CHAPTER - 6

DURICRUSTS AND PALAEOCLIMATIC IMPLICATIONS

DURICRUSTS AND PALAEOCLIMATIC IMPLICATIONS

INTRODUCTION

In the Thar desert the scenario on Quaternary - Holocene climatic vicissitudes remain perplexing, inspite of ample contributions made by the scientists belonging to various discipline The antiquity of continental Quaternary sediments of Thar is reflected in varied forms viz fluvial, aeolian, lacustral, residual etc Their spatial distribution under present day sand veneer and terrain settings has inturn created gaps in building up a full fledged stratigraphy and climatic events therein. The author's endeavour of understanding the past climatic change is restricted to the duricrusts. However, based on accounted field studies and the laboratory data, author has been able to delineate various pedostratigraphic units in the study area vis-a-vis climatic events The account on the palaeoclimatic implications is based on the following approach.

1 Reappraisal of existing literature on the palaeoclimatic aspects of the Thar
2 Establishing pedostratigraphic correlations with the available records.
3 Deduction of soil microenvironments and their implications with regard to regional climatic changes

I. QUATERNARY PALAEOCLIMATIC FRAMEWORK - A REAPPRAISAL

Singhvi et al ,(1994) based on thermo-luminescence (TL) dating of dunal profile from the Buddha Puskar have accounted the dune building activity in two main phases viz 25 Ka and 15 Ka B P, there by indicating the pre-antiquity of aeolian accumulation in the Thar desert The rubified soil horizon within the soil profile (having hornblende and other easily weathered minerals) has been dated to 15 Ka in a semi arid climate with better rain fall The underlying light brown sand with calcrete nodules dates back to 22 Ka The earliest phase of dune accumulation in this area has been dated back to 34 Ka. B P

Chawla et al (1992) accounted the dune accretion rates around Awai, Nachna and Bikaner areas by thermo-luminescence study of dunal and interdunal profiles. The salient conclusions of their study are .

1 Dunal activity is older than 40 Ka
2 A peak in the sand mobilization and accretion at 14 Ka B.P.
3 A hiatus in sand mobilization during 13 - 6 Ka B.P and 40 - 20 Ka B P.
4 Second phase of enhanced sand mobilization around 3 Ka.
5. Radio carbon dates of five calcrete layers from Awai profile (Figure 2. 4 b) point to elevated moisture regime around 11 4 Ka, 12.73 Ka, 24 45 Ka, 25.43 Ka and 29 Ka

Wasson et al.,(1983) determined the TL ages of the dunal sections around Amarpura, Langhnaj, Rang Mahal and Bahawalpur and suggested that dunes in the Thar desert were accumulating often on older dunes, well before the beginning of the Holocene His opinion is also parleys with the observations of Singhvi et al. (op. cit), Chawla et al. (op. cit.) and Raghavan (1987a). At Andhario Timbo, from the TL dates it seems that the last phase of dune construction started before 25,000 yr. B.P

Singh et al , (1974) from the detailed study of pollen assemblages from Lunkaransar, Sambhar and Didwana lakes elucidated a complete sketch of Holocene vegetational changes in the Thar The very similarity of the vegetational changes in all the three lakes point to the regional climatic changes rather than the local effects. The different phases of climatic changes advocated by him are :

First phase of active dune formation as indicated by the dune sand strata below the Holocene lacustrine sediments, marking a period of strong aridity before 10,000 yr B P that lead to choking of river valleys and the formation of playas

The second phase of 10 Ka to 9 5 Ka is a period of higher rainfall with prevalence of fresh water conditions in these lakes The third phase (9 5 Ka - 5 Ka) evidenced periods of wetter and drier conditions, but relatively higher rainfall than that of the present. Phase four (5 Ka - 3 Ka) is the wettest period with lacustrine conditions and swamp vegetations indicating increased rainfall. Drying of the lakes and a lack of good pollen assemblages pointing to the dry arid conditions between 3000 and 1100 yr. B.P

Refined work of Wasson et al., (1983) on the chronology and palaeoclimatic inferences of Didwana lake point that (Figure 2.10) prior to 12,500 yr B.P the lake was hyper-saline with halite precipitations. Between 12,500 and 6000 yr B.P the lake fluctuated between hyper-saline and moderately fresh water conditions as evidenced by the primary subhedral aragonite in the sediments. By 6000 yr B.P the fluctuations in salinity and lake level ended with the phase of fresh water. Deposition of laminated clays and clastic sands are also part of this phase At about 4000 yr B P the desiccation of the lake resulted in the development of cracks in the clays and absence of any pedogenesis in these sediments point to a short span for this phase. The water level fluctuations though are in conformity with the observations of Singh et al., (1974), there prevails a discrepancy in the climate between 3000 - 1700 yr B.P , for which Singh (op.cit) proposed a climate drier than the present.

Swain et al , (1983) estimated the rainfall in the Thar between 10,000 and 3500 yr B P from the pollen assemblages and lake level fluctuation data They estimated an annual precipitation of 200 mm above the present one during 10,500 to 5,500 yr B P The interval from 5500 to 3500 yr. B P has the highest winter rain fall in the entire Holocene period Uptill this period the lakes remained fresh. The interval between 3500 to about 1500 yr B P represent an arid phase as indicated by the dryness of the lakes without any pollen assemblages Following this recent period of dryness, the prevalence of a wetter ınterlude from 1500 to 1000 yr B P with rain fall akin to 5000 - 3500 yr B P In the last 1000 yr , the smoothed estimates of summer and winter precipitations are similar to today

Agrawal (1992) has thrown further light on the observations of the earlier works of Misra and Rajaguru (1986) on the geochronology and palaeoclimatic significance of the 16 R dunal profile near Didwana. The salient conclusions of their study are :

a) The uncorrected U/Th dates for the lithounit III of the profiles are 144 ± 12 Ka; 150 ± 10 Ka, 390 ± 50 Ka. This progression with depth point to the middle - Pleistocene antiquity for the aridity in Rajasthan
b) The period between middle-Pleistocene to late-Pleistocene (26 Ka-17 Ka) signify fluctuating arid and semi arid phases (correspondingly periods of dunal accumulation and stabilization) as indicated by the intense pedogenesis and stabilization of lithounit II and III
c) Correlation between the halite layer of Didwana lake (20 to 13 Ka) and the upper most pale yellowish brown lithounit I indicate an arid climate between 20 Ka till 13 Ka.

Hashmı and Nair (1986) established the aridity of late Pleistocene to early Holocene from quartz and feldspar contents of shelf sediments of Arabian ocean The results of their study indicate that the feldspar content in the relic (9 - 12 Ka) outer continental shelf sediments exceed the feldspar content in modern inner continental shelf sediments The high value of the feldspars of the outer shelf is attributed by the authors to the arid conditions on land which prevented feldspars from weathering.

The author's observation on the occurrence of ferricrete as capings on the Tertiary sandstones and limestones in the Jaisalmer basin point to the late Neogene hot humid climatic regıme under which they developed Similar views are also expressed for these ferricretes by Dhir, 1977, Agrawal, 1992 The early Pleistocene wetter climate with well knitted drainage system (Ghose and Singh, 1972, Singh, 1992) represented by palaeochannels, fluviatile and fluvio-lacustral sequences (Tiwari and Ramakrishnan, 1995, Singh, 1982) are also established beyond doubt

II. PEDOSTRATIGRAPHY

In the absence of absolute age of soils, concept of relative and effective age is frequently employed to greater degree of success Relative age sequences are commonly established within a 'stratigraphic framework by applying soil stratigraphic principles to layered weathered materials. Pedostratigraphy (Butler, 1959; Morrison, 1978, Finkl, 1980,1984) which provide relative age of the soils, is based on comparative soil anatomies, stratigraphy, sedimentary properties of parental material, soil - landsurface relations, intensity of profile development Finkl (op. cit.) stressed the supplementation to geological order of superposition by pedogeomorphic features, persistence of micro and macro pedogenic features, intensity of weathering, neoformations, and pedochemistry as criteria for recognizing a pedounit and establishing correlation among different soil profiles

The application of the pedostratigraphy has widely been used to compare and to estimate the age of the palaeosol profiles (Birkeland, 1974; Bronger, 1979; Retallack, 1990; Catt, 1985 and Meyer, 1997) from different parts of the world. In the absence of radiometric dates, the author has attempted to correlate the illustrious profiles of his studies to the radiometrically dated profiles (Raghavan, 1987a ; Dhir, 1992 a, Singhvi, 1994) by means of pedostratigraphic principles to arrive at a possible age, micro - environments and the climatic conditions at which they are formed

Formation of calcretes has widely been considered as sinoquin of hot arid conditions typical of desertic environments (Gile, 1965; Dhir, 1977; Watts, 1980; Klappa,1983 etc.) . But, their prevalence in various climatic regimes in general and in particular colder climatic regions (Goudie, 1984, Reeves, 1976) raise the limitations in their utility as an independent entity for deciphering the past climatic conditions

However, the micro and macro pedological features, intensity of weathering, pedochemistry, types and quantity of neoformations within calcretes and associated soil profile are some of the definite indicators reflecting the microenvironmental conditions that inturn corroborate the climatic regime under which the calcretes are formed and have undergone changes (Meyer, 1997) Pedological characteristics of Thar desert calciorthid, argid soil profiles (Dhir, 1977; Courty and Fedoroff, 1985, Raghavan and Courty, 1987; Courty et al , 1987; Courty, 1990,1992, Ramakrishnan and Tiwari, 1996b) clearly ascribe that the calcretization in the study area has predominantly taken place in a semi-arid climatic regime with enough soil moisture that favoured the accretion of lime within the soil profile. Considering the sequence of calcretization from calcified soil to the hard pan varieties, a broad correlation can be established among the pedogenic calcrete profiles of the study area (Figure 6 1)

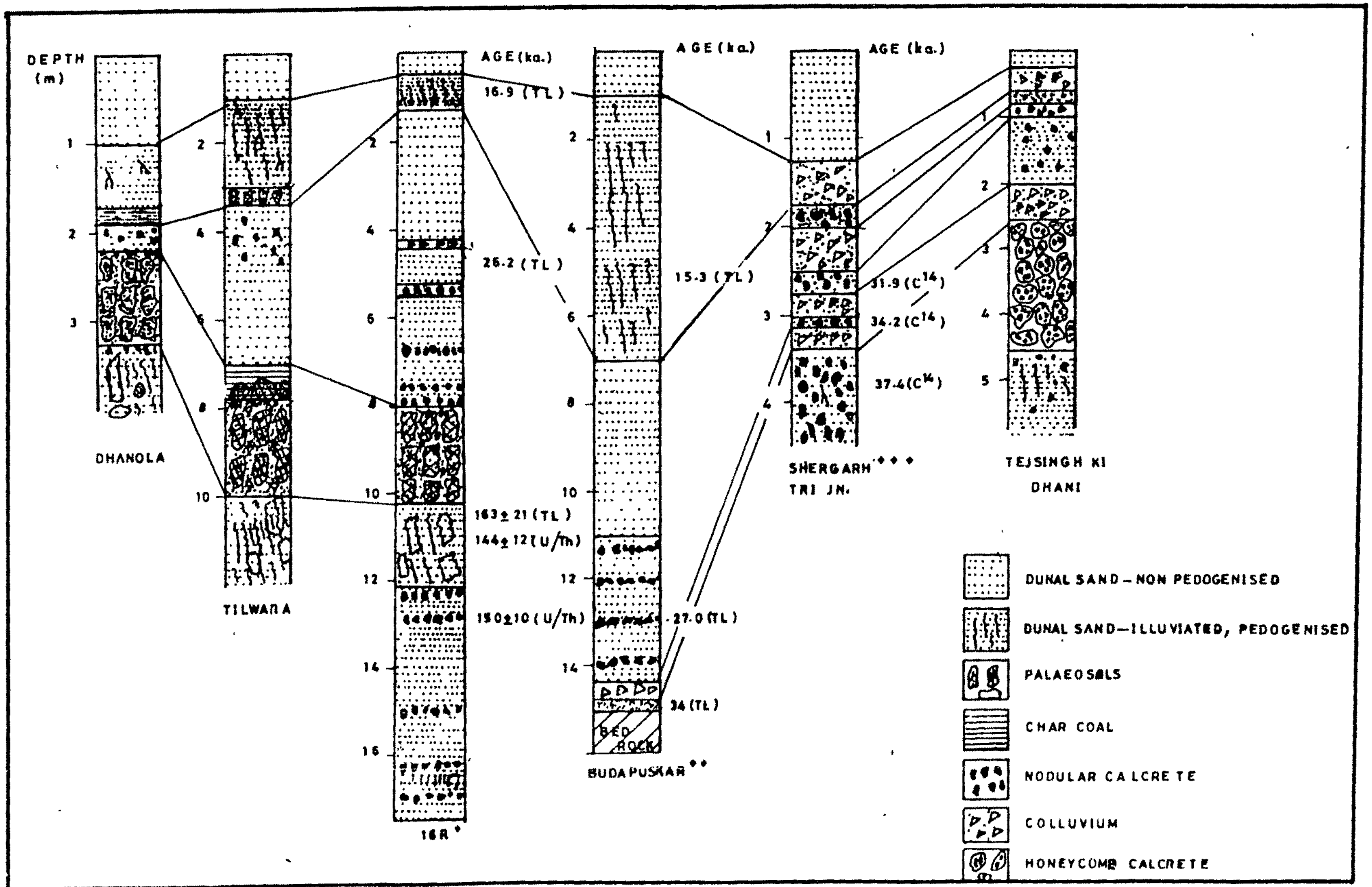
A comparative study of the various pedogenic calcretic profiles has resulted in establishing identical characteristics among six of the studied dunal profiles viz Dhanola, Tilwara, 16 R, Budhapuskar, Shergarh tri junction and Tej singh ki dhani (Figure 6.2). By using the pedological, mineralogical, and geochemical characteristics of the individual horizons of these profiles, correlations are made and micro environmental implications vis-a-vis past climatic changes are attempted The micromorphological descriptions of 16 R and Budhapuskar profiles are after Raghavan (1987a).

PEDOSTRATIGRAPHY OF DUNAL PROFILES

The lowest palaeosol horizon (Figure 6.2 of Dhanola profile (depth > 3.20 m) - yellowish brown fine sand horizon with strongly developed peds - can be correlated with the yellowish brown pedogenised sand horizons of Tilwara (depth 10 m) and 16 R (depth 10 - 12 m). This is attributed to the following identical characteristics

1 In all the three locations, this unit is marked by the well developed ped faces with lime coatings.

2 Lime redistribution within the layer is feeble with occasional micritic mottles



* after Misra and Rajaguru (1986)
** Singhvi et al (1992)
*** Dhir (1992)

Fig. 6.2. Chronology of dunal profiles from the study area.

3 In all the three locations this lithounit has sharp, wavy contact with the overlying unit

4 Micromorphological observations suggest reddish brown clayey coated skeletal grains with pellicular grain micro aggregate structure and the presence of allothic calcretic nodules at the upper boundary These features give indications of break in the dune accretion and stabilization that caused reddish brown oriented, birefriengent clay coating around the skeletal grains The presence of allothic nodules at the top again indicate the transported nature of the nodule pointing to the operation of erosional processes.

5 In all the three localities iron bearing minerals are completely altered with relics of ferrugenous halo

6 Neoformation is poor and include mainly the development of montmorillonite, chlorite, illite, and microsparites

7 REE concentration of this horizon at Dhanola shows manifold enhancement than the other horizons of the profile

Radiometric dating of this correlatable horizon of 16 R gave an age around 163 Ka (TL) and 144 Ka (U /Th) i.e. the middle Pleistocene period, Agrawal (1992)

The second palaeosol horizon of the Dhanola profile is a loamy sand characterized by distinct clay illuviation, strong development of peds with some features of lime redistribution. These characters are in conformation with the rubified (7.5 YR 7/4), well pedogenised lithounits of Tilwara (depth 7 - 10 m) and 16 R (8 - 10 m) The micro morphologic characters of these profiles show

1 Well oxidized skeletal grains having thick coatings of oriented, birefriengent clays The mica and pyroxene detritals are in the terminal stages of weathering with ferrugenous clay neoformations The feldspar grains show alteration to clay and even quartz detritals show etching and corrosion

2 The fabric is of typical intergrain microaggregate type with a distinct presence of illuvial clay

3 The lime nodules are of both orthic and allothic in nature However allothic nodules are observed at the boundary with the overlying units.

4 Besides the occurrence of montmorillonite, chlorite, illite starts appearing in the 16R profile at this horizon only However, illite and dolomites are characteristically present in Dhanola profile.

5 The REE geochemistry carried out for Dhanola profile indicates clear fractionation and strong depletion of REE at this horizon

All these above mentioned characteristics of this litho unit indicate that it is a palaeosol horizon The strong features of clay illuviation suggest that this could be a part of Bt horizon of a palaeo soil profile. No radiometric dates are available for this horizon However, this period marks a definite warm humid phase followed by a major arid phase probably assigned to terminal part of middle Pleistocene This is obvious as the overlying lithounit at 16 R has been ascribed to the middle late Pleistocene period, represented by the over lying lithounit at 16 R.

The last phase high aridity is characterized by a weakly pedogenised, poorly illuviated sandy loam of Dhanola, Tilwara, 16 R and Budhapuskar Amongst these, the most conspicuous correlatable parameter is a typical undifferentiated single grain microstructure with type I calcitic features. The skeletal grains remain almost fresh and free from any coatings. This phase of dunal accumulation by all probability can be correlated to the 14 - 15 Ka B P sand accretion (Chawla et al ,1994) as evidenced from the TL dates (16 9 Ka at 16 R ; 15.3 Ka. at Budhapuskar)

Intercalations of colluvium and calcretized dunal sand at Shergarh tri junction has yielded C^{14} ages between 37 4 - 34.2 Ka / for the lowest colluvial unit; 34.2 - 31.2 Ka for the II colluvial unit, pointing to the ameliorating climate from 37.4 Ka to atleast up to 26 Ka The TL date for Budhapuskar colluvial unit (34 Ka) is also in conformity with the dates obtained for the lowest colluvial unit of Shergarh tri junction Similarly good correlation do exist between the colluvium - calcrete sequence of Derasar and Shergarh tri junction.

Coming to the interdunal profiles, good correlation can be established between Raneri and Belwa profiles. However in the absence of radiometrically dated profiles from such geomorphic expression, the inferred sequence of events are given as under .

1 An earlier phase of aeolian activity at Belwa evidenced by calcretized and non calcretized aeolian sand layers resting on sandstones Similar observations are inferred at Raneri wherein, the incorporation of allothic calcitic nodules with an aeolian soil fabric is noticed in the overlying fluviatile layer

2 An intermediate fluviatile layer marked by poorly sorted gravelly sand at Raneri and coarse sand at Belwa Subsequent calcretization in the gravelly sand at Raneri signify ameliorating climatic conditions.

3 Indications of onset of aridity and subsequent amelioration is also evidenced by the overlying weakly pedogenised aeolian sand with aggregate grain microstructure. .

4 Pedogenic carbonate accumulations at the upper part in both the profiles (Figure 6.1) also match well and point to the prevalence of semi arid conditions before the last phase of dunal sand accumulation

SOIL MICRO ENVIRONMENTS

Soils do bear imprints of the fluctuating climates by way of pedofeatures such as eluviation, illuviation, types of channel, stages of mineral weathering, neoformations, types of nodule, besides soil chemistry and mineralogy The pedofeatures characteristic of a particular climatic regime are seldom completely obliterated with subsequent unfavourable conditions. Preservation of clay illuviation and rubified horizons in soil profiles, within the arid domains are the clear manifestation of this. Thus the pedo relics within a weathering profile especially in an arid, semi - arid terrain (where intensity of pedogenesis is weak during drier phases) offer copious information on the palaeo - soil micro-environments

DUNAL PROFILES

It is evident from the above discussions that dune building activity in the study area is of multiphased and the intermittent ameliorating climatic regime has caused the stabilization. The dunal profile at Dhanola, Tilwara and 16 R displays minimum three phases of dune accretion and the subsequent stabilization. The presence of reddish brown clay coated detritals in the palaeosol - I with ferricutans suggests illuviation in a near neutral pH with an oxidizing soil micro environment. The evidences of lime redistribution (indicative of an alkaline condition) ought to be a latter phenomena, and perhaps mark the onset of the second phase of semi-aridity.

The paiaeosol-II as elucidated preserve the characteristics of a palaeo Bt horizon The strong features of clay illuviation, with completely altered detrital grains indicate a near neutral or acidic pH Insitu weathering of micas, pyroxenes with released iron to plasma with the etched quartz are suggestive of reducing environment due to the complex organic acid activity in an high soil moisture regime (Hung and Keller, 1972 Bronger, 1978, Finkl, 1984, Morris and Fletcher, 1987; Koln, 1992) These features in turn reflects prevalence of dense vegetational cover during that period REE geochemistry of this palaeosol unit is also characterized by a strong depletion, which would have been possibly carried by water with a pH > 6 (Smedley, 1991) in a reducing environmental condition (Ramakrishnan and Tiwari, 1996d). Occurrence of charcoal layer in the equivalent (Tilwara) palaeosol also point to the reducing environment. Formation of illite, montmorillonite, chlorite and dolomite (features indicative high pH) are attributable to the latter phenomena, marking the lime mobilization within the profile The possibility of transformation of kaolinite to illite under a poor drainage conditions can not be overlooked (Bronger, 1979). The salient micromorphological, chemical and mineralogical characteristics of calcrete profiles and their microenvironmental significance are outlined below :

1 Displacive calcites with corroded and dissolved quartz skeletal grains in B/C - horizons at Belwa, Raneri and Vav profiles point to an alkaline, high moisture regime (Sharma and Tandon, 1983).

2 Insitu fracturing of quartz detritals observed in B horizon of Vav and Sardharsahar profiles are attributable to the elevated thermal gradient caused in a hot, arid conditions (Verheye, 1976).

3 Testimonies for waterlogging especially in the profiles from interdunal area viz Raneri and Belwa are evidenced by meniscus cements, needle fibres and sesquioxidic impregnations and dendrites

4 Neoformed dolomites of Dhanola, Belwa and Bhaleri profiles, besides a high alkalinity, indicate reducing environment under which Mg^{+2} was incorporated into calcite

5 Mn^{-2} is observed to accumulate in two different environments within the calcrete profile The first one is associated with hematite in the upper well oxidized parts Their concentration in the lower parts are attributable to the poorly drained conditions (Meyer,1997).

6 REE fractionation, depletion in palaeo Bt - horizons (Dhanola and Bhaleri profiles) and sudden spurt in their concentration in underlying horizon are attributable to acidic, reducing microenvironmental conditions of the palaeo Bt horizon and alkaline or near neutral conditions of the underlying horizon.

7 Prevalence of chlorite, montmorillonite in almost all horizons of calcrete profiles indicate an alkaline environment throughout the calcretization. However, presence of illite (Dhanola), vermiculite (16R) indicates alkalinity and a poorly drained nature of the solum (Grim.1968) in which K ions are not leached

8 Presence of allothic nodules within the calcrete profiles, especially at the contact of lithounits mark a definite break in dune building activity Transformation of orthic nodules to disorthic nodules indicates intense pedoturbations (Federoff et al., 1990)

9 Presence of kaolin, highly corroded, dissolved quartz detritals within the ferricretes and associated mottled horizons is a strong evidence for the dissolution of quartz in strongly acidic environment (Finkl, 1984; Morris and Fletcher, 1987, Koln, 1992).

10 Dismantling of ferricrete profiles with two phases of weak calcretization, mark micro environmental changes from acidic to alkaline conditions.

11 Association of sparry calcites and secondary silica within channels at the mottled horizons of ferricrete profiles (RD 105, Ramgarh, Chetral) indicate fluctuating pH conditions from near neutral to alkaline conditions

Based on field occurrences, micromorphological, mineralogical and geochemical studies of the calcretic and ferricretic duricrusts, the author has buildup a pedostratigraphy of the Thar desert. The various pedostratigraphic units have further been correlated with the prevailing processes and the climatic events.

The deduced pedostratigraphic and palaeoclimatic events in the Thar desert show following sequences -

1 After the recession of Tertiary sea, the rocky upland underwent ferricretization in a warm, humid conditions This can be ascribed to the Neogene period

2 A wetter and well knitted drainage supported early Pleistocene period with fluvio-lacustral sedimentation histories, responsible for the dismantling of ferricrete profiles and deposition of Shumar formation (Singh, 1984).

3 The onset of the first phase of aridity during middle Pleistocene as indicated by the dated dunal sediments (~ 390 Ka.) (Agrawal, 1992)

4 An ameliorating middle Pleistocene - late Pleistocene period (26 Ka - 17 Ka) with interludes of aridity and semi aridity that caused pedogenesis and stabilization of earlier phases of dunal accumulations

5 A Period of maximum aridity indicated by the dune accretion around 15 ± 2 Ka., i e Last Glacial Maximum

6 A relatively wet early Holocene period (10 Ka - 5.5 Ka) with a rainfall of 200 mm above the present one. The onset of summer and monsoon at around 6 5 Ka (Singh et al, 1974, Swain et al., 1983)

7 The wet period (5 5 Ka - 3 5 Ka) with fresh water lakes

8 An arid phase from 3 5 Ka to 1 5 Ka with dry lakes

9 A period of wet phase akin to 5 5 - 3 5 Ka during 1 5 Ka - 1 Ka period

10 Existence of the prevailing climatic conditions since the past 1000 yr.

A concise account on various pedostratigraphic and palaeoclimatic events in the Thar desert, as inferred from aforesaid sequence is given in Table 6 1

Although, the interpretation of palaeoclimate from the soil micro environments are fairly accounted, non availability of radiometric dates for the soil horizons has jeopardized in providing an absolute time frame to various climatic events.

Process(es)	**Pedostratigraphic unit**	**Pedological characteristics**	**Climatic conditions**	**Age**
Dune building	un-stabilized sediments	----------	Semi- arid to arid	Since 1 Ka
Pedogenesis and stabilization Dune Building	Feebly pedogenised, stabilized aeolian sands	Poor clay-illuviation & formation of peds	Wet Arid	Early Holocene 10-5 5 Ka Late Pleistocene 15 ± 2 Ka
Dune building and stabilization	powdery calcrete with intercalated layers of colluvium	Type I , II Pedogenic carbonates	Arid - semi arid *fluctuating*	Late Pleistocene 37 4 - 26.2 Ka .
		III rd Erosional surface		
Dune building & Stabilization	Palaeosol - II	Clay-illuviation, well developed peds, allothic nodules	Arid - semi arid	Middle - late Pleistocene.
		II nd Erosional surface		
Dune building & stabilization	Palaeosol I	Ferricutans, argillans, clay illuviation, allothic nodules	Semi arid - sub humid.	Middle - late Pleistocene
Ferricrete dismantling , Fluvial deposits	Brecciated ferricretes, (Shumar formation)	Pisoliths dismantling, solution along fractures,	Wet	Neogene - Early Pleistocene.
		Ist erosional surface		
Ferricretization	Ferricretes	Desilicification, Al-goethites, pisoliths	Warm and Humid	Neogene (> 1.65 M Y)

TABLE 6.1 QUATERNARY PEDOSTRATIGRAPHY AND PALAEOCLIMATIC EVENTS