Chapter 1

INTRODUCTION

1. INTRODUCTION

Calcretes are ubiquitous features of semi-arid landscapes. They are characteristic of hot deserts and their margins which experience mean annual rainfalls ranging between 100 mm to 700 mm i.e. regions where evaporation exceeds precipitation.. The term calcrete is synonymous with *caliche*, *croûtes calcaires*, *nari* and *kunkar*. Calcretes are understood to form through soil-forming (pedogenic) as well as groundwater processes.

The term 'calcrete' was first coined by Lamplugh in 1902 (cf. Goudie, 1972). At around the same time another term 'caliche' was also conceived (Aristarain, 1971). Goudie (1972) presented arguments to promote usage of the term 'calcrete'. Though 'calcrete' is in wide usage, articles on soil carbonates also adopt the term 'caliche' even today. Goudie (1972) defined calcrete as:

> *'A term for terrestrial materials composed dominantly but not exclusively of calcium carbonate which occurs in states ranging form powdery to nodular to highly indurated and involve the cementation of, accumulation in and/or replacement of greater or lesser quantities of soil, rock or weathered materials primarily in the vadose zone. It does not however embrace cave deposits (speleothems), spring deposits (for which tufa or travertine are accepted terms), marine deposits (such as beachrock) or lacustrine algal stromatoliths'.*

Subsequently Wright & Tucker (1991) modified this definition to:

> *'Calcrete is a near surface, terrestrial, accumulation of predominantly calcium carbonate, which occurs in a variety of forms from powdery to nodular to highly indurated It results from the cementation and displacive and replacive introduction of calcium carbonate into soil profiles, bedrock and sediments, in*

areas where vadose and shallow phreatic groundwaters become saturated with respect to calcium carbonate'.

The works of Reeves, (1976) and Netterberg (1980) provided thorough descriptions of the various occurrences of calcretes and demonstrated that calcretes show a whole range in surface morphology from powdery states to nodules to bouldery and brecciated calcretes. In the pedologist's world, calcretes gathered immense interest after the publication of two articles by Gile and co-workers in the 1960's (Gile et al., 1965; Gile et al., 1966). In the earlier article they suggested that continuous leaching may cause calcium carbonate to accumulate in desert soils as a laterally persistent horizon. This persistence led to the recognition of the K or Cca horizon. The other paper dealt with the time-dependence of carbonate nodule size in soils. This again had wide usage amongst palaeo-pedologists as it provided them a criteria to assess the maturity of a palaeosol. Since then, the calcrete morphogenetic sequence has been modified to include different rates of accumulation in gravelly and non-gravelly soils (Machette, 1985). Table 1.1 lists certain articles that provide an overall perspective of calcrete research.

Calcretes also play a major role as a sink of carbon in the global biogeochemical cycle. About 1200 gT of carbon is arrested as pedogenic carbonate (Chadwick et al., 1994). Hence it is important to know at what time scales carbon remains sequestered in such carbonate nodules in semi-arid regions. Calcretes are also valuable repositories of palaeoclimatic and palaeovegetational information. By studying the stable isotopic content ($\delta^{13}C$ and $\delta^{18}O$) it is possible to evaluate shifts in vegetation ecosystems from C3 (woodland = wet climate) to C4 (desert grasslands = dry climate) dominated ones (Cerling, 1984; Quade et al., 1995). Based on detailed isotopic studies of soil carbonates, it has been possible to demonstrate the demise of extensive woodland communities in the vicinity of the Himalayas at around 4 Ma (Quade et al., 1995) and the consequent advent of grassland ecosystems.

AUTHORS	YEAR	THEME
Gile et al	1965	Recognition of a master horizon of calcium carbonate in soils
Gile et al	1966	Description of morphogenetic sequences.
Goudie	1972	Definition of calcrete and an appeal for the usage of 'calcrete' over 'caliche'
Reeves	1976	Detailed field description of calcretes from semi-arid regions of the USA.
Klappa	1978	Article assessing the origins of *Microcodium*
Klappa	1980	Detailed descriptions and classification of rhizoliths.
Netterberg	1980	Description of various forms of calcrete and its classification
Goudie	1983	Review article on calcrete; introduction of per ascensum and per descensum models
Cerling	1984	Model development for palaeoenvironmental significance of stable oxygen and carbon isotopes of soil calcretes
Machette	1985	Revision of morphogenetic sequences of Gile et al., 1966
Wright & Tucker	1991	Review article on calcretes that addresses all facets of calcrete research.
Milnes	1991	Review article on calcretes that addresses all facets of calcrete research.
Jones & Kahle	1993	Description and review of fiber and dendrite calcite crystals
Wang et al	1994	Chemical model for calcrete formation
Retallack	1994	Relationship between depth to carbonate accumulation and mean annual rainfall
Verrecchia & Verrecchia	1994	Review article on needle-fiber calcite

Table 1.1: Articles that provide an overview of calcrete research today (Arranged in chronological order).

Calcretes also yield information on mean annual rainfalls. This is derived by measuring the *depth to* calcic horizon within a soil profile. Retallack (1994) has reviewed the empirical relationship between mean annual rainfall and depth to calcic horizon and opines that it is a polynomial function rather than a simple linear relationship. This is given by the equation:

$$\text{Mean annual rainfall} = 139.6\text{-}6.388(D)\text{-}0.01303(D)^2$$

where D = depth to Bk horizon.

The continental deposits of Gujarat are spread over a vast expanse of land whose northern and northeastern extremities constitute the foothills of the Aravalli mountain ranges, the southern limits defined by the Gulf of Cambay and the western limit by the Little Rann of Kachchh. This area is commonly designated as the 'Gujarat Alluvial Plains' (Merh & Chamyal, 1997). Within this region two roughly north-south flowing major rivers, the Mahi and the Sabarmati dissect these plains. Holocene incision of these rivers has exposed the history of continental sedimentation along the cliff-like banks (Maurya et al., 1997). These deposits, earlier, drew the attention of archaeologists for their rich assemblage of prehistoric Palaeolithic artefacts. The sediments are believed to have been formed in transitional estuarine-fluvial-aeolian environments (Khadkikar et al., 1995).

A remarkable characteristic of these deposits is the facies-independent copious occurrence of calcretes within them. Calcretes are profusely developed in the aeloian-fluvial succession, yet till date no systematic study on them has been attempted. Calcretes occur in a variety of forms, ranging from sheets to small diffuse nodules to large decimetre nodules. These deposits provide an opportunity to assess the role and degree of calcretization in a semi-arid alluvial system. This diversity in external morphology and occurrence is best understood as the result of combined geosphere-hydrosphere-pedosphere interactions. Through the present study it has been possible to demonstrate the formative pathways and sinks within an evolving alluvial system. Further, it is shown that pedogenic calcretes form in sediments that contain pre-existing calcite that formed through groundwater processes whose pedogenic remobilization led to the development of large nodule dimensions. An attempt has also been made to assess the inadequacies in the existing definition of calcrete, a most obvious lacuna being the exclusion of rhizoliths. A modified definition of calcrete after reviewing the various facets of calcretes is proposed.

Prior to the present study there have been mentions of the occurrences of calcretes in the stratigraphic record of Mainland Gujarat (Foote, 1898; Allchin et al., 1978; Pant & Chamyal, 1990). It is only recently that calcretes from Mainland Gujarat have been systematically documented (Sareen & Tandon, 1995; Khadkikar et al., 1995; Merh & Chamyal, 1997).

Interestingly all sedimentological phenomena in the area covered by Gujarat Alluvial Plains are essentially governed by the vagaries of the Southwest Indian Monsoon. Hence these deposits record the changing intensity of the Indian Monsoon over the past 200 ka BP. Although not as sensitive to decadal and century scale climate changes like most ocean-core and ice-core records (Sirocko et al., 1993; Thompson et al., 1996), fluvial, aeolian and pedogenic responses to climate change are only effected in durable climate shifts lasting several thousands of years. Nevertheless, such deposits constitute an important record of subdued responses of terrestrial ecosystems to rapid climate change. An attempt has thus been made to decipher the signatures of past climate changes in Gujarat from the sedimentological and geochemical record of clastics and calcretes respectively.

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