To Prof S. Sengupta
with regards

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# EVIDENCE OF SUPERIMPOSITION OF STORM WAVES ON TIDAL CURRENTS IN ROCKS FROM THE TITHONIAN–NEOCOMIAN UMIA MEMBER, KUTCH, INDIA

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## ABSTRACT

Bose, P.K., Ghosh, G., Shome, S. and Bardhan, S., 1988. Evidence of superimposition of storm waves on tidal currents in rocks from the Tithonian–Neocomian Umia Member, Kutch, India. Sediment. Geol., 54: 321–329.

The general opinion is that hummocky cross-stratification is generated from superposition of storm waves on a unidirectional current. However, constraints on the type of the current field have not been clearly established. Sedimentary structures preserved in rocks of the Tithonian–Neocomian Umia Member, Kutch, India, indicate hummocky cross-stratification developed from storm wave interference with ebb-tide currents.

Facies indicate repeated progradation of the shoreline and the increasingly important role of sand transport by currents in offshore direction. Stratigraphic analyses identify two major stages of shoreline progradation. Each is composed of distinctive shelf to shoreface transitions. In the tidally influenced shoreface parts of these transitions, the azimuths of units with nearly unidirectional hummocky cross-stratification are consistent with the direction of ebb-tidal cross-stratification, suggesting offshore sand transport by superposition of waves on an ebb-tidal current.

## INTRODUCTION

Sand transport in deep shelf settings, though infrequent in the context of a man's lifetime (Walker, 1984), is significant when considered in the context of geologic time. Offshore-moving turbidity currents and oscillatory storm ebb flows (Johnson, 1978) are the two mechanisms envisaged as capable of transporting sand beyond the fair-weather wave base. The long wave periods (Allen, 1985) extrapolated from hummocky bedforms and cross-stratifications (Harms et al., 1975; Hamblin and Walker, 1979; Bourgeois, 1980) commonly indicate a storm origin (Bose and Chanda, 1986, and references therein). The characteristics of symmetrical ripples (wave length, amplitude and grain size) in Cretaceous hummocky cross-stratified

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beds of Oregon do not fit the usual direct relationship with water depth as can be applied in normal wave ripples (Komar and Miller, 1973; Komar, 1974) and thus were designated as an orbital by Hunter and Clifton (1982). A consensus seems to have been reached now that the hummocky cross-stratifications are not products solely of oscillation, but simultaneous involvement of a unidirectional current is deemed necessary (Allen and Pound, 1985). However, the nature of the unidirectional current is still under speculation. Tidal currents (Johnson, 1977), shelf turbidity currents (Walker et al., 1983) and wind-driven currents (Swift et al., 1983) are those suggested as influencing hummocky cross-stratifications. The "incremental sand transport" resulting from such flows or combination of flows could never be satisfactorily documented either from present oceans or ancient marine sequences (Walker, 1984). Monitoring of major episodic storms such as those following long intervals possibly spanning over thousand years (Walker, 1984) is hardly feasible, and as Duke (1985) predicts, products of such catastrophic shelf storm surges are the ones likely to escape reworking by fair-weather processes and be preserved in the rock record. Thus, the insight necessary in reconstructing the depositional mechanism from such storm surges is expected from geologists rather than from oceanographers. However, an explanation of hummocky cross-stratifications in the rock record must fit into the framework of modern oceanographic processes. Turbidity currents with storm-generated flows are considered dynamically unreasonable and unnecessary in terms of modern oceanographic data (McCave, 1985). This paper documents combinations of sedimentary structures from the Umia Member, Kutch, India, which suggest superimposition of storm waves on tidal currents.

## UMIA SEQUENCE

The predominantly terrigenous sequence of the Tithonian–Neocomian Umia Member (Waagen, 1871, 1876; Kitchin, 1903; Raj Nath, 1932; Spath, 1933; Cox, 1940; Krishnan, 1968; Mehra et al., 1977; Shome and Bardhan, in press) is best exposed northward from the Katesar Temple (23°47′N, 68°55′S), Kutch, India (Fig. 1). In the section (Fig. 1) beds dip towards 165°, the relative position of the palaeoshoreline being southward.

Broadly, three facies constitute the sequence: A heterolithic facies consisting of thin (3–6 cm), sharp based, laterally discontinuous and hummocky sheet sandstones embedded within massive or plane-laminated mudstones (silty, shaly or rarely limy) characterized by abundant *Cruziana* traces. This facies seems to be a product of episodic storm pulses into the quiet mud depositing deep shelf below the fair-weather wave base.

Progressive upward increase in lateral persistence, thickness and frequency of sand beds and their more frequent amalgamation (Aigner, 1982; Bose, 1983; Bose and Chanda, 1986) often led to development of a thick sandstone facies. Mudstones

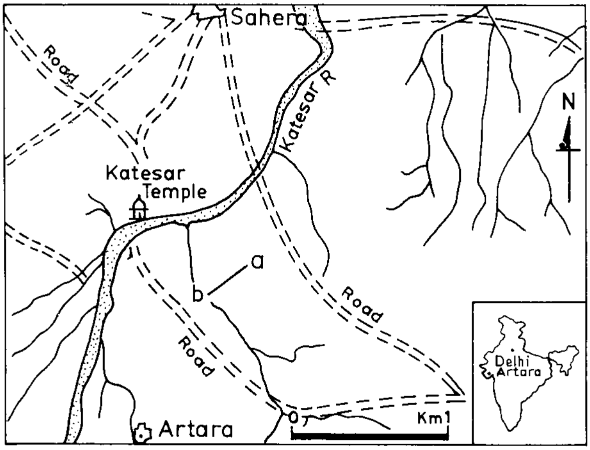

Fig. 1. Location map (*a*–*b* = studied section).

occur occasionally in the form of paper-thin torn sheets between the sandstone beds. They remain confined to the lower part of the thick sandstone subsequences. At the upper part of such subsequences, wave ripples with straight and bifurcated crests are occasionally preserved on bedtops. The depositional environment appears to have straddled the fair-weather wave base. Repetitive alternations between *Skolithos* and *Cruziana* trace-fossil facies support the alternate establishment of storm and fair-weather conditions (Pemberton and Frey, 1984).

With gradual upward increase in grain size the sandstones in some instances pass imperceptibly into gritty sandstone and then to grit. Occasional wave-rippled bed surfaces in the gritty facies indicate deposition above fair-weather wave base and internal structure of large-scale cross-stratifications suggest a shoreface environment.

In major regressive subsequences, with attendant increase in average grain size, evidence of gradual dominance of current transport over waves becomes apparent as one moves upward. An energy gradient curve (Fig. 2) has thus been drawn against the studied stratigraphic sequence for showing of the variation in power or depositional energy through time and to highlight phases of significant progradation and regression of the shoreline. Successive higher denominations of 1, 2 and 3 are allotted to the heterolithic facies, sandstone facies and gritty facies, respectively, indicating the relative rise in their depositional energy. The product of thickness of each facies subsequence and its allotted energy denomination was plotted against the distance of the top of the subsequence from the base of the measured vertical sequence. The resultant curve provides a fair representation of the variation in the energy spectrum through time and two major phases of regression intervened by a short phase of significant transgression of the sea have been interpreted. Coinci-

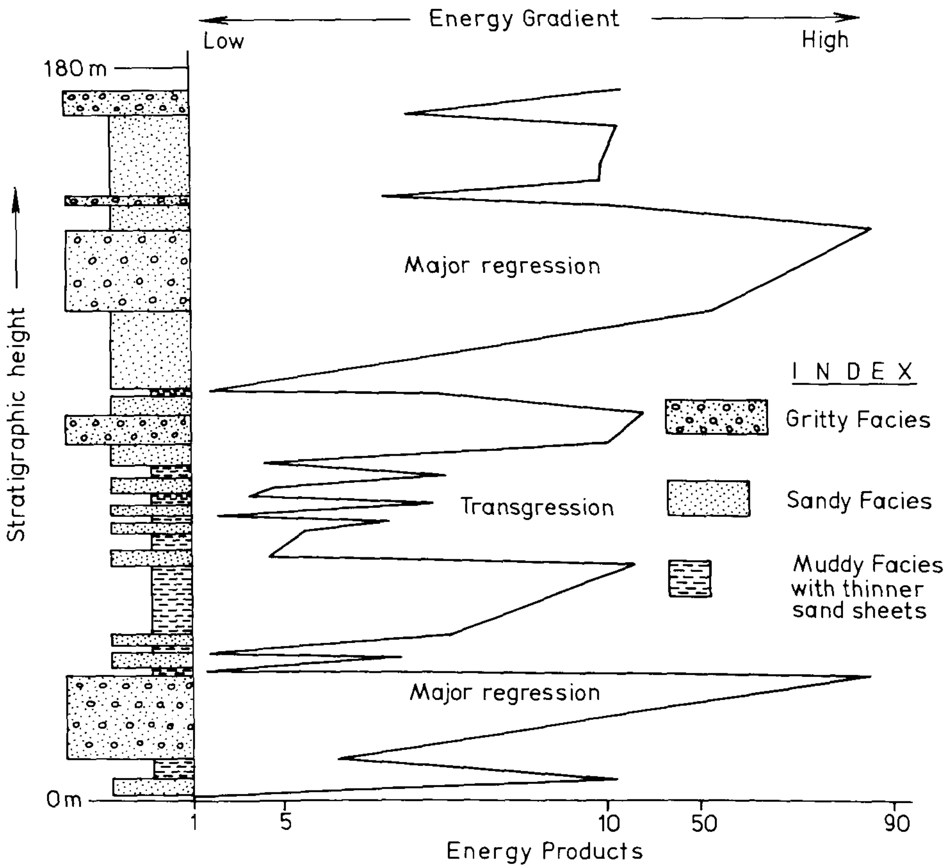

Fig. 2. Energy gradient curve against facies sequence (semi-log) and interpretation of relative rise and fall in sea level through time.

dence of the abrupt decline in ammonite populations with the inferred culmination of regression of the sea provides adequate confirmation for the interpretative framework (cf. Clarkson, 1979).

## DOCUMENTATION OF SUPERIMPOSITION OF STORM WAVES ON TIDAL CURRENTS

The thick gritty facies at the upper part of the major regressive subsequences (Fig. 2) displays intricate intertwining between small lenses of gritty sandstones and fine sandstones. The gritty sandstones with a bipolar and bimodal paleocurrent pattern (Fig. 3) with occasional development of herringbone structures strongly suggest tidal current activity. The grit usually concentrates along the foresets. The palaeoshoreward-directed cross-strata of flood tides incorporate lesser amounts of

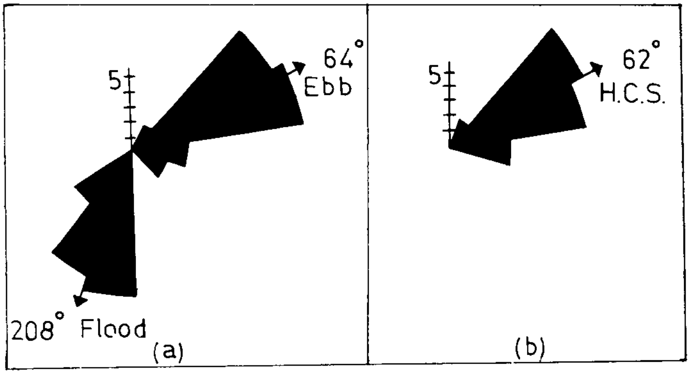

Fig. 3. Palaeocurrent roses. (a) Bimodal tidal cross-stratifications; (b) unidirectional cross-stratifications within hummocky bedforms.

grit than the products of ebb tides. Evidently there was a strong tidal asymmetry with ebb-tide currents being considerably stronger than flood-tide currents. The fine, well-sorted sandstones, on the other hand, are characterized by hummocky bedforms as well as hummocky and swaley cross-stratification (Leckie and Walker, 1982). Here it is pertinent to mention that McCrory and Walker (1986) have recently reported tidal bundles of cross-stratifications within storm-laid sediments.

The hummocky bedforms in Umia only occasionally have grits along cross-stratifications; grit, if present, concentrates preferably along the cross-set boundaries. The lack of grit within hummocky/swaley cross-sets is presumably due to failure of storm oscillation to carry grit-sized materials in suspension, the general mode of transport. The average amplitude and wavelength of the hummocky bedforms are 5.2 and 42 cm, respectively. Their internal cross-stratifications are not always, as expected, symmetrically poised (Fig. 4) with radial orientations and low angle. In fact, the full spectrum of variation from typical HCS through asymmetric but still multidirectional cross-strata to distinctly unidirectional and comparatively high-angle (12–22°) cross-strata (Fig. 5) is observed. The high-angle asymmetric unidirectional cross-strata within the hummocky bedforms could have formed owing to syndepositional reworking by some unidirectional current (Cotter, 1985), which, in this setting, is evidently tidal.

The offshore-directed cross-stratification in grit and sandy grit reveal mean direction of tidal ebb towards 64° while the cross-strata in gritty sand deposited from weaker flood tide indicate mean palaeoflow towards 208°. The close match between the mean tidal ebb flow and the mean direction of inclination (68°) of unidirectional cross-strata in hummocky bedforms (Fig. 3) of well-sorted fine sands provides clear indication that tidal ebbs reworked the storm-generated hummocky bedforms syndepositionally and offshore sediment transport must have been enhanced by the combined effect of the two flows. During storms, deposition mostly

Fig. 4. Asymmetric set of hummocky cross-stratification. Note erosion of the lower set of overturned cross-stratification and smooth draping of erosion surface by successive set of laminae.

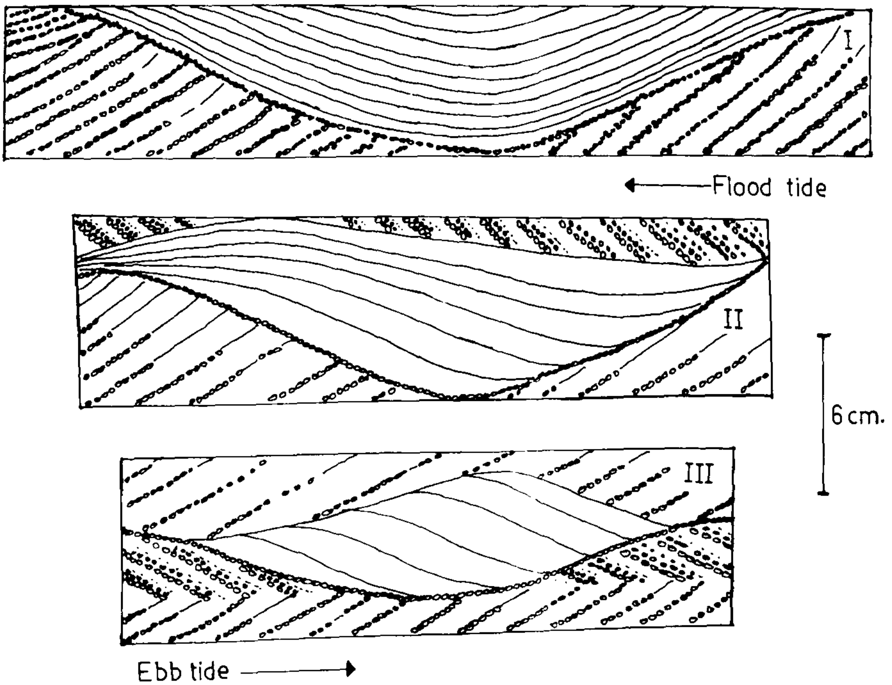

Fig. 5. Field sketches compiled to depict the sequential variation from symmetrically poised multidirectional (I)–asymmetric, yet multidirectional (II)–perfectly unidirectional hummocky cross-stratifications (III) in association with tidal cross-stratification defined by grit. Grit accumulated preferably along cross-set boundaries within hummocky bedforms.

takes place from the offshore-moving ebb surges (Johnson, 1977). When the tide (flood) opposes immensely stronger storm ebb surges, the drag of the unidirectional current should be effectively suppressed. But the unidirectional drag is sustained when the tidal current (ebb) moves in the same direction with the storm generated flow. This observation perhaps explains the invariable parallelism between the tidal ebb cross-stratifications and the unidirectional cross-stratifications within asymmetric hummocks.

## CONCLUSION

The studied hummocky cross-stratified facies sequence of the Tithonian–Neocomian Umia Member, indicates recurrent progradation of the shoreline. Two major regressive cycles document offshore (below fair-weather wave base) to shoreface transitions. Current-related sedimentary features dominate in the shoreface facies. Distinctive gritty tidal cross-stratified beds containing small lenses of fine sandstone characterized by hummocky bedforms are typical of the shoreface deposits. The perpetual tidal current effected syndepositional reworking of the sediment laid by storm waves. The offshore sand transport was enhanced by superimposition of storm waves on an ebb-tidal current. Superimposition of storm-generated oscillatory flows on perpetual tidal flows, as envisaged here, could be a regular phenomenon through space and time.

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