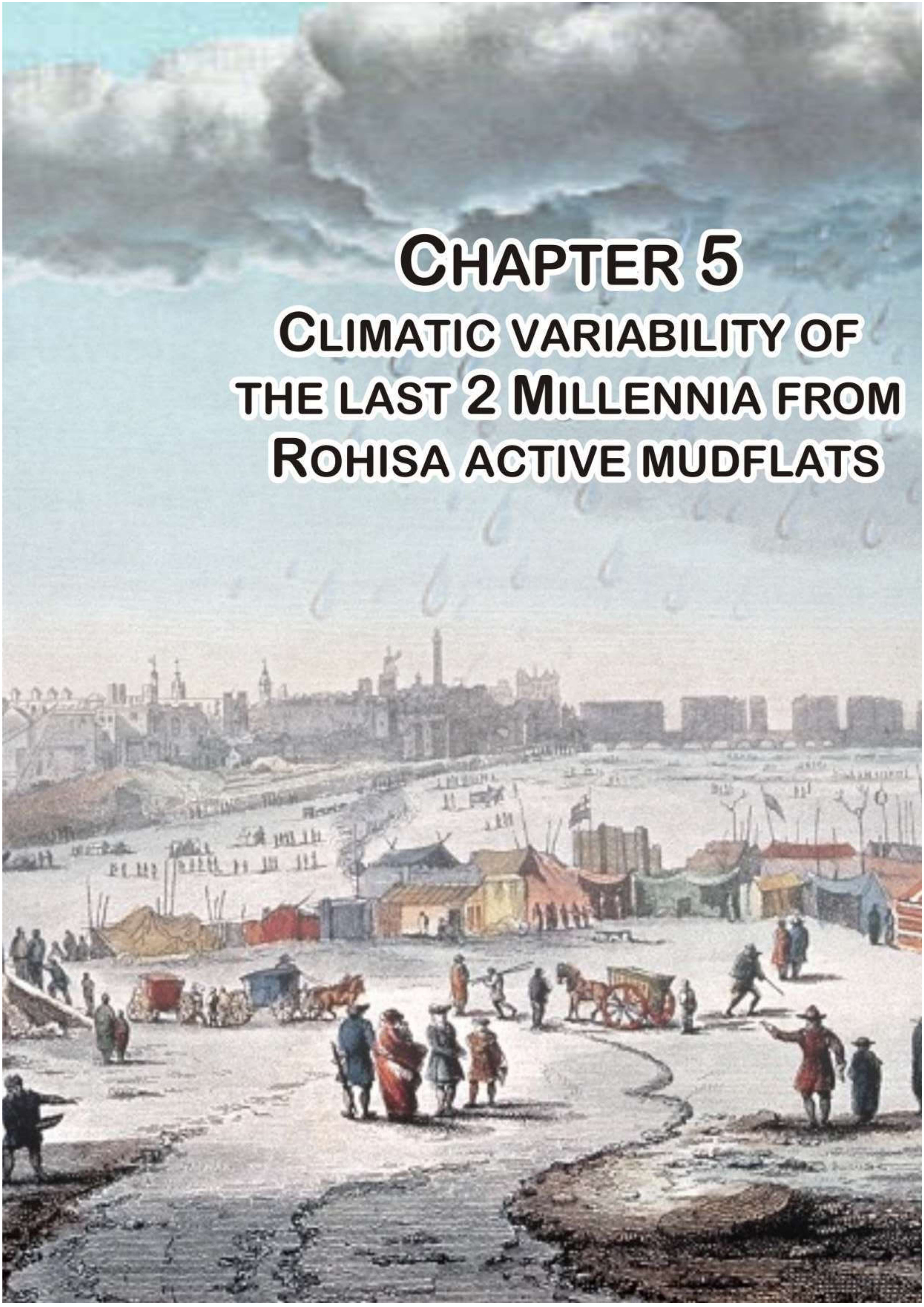
CHAPTER 5

CLIMATIC VARIABILITY OF THE LAST 2 MILLENNIA FROM ROHISA ACTIVE MUDFLATS



5.1 Active mudflat: Rohisa

Globally, the last 2 millennia have been significantly explored scientifically for the climatic reconstruction due to the fact that this period represents substantial intervention of human civilization on the natural climate variability. As mentioned in the previous chapters, Gujarat being climatically variable has been studied for its paleoclimatic reconstruction by various researchers (Kusumgar et al., 1998; Prasad et al., 2007; Sridhar, 2009; Laskar et al., 2013; Prasad et al., 2014; Sridhar et al., 2014). However, only a few studies have addressed major climatic perturbation during the last 2000 yr BP (Sridhar, 2009; Sridhar et al., 2014; 2015). The present study is an attempt to provide a high resolution climatic reconstruction during last 2000 yr BP contributing to the current understanding of the late Holocene climate of Gujarat.

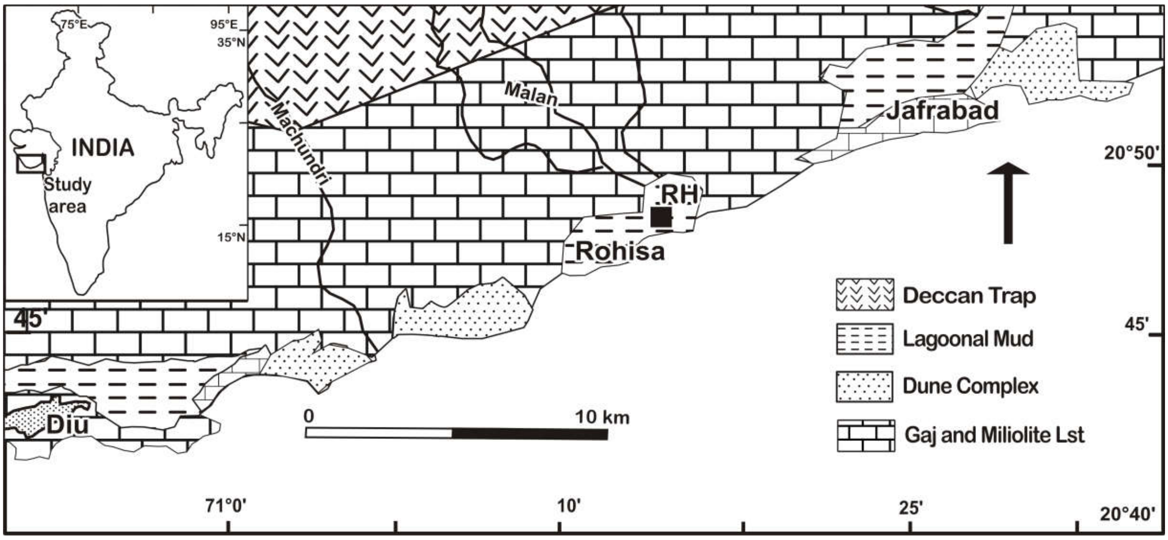


Figure 5-1. Geology around the active mudflat region of Rohisa (RH), southern Saurashtra. Filled square indicates sediment core collection site (Modified after Pant and Juyal, 1993).

In the previous chapters, although the climate history for the past 5000 yr has been reconstructed from the relict (VV) and active mudflat (DV) (Discussed in Chapter-3 and 4), but due to low resolution the climatic variability during last 2000 yr could not be resolved. In view of this, a sediment core from the active mudflat of Rohisa (RH), southern Saurashtra coast was raised and studied for various geochemical and isotopic parameters. The sampling location lies in creek region and presently receives sediments primarily during high tides. This suggests that sedimentation rate in Rohisa (RH) is probably high as compared to the active mudflat near Diu (DV). It is very important to verify that the climatic variability preserved in one mudflat sediment core also corroborates well with the other mudflat archive of the same region.

5.2 Core location

The core RH was collected from the active mudflats of Rohisa village (20°48'59.1"N; 71°13'30.0"E) of Jafrabad Taluka of Amreli district situated in the southern coast of Saurashtra, Gujarat. Being an active mudflat, the area receives sediment during high tides twice a day. At the present location, there is sea water ingression during high tides and during monsoon the Malan River (an ephemeral river) gets activated and deposits detrital sediment. A sediment core of 62 cm length was raised with the help of PVC hand driller. The entire core was clayey indicating that the sediment deposition takes place under calm conditions. A geological map (Fig. 5–1) is represented for ready reference.

5.3 Chronology

The chronology of the core was established using radiocarbon dating of organic carbon fraction at depths of 39 cm and 61 cm. The radiocarbon ages obtained are 1864 ± 43 (39 cm) and 2273 ± 39 (61 cm) yr BP, with the surface being active, is considered as the year of collection. The radiocarbon ages thus obtained were calibrated by mixed Marine Northern hemisphere calibration curve (Stuiver et al., 1998; Reimer et al., 2009;

Reimer et al., 2013) using CALIB 7.0 and the reservoir age correction (ΔR) of 165 ± 57 (Dutta et al., 2001; Southon et al., 2002) for the northern Arabian Sea was applied on the calibrated ages. The calibrated ages after correcting for reservoir ages are 1440 ± 23 cal yr BP and 1910 ± 3 cal yr BP for depths 39 and 61 cm respectively.

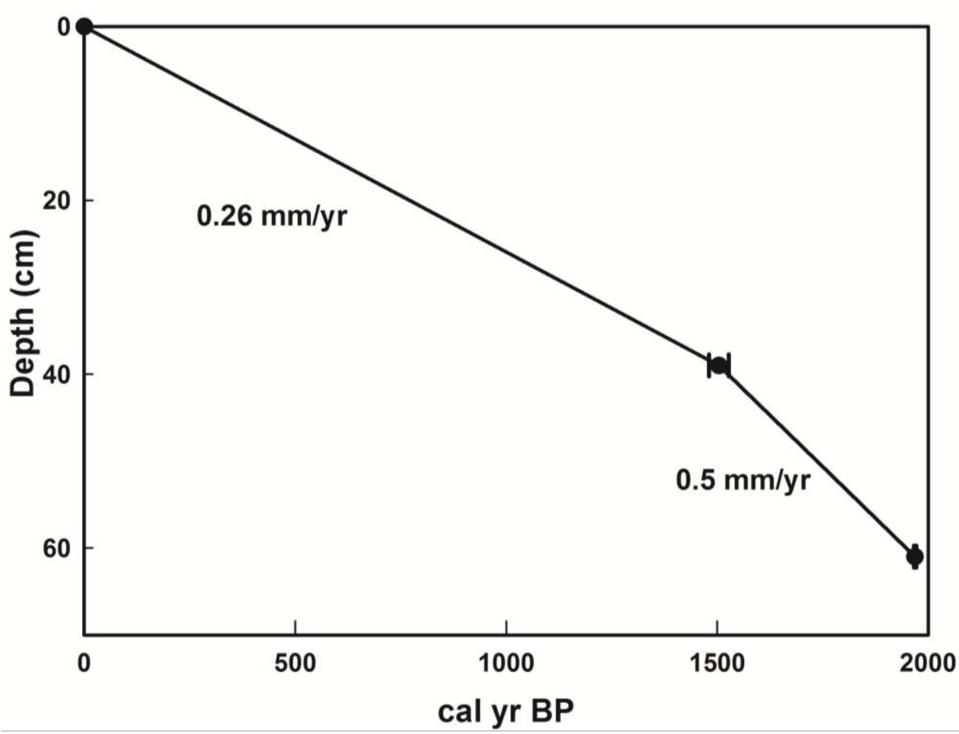


Figure 5-2. Age-Depth model for the active mudflat of Rohisa (RH). The surface is taken as year of core collection as the region receives sediment during high tides and gets exposed during low tides.

5.4 Active Mudflat of Rohisa (RH)-Results

To reconstruct the paleoclimatic history of last 2000 yr, the sub sample of the sediment core raised from the Rohisa mudflat (RH) is analysed for various geochemical and isotopic parameters which are commonly used as paleoclimatic proxies for detrital, productivity and weathering studies. On the basis of the geochemical analysis, the entire core has been divided into four sub-divisions viz. Unit-I (62–40 cm), Unit-II (40–14 cm), Unit-III (14–6 cm) and Unit- IV (6 cm– surface). The age bracketing calculated are for Unit-I from 1971–1506 cal yr BP (43–508 AD), for Unit-II-1506–503 cal yr BP (508–1511 AD), for Unit-III-503–272 cal yr BP (1511–1742 AD) and for Unit-IV-272 cal yr BP–Present (1742–2012 AD).

(a) Unit-I (62–40cm; 1969–1546 cal yr BP) (43–508 AD)

In this unit, Al_2O_3, FeO, CaO, TiO_2 and MgO range from 3–15 %, 8.9–11.3 %, 4.8–17 % 10–14 % and 1–4.8% respectively (Fig. 5–3). The trace elements (Sr, Ba and Cu) vary between 250–519 ppm, 83–168 ppm and 84–105 ppm respectively. The $CaCO_3$, TOC, TOC/TN, $\delta^{13}C$ and $\delta^{15}N$ values are between 7.5 to 25 %, 0.8 to 1.5 %, 17 to 32, -19.5 to -20.75 ‰ and 4.6 to 8 ‰ respectively (Fig. 5–4 and 5–6).

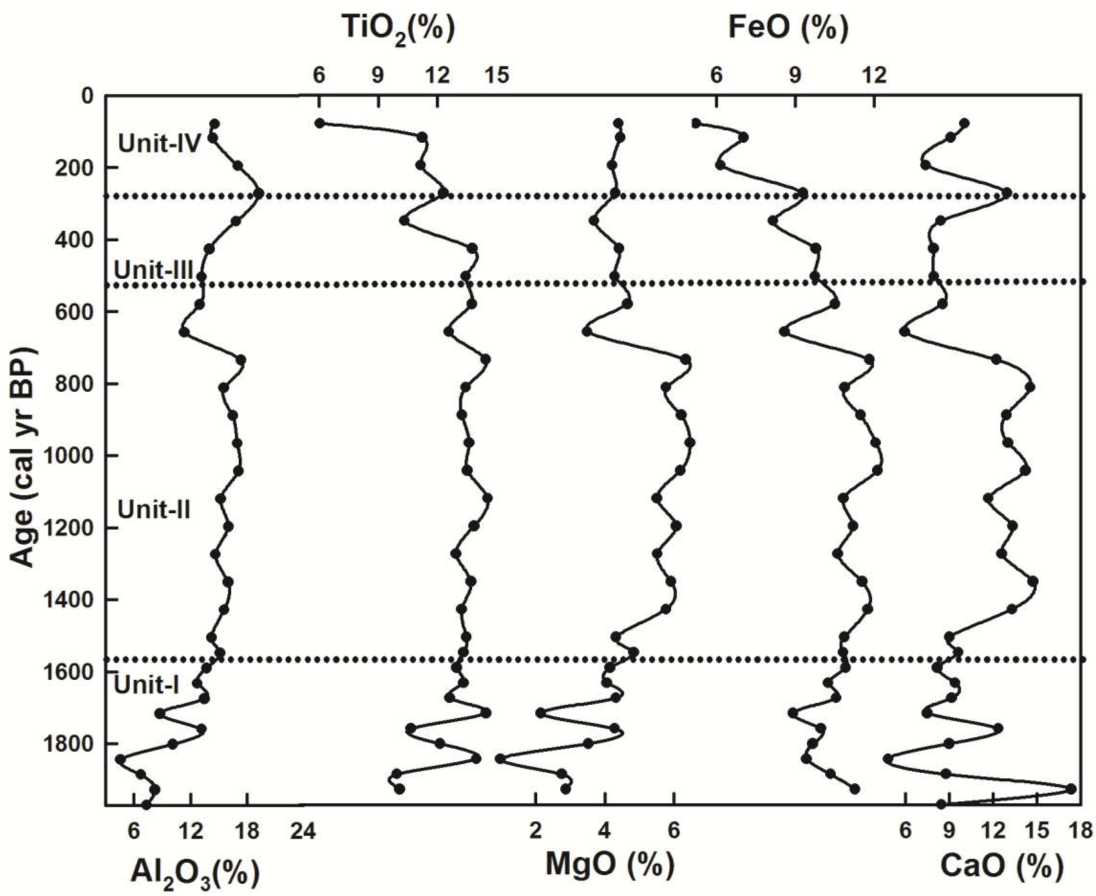


Figure 5-3. Downcore variation of detrital elements in active mudflat of Rohisa (RH) during last 2000 yr BP.

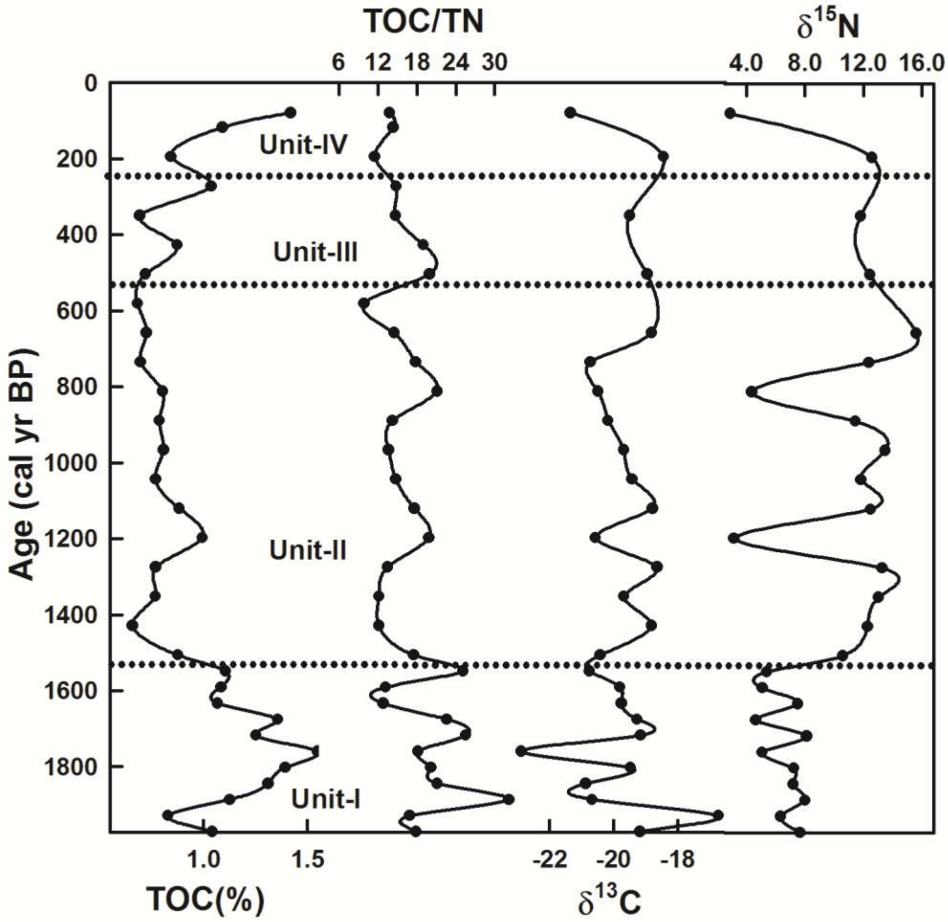


Figure 5-4. Downcore variation of TOC, TOC/TN and $\delta^{13}C$ for the active mudflat of Rohisa (RH).

The detrital proxies Al_2O_3, FeO and TiO_2 display identical variations in their distribution throughout the sediment core (Fig. 5–3). A gradual increase in the detrital proxies with marginal fluctuation is observed during the deposition of Unit I. In case of TOC, a gradual increase till 1760 cal yr BP followed by a gradual declining trend till 1545 cal yr BP has been observed. The TOC/TN ratio shows fluctuating values mostly >12 indicating dominance of terrestrial organic matter (Fig. 5–4). In case of $\delta^{13}C$, a general decreasing trend has been observed till 1760 cal yr BP, showing sudden depletion at 1760 cal yr BP coinciding with high TOC. $\delta^{15}N$ does not show any significant trend but minor fluctuation can be seen. The productivity and weathering proxies (Fig. 5–6 and 5–5) followed similar trend with a gradual decrease.

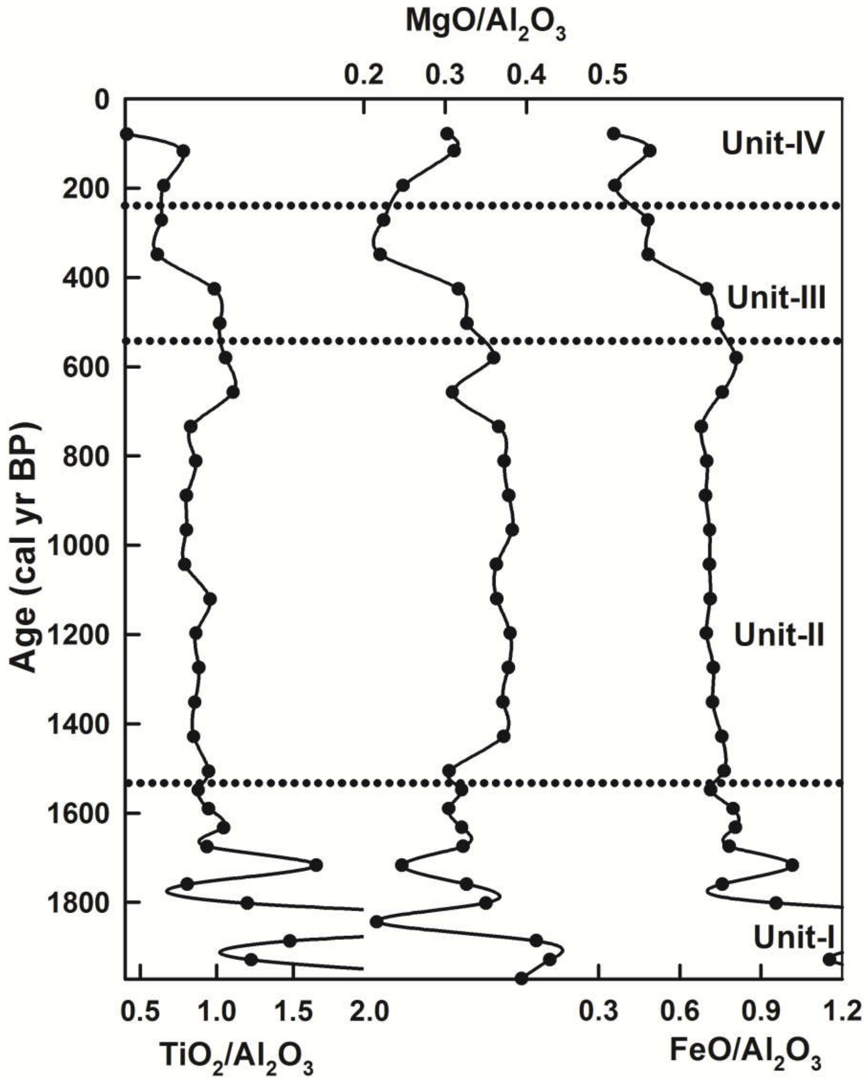


Figure 5-5. Downcore variation of weathering proxy of active mudflat of Rohisa (RH) during last 2000 yr BP.

(b) Unit-II (40–14 cm; 1546–503 cal yr BP) (508–1511 AD)

In unit-II major oxide Al_2O_3, FeO, CaO, TiO_2 and MgO concentrations vary from 11.3–17.4 %, 8.6–11.8 %, 5.96–14.5 %, 12.58–14.5 % and 3.5–6.4 % respectively (Fig. 5–3). The Sr, Ba, Cu and $CaCO_3$ range between 167.8–253 ppm, 153–224 ppm, 97–130 ppm and 5.6–8.2 % respectively. The TOC, TOC/TN, $\delta^{13}C$ and

$\delta^{15}N$ are from 0.66 to 0.99 %, 9.9 to 21, -18.8 to -20.49 ‰ and 3.1 to 15.6 ‰ respectively (Fig 5–4).

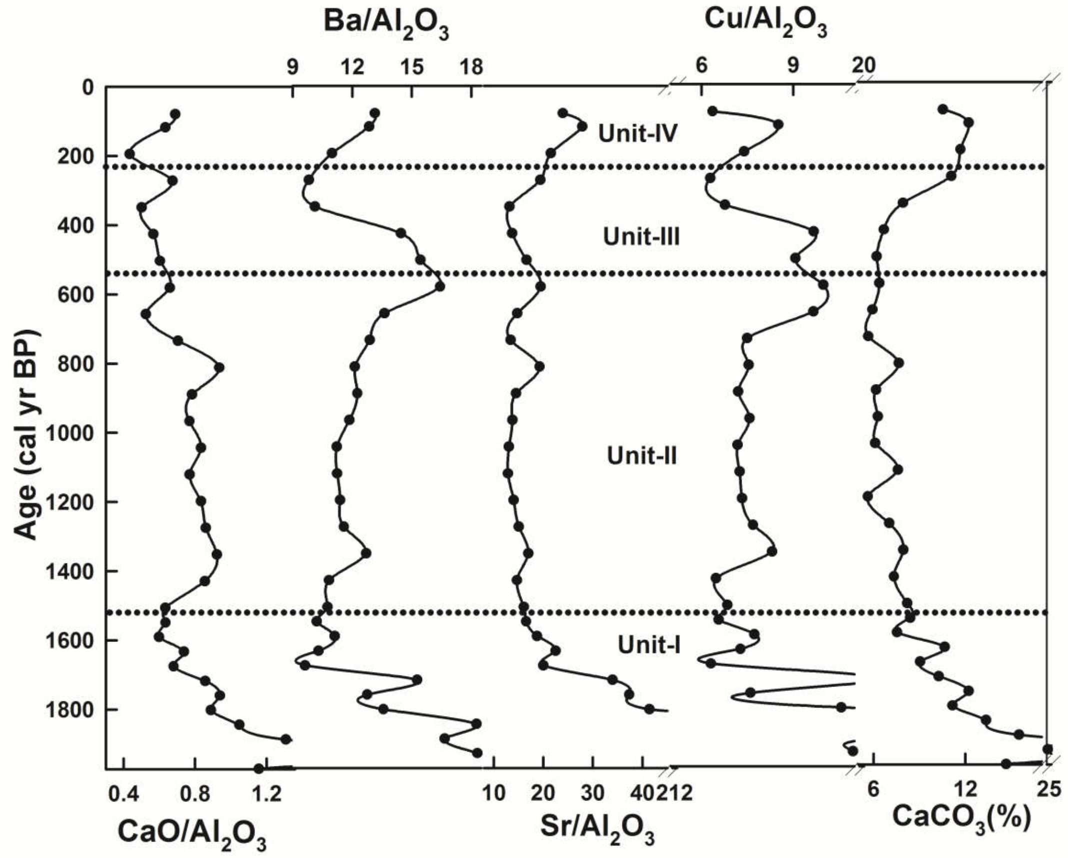


Figure 5-6. Downcore variation of productivity proxy during last 2000 yr BP for the core RH, wherein enhanced productivity is observed in Unit-I with a decreasing trend towards Unit-II.

Near constant values have been observed for the terrestrial proxies in Unit-II which show a declining trend after 800 cal yr BP. With the beginning of Unit-II deposition, the in–situ productivity proxies such as CaO/Al_2O_3, Ba/Al_2O_3 and Cu/Al_2O_3 manifest a marginal increase following which a consistent values with no significant fluctuation has been observed till 800 cal yr BP. After 800 cal yr BP both Ba/Al_2O_3 and Cu/Al_2O_3 show a gradual increase till the end of Unit-II deposition while CaO/Al_2O_3 shows a decreasing trend. Sr/Al_2O_3 and $CaCO_3$ show constant values throughout the deposition of sediments. Weathering proxies exhibit near consistent values for

TiO_2/Al_2O_3 and FeO/Al_2O_3 till 800 cal yr BP, following which a marginal increase has been noticed till the end of deposition. In the case of MgO/Al_2O, after a marginal increase during 1550 cal yr it remained consistent till the end of this unit. The TOC showed a marginal increase at 1200 cal yr BP followed by a decreasing trend. $\delta^{13}C$ also shows a similar pattern with an increasing trend punctuated by a marginal fluctuation till 1200 cal yr BP followed by a decreasing trend. The $\delta^{13}C$ values mostly remained within the marine ranges. In case of TOC/TN, it shows marginal increase in values at 1200 cal yr and 800 cal yr. In the case of $\delta^{15}N$, after initial increase in Unit-II, the values remained nearly consistent with two major excursions at 1195 and 800 cal yr BP, where depleted values have been observed. In general, the $\delta^{15}N$ values for Unit-II are more enriched compared to Unit-I.

(c) Unit-III (14–6 cm; 503−193 cal yr BP) (1511−1742 AD)

The major element concentration of Al_2O_3, FeO, CaO, TiO_2 and MgO for the Unit-III range from 13.2−19.2 %, 8.1–9.8 %, 7.9−13 %, 10.3–13.8%, and 3.7–4.4 % respectively (Fig. 5–3) while $CaCO_3$ content ranges from 6.2−11.1%. The trace elements Sr, Ba and Cu range from 192–374 ppm, 170–203 ppm and 114–35 ppm respectively. The TOC, TOC/TN, $\delta^{13}C$ and $\delta^{15}N$ ranges from 0.69−1.04 %, 14.7−19.9, nearly -19 ‰ and 12 ‰ respectively (Fig. 5–4).

In the Unit-III, Al_2O_3 shows an increasing trend towards top. While TiO_2 and FeO show declining trend with minor fluctuations, MgO remain nearly constant with no significant change. The weathering proxies (TiO_2/Al_2O_3, FeO/Al_2O_3 and MgO/Al_2O_3) show decline in this unit. Similar declining trends for productivity proxies (CaO/Al_2O_3, Ba/Al_2O_3 and Cu/Al_2O_3) towards the top of this unit has been indicated. A fluctuating

TOC with increasing pattern towards end of deposition has been observed while TOC/TN shows a declining trend similar to weathering and productivity proxies. $\delta^{13}C$ and $\delta^{15}N$ do not show much fluctuations.

(d) Unit-IV (6 cm – surface; 193 cal yr BP–Present) (1742 –2012 AD)

In this unit, of Al_2O_3, FeO, CaO, TiO_2 and MgO vary from 14−17 %, 5.2−7.0 %, 7.4–10 %, 6–11.23 % and 4.2–4.5 % respectively (Fig. 5–3). The trace element concentrations of Sr, Ba and Cu range from 349−400 ppm, 185−192 ppm and 93−126 ppm respectively. $CaCO_3$ varies between 11.5 and 12.2 % (Fig. 5–6). The TOC, TOC/TN, $\delta^{13}C$ and $\delta^{15}N$ range from 0.84 to 1.42 %, 11.5 to 14.4, -18.4 to -21.3 ‰ and 2.9 to 12.6 ‰ (Fig 5–4) respectively.

In this unit, an overall decrease in the concentrations of Al_2O_3, FeO and TiO_2 is observed while MgO remains nearly constant. In the case of productivity and weathering indicators, an increasing trend towards top of the unit has been observed. Similarly TOC and TOC/TN have also indicated a marginal increasing values towards surface of the core, while $\delta^{13}C$ and $\delta^{15}N$ show a decreasing trend.

5.5 Discussion- Rohisa Active Mudflat (RH)

Globally, the climatic history of last 2 millennia has been divided into five major climatic events viz. Roman warming period (RWP) (Frisia et al., 2005; Chen et al., 2011), Dark Ages of Cold Period (DACP) (Norgaard-Pedersen and Mikkelsen, 2009; Oppo et al., 2009), Medieval Warm Period (MWP), Little Ice Age (LIA) (Lamb, 1965) and Modern Warming (MW). In the Indian context, various studies have been carried out in order to ascertain the coexistence of global climatic events in the Indian climatic archives. Most of the former study have focussed on the MWP and LIA

(Agnihotri et al., 2002; Rühland et al., 2006; Warrier and Shankar, 2009; Quamar and Chauhan, 2014; Warrier et al., 2014). Previous studies have confirmed the MW during last 200 yr (Chaujar, 2006; Rühland et al., 2006), while only a few researchers have ascertained the existence of RWP in the Indian context (Banerji et al., 2015). The present work attempts to reconstruct the climatic history of last 2000 yr along Gujarat coast to ascertain the signatures of global climatic events such as RWP, MWP, LIA and MW.

The sedimentation rate of the study region varied from 0.5 to 0.3 mm/year between 1971 BP– Present (43 AD–2012 AD) (2012 AD: year of core collection). Since the area is deprived of perennial river, even a marginal increase in the detrital proxy reflects the improved hydrological conditions due to the activation of Malan River during enhanced monsoonal event. Similar pattern has been followed by the weathering and productivity proxies throughout the downcore variation. Intense weathering results due to warming in the climate (Burton and Vance, 2000; Cohen et al., 2004) and a simultaneous increase in the productivity indicates that the latter has been induced by the climate warming. Therefore, based on the variation in the proxies, the entire core has been divided into four climatic phases which corroborates with corresponding global climatic events during the last 2 millennia.

(a) Phase-I (1969−1546 cal yr BP; 43−508 AD)

In the Phase-I, a gradual increase in the terrestrial proxy indicates improvement in the hydrological conditions in the study area. Enhanced productivity and weathering have been observed during the deposition of Unit-I. The productivity proxies show a declining trend between 1969 and 1546 cal yr BP and the terrestrial tagged elements show an increase trend. The relative dilution effect of $CaCO_3$ due to enhanced terrestrial flux might have caused the opposite trend for the terrestrial proxies. However, TOC/TN >12 (Allen et al., 2007) supported by depleted $\delta^{13}C$ around −20 ‰ (marginal shift towards depleted side) indicate terrestrial flux. The enhanced but fluctuating productivity and weathering proxies imply that the region experienced warm and humid climate with fluctuating monsoonal conditions.

Phase-I, covering a period between 1969–1546 cal yr BP correspond to RWP of global climatic event. Furthermore, enhanced precipitation between ~ 3238 and 1297 cal yr BP has been observed from Wadhwan lake, Mainland Gujarat, western India (Prasad et al., 2014). A paleoclimatic reconstruction based on relict mudflat along the southern Saurashtra coast also indicated an increased monsoon during 1835−1500 cal yr BP (Banerji et al., 2015; Chapter-3). A study carried out at Nal Sarovar Lake, central Gujarat indicated that there persisted reduced aridity with short monsoonal spells during this period (Prasad et al., 1997). A recent multiproxy study carried out at lower Narmada valley, mainland Gujarat indicated the presence of high magnitude flooding events between 1809–1487 cal yr BP (Sridhar et al., 2015). The reduced productivity observed during the transition between Unit-I and Unit-II (423–508 AD) may represent the occurrence of DACP in the region. However, the paucity of data points does not allow to pin point the response of mudflat towards the DACP event.

(b) Phase-II (1546–503 cal yr BP; 508–1511 AD)

Marginal increase in the detrital proxies in Unit II point towards improved and consistent hydrological conditions. This is supported by an increased productivity proxies after a reduced value during the transition period between Unit-I and II, as discussed above. A consistency in almost all the proxies indicate that the region was experiencing constant and similar climatic conditions with no major fluctuation.

Marginal high terrestrial proxy, with enhanced productivity indicates a warm and humid condition but unlike the previous Unit-I, major climatic fluctuations has not been indicated. The warming and humidity in the climate was at its peak during the end of the deposition of Unit-II as revealed by the detrital, weathering and productivity proxies. The period corresponds to MWP, and enhanced monsoonal conditions has been inferred from the flood deposits of Mahi river basin (Sridhar, 2009). Similarly, the palynological study of sediment core raised from Khedla Quila Lake, Betul District, southwestern Madhya Pradesh also connote a warm and moderately humid climate phase during 534−1444 AD (Quamar and Chauhan, 2014).

(c) Phase-III (503−193 cal yr BP; 1511−1742 AD)

With the beginning of Phase-III low detrital flux compared to Phase-II has been observed but with an increasing trend. But decrease in productivity and weathering related variables are observed. As a matter of fact, humid climate and temperature induces the intensity of weathering, while the present Phase-III, suggests a short monsoonal spell with reduced weathering and productivity in the region, though there was an increased detrital flux as indicated by the increase of Al_2O_3 supported by fluctuating TOC and depleted $\delta^{13}C$ after 426 cal yr BP.

Indian subcontinent being a tropical region experiences shift in Intertropical Convergence Zone (ITCZ) that causes significant changes in summer and winter precipitation. The ITCZ is a narrow latitudinal zone of wind convergence and precipitation that determines the onset, duration and termination of rainy season in the tropics and sub-tropics (Fleitmann et al., 2007). Studies suggest that shifts in the mean latitudinal position of ITCZ resulted into significant changes in the hydrological cycle (An et al., 2000; Maslin and Burns, 2000; Ortiz et al., 2000; Luckge et al., 2001). In the western India, the northward shift of ITCZ results in the summer monsoon while the southward shift results in the winter monsoon caused by the westerlies. In this phase, decreased productivity and weathering with marginal increase in the detrital flux are evidence of cool and humid climate in the region which in turn suggests enhanced winter precipitation in the region. Studies have suggested the migration of ITCZ towards southern hemisphere which might have caused enhanced winter precipitation due to westerlies (Luckge et al., 2001; Kotlia et al., 2012). Phase-III corresponds to global LIA period and studies have also shown shift in ITCZ during LIA (Brown and Johnson, 2005; Newton et al., 2011; Konecky et al., 2013). Therefore, during this phase corresponding to LIA period, cool and humid climate persisting in the region might have resulted due to the enhanced winter precipitation caused by the westerlies, while increased western disturbances might have resulted due to the shift of ITCZ.

Nevertheless, monsoonal activity was reduced in Unit–III compared to Unit-II representing MWP. During LIA enhanced monsoonal event has been inferred by various studies from the Indian Subcontinent LIA (Rühland et al., 2006; Warrier and Shankar, 2009; Quamar and Chauhan, 2014). A recent multi proxy study carried out at the Narmada valley, mainland Gujarat, also supports a pulse of enhanced precipitation post 1187 cal BP (Sridhar et al., 2015).

(d) Phase-IV (193 cal yr BP– Present; 1742 –2012 AD)

Phase-IV represents the climatic conditions during the last ~200 yr. The decreasing trend of detrital elements shows reduced hydrological conditions. In case of insitu productivity, initially an increased productivity has been observed followed by a marginal decline at the surface. Similar is the case for weathering proxies with initial enhanced values with decreased surface value. Such declining pattern in the terrestrial proxy with gradual declining of productivity and weathering proxy signifies a suitable conditions persisted during 190 cal yr BP (i.e. at the beginning of Phase-IV) that enhanced productivity and weathering in the region as shown by the continuous declining trend of terrestrial elements. Therefore, the unit represents warm conditions but with reduced monsoonal events as reflected by the detrital flux. However, the last century climate could not be resolved as it is represented by only one data point, wherein all the proxies including terrestrial, productivity, weathering show declining trend. A similar warming during last 200 yr has been interpreted from the study of peat in Pinder valley, Northern India (Rühland et al., 2006). Similarly, the retreating glaciers punctuated by numerous advances and retreats have been observed in the Himalayan region with the culmination of LIA after 1795 AD (Chaujar, 2006; 2009).

5.6 Climatic reconstruction during last 2000 yr BP

The sediment core raised from the active creek of Rohisa from the southern Saurashtra has archived the climatic history of the last two millennia. Based on the geochemical and isotopic proxies, it appears fair to conclude that the active mudflat has responded towards the major global climatic events of last two millennia. The RWP was warm and humid with fluctuating monsoonal conditions followed by DACP which lasted for very short duration.

The MWP was humid and no major climatic fluctuation interferred during this period. However, the LIA was cool and humid due to the enhanced winter precipitation caused by the southward migration of ITCZ (Fig. 5−7). During last 200 yr, the region has experienced warm climate. Nevertheless, further proxies are required to delineate between the winter and summer monsoon as the area is too sensitive towards the detrital contribution due to the absence of any perennial rivers draining in to the region.

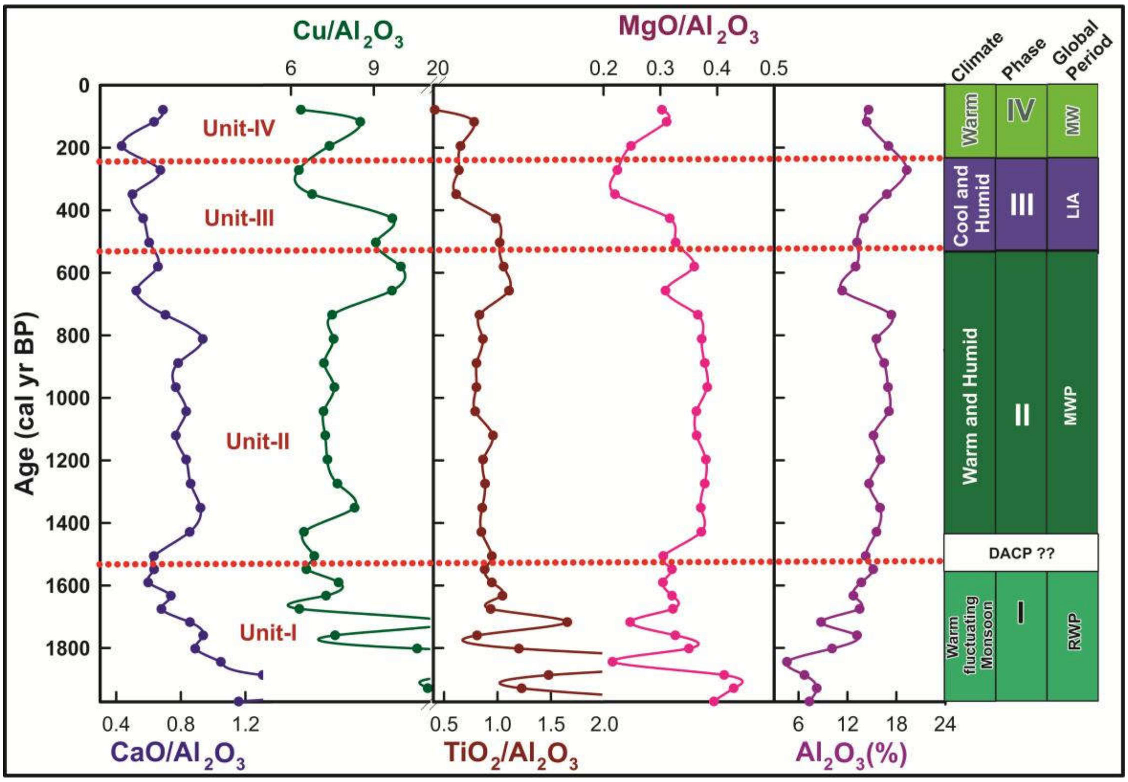


Figure 5-7. Reconstructed climatic variability of the region based on active mudflat of Rohisa (RH) and its comparison with global climatic period.