (M.A.)

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