8.1. Introduction

Palaeoclimate is the study of past climates. It is a fascinating multidisciplinary field which combines history, anthropology, archeology, chemistry, physics, geology, atmosphere and ocean sources. The palaeoclimatic conditions are established by a proxy or more proxies. Proxies are the indirect form of evidence that can be used to infer the palaeoclimate. They include isotope geochemical studies, dendrochronology, pollen analysis, lake varves, coral bed rings, fossils, geological setting and historical documents. The Palaeoclimate of calcrete deposits is established by the proxies, such as major element geochemistry, isotope geochemistry and clay minerals etc. The palaeoclimate study of calcrete deposits of Sathankulam is mainly discussed by the above proxies.

8.2. Climates of India

India is a country of different climatic diversities. They are expressed in the variation in the distribution of temperature, pressure, winds and amount of precipitation. The factors influencing the climate of India are 1. Location and latitude extent 2. Distance from the sea 3. Northern mountain ranges 4. physiography 5. Monsoonal winds 6. Upper air circulation 7. Western disturbances and tropical cyclones 8. El-Nino effect 9. Southern Oscillation and its effect. Meteorologically, the year in India is divided into four seasons like as 1. Cold weather season 2. Hot weather season 3. Advancing southwest monsoon season and 4. Retreating South-West monsoon season. These seasons have different characteristics of weather conditions. The temperature, pressure, wind and amount of rainfall maps show the
climate diversity of the Indian Sub-Continent (Fig. 8.1a-i). The mean monthly temperature and rainfall in major meteorological centers of India is given in the (Table 8.1).

8.3. Climate of Sathankulam Region

The Sathankulam region experiences tropical or arid or semi-arid climatic conditions. It is a rain shadow region in Tuticorin district, when compared to other places. The area has been severely affected by a period of every ten years in drought condition continuously in the climate history of the district. The experimental climate history result of the study area is given in the (chapter - 1). Most of the vegetation in the study area indicates the arid and semi-arid climatic conditions. They are given in the first chapter of the study area. Due to the arid and semi-arid climatic conditions, calcrete has been formed as a widespread regolith deposits in the study area.

8.4. Geochemical Proxies:

The climatic changes are mirrored in geological, sedimentological and biological events. The evaporate mineralogy and major element geochemistry have been used as proxies for palaeoclimate investigations from Playa Oum el Krialate in Tunisia, Wadi Natron in Egypt and East African Rift Valley (Werner Smykatz-Kloss et al., 2010) and also in Sambhar Playa region in Rajasthan (Sinha et al., 2006). The evaporates are generally double salts that are having the combination of Na, Mg, Ca and K. The frequently occurring minerals Gypsum (CaSO$_4$.2H$_2$O), Anhydrite (CaSO$_4$), Calcite (CaCO$_3$), Dolomite (CaMg(CO$_3$)$_2$) and Halite (NaCl) in an evaporation deposits indicate normally the proxies for arid environment (Werner Smykatz et al., 1992)
Despite the climate study through geomorphological and mineralogical criteria, the major element geochemical criteria are mostly used as proxies to interpret humid, arid and semi-arid palaeoclimatic investigation. The behavior of highly soluble oxides Na$_2$O, MgO, K$_2$O and relatively insoluble or hydrolysate TiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ are used to interpret the palaeoclimate studies of calcrete profile of the present study area. The ratio of alkaline/hydrolysate is low in the humid climate and high in the arid climate (Sinha et al., 2006). The ratio of Na$_2$O/Al$_2$O$_3$, Na$_2$O/Fe$_2$O$_3$, Na$_2$O/K$_2$O, Na$_2$O/TiO$_2$ and CaO/MgO of the Nedungkulam and Thoppukulam regolith calcrete profiles of the study area is given in Table (8.1 and 8.2) respectively, and its ratio plots of climate model diagram related to depth are shown in the diagram (Fig. 8.2 and 8.3) (After Smykatz et al., 1992; Udayanapillai et al., 2015).

The geochemical ratio plot of the various calcrete samples of these two profiles of the study area shows arid and semi-arid environmental condition prevailing during the depositional environment. Further, it is observed that evapo-transpiration of calcium carbonate (high alkalinity) rich groundwater process is more dominant than the pedogenic leaching process of surface water in the study area. Geochemistry of palaeosol and calcrete are important proxies for palaeoclimate history of soil (Ceren Kucukuysal and Selim Kapur, 2014). The Na$_2$O/K$_2$O ratio or salinization increasing towards the upper horizon of regolith calcrete profile is the evidence of evaporation and evapo-transpiration. The salinization for the arid climatic condition should be greater than 1 (Ceren Kucukuysal and Salim Kapur, 2014; Udayanapillai et al., 2015). In the study area, the salinization in the profiles of the study area ranges from 0.5 to 2.64 which indicate the high aridity of the study area. The increasing calcification in the Nedungkulam profile (0.63 to 10.16) and Thoppukulam profile (11.29 to 26.38) in the study area indicate calcification is highly prevailing throughout
the section which reflects evaporation and evapo-transpiration process activity in the regolith part. Minyuk et al. (2007) established the increased concentration of SiO$_2$, CaO, Na$_2$O, K$_2$O and Rb and decreased content of TiO$_2$, Fe$_2$O$_3$, Al$_2$O$_3$ and MgO in calcrete under arid environment. The Na$_2$O/K$_2$O, Na$_2$O/Al$_2$O$_3$, and Na$_2$O/TiO$_2$ ratio will be increasing in arid environment and vice versa in humid environment (Werner Smykatz-Kloss et al., 2010).

The relationship between SiO$_2$ and (Al$_2$O$_3$+K$_2$O+Na$_2$O) was used to identify the climatic condition of the sediment. (Suttner and Dutta, 1986). Udayanapillai et al. (2013) also discussed the teri deposits geochemistry of Surangudi and Kulathur, Tuticorin district, Tamilnadu for indicating palaeo-climate based on the above standard plot. They established the Surangudi and Kulathur teri deposit is formed under arid and semi-arid climatic condition. The SiO$_2$ and Al$_2$O$_3$+K$_2$O+Na$_2$O ratio plot of Regolith calcrete profiles of the study area plotted on the climate model diagram (Fig. 8.4) reveals arid and semi-arid climatic conditions.

8.5. Clay Mineral Proxies

The calcrete possesses the regolith clay minerals and neo-formed clay minerals which indicate the climate history. The identified clay minerals from the study area are discussed in the chapter-4 and are given in the clay minerals XRD analysis (Table 4.1-4.6 and 4.12-4.18) and DTA analysis (Table 4.23). Clay mineral in soil is an evidence of Holocene climate change (Pankaj Srivastava et al., 1998). Clay is regarded as products of hydrolysis of weatherable silicate minerals. They can be linked to the amount of precipitation available for soils (Folkoff and Meetenmeyer 1987). Clay composition in soil is controlled by the grain size and mineral composition of parent materials, temperature, seasonal rainfall and time for formation of a soil. In wet climate, the clay is more likely to possess a 1:1 rather than a 1:2 layer...
structure. They obtain fewer cations and are lower in general weathering sequence of clay-sized minerals. Especially in vertisols under dry climate, swellable clays like sodium smectite produce a distinctive soil structure of domed columnar peds (soil surface) extending throughout the horizon (Veronika Geibler et al., 1998). Deepthy and Balakrishnan, (2005) observed climate control on clay mineral formation from weathering profiles of Western Ghats. The Clay mineral indices smectite/chlorite and smectite/illite of the alluvial palaeosol have been used as proxy indicators of climate change (Jain and Tandon, 2003). Pal et al. (2012) established clay mineral indicate the provenance and climate change from Himalayan Sediments.

Some of the clay mineral is considered as indicative of climate. Cahon and Miller (1997) has given the indicative of clay minerals for climate, as palygorskite and sepiolite indicative for the arid climate, smectite for mean annual rainfall <1000 mm; Kaolinite for mean annual rainfall between 1000-2000 mm and Iron oxide and alumina for mean rainfall >2000 mm. Udayanapillai et al. (2015) established from the Pandalgudi region of Tamilnadu that availability of neo-formed clay mineral palygorskite and sepiolite in calcrete indicate arid climate, whereas other clay minerals kaoline, Illite, Smectite and Sesquioxide indicate the semi-arid climate. The XRD, SEM, DTA and TGA results of the study area profiles reveals that clay minerals, palygorskite, sepiolite, smectite, kaoline, montmorillonite, Illite and Beidellite are available in the study area. The calcite pseudo morphologically replace all underlying silicate rock and form palygorskite and sepiolite in lower calcrete profile under arid climate (Yifeng Wang et al., 1993). Palygorskite are formed with calcite mineral under the influence of arid climate (Rodas et al., 1994). The neo formed clay mineral palygorskite and sepiolite in all profiles of the study area shows the arid climate, whereas the other clay minerals Kaoline, Illite, Smectite and
Sesquioxide indicate the semi-arid climate. So the clay mineral helps to understand the regolith calcrete deposit of the study area formed under arid and semi-arid climatic conditions.

8.6. Isotope and climate

The stable isotopic value of Nedungkulam and Thoppukulam calcrete profiles are given in the (Table 7.1 and 7.2) in the previous isotope geochemistry chapter-VII. The Diagenetic environment, biogenic activity and meteoric influences are also discussed in the previous chapter-VII. The C and O isotope composition in calcrete is used as proxies for palaeoclimate at the time of formation (Talma and Nettenberg, 1983; Cerling, 1984). Julian E. Andrews et al. (1998) discussed the stable isotopic composition of δ¹³C and δ¹⁸O of calcrete of Thar Desert with Monsoonal climate (Arid) and Stronger Monsoonal climate (Semi-arid). The isotopic signature of δ¹³C and δ¹⁸O of the Nedungkulam and Thoppukulam of calcrete profile samples plotted on bivariate climate plot of (Julian Andrews et al., 1998). The diagram indicates the results of both arid and more predominance of stronger monsoonal climate or favored by hot wet summers or semi-arid climate (Fig. 8.4).

Numerous researchers have concentrated their research on climate and stable isotope signature of δ¹³C and δ¹⁸O of calcrete deposits from various places. The isotopic composition of δ¹³C values between from -7.5% to -3.5% and δ¹⁸O values between from -9.68% to -8.57% observed in the calcretes of Chinese Loess Plateau, region established the calcrete formed during the non-interglacial period (Rowe and Maher, 1999). The isotopic signature of δ¹³C values between from -0.6% to -6.9% and δ¹⁸O values between from -6.5% to -10.5% data from pedogenic calcrete from Holocene soil of Gangetic plain indicate that the calcrete is formed by evapo-transpiration process under arid and semi-arid climatic condition. The enrichment of
\( \delta^{13}\text{C} \) in the lower horizon is due to extensive dissolution and re-precipitation during humid climate (Pangaj Srivastava, 2001).

Stuart and Rabinson et al. (2002) discussed the soil calcrete of Banneman region. The isotopic signature of \( \delta^{13}\text{C} \) from -15.2% to -9.19% and \( \delta^{18}\text{O} \) from -6.3% to -2.2% established that calcrete is formed under semi-arid climate due to palaeo-atmospheric CO\(_2\). The isotopic signature of \( \delta^{13}\text{C} \) from +2.5% to -6.1% and \( \delta^{18}\text{O} \) from +0% to -10% obtained from Palustrine calcrete of Korea illustrate the climate of arid to semi-arid (In Sunk Paik and Hyum Jookim, 2003). The stable isotopic values of \( \delta^{13}\text{C} \) from -0.2% to -1.2% and \( \delta^{18}\text{O} \) from -5% to -6% observed from calcrete of Thar Desert indicate the dry or arid climates (Dhir et al., 2004). Singh and Yong II Lee, (2007) observed the covariance between \( \delta^{18}\text{O} \) and \( \delta^{13}\text{C} \) in the calcrete of Himalayan Foreland suggests that higher atmospheric CO\(_2\) may be responsible for higher temperature. The stable isotopic values of \( \delta^{13}\text{C} \) from -8.8% to -1.56% and \( \delta^{18}\text{O} \) from -4.7% to -2.13% observed from the calcrete of Bengal basin, Bangladesh indicating \( \delta^{18}\text{O} \) values are largely controlled by palaeo-temperature and strong rainfall (Hussian et al., 2013). The lack of significance of covariance in the stable isotopic values of \( \delta^{13}\text{C} \) and \( \delta^{18}\text{O} \) in the calcrete in South-West Anatolia indicates sub-humid or semi-arid climatic condition (Hulya Alcicek and Mehmet Cihat Alcicek, 2014). Such lack of co-variance or low degree of co-variance in the isotopic values of \( \delta^{13}\text{C} \) and \( \delta^{18}\text{O} \) existed in Thoppukulam calcrete profile of the study area also indicate the sub-humid or semi-arid climatic condition which may be due to the inherited isotopic values from the sources of shell limestone basement rocks. In general, the isotope signature of \( \delta^{13}\text{C} \) and \( \delta^{18}\text{O} \) of calcrete profile of the study area indicates the arid and semi-arid climatic condition.