Chapter 8

CONCLUSIONS

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The present study has enabled to arrive at the following conclusions:

1) The continental Late Quaternary record of Mainland Gujarat is represented by a dominantly fluvial succession with a capping aeolian member. The sediments may be grouped into five facies which include trough cross stratified gravels (Gt), planar cross stratified gravels (Gp), horizontally stratified sands (Sh), trough cross-stratified sands (St) and massive silts (Sim). The Gt facies forms through multiple origins and may be differentiated into Gt_d (3D gravel dune migration), Gt_c (formation at confluence pools) and Gt_b (formation through bedload sheets in channels). 'Gp' is interpreted to be the result of downstream migrating bars or 2D bedforms or bars. 'St' represents ancient sandy channels in which sediment deposited as suspension fall-outs when the flood-waters waned. 'Sh' is the product of upper flow regime hydraulic conditions associated with sheet flow (unconfined flow). While the various facies described till now are unequivocally fluvial in origin, facies 'Sim' formed through the entrainment and subsequent deposition from dust-laden winds called dust-devils or haboobs.

2) Two principal types of soils are recognised. One is the vertisol and the other a red-bed. Red beds form either through pedogenic processes and are associated with pedogenic calcretes and clay illuviation or are transported or form through groundwater activity when associated with fresh feldspars and directional sedimentary structures. The red-bed of pedogenic origin is classified as a ferric calcisol. Both soils contain a similar suite of clay minerals which comprises montmorillonite, kaolinite and illite. In the vertisol presence of slickensides, pseudo-anticlines and fissures point to the overwhelming importance of shrink-swell phenomena in the evolution of the

soil. Red beds may be of both pedogenic as well as groundwater or river water (transported origin). Pedogenic varieties of red-beds may be identified with patterns of clay illuviation and absence of easily weatherable minerals such as feldspar whereas groundwater or river water red beds exhibit fresh feldspars, little clay segregation and show sedimentary structures indicative of mechanical transport.

3) Five varieties of calcretes are observed. These include pedogenic calcretes, groundwater calcretes, cauliflower calcretes, rhizogenic calcretes and detrital calcretes (calcrete-conglomerates). It is possible to discriminate between groundwater and pedogenic calcretes using characteristic microfabrics. The transition from groundwater to pedogenic calcretes is accompanied by an increase in the micritic content, density of sparitic/microsparitic veins and appearance of replacive and displacive textures in the pedogenic calcretes.

4) Mineralogically calcretes contain low Mg calcite which is well reflected in X-ray diffractometry studies. Spectroscopic studies reveal a OD (oxygen-deuterium) vibration peak accompanying strong adsorbed water peak and bending and stretching vibration modes of the carbonate molecular group. The presence of deuterium may not be very unusual as modern groundwaters are enriched in the heavier isotope of hydrogen. This may help discriminate between meteoric and marine calcites.

5) The strontium contents of calcretes appear to be characteristic enough to enable its usage in identifying such carbonates. Strontium levels in the calcretes from Mainland Gujarat are between 60 to 240 ppm while in marine abiotic calcites the lower limit is around 1000 ppm. The stable isotopic composition of calcretes ranges between -7 to -1 ‰ for $\delta^{13}C$ and -4.5 to -3.5 ‰ for $\delta^{18}O$ values. The negative isotopic values for carbon suggest the influence of a C3 dominated vegetation biomass during the formation of vertisol calcretes. The oxygen isotopic values are between 2.5 and 5.5 ‰

which is typical for calcites precipitated from meteoric waters. The deduced isotopic composition of parent meteoric waters assuming temperatures of precipitation between 20-25 ^{o}C are in good agreement to present day isotopic values for groundwaters.

6) It is demonstrated that pedogenic calcretes form over calcretized sediments. This may lead to accelerated rates of nodule accretion due to the pre-existence of ample calcium in the host sediment. In such cases the maturity of paleosols using carbonate nodule size may be misjudged if the calcareousness of the non-pedogenised sediment is not assessed.

7) Three aggradation phases representing a progressive deterioration in climatic conditions are recognised. Aggradation phase 1 is represented by seasonal rivers, Aggradation Phase 2 by deposits of ephemeral rivers with flashy discharges and Aggradation Phase 3 by sandy-loess aeolian dust deposits. During Aggradation Phase 1 rivers had steeper cohesive banks. Bank stability was also effected by the development of groundwater calcretes in them. The instantaneous discharges during floods led to the formation of upper flow regime bedforms such as gravel dunes. During Aggradation Phase 2 the rivers were poorly channelised and flows were largely unconfined. In the final phase of aggradation underlying sheet flood sediments of the previous phase were reworked to form massive silts deposited as suspension fall-outs from dust laden winds such as haboobs.

8) These aggradation phases manifest three types of climatic conditions related to the changing vagaries of the southwest Indian monsoon. Records from ice and ocean cores and mathematical models support the multi-state climate change from interglacial (Climate Phase 1) to mild interglacial (Climate Phase 2) to full glacial (Climate Phase 3). Climate Phase 'n' (n=1,2,3) correspond to Aggradation Phase 'n'

(n=1,2,3). The present study suggests that continental ecosystems respond in a subdued manner. Within an inter-stadial, brief periods of colder climates/weaker monsoon do not affect either the nature of the vegetational community, or the hydrological budget of the area. This suggests that for climate shifts to effect durable changes in the continental ecosystem, a period between >5 kyrs and 20 kyrs is the minimum time required to permanently change the landscape of an area.

9) Based on a survey it has been found that existing definitions of calcrete are inadequate. The following definition of calcrete is proposed which essentially adds on earlier definitions.

Calcrete is a near surface accumulation of predominantly calcium-carbonate. It ranges in form from powdery to noduler states to boulders. It forms through the passive and/or replacive and/or displacive introduction of calcium carbonate into soil, sediment or bedrock. It forms through pedogenic and/or rhizogenic and/or groundwater and/or microbial processes in the vadose and phreatic zones of regions experiencing a mean annual rainfall between 50-700 mm. It shows typical microfabrics such as clotted micrite, alveolar septal structure, spar filled sinuous cracks, circum-granular cracks. floating siliciclastic grains, grain coating cement, exploded framework grains and needle fibre calcite and exhibits a $\delta^{18}O$ composition ranging from -9 ‰ to +3 ‰ and a $\delta^{13}C$ content between -12 ‰ to +2 ‰.