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Micromorphology of Quaternary Calcretes around Didwana in Thar Desert of Rajasthan

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Abstract: Quaternary calcretes within the dunes and interdune pan deposits around Didwana have been classified on the basis of their field occurrences, morphology, microtexture and microfeatures. Micromorphological analyses helped to understand the development of these calcretes. The study reveals that the calcium carbonate nodules in the lower horizons of the dune profiles, and in the interdune pans have been formed by the complex process of pedogenesis and ground water action in semi-arid to arid climate.

Key words: Calcretes, micromorphology, pedogenesis, ground water.

Soils with prominent accumulation of calcium carbonate nodules are widespread in arid western Rajasthan, containing the Thar desert (Dhir, 1995). Such deposits are very common in ancient continental and marginal marine sequences (Goudie, 1973; Allen, 1985). In western Rajasthan 'calcretes' or calcium carbonate nodules are locally known as *murad*. These occur within the stabilised sand dunes, calc-pans and pediment surfaces (Raghavan, 1987; Raghavan and Courty, 1987; Raghavan *et al.*,1991; Courty *et al.*, 1987; Dhir, 1995). Their origin, rate of development and significance as palaeoclimatic indicators have always intrigued the geologists, pedologists and geomorphologists (Courty and Federoff, 1985; Dhir, 1995). Yet, very little microscopic studies have been carried out to understand the process of calcrete formation in the Thar. In this paper micromorphological analysis has been applied to explain the plausible formation of calcretes. The importance of this analysis lies in the fact that the data can be used to draw inferences concerning the provenance of a given material, its mode of formation and any processes that might have modified it subsequent to its emplacement (Courty *et al.*,1989).

Study Area

The study area, Didwana (74°35′ E, 27°22′ N) in Nagaur district of Rajasthan (Fig. 1), is situated along the eastern margin of Thar desert. It consists of a flat to undulating sandy plain, partly covered with stable longitudinal dunes, especially on the eastern and western margins of the Didwana salt lake. A hill of Aravalli quartzite and carbonaceous phyllites forms the south-western limit of the salt lake. The Quaternary deposits of the area are of fluviatile, aeolian and lacustrine origins. These are more than 40m thick and overlie the Precambrian meta-sediments (Misra *et al.*, 1982; Raghavan, 1987). The sites around Didwana where detailed sampling was carried out occur

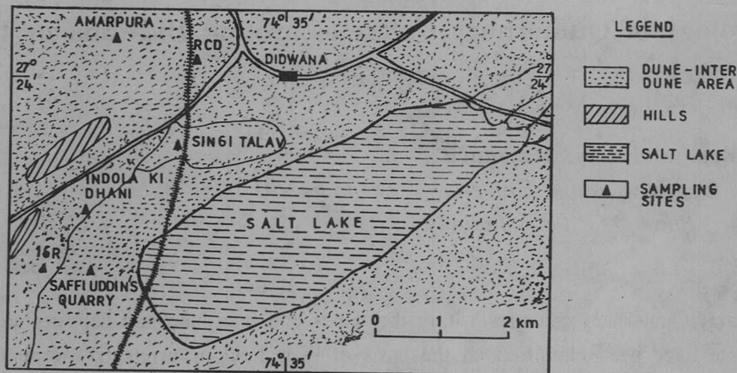

Fig. 1. Study area.

at Indola-ki-Dhani, Amarpura, Railway Cutting Dune (RCD) and Saffiuddin's well section.

Methodology

Calcretes exposed in several quarries, nalas, dune cutting and excavated trenches were examined in field and the soil profiles were classified following Gile *et al.* (1966). The litho sections of calcretes studied are described in Tables 1 to 4.

For micromorphological analysis, oriented samples of calcretes were collected and thin sections of 14.5 cm X 6.5 cm size were prepared following the procedure of Guillore (1980). Chemical staining of the thin sections was done as per the procedure given by Dickson (1965). The calcitic features were identified and described fol-

Table 1. Profile characteristics at Indola-ki-Dhani

Layer	Depth (cm)	Litho units
1	0-60	Light yellowish brown (10 YR 6/4, 5/4); structureless, slightly pedogenised, non-calcareous, well sorted, well rounded sand (AB horizon).
2	Disconformity 60-135	Pale brown colour (10 YR 6/3, structureless, moderately sorted, well rounded, fine sand. Weakly calcretised with diffused carbonate and soft $CaCO_3$, sub-rounded pellets in the basal part.
3	Sharp contact with the lower layer 135-240	Pale grey (10 YR 7/1); represents a calciorthid.
4	Gradational contact 240-272	Grey colour (10 YR 7/1, 10 YR 6/1), strongly calcretised nodules (4 to 6 cm across) with matrix of calcareous loam, poorly sorted, with occasional pieces of carbonaceous phyllitic schists and quartz gravels (0.3-0.5 mm across).
5	Gradational contact 272-410	Light grey (2.5 Y 7/1), calcareous, amorphous nodules (0.5 to 1 cm acros) in moderately sorted subangular to angular fine sand. Obscure lamination present. Carbonate concretions decrease in their abundance as well as in their size (below 330 cms).

Table 2. Profile characteristics at Amarpura quarry

Layer	Depth (cm)	Lithology
1	0-110	Light yellowish to brown (10 YR 6/6) representing AB horizon.
2	Sharp contact with lower layer 110-160	Greyish (5Y 7/1), Pebbly gravel of well rounded $CaCO_3$ pellets and nodules. Matrix between gravel nodules is subangular to sub-rounded, moderately sorted. In the lower part of this horizon (120-160 cm) there is an increase in the size of $CaCO_3$ nodules (2 to 4 cm) which are highly crystalline.
3	Gradational contact with the lower unit 290-380	Pale grey (10 YR 7/2) or light brownish grey (10 YR 6/2) subrounded to sub-angular, poorly sorted clayey sand, with $CaCO_3$ nodules (3 to 4 cms across) forming a band at a depth of 260-290 cm. The matrix is mottled at places.
4	Sharp contact to 380-675	Strong brown (7.5 YR 5/6), well rounded to angular, moderately sorted, medium coarse sand alternating with brown, pale brownish (10 YR 6/2) or brown (10 YR 5/3) subrounded, poorly sorted, fine clayey silt. Pockets of fine sandy clay of brown (10 YR 5/3) occur within the latter. These pale brown alternations are indurated, mottled at their edges with 7.5 YR 8/3 hue. $CaCO_3$ nodules vary in size (3 to 4 cms). Two calc bands occur at a depth of 4.5 to 4.6 cm and 540 to 545 cm. The alternations have a planar bedding, gently dipping towards Singi Talav (2° to 3°) in a southeast direction. Some $CaCO_3$ nodules between 510 to 530 cm and 650 to 675 cm exhibit dendritic pattern of iron oxide.

lowing Bullock *et al.* (1985). In order to study the alignment and size of calcitic crystals in the pore spaces, cavities and cracks, some carbonate nodules were studied by using Scanning Electron Microscope (SEM).

Results

Calcium carbonate accumulates at the average depth of leaching. With increasing soil age it forms a recognisable sequence of morphological features (Gile *et al.*, 1966;

Table 3. Profile characteristics at railway cutting dune (RCD)

Layer	Depth (cm)	Lithology
1	0-70	Light yellowish brown (10 YR 6/4) to brownish yellow (10 YR 5/8), AB horizon.
2	70-115	AB horizon with few $CaCO_3$ nodules well rounded (1 to 2 cm across) with diffused carbonate between them.
3	115-160	Same as layer 1, except that $CaCO_3$ nodules increase in their density and are amorphous.
4	160-300	Yellowish brown (10 YR 5/6), well rounded, well sorted fine sandy silt with large size microcystalline calcium carbonate nodules (2 to 4 cm across).

or radial fractures, cracks and channels. The channels are lined by quasicoatings or hypocoatings of clays. Many channels are partially or completely filled up by microsparite or sparite. Some channels are tubular, with tapering or rounded ends, but others are cylindrical. Magnans are common along the edges of the nodules. The N3 calcretes are best seen at the base of Amarpura Quarry (depth 650 to 675 cm).

N4 and N5 Calcretes

Compound (N4) and hardpan calcrete nodules (N5) mainly consist of microsparite and sparitic calcite. Their ground mass is micro-crystalline to crystalline. The nodules are of 0.1-0.5 mm size, with a spherical or ellipsoidal shape and having concentric rim of clear micrite. Under the microscope the nodules show a mosaic with few detrital grains floating in it. The calcitic mosaic comprises a rather densely packed sparite and microsparite crystals. Some of the sand grains and cracks are lined with radially crystallised microsparite (4-5 μm) in association with micrite (Courty *et al*., 1987). The compound nodules (Fig. 2d) are also traversed by channels and fractures of varying sizes and shapes. Dissolution cavities with subsequent overgrowth and pits are also seen.

In the hardpan calcretes (N5) relict nodules occur. Sharp boundaries occur between the relict nodules and the surrounding matrix. The hardpan calcretes are also composed of micritic and sideritic nodules within the larger size microsparitic and sparitic nodules. Magnans and meniscus cement are common features. Biotite and hornblende grains often show signs of alteration. The released iron oxide forms a halo around these mineral grains (Fig. 2e).

At places the original fabric is altered. The microsparite/sparite cement is dissolved, especially at the edges of the nodules and around the grains. Due to dissolution, the nodules appear corroded and loosely cemented.

Discussion

Micromorphological analyses suggest that all the calcrete types are not the products of simple dissolution and reprecipitation, or recrystallization. The strong development of sesquioxidic magnans, calcitic rims around the detrital grains and nodules, alteration of hornblende, plagioclase and chlorite, as well as meniscus cement (as observed in N3, N4 and N5 nodules) indicate marked hydromorphy (waterlogging), at least intermittently, in the area. The dissolution phases need not necessarily be related to hydromorphism, but could reflect periods when the depth of leaching was greater (Wright and Peeters, 1989). Sesquioxidic magnans are characteristic features of very dense nodules or nodules in deeper horizons. Their presence can be explained by reducing conditions which favour the mobility of ferrous compounds. The reduction of Mn under suboxic condition is a common process in soils (Duchaufour, 1982).

Soil carbonates commonly develop at the evapotranspiration front (Weider and Yaalon, 1974), but this being a mobile zone, phases of dissolution alternate with phases of superposition, depending on subtle changes in the soil moisture budget (Wright and Peeters, 1989). This phenomenon is explained by $CaCO_3$ being carried in solutions by rain-water and ground water.

The soil fauna creates channels and voids through which the solutions flow. $CaCO_3$ that is dissolved and removed from the upper horizons of the soil, moves through the voids and channels to the lower horizons. The solutions evaporate and $CaCO_3$ precipitates as micrite/microsparite crystals. This is a common feature as soil solutions dissolve small amount of calcium carbonate (Courty and Federoff, 1985).

This crystallisation affects the walls of the channels and the voids, giving rise to hypercoatings and impregnative in-fillings. These two types are the only dominant calcitic features observed, and represent the first stage of calcitic culminates in the precipitation of micrites in the diffused form. Powdery (N1) and diffused nodules (N2) are initially formed by the process of dissolution and reprecipitation of calcic sand size grains (Fig. 2f). The occurrence of non-carbonate clay with micrite suggest its pedogenic origin. It is also noted that the size of calcite crystal increases as the clay content decreases. This may be due to aggregation of clay minerals along the grain boundaries.

Hypocoatings and impregnative in-fillings gradually coalesce and the nodules become denser as simple packing voids and grain pores are filled with secondary calcite crystals. As accumulation of calcium carbonate increases, the porosity and permeability of the soil decrease. The original constituents of the host material are then progressively replaced by increasing amount of calcite. In the deeper horizons, due to the complex processes of ground water and pedogenesis, the individual nodules are observed to be disrupted, with edges dissolved and eventually recemented, giving rise to compound nodules. Distinct micritic layers occurring as enveloping features around the nodules indicate that the calcretes have undergone polyphased accretion. The in situ occurrence of diffused calcitic nodules suggests a transitional stage between the indurated calcitic nodules and the compound nodules. Pedogenic calcretes possess complex crystal fabrics in comparison to ground water calcretes (Courty *et al.*, 1987). Crystal size has also been used as an indicator of climatic conditions, with coarser crystal presumed to indicate wetter conditions (Drees and Wilding, 1987) but crystal size on its own is not a reliable indicator to differentiate between the ground water calcretes and the pedogenic calcretes in the geological record. The calcretes must be observed in their totality, geometry of formation, composition, crystal fabric, biological and textural features.

The presence of floating grains within the crystalline calcite mosaics and the absence of competitive comprise boundaries between crystals reflect the displacive growth mechanism of the calcite crystals. Cracks and fractures within the nodules are generally produced by the process of shrinkage (Tandon and Friend, 1989) and the voids or pore spaces are formed by dissolution. The growth of calcite within the voids and pore spaces is determined by the size of the void (Fig. 3). Cementation occurs as calcite crystals adhere to each other through chemical intergrowth and physical interlocking process. Raghavan and Courty (1987) suggested that sparitic calcrete mosaics (crystal size average 40 μm) were precipitated from ground water during humid (high water table) phases, whereas

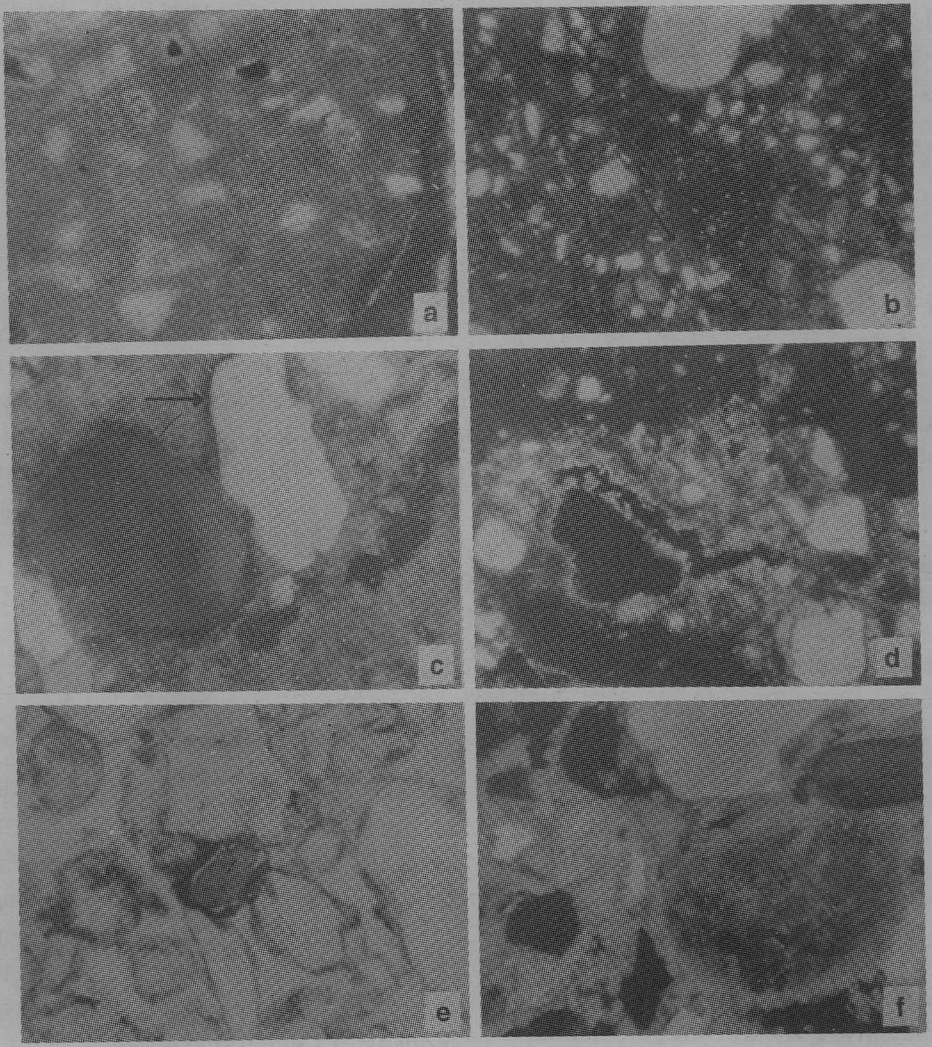

Fig. 2a. Micrite occurs as a rim around the micritic nodules. BXN; magnification x 60.

Fig. 2b. The detrital grains within nodules are similar to the surrounding material and the transition to soil matrix is diffused and gradual (arrow marked). BXN; magnification x 60.

Fig. 2c. The grain margins are coated by very fine clay fractions of illite-vermicullite intermixed layers (arrow marked). BXN; magnification x 100.

Fig. 2d. The compound noudles are traversed by fractures varying in size and shape. BXN; magnification x 60.

Fig. 2e. Hornblende grain has been altered releasing iron which forms a halo around the grain. PPL; magnification x 60.

Fig. 2f. Dissolution of sand size calcic grain reprecipitated as micrite or microsparite. BXN; magnification x 80.

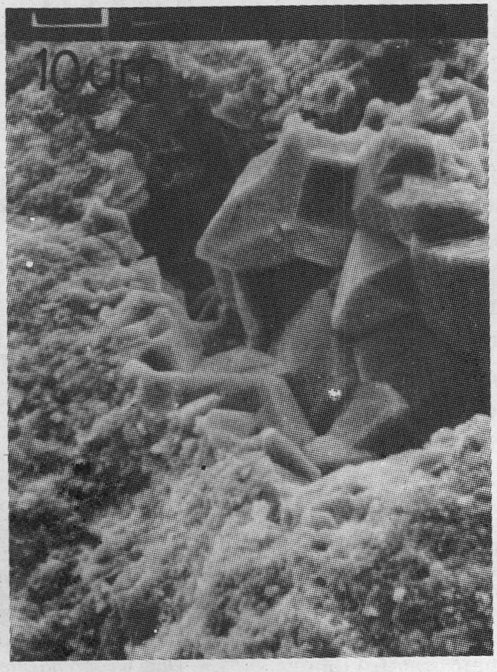

Fig. 3. SEM photograph of N3 type nodules. Note the sparite growth in the void. Growth of calcite is determined by the size of void. Magnification x 500.

more finely crystalline forms, typically exhibiting dissolution and reprecipitation cycles reflect pedogenic processes under semi-arid or arid conditions. Pedogenic processes, particularly the processes of replacement and recementation of calcite, have led to the fossilisation and induration of calcrete nodules, like those observed in Saiffudin's quarry in the deeper, lower horizons (Stage IV). Repeated occurrence of these processes, supplemented by geochemical processes, give rise to complex features which lead to the development of compound and hardpan calcretes (Stages V and VI). Probably, these are also formed as climax products of relatively continuous carbonate accumulation over millions of years (Machette, 1985).

In the interdune and low lying areas, some calcitic nodules perhaps get concentrated during erosional phases, marked by heavy rainfall and occur as coarse sediments. These nodules act as nuclei for further growth and are recemented by calcium carbonate. Rock fragments and relict calcitic nodules also get cemented with the calcium carbonate nodules, thus forming compound nodules (Stage III).

Conclusions

In this study, calcretes occurring within the dunes and interdune pan deposits have been classified on the basis of their morphology, microtexture and microfeatures. Detailed micromophology of calcretes indicates that stages of $CaCO_3$ nodules reveal complex process of pedogenic and ground water phenomenon. In the deeper horizons, occurrences of sesquioxidic magnans, alteration of Fe-rich minerals, calcitic rims around the detrital grains and nodules indicate fluctuating ground water action. Pedogenic processes, such as dissolution, replacement of calcite and recementation have led to the fossilisation and induration of calcretes. Repeated occurrences of these processes, supplemented by geochemical activity, has given rise to complex features leading to the development of compound and hardpan calcretes (Stages V and Vl). The Quaternary calcretes in the study area have developed in semi-arid to arid climate.

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