CHAPTER VIII

TRANSPORT AND DEPOSITION

PREAMBLE

The presence of marine microfauna in the miliolitic rocks of Kutch has prompted some of the previous workers (Hardas & Merh, 1968; Merh, 1980; Desai et al, 1982) to invoke a marine environment of deposition for these carbonate sands by postulating high sea levels during Quaternary time. Perhaps a comparison drawn between the miliolite occurrences of Saurashtra with those of Kutch led these workers to attribute marine origin to sheet-deposits and aeolian origin to dunal accumulations.

Applicability of such a picture to Kutch needs recapitulation. Detailed mapping by the present author of almost all miliolite occurrences, has very clearly established that sheets of miliolite occur at different altitudes, and it would be most unrealistic to invoke several high strandlines to explain marine deposition at various levels. Invoking tectonism too is not possible because there are few evidences to support tectonic uplifts to explain the different heights of sheet miliolites. On the other hand there is a strong case defacto for an aeolian transport and deposition, originally invoked by Biswas (1971). The present author has collected numerous evidences in favour of aeolian action which have been enumerated below:

(a) Absence of megafossils

(b) Presence of truncated dune current-bedding and absence of truly horizontal bedding between two sets of cross-strata.

(c) Absence of mica flakes

(d) Absence of miliolite rocks (identical to those of Kutch Mainland) in Wagad area and islands of Pachham, Khadir and Bela, overlooking the Rann.

(e) Absence of graded bedding in miliolites.

(f) Discontinuous and patchy occurrences.

(g) Absence of 'shingle' accumulation in or near miliolites, which is characteristic of beach material.

(h) Total absence of chalk beds, so typical of marine carbonate accumulation.

(i) Absence of coastal features in 'infra-miliclitic' surfaces.

(j) Loose compaction and friable nature and high degree of porosity of miliolite.

(k) Restriction of miliolite occurrences to a well-defined north-easterly band, facing the present day sandy beach of South Kutch Coast, confined between Suthri and Mandvi.

(l) Absence of miliolite in Western part of Kutch Mainland, beyond Nakhatrana.

(m) Almost uniform lithological characters in unconnected outcrops.

(n) Discontinuous extension of miliolites along the river banks.

(o) Reduction of allochem sizes from southwest to northeast direction and increase in degree of sorting.

(p) Alternating fine and coarse laminations pointing to selective settling of grains in instalments by winds of varying energy.

(q) Presence of the coarse sand band almost devoid of fine sediments ($< 63\mu$) typically corresponding to sorted dune sands. Such well defined sorting has been attributed to wind action by Sarnthein & Diester-Hass (1977).

(r) Presence of angular fragments of older rocks of boulder and pebble sizes in miliolite rocks, which have not undergone transportation.

(s) Presence of obstacle deposits at lower altitudes than the sheet deposits at same locality (e.g. Sanatorium), without any sign of vertical fault displacement.

(t) Location of a majority of the obstacle deposits are on the SW or NE slopes of the hill and ridges; larger accumulations supporting major quarries restricted to the southern parts of the Central Highland.

(u) Presence of dog-tooth cement which is according to Flügel (1982) typical of aeolianite accumulations.

The presence of above mentioned features in miliolite rocks of Kutch, have enabled the author to conclude that these are wind-borne sands, having been deposited at various sites showing different modes of accumulation. The southwesterly onshore winds transported loose beach sands inlandward and deposited in different forms at such places where the topographic features caused the reduction in the wind velocity and behaved as protected areas for the accumulation of these sands. The later cementation processes in a vadose environment converted these carbonate sands into consolidated miliolite limestones. The aspects of the fresh water diagenesis and field characters of these rocks have already been described in Chapters IV and VI.

TRANSPORT MECHANISM

Under arid and desertic conditions, wind plays an effective role in transporting sediments. An essential requirement for the effectiveness of aeolian action is that the sediments have to be dry. Bagnold (1941) who investigated physics of movement of sands by the wind action in deserts has distinguished three types of movements as; (a) surface creep, (b) saltation and (c) suspension. The movement of dust and sand particles by process of suspension and saltation takes place faster than that of the coarse debris by surface creep. This selective transport would give rise to the sorting action of the wind (Fig.VIII.1).

During aeolian transport the bulk movement of particles larger than silt and clay is brought about by processes of

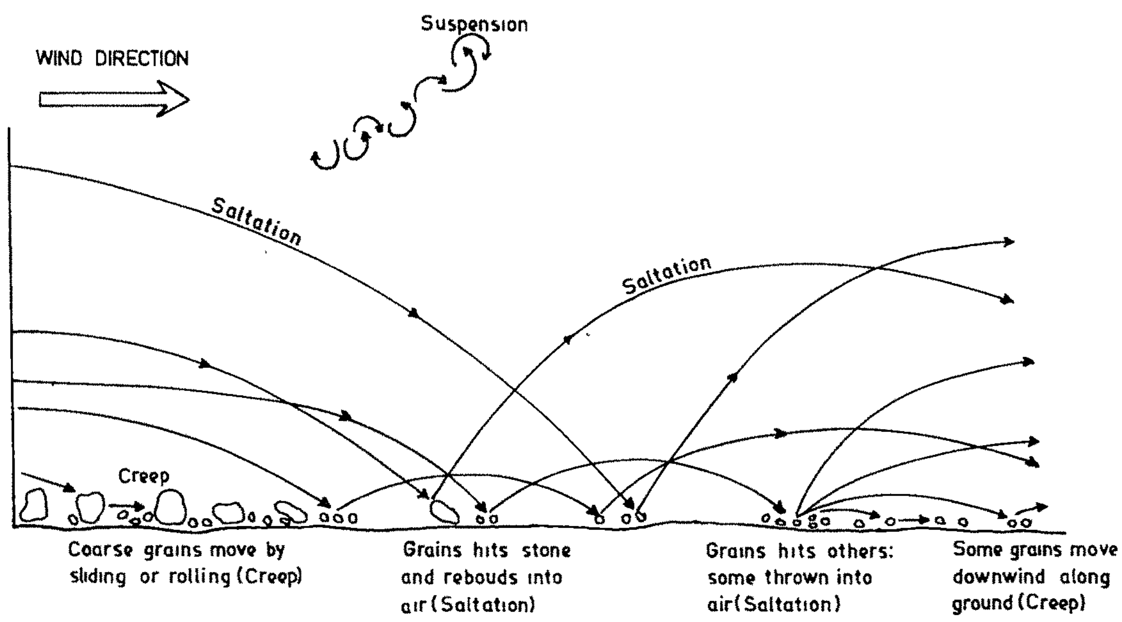

Fig.VIII.1 Schematic diagram showing the transportation and the sorting action of sediments by wind.

the saltation and surface creep. Saltation results in a series of elastic bounces (jumps) and sand grains move forward. The initial energy that lifts the grain into the air comes from impact with other particles. When the wind reaches a critical velocity, grain of sand begins to roll forward along the surface, suddenly, one rolling grain collides with another; the impact may cause one or both of the grains to bounce into the air, where they are forced forward by the stronger wind above the ground surface. The resulting course of the sand grain is parabolic from the point where it was first thrown into the air to the point where it finally hits the ground, at an angle of impact generally ranging from 10° to 16° (Leet & Judson, 1969). When the grain strikes the surface, it may either bounce off a large particle and be driven forward once again by the wind or it may bury itself in the loose sand, or may throw other grain into the air by its impact (Fig.VIII.1).

Some sand grains are too large and can never rise into the air at all, even under the impact of other grains. They move by the surface creep (rolling and sliding), perhaps 25 % of the sand travels by rolling and sliding and 75 % shows forward movement by means of saltation. According to Twidale (1976, p.288) " the initial sand movement always occurs at the downwind end of an exposed sand surface and that the grains are put in motion farther and farther upwind as the wind velocity increases. In general, however, it may be stated that a wind of 16-20 km/hr is needed to put sand grains into motion". Pethick (1984) has also observed that the wind with speed of 5 m/sec (18 Km/hr) is required to initiate the sand movement.

It is significant that of the above three processes, those of seltation and surface creep are better observed. The transport by suspension is no doubt dependent on the fineness size of the particles, but its selective effectiveness depends also on other factors, e.g. the clay particles are small and of low mass, they do not get readily lifted by the wind because they are plate-shaped and tend to pack down well to form a smooth surface and because many clays are bonded by ionic charges. Twidale (1976, p.285) has stated that "initially many clay particles are lifted from the surface and into the air by turbulent eddies, which develop as a result of the passage of the air over roughened surface, some are lifted by distinct vortices and minor eddies called dust devil".

The high velocity winds thus tend to keep fine silt and clay particles in suspension and carry them over large distances, and settle when the turbulent wind ceases.

It is not however very correct to rule out transport of sand size particles by the process of suspension. In exceptional circumstances which are not uncommon, winds can lift heavier material in suspension also and transport it to considerable distances. The sand grains can be lifted from the surface into the air by turbulent eddies/ vortices/ whirlwind. According to Twidale (1976, p.285-286) " Each sand grain exposed at the land surface lies in a zone of low velocity caused by the frictional drag due to the sand grains themselves, pebbles, vegetation and other obstruction to the air-flow over near the ground. However, there is a rapid increase in velocity a short distance above the surface, after which it remains essentially steady. The precise nature of the velocity gradient above the ground varies with the character of the surface. Turbulent eddies, which involve a dissipation of energy, are formed partly because of the roughness of the surface which induces pressure contrasts between the upwind and lee side of any obstacle, and partly because of the large temperature differences commonly developed between the air and the sand surface in hot desert region (temperature of upto 84°C have been measured on sand surfaces in Africa).. Yet this near-surface turbulence which poses the main problem to transport is also the means whereby clay and sand particles are put in motion. Sand grains are lifted out of this low near-ground velocity zone and follow short parabolic paths downwind. The initial lift is provided by numerous turbulent updrafts of air, which provides an upward suction. The height to which the grains are lifted varies according to their mass and to the force of the updraft. The larger vortices are capable of lifting not only dust, but also leaves, twigs and other debris high into the air. They are probably responsible for lifting the small animals which are occasionally reported as falling from the sky in the tropical deserts".

In this context, the present author would like to refer to a recent news item (The Times of India, 30-5-86) reporting an interesting phenomenon from China "A Freak wind roared through the West China Oasis of Hami, sucked 13 school children into the air and carried them upto 20 km before depositing them unharmed into sand dunes and scrub, an official newspaper reported in Beijing..... after a two day search, all the children were finally found with scratches where they had been lashed by swirling sands". The foraminifers in miliolite rocks of Kutch with their well preserved surface ornamentations indicate that they could have been transported inlandward from the coast by the action of wind (whirlwind)described above.

Obviously, it is not necessary to invoke a wind with speed of 500 km/hr to lift a sphere of 300 μ m diameter to a height of 1 km above the ground as envisaged by Baskaran (1986). Moreover, the Stoke's Law can not be made applicable in the present case because the miliolitic particles are in most cases not spherical.

On the basis of the present day observations in desertic and arid zones, identical phenomenon as transporting agents should not only be invoked but their effectiveness should appropriately be highlighted for the transportation of sand size miliolite particles in Kutch.

The present author has visualised a transport mechanism for the Kutch miliolites, which could be comprising diverse combinations of all the three processes viz. suspension, saltation and surface creep. The gentle to moderate topographic rise was an important factor to have enabled the aeolian sands to travel long distances inlandward from the coast. Moreover, the gaps provided by the valleys of the rivers Kankawati, Chok, Sai, Vengdi, Kharod, Rukmavati must have offered more favourable conditions. The effectiveness of surface creep, according to the author, should not be minimised, because from his personal observations in the study area, as well as in the Rann of Kutch he can vouch for the shifting of sand particles to several kilometers, even climbing up moderate slopes. The surface creep need not act alone. It might have shifted the sediments at a reasonable..

distance from the source from where it could be subsequently transported further inlandward by other two processes. The vice versa could also be true. Sand particles, transported to long distances by action of whirlwind, could also be affected by further surface creep or saltation. Obviously, strong winds, quite often of whirlwind type, operating in instalments, would ultimately give rise to the different transport mechanisms acting in succession, controlled by aeolian processes operating in a variety of modes, at different velocities at different periods at different locations. What one observes today is the sum total of processes involving high velocity winds that operated over a period of time and lifted up or pushed the coastal as well as inland sands to their present day resting places, by drop in their velocities on account of their long distance travel or on meeting obstacles. Of course, the entire process of transport and deposition must have taken place in a protracted manner, spreading over a reasonably long time-span and involving, in many gases, more than one periods and events of transport and deposition resulting into considerable reworking of the already once deposited material (Fig. VIII.2); the total picture is thus quite complex.

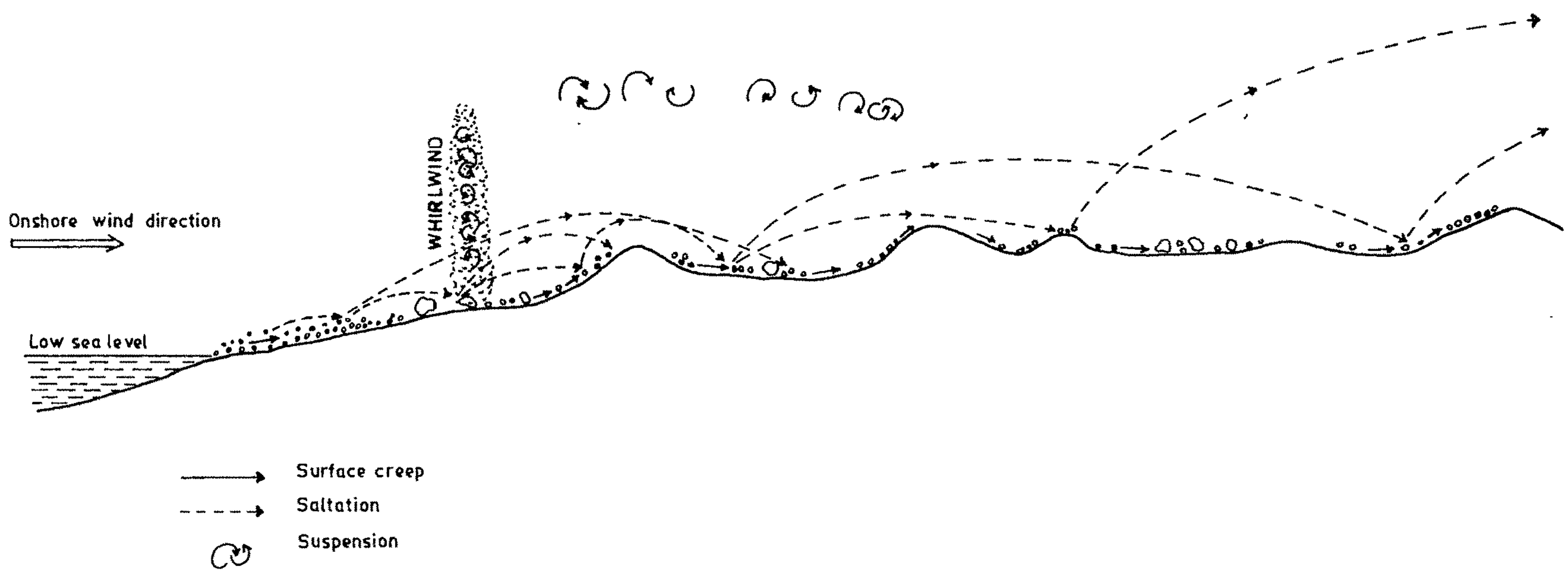

Fig.VIII.2 Schematic diagram showing inlandward shifting of miliolitic sands of Kutch by various transportation processes of wind.

DEPOSITION

Winds commonly deposit sands in the form of dunes and sheets which tend to progressively migrate downwind. The shapes, sizes and transported distances of aeolian sands are controlled by the following factors.

(1) Nature and quantity of sand supply
(2) Wind velocity and direction
(3) The characteristics of the creep surface

Even to-day, in Kutch as well as the Great Rann, the dominantly southwesterly direction of the wind has been responsible for the aeolian transport and deposition of sand size particles. With the presumption that there has been no siginificant change in the wind direction during most part of the Quaternary period, the present day behaviour of coastal sands under the influence of southwesterly winds, provides vital information. The author is inclined to agree with the model invoked by Sperling & Goudie (1975) and Goudie & Sperling (1977), wherein southwesterly winds have been thought responsible for the transport of foraminiferal beach sands in Saurashtra, Kutch and Thar Desert of SW Rajasthan.

Strong winds, appear to have been generated in instalments, with some likely calm intervening periods. In most cases aeolian accumulations are originated, where an obstacle, such as local topography and even vegetation, reduces the wind velocity to a point where deposition occurs. According to Twidale (1976 ,p.309),"many masses of sand and clay have accumulated around obstacles such as shrubs, outcrops and ridges, which disturbs the air flow by diverting the wind over and around them. Secondary eddies and currents are set up, and zones of low velocity, or dead areas, are produced (Fig.VIII.3)". This author has further observed that "if the height of the obstacle is designated 'h', the area of accumulation extends '1.5 h' on the windward side and '6 h' on the lee side (Fig.VIII.4). Debris such as sand, silt or salt accumulates in these shadow zones in front of, behind, or, in the case of shrubs, actually within the obstacle".

The mechanism invoked by Twidale (op.cit), is very well applicable to the deposition of carbonate sands on the Mainland Kutch. The irregularities and obstacles due to an uneven topography in Kutch provided ideal conditions for the generation of turbulence in the air flow near the ground (Fig.VIII.5). The internal structures of the various dunal accumulations are thus characterised by variable angled cross stratification, almost parallel to the prevailing wind direction. At most of the localities the leeward deposits follow the slope of the obstacle and as a whole, show a concave profile characterised by planar dune bedding

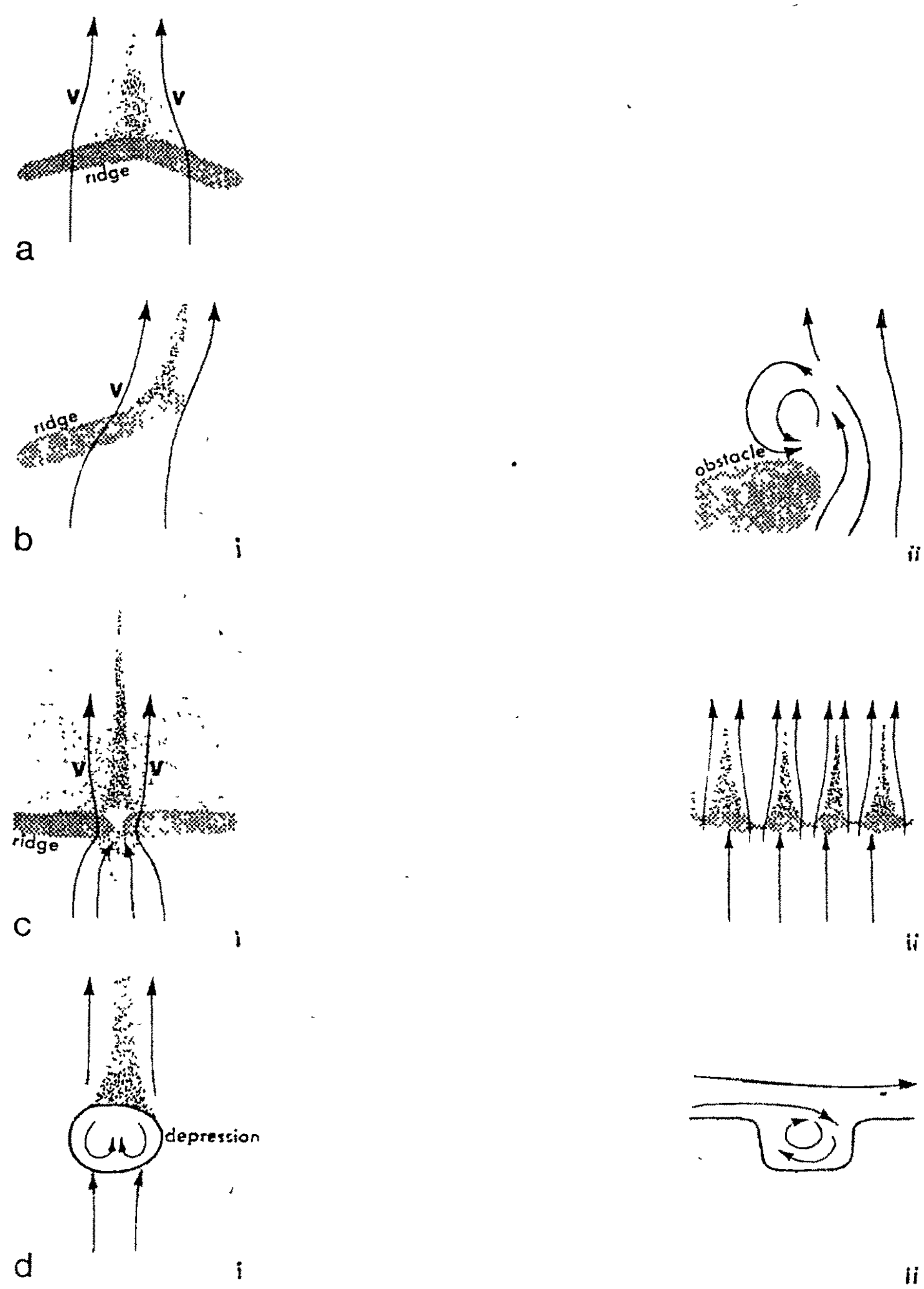

Fig. VIII.3 Deflection and diversion of airflow over obstacles and deposition of sand in their lee as shown in wind tunnel experiments. V, vortex, (a) and (b) show deflection over crescentic and diagonal obstacles; (c) distortion of angular through gaps or cols, (d) the effect of a depression. (after Twidale, 1976).

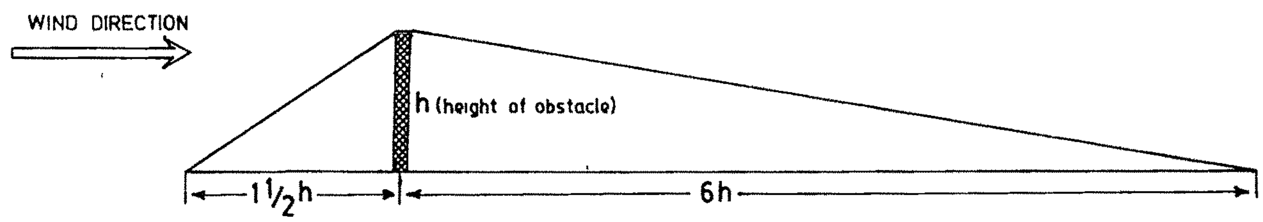

Fig.VIII.4 Diagram showing deposition of debris around an obstacle
(after Twidale,1976)

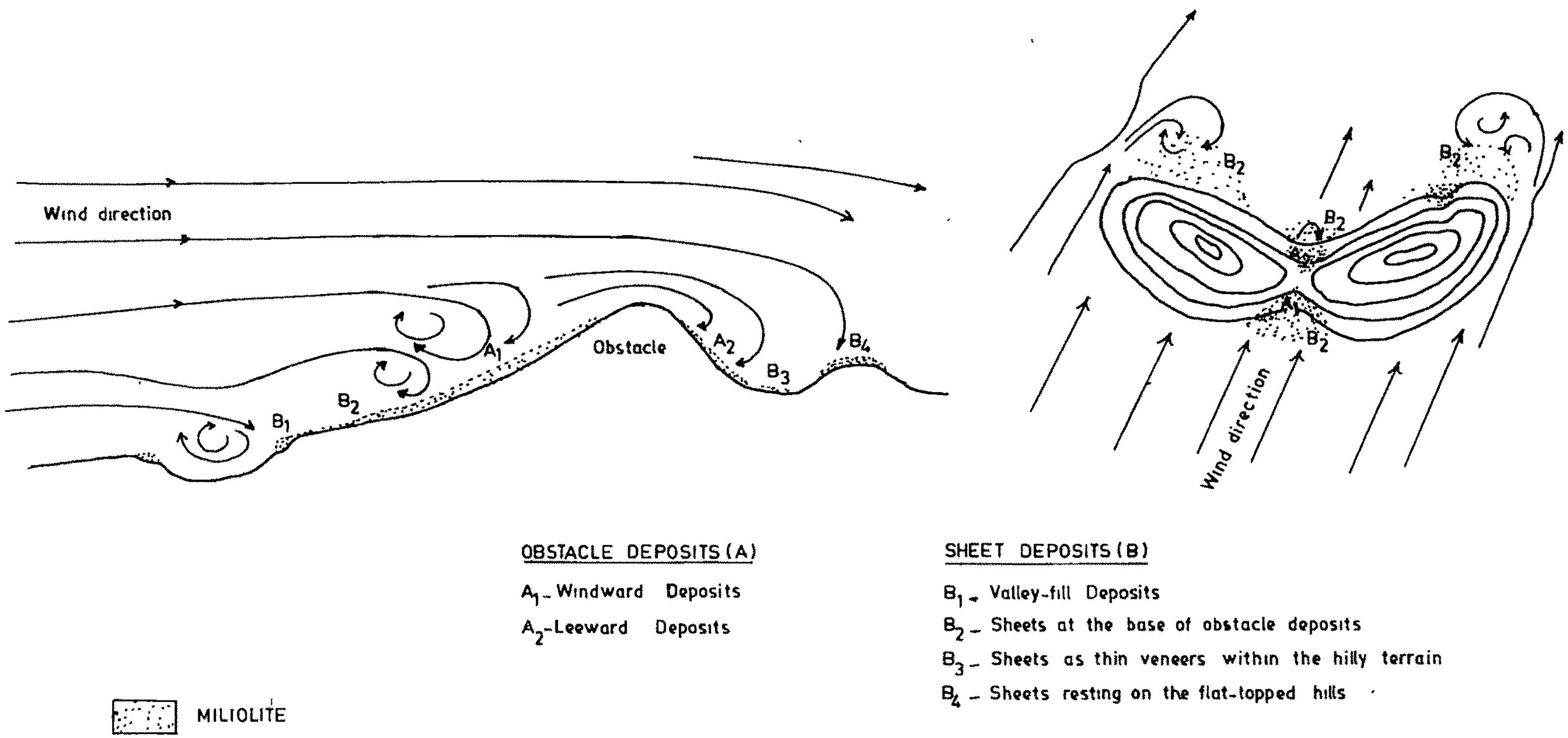

Fig. VIII. 5 Schematic diagram showing diversion of wind over and around obstacles (hills and ridges) and deposition of miliolitic sands in different modes with gentle angle of dip varying from few degrees to as high as 20°, depending on the slope of obstacle. In most protected areas (amphitheatres and river valleys) these sand deposits form featureless sand sheets of few cm to as thick as 10 m. The presence of alternate coarse and fine grained laminae suggests their transportation and deposition in instalment, with varying wind velocities. To obtain a clear picture and understanding in extense the transportation and deposition of calcareous beach material (miliolitic sands) inlandward from the coast, by the aeolian processes, the present author made a clay model of Kutch Mainland (Plate VIII.1). The medium to fine grained sands were placed in the southwestern part of the model supposed to represent the coast and were blown landward with the help of a table fan. It was observed that the blown material occupied the notches and depressions on the slopes of the obstacle (hills and ridges) and also spread as thin veneers covering the low pedeplains, base of the obstacle and 'intermontane' areas, exactly in the manner in which the miliolite occurs across the Mainland Kutch. It was also observed that the deposition did not take place on the Convex part located on either side of the depression and notches of the obstacle; this is because they disturb the air-flow by diverting the wind carrying sands, around and over them towards the depressional portion. Thus, the sporadic nature of the miliolite

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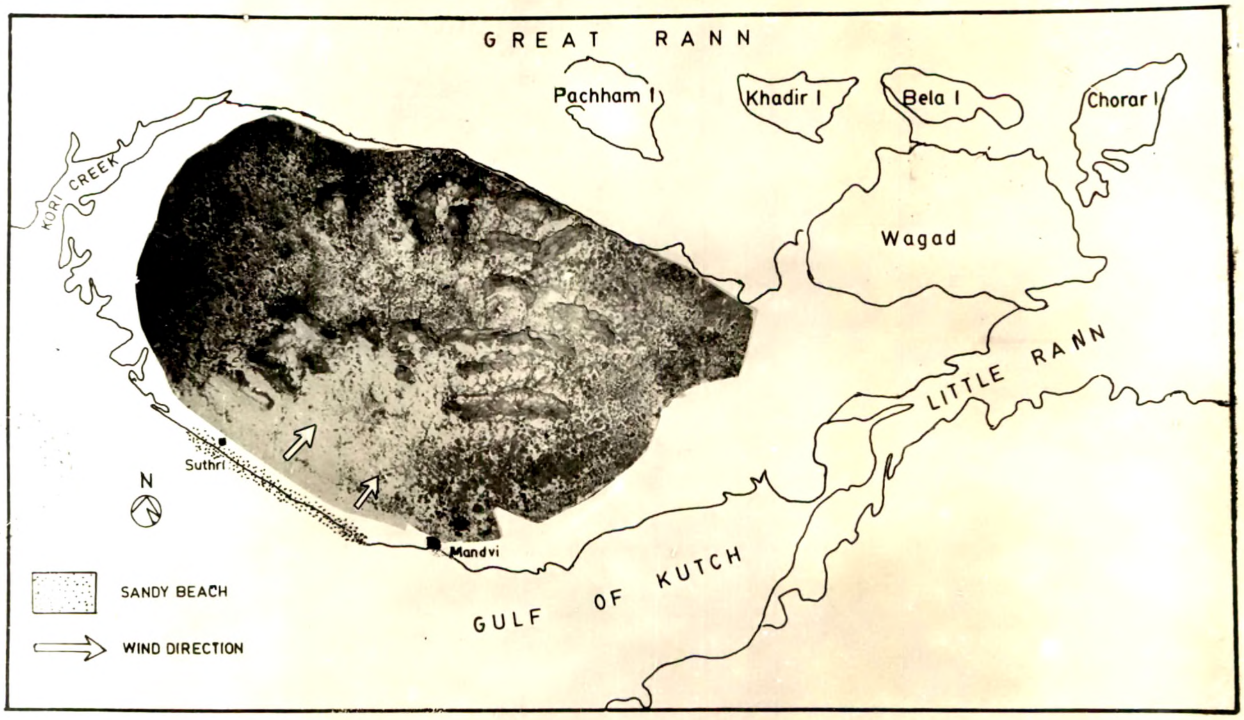
Plate VIII.1



Photograph of a clay model illustrating the transportation and deposition of beach sand into inland areas of Mainland Kutch.

occurrences in Kutch could be partly due to (i) selective deposition originally and (ii) their subsequent removal by fluvial agencies.

Although the author has invoked a dominant role of wind-borne transport and deposition for most of the sheet miliolite deposit occupying low-lying areas, he is of opinion that quite a few sheet occurrences especially those which contain cobbly and pebbly layers and calcrete crusts are typically indicative of fluvio-aeolian deposition. In such cases erosion of dunal material during sudden spells of heavy downpour and its subsequent transport, deposition and consolidation in nearby valley sites, appear to be the main processes, giving rise to sheets which have been referred to as 'wadis' by Glennie (1970).