Chapter 8

PALYNOLOGICAL STUDIES

Paleoenvironmental evolution of Holocene period from the arid, semi-arid and sub-humid regions in northwestern India that shares its border with the Arabian Sea suggest that the strength of the Indian summer monsoon (ISM) from this region has varied across this epoch (e.g., Prasad et al., 1997; Enzel et al., 1999; Roy et al., 2009; Laskar et al., 2013). This was mainly mediated by the latitudinal shifts within ITCZ (Inter Tropical Convergence Zone) and ISM changes driven by ENSO (El Niño–Southern Oscillation) and moreover it also shows other teleconnections (Haug et al., 2001; Prasad et al., 2014a). Specifically, these regions witnessed periodic incursions of winter precipitation with the southward shift of westerly winds during the mid-Holocene (Prasad and Enzel, 2006), whereas current day precipitation in this region is dominated by the ISM (Gujarat Institute of Desert Ecology (GUIDE), 1998). Likewise, paleovegetation investigations from these regions show fluctuations within the relative presence of mesic and arid taxa in these regions which corresponding to wet and dry spells until the mid-Holocene (e.g., Singh et al., 1974; Prasad and Enzel, 2006; Prasad et al., 2014b). However, the history related to savanna and grassland ecosystems from the mid-to-late Holocene is still unclear. The role of Vegetation is critical in the Earth's climate as it effect the surface albedo (Mykleby et al., 2017), atmospheric aerosol (Jin and Wang, 2018) The greenhouse gas composition and global carbon cycle are also affected by the same (Piao et al., 2009). This may be concluded as vegetation and ecosystems are extremely sensitive to climate change.

Pollen grains and spores, produced by the plants, has the tendency to get preserved in the sedimentary environments which serve as a important proxy and evidence for palaeovegetation and palaeoclimate reconstructions (Faegri and Iversen, 1964; Sun and Wu, 1987; Gasse et al., 1991; Gunnell, 1997; Bonnefille et al., 1999; Chen et al., 2006 Quamar et al., 2017; Quamar and Bera, 2017; Kar and Quamar, 2019; Quamar, 2019). The Mangroves are mostly well found in tropical regions due to their nature of adaptation strategies; their ecological dynamics can be closely linked with the changes in sea level. Pollen analysis of mangroves is important in respect to palaeoecological reconstructions of coastal vegetation and determinations of palaeoenvironment in tropical and subtropical regions (Muller, 1964, 1968; Muller and Caratini, 1977; Woodroffe, 1981; Semeniuk, 1983; Thanikaimoni, 1987; Grindrod, 1988; Baldibeke and Baldi, 1991; Larcombe and

Carter, 1998; Chateauneuf et al., 2006; Farooqui and Achyuthan, 2006; Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008; Berkeley et al., 2009). The research carried out on the succession of coastal vegetation, ecosystem dynamics and sea-level changes in connection of mangrove response to sea level have been published (Woodroffe, 1988; Mildenhall, 1994; Parkinson et al., 1994; Blasco et al., 1996; Grindrod et al., 1999, 2002; Rull et al., 1999; Jaramillo and Bayona, 2000; Behling et al., 2001; Behling, 2002; Berdin et al., 2003; Behling and da Costa, 2004; van Campo and Bengo, 2004; Yulianto et al., 2004; Ellison, 2005; Kumaran et al., 2005; Scourse et al., 2005; Engelhart et al., 2007; Cohen et al., 2009; Hait and Behling, 2009; Jarzen and Dilcher, 2009; Monacci et al., 2009, 2011; Gonzalez et al., 2010;Barui, 2011; Bian et al., 2011).

PALYNOLOGICAL STUDIES IN GRK

The palynological study was carried out on the two recovered cores from GRK, Dhordo and Berada to decipher the palaeoenvironmental and paleoclimatic condition from the GRK. Counting of pollen and spores was carried out under a transmitted light microscope (Olympus BX50) with attached DP 26 software for photography, using X40 objective lens at the Quaternary Palynology Laboratory of the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow. The published reference materials (Mao et al., 2012, Pandey et al., 2014; Quamar and Chauhan, 2012; Quamar and Bera, 2017; Quamar and Kar, 2020, Rao et al., 2020 and references cited therein) were utilized for the identification of the recovered palynomorphs under the microscope (Figure 8.1 and Figure 8.3). The description of pollen variability in both the cores is described below.

DHORDO CORE

The location marks the central part of the Great Rann of Kachchh basin known for its supra tidal conditions settings (Maurya et al., 2013). Water from ocean dispersed over land and evaporates, adding to increased soil salinity. When land contains high concentration of solutes and there is no opportunity to flush out accumulated salts to drainage system, salts can quickly reach levels that are injurious to salt sensitive species. High concentrations of salts have detrimental effects on plant growth (Garg & Gupta 1997, Mer et al. 2000) and excessive concentrations kill growing plants (Donahue et al. 1983). Species varies at different locations which might be possible due to retardation of germination and growth of seedlings. During earlier study many investigators have reported retardation of germination and growth of seedlings at high salinity (Bernstein, 1962; Garg & Gupta, 1997; Ramoliya et al., 2004).

Palynological studies on Dhordo core

A minimum of 300 pollen and spores (Total Pollen Count) were counted per sample (Table 8.1); however, a few samples were barren and non-productive. The pollen diagram (Figure 8.2) was constructed using TILIA (Grimm 1991). The recovered palyno taxa are arranged in the pollen diagram as mangroves taxa (comprising core mangroves and peripheral mangrove), shrubs, midland taxa/ubiquitous taxa (comprising terrestrial herbs, marshy/wetland taxa, algal remains, aquatic taxa, pteridophytic taxa as ferns and allies, drifted taxa or long- distance pollen taxa (from the higher reaches of the Himalaya) and NPPs (comprising dinoflagellate cysts, foraminiferal linings, fungal spores and other NPPs, if any).

The pollen diagram (Figure 8.2) has been divided into three distinct pollen zones (DH-I, DH-II & DH-III) based on the varying frequencies of the prominent arboreal and non-arboreal taxa to enable a more detailed description of the pollen data zone-by-zone. These pollen zones are designated with the initials 'DH' after the name of the site of investigation Dhordo Core. The pollen zones numbering from bottom to top are described as below:

<u>Greenlandian Stage</u>

DH -I (60-37 m; ca. 10.2 and 8.1 kyr)

This pollen zone, covering the time bracket of ca. *10.2 to 8.1 kyr*. The pollen assemblage shows that the core mangrove taxa, such as *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avicennia* sp., as well as the peripheral mangrove taxon (*Nypa*) contributed with an average sum of 21.9% pollen and 0.4 % pollen, respectively. However, the midland taxa, such as *Syzygium* sp., *Holpotelea* sp., Cortolaria sp., Terminalia sp., Tinospora cordifolia sp., Corton sp. and *Casuarina* sp. have lesser values in the pollen assemblages (2.7% pollen). Poaceae represent an average value of 10.9% pollen of the pollen assemblages. Cerealia has an average value of 17.4% pollen, whereas other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilsis* and *Cannabis sativa* contribute with an average sum of 6.2% pollen. Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* contribute with an average sum of 4.1% pollen.

Table 8.1 Showing percentage of pollen grain abundance in the samples analysed for Dhordo core.

Taxa/ sample number	**1.0**	**5.0**	**6.0**	**8.0**	**11.0**	**16.0**	**21.0**	**26.0**	**31.0**	**36.0**	**41.0**	**47.0**	**51.0**	**56.0**	**61.0**	**65.0**	**70.0**	**75.0**	**80.0**	**84.0**
Rhizophoraceae	0.0	0.0	0.0	0.0	0.0	14.8	20.0	0.0	19.0	83.3	30.0	10.5	0.0	33.3	0.0	7.1	0.0	0.0	0.0	8.3
Bruguiera sp.	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	5.0	0.0	0.0	28.6	0.0	0.0
Sonneratia	0.0	0.0	0.0	16.7	0.0	3.7	0.0	0.0	0.0	0.0	0.0	5.3	0.0	16.7	0.0	7.1	0.0	0.0	0.0	0.0
Typha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avecennia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nypa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Casuarina	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7
Acasia (Fabaceae)	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utricularia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Emblica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terminalia	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
Crotolaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syzygium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Holoptelea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acanthaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tinosporcordifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poaceae	0.0	0.0	33.3	0.0	0.0	0.0	10.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	8.3
Cerealia	0.0	0.0	0.0	16.7	0.0	37.0	30.0	0.0	42.9	8.3	10.0	21.1	0.0	0.0	0.0	14.3	0.0	28.6	0.0	8.3
Amaranthaceae	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brassicaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caryophyllaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Artemisia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternanthera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cannabis sativa	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
Malvaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0
Asteroidae/Tubuliflorae	0.0	20.0	0.0	0.0	0.0	7.4	5.0	0.0	4.8	0.0	0.0	5.3	0.0	33.3	0.0	7.1	0.0	0.0	0.0	0.0
Cichorioideae/Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xanthium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperceae	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	7.1	0.0	0.0	0.0	0.0
Polygonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zygnema	0.0	0.0	0.0	8.3	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Spirogyra	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudoschizaea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	66.7	0.0	0.0	8.3
Lemana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monlete fern spore	0.0	0.0	0.0	16.7	0.0	7.4	5.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	5.0	7.1	0.0	0.0	0.0	16.7
Trilete fern Spore I	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	33.3	14.3	0.0	0.0
Trilete fern Spore II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0
Pinns	0.0	0.0	0.0	16.7	0.0	11.1	5.0	0.0	0.0	8.3	10.0	26.3	0.0	0.0	5.0	28.6	0.0	28.6	0.0	16.7
Cedrus	0.0	0.0	0.0	16.7	0.0	3.7	0.0	0.0	9.5	0.0	10.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0
Picea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dinoflegellate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Foraminifera lining	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glomus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigrospora	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0
Alternaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helmintho	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lesiodiplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Globose misofossil with long protubleances	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Croton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Taxa/ sample number	88.0	93.0	98.0	104.0	107.0	112.0	117.0	120.0	124.0	129.0	134.0	138.0	143.0	147.0	152.0	157.0	162.0	164.0	167.0	172.0
Rhizophoraceae	5.9	0.0	8.1	0.0	0.0	0.0	13.0	0.0	0.0	0.0	14.3	11.1	20.0	22.2	0.0	0.0	35.7	0.0	0.0	33.3
Bruguiera sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
Sonneratia	0.0	0.0	0.0	0.0	0.0	0.0	13.0	16.7	13.3	0.0	0.0	0.0	20.0	33.3	0.0	0.0	14.3	0.0	0.0	0.0
Typha	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
Avecennia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nypa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Casuarina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	5.6	0.0
Acasia (Fabaceae)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utricularia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emblica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terminalia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crotolaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syzygium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Holoptelea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acanthaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1
Tinosporcordifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poaceae	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	16.7	0.0
Cerealia	5.9	0.0	24.3	85.7	14.3	17.6	21.7	16.7	20.0	0.0	28.6	33.3	10.0	11.1	0.0	0.0	0.0	33.3	11.1	22.2
Amaranthaceae	0.0	0.0	5.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0
Brassicaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caryophyllaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1
Artemisia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
Ranunculaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternanthera	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cannabis sativa	5.9	0.0	5.4	0.0	0.0	17.6	4.3	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malvaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0
Asteroidae/Tubuliflorae	0.0	0.0	2.7	0.0	0.0	11.8	4.3	0.0	6.7	0.0	0.0	0.0	0.0	11.1	0.0	0.0	7.1	0.0	0.0	0.0
Cichorioideae/Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xanthium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperceae	29.4	0.0	13.5	0.0	14.3	5.9	8.7	0.0	10.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	5.6	11.1
Polygonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zygnema	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0
Spirogyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudoschizaea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	17.6	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lemana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monlete fern spore	11.8	0.0	8.1	0.0	42.9	11.8	0.0	0.0	6.7	0.0	14.3	11.1	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trilete fern Spore I	0.0	0.0	5.4	0.0	28.6	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	5.6	0.0
Trilete fern Spore II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinns	0.0	0.0	13.5	0.0	0.0	23.5	17.4	0.0	10.0	0.0	14.3	11.1	10.0	11.1	0.0	0.0	7.1	33.3	0.0	11.1
Cedrus	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Picea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
Alnus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dinoflegellate	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
Foraminifera lining	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	27.8	0.0
Glomus	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigrospora	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0
Alternaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helmintho	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lesiodiplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Globose misofossil with long protubleances	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deplodia	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Croton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Taxa/ sample number	178.0	181.0	186.0	190.0	194.0	199.0	204.0	209.0	214.0	224.0	229.0	239.0	247.0	269.0	274.0	279.0	283.0	287.0	289.0
Rhizophoraceae	0.0	0.0	14.3	0.0	33.3	8.3	0.0	17.8	0.0	0.0	35.3	14.3	0.0	0.0	0.0	50.0	29.4	0.0	20.0
Bruguiera sp.	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sonneratia	0.0	12.0	0.0	0.0	0.0	8.3	0.0	2.2	0.0	50.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	14.3	20.0
Typha	0.0	4.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.1	0.0
Avecennia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nypa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Casuarina	0.0	4.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0
Acasia (Fabaceae)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utricularia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emblica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terminalia	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crotolaria	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syzygium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Holoptelea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acanthaceae	0.0	4.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tinosporcordifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Poaceae	0.0	8.0	0.0	0.0	16.7	0.0	0.0	8.9	50.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	14.3	0.0

Cerealia	0.0	16.0	14.3	0.0	25.0	16.7	50.0	13.3	0.0	0.0	11.8	57.1	27.3	0.0	0.0	50.0	29.4	0.0	20.0
Amaranthaceae	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0
Brassicaceae	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caryophyllaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Artemisia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternanthera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cannabis sativa	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malvaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asteroidae/Tubuliflorae	0.0	8.0	14.3	0.0	8.3	0.0	0.0	11.1	0.0	0.0	0.0	0.0	18.2	0.0	0.0	0.0	5.9	0.0	0.0
Cichorioideae/Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	5.9	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Xanthium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperceae	0.0	8.0	14.3	0.0	0.0	0.0	50.0	15.6	0.0	0.0	5.9	0.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0
Polygonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zygnema	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spirogyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0
Pseudoschizaea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	0.0	4.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lemana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monlete fern spore	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.8	0.0	4.5	0.0	0.0	0.0	0.0	0.0	10.0
Trilete fern Spore I	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Trilete fern Spore II	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinns	0.0	12.0	14.3	0.0	0.0	16.7	0.0	8.9	0.0	25.0	5.9	0.0	4.5	0.0	0.0	0.0	35.3	0.0	10.0
Cedrus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Picea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephedra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dinoflegellate	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	14.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Foraminifera lining	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glomus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigrospora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helmintho	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lesiodiplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Globose misofossil with long protubleances	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deplodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Croton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Cyperaceae and *Polygonum* spp. (marshy/wetland taxa), *Potamogeton* sp. and *Lemna* sp. (aquatic taxa), have an average sum of 1% pollen and 1% pollen, respectively), whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* (algal spores) contributed with an average sum of 0.5%. Monolete and trilete fern spores have an average sum of 3% in the pollen- rain. *Pinus* sp., *Cedrus* sp., *Picea* sp. and *Ephedra* sp. (drifted plant pollen taxa), transported from the higher altitudes (the Himalaya), are represented with an average sum of 3% pollen). Dinoflagellate cysts (0.1%) and foraminiferal linings (0.1%), as well as other non-pollen palynomorphs (NPPs; 0.02%) have lesser values. The fungal spores are recorded in lower frequencies (0.3%) in this zone.

Northgrippian Stage

DH -II (37-14 m; ca. 8.1 and 5.2 kyr)

This pollen zone, covering the time span of ca. 8.1 to 5.2 kyr, show a marked decrease (15.8 % pollen) in the existing core mangrove taxa, such as Rhizophora spp., Bruguiera sp., Sonneratia sp., Avicennia sp., as well as the peripheral mangrove taxon

(Nypa) and the midland taxa, such as Syzygium sp., Holpotelea sp. and Casuarina sp. (3.5% pollen). Poaceae has an average value of 8.5% pollen of the total pollen assemblages. Moreover, Cerealia shows dramatic increase in values and contributed with an average value of 16.4% pollen. Other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilsis* and *Cannabis sativa* also decreased considerably (an average sum of 5% pollen). Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* contribution have average values of 4% pollen, showing a bit decreased value. Cyperaceae shows an increase in its value compared to unit I where it shows an average of 3% contribution. *Polygonum* spp., as well as *Potamogeton* sp. and *Lemna* sp. have an average sum of 4.6% pollen and 0.1% pollen, respectively), whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* have a contribution in average of 0.2%. Monolete and trilete fern spores show increased in its contribution (average sum of 5 %). *Pinus* sp., *Cedrus* sp. and *Ephedra* sp. have an average sum of 2% pollen. Dinoflagellate cysts (0.1%) and foraminiferal linings (0.2%), as well as fungal spores (0.3%) and other NPPs 0.1%) have lesser values in this zone too (Table 8.1).

Meghalayan Stage

DH -III (14-0 m; ca. 5.2 to present)

This pollen zone, encompassing a time frame of 5.2 kyr to the Present, is again demonstrating the comparative higher values of especially the core mangrove taxa, such as Rhizophora spp., Sonneratia sp., Bruguiera sp., Avicennia sp. (average sum of 17% pollen). However, the midland taxa, such as Casuarina sp. and Syzygium sp. have made their presence felt, although in lesser values (4.5% pollen) (Table 8.1). Poaceae has comparative increased frequencies and represented with an average value of 7.8% pollen of the pollen assemblages. Cerealia also show increased values but less than the below pollen zone II (average value of 11.5 % pollen). Other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., and *Cannabis sativa* contribute with an average sum of 5% pollen, showing comparative increased frequencies in this pollen zone. Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* have average 3% pollen. Cyperaceae and *Polygonum* spp., as well as Potamogeton sp. and *Lemna* sp. contributed with increased values (average sum of 2% pollen), whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* have also comparative increased frequencies with an average value of 0.2%. Monolete and trilete fern spores increased in this pollen zone with an average value of 2 % pollen. *Pinus* sp., *Cedrus* sp., *Picea* sp., *Alnus* sp., and *Ephedra* sp. also showed increasing tendency (average 1% pollen) (Table 8.1). Dinoflagellate cysts (0.1%) and foraminiferal linings (0.2%), as well as fungal spores (0.1%) and NPPs (0.3%) have comparative higher values.

Palaeoenvironmental conditions of Dhordo core

Pollen analytical investigation of a 60 m deep sedimentary core (Dhordo core) provides insights into the vegetation and climate changes since the Holocene from the central basin of GRK (Great Rann of Kachchh), Gujarat, India. The pollen assemblages have demonstrated the presence of *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avecennia* sp., and *Aegiceras* sp. (core mangrove taxa), along with *Nypa* (peripheral mangrove taxon) and *Syzygium* and *Holoptelea* (midland taxa) between ca. 10.2 and 7.7 kyr (Pollen Zone DH -I) (Figure 8.2), the eatablisment of mangrove forest under enhanced monsoonal rainfall and humid condition at Dhordo site (Quamar et al., 2017; Quamar and Bera, 2017; Kar and Quamar, 2019; Quamar, 2019) (Plate 1). The presence of pollen such as Cerealia and other cultural plant pollen taxa, like Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilis* and *Cannabis sativa* suggests that incipient cereal-based agricultural practice and other anthropogenic (human) activities around the core site. The presence of freshwater algae *Zygnema* and *Spirogyra* (zygospores), and *Pseudoschizaea* (*Concentricystis*) as well as *Potamogeton* sp. and *Lemna* sp. (aquatic elements) indicates the presence of marshy condition and freshwater input, as Cyperaceae and Polygonum spp. (marshy/wetland taxa) presence also confirms the existence of marshy condition in and around the core area (Chen et al., 2006 Quamar et al., 2017). Monolete and trilete fern spores grew locally in the moist and shady environment close to the sampling site around the study area. The encounter of conifers, such as *Pinus* sp., *Cedrus* sp., and *Picea* sp. in the sediments of this zone point to the contribution sediments which ae long-distance air and/or water transported from the higher reaches of the Himalaya (Khonde et al., 2107a; Khonde et al., 2017b).

The presence of dinoflagellate cysts and foraminiferal linings indicates tidal influence from this zone, however a reduction in the core mangrove taxa and a simultaneous presence of a few midland taxa, such as *Casuarina*, *Syzygium*, and *Holoptelea*, as well as comparative increase in Poaceae, suggesting a relatively lesser monsoonal condition (relatively less warm-humid conditions) around the study area during the end Greenlandian Stage (Figure 8.2). Agricultural practice and other human activities also decreased, as indicated by comparatively lesser values of Cerealia and other cultural plant pollen taxa. The dimension of lake/water body, as well as swampy area decreased, as evidenced by the decrease in the existing aquatic elements, along with freshwater algae and marshy/wetland taxa at the end of this stage (Figure 8.2).

During the Northgrippian Stage Monolete and trilete fern spores grew locally in moist and shady conditions around the studied area. Subsequently, between ca. 7 and 5 kyr (Pollen Zone DH -II), the core mangroves, as well as the peripheral mangrove taxa and midland taxa show a comparative decrease in this phase under a weakening of monsoon rainfall and decreasing humid climate (Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008; Berkeley et al., 2009). The agricultural practice comparatively increased in the region with increase in Cerealia and other cultural plant pollen taxa. A comparative increase in the number and frequencies of the existing aquatic taxa, together with freshwater algae and marshy/wetland taxa is indicative of a comparative well established swampy margin (Chen et al., 2006 Quamar et al., 2017). Monolete and trilete fern spores continued to thrive locally close to the lake/water body around the study area in comparative lesser values to the moist and shady conditions. The record of pollen of *Pinus* sp., *Cedrus* sp., and *Ephedra* sp. (Plate 1) indicates long-distance air and/or transport from the far-off Himalaya. The presence of the pollen of *Pinus* sp., *Cedrus* sp., and *Ephedra* sp. suggests their long-distance air and/or transport from the Himalaya.

During Meghalayan Stage finally during 5kyr to the Present (Pollen Zone DH -I), the mangrove taxa, as well as the midland taxa show a marked decrease in this phase under a decreased monsoonal rainfall at the onset of this stage. Whereas increase in mangrove taxa, as well as the midland taxa is noted from the 3.9 kyr which reduces towards the end of the stage. Further, the overall decreasing pollen assemblage from ~5 kyr, therefore, marks the initiation of the aridity that established by ~4kyr which correlates well with the other records from the NW Indian archives. Moreover, the simultaneous record of comparative increased values of aridity-tolerant herbs, such as Amaranthaceae and *Artemisia* sp. (growing in arid and semi-arid climates), followed by Poaceae, Asteroideae, Malvaceae and *Cannabis sativa* (although in lesser values) suggest decrease in both vegetation cover and monsoonal rainfall, as well as drier climate (Muller, 1964, 1968; Muller and Caratini, 1977; Woodroffe, 1981; Semeniuk, 1983; Thanikaimoni, 1987; Farooqui and Achyuthan, 2006; Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008; Berkeley et al., 2009; Limaye and Kumaran, in press).

Negligible abundance in the pollen during past ~2 kyr suggests the degradation of mangrove forest, swampy-marshy land that probably also marks the phase of drying of Banni plain, its conversion to grassland might have started since then. The pace of agricultural practice and other anthropogenic activities started decreasing, as the values of Cerealia and other cultural plant pollen taxa, such as Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia* sp., and *Alternanthera* sp. started decresing till 2 kyr (Figure 8.2). The swampy margin of the existing water body also decreased, as the marshy/wetland taxa, as well as the freshwater algae and aquatic elements show decreasing trend. Monolete and trilete fern spores also decreased comparatively during this phase close to the lake around the study area in the milieu of moist and shady situation. The stray presence of Cedrus sp. and *Picea* sp., is suggestive of their long-distance air and/or water transport from the far away Himalaya.

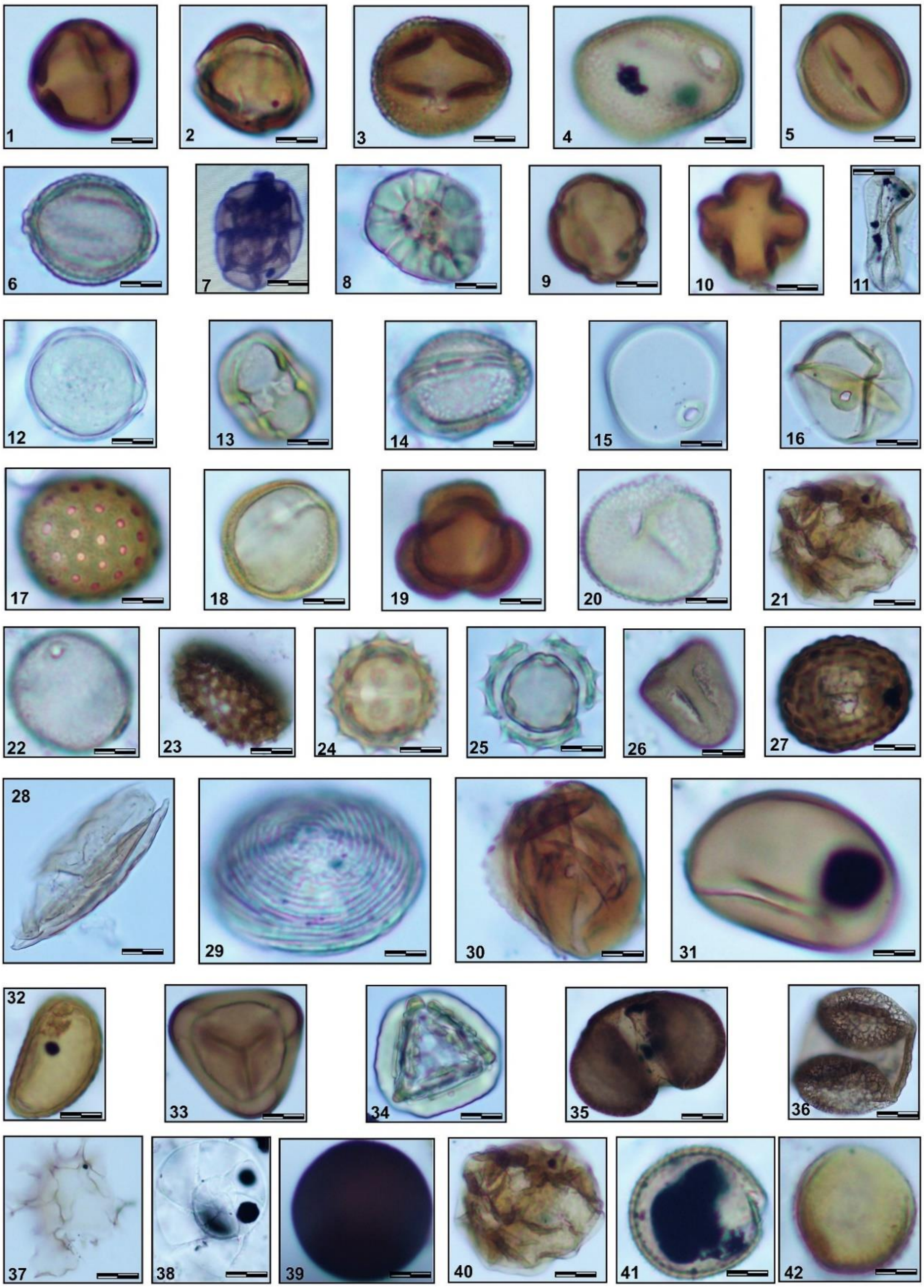

Figure 8.1: - The microphotographs shows morphology of pollens collected from the Dhordo core. 1&2. *Rhizophora* spp., 3. *Sonneratia* sp., 4. *Typha*., 5. *Avicennia*., 6. *Casuarina*., 7. *Acacia*., 8. *Utricularia*., 9. *Emblica*., 10. *Terminalia*., 11. *Crotalaria*., 12. *Holoptelea*., 13. *Acanthaceae*, 14. *Tinospora cordifolia*, 15. Poaceae., 16. *Cerealia*, 17. Amaranthaceae., 18. *Brassicaceae*., 19. *Artemisia*., 20. Ranunculaceae., 21&40. *Alternanthera*., 22. *Cannabis sativa*, 23. Malvaceae., 24. Asteroidea/Tubuliflorae., 25. Cichorioideae/Liguliflorae., 26. *Cyperceae*., 27. *Zygonema*., 28. *Spirogyra*., 29. *Pseudoschizaea*., 30. *Potamogeton*., 31. Monlete fern spore I., 32. Monlete fern spore II., 33. *Trilete fern Spore* I., 34. Trilete fern Spore II., 35. Pinns., 36. Picea., 37. Dinoflegellate cysts. 38. Foraminiferal linings. 39. *Nigrospora*., 41. Globose microfossil with long protuberances., 42. Croton.

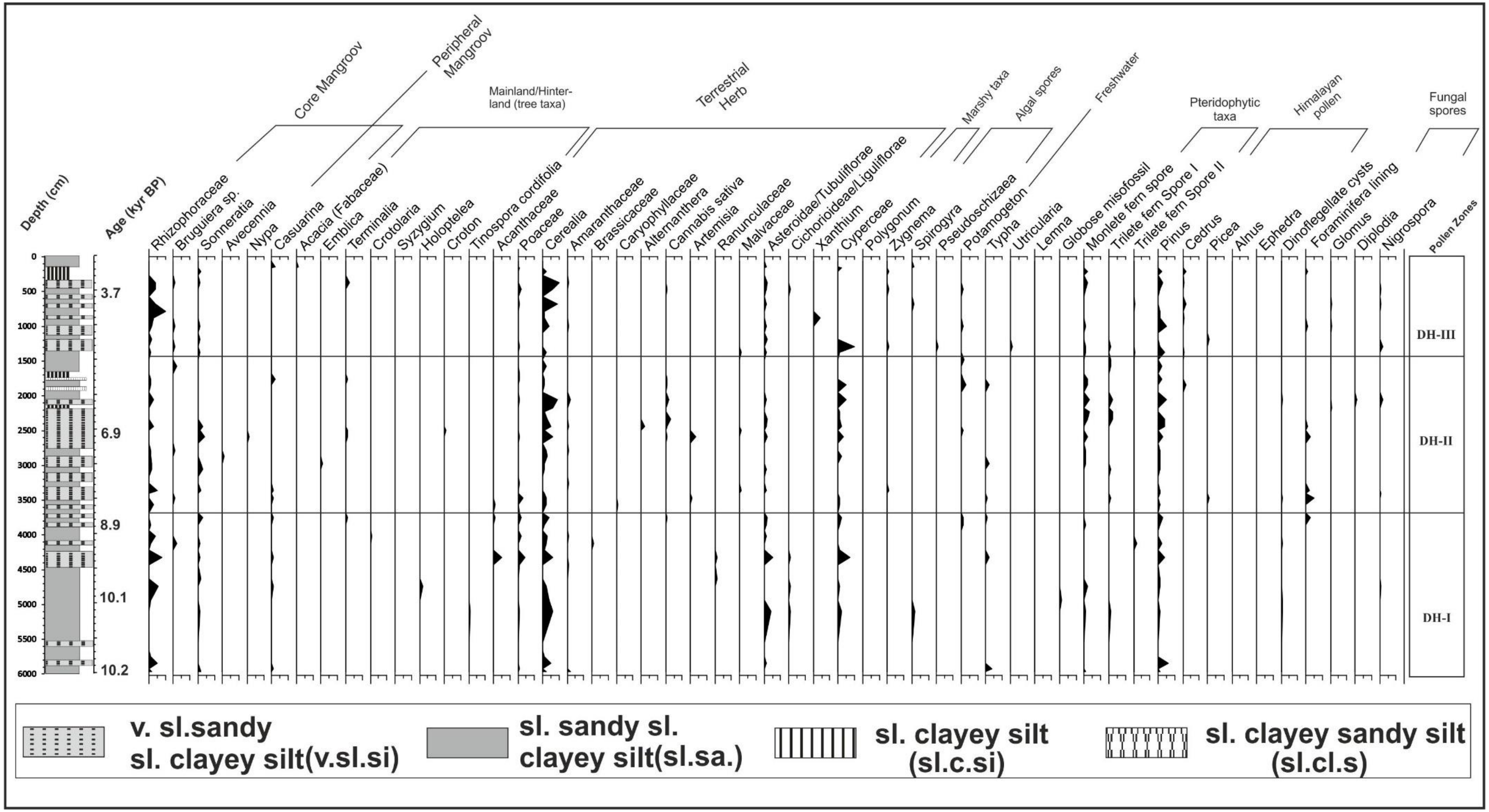

Figure 8.2 Pollen diagram represented in-depth showing percentages of main pollen taxa of Dhordo core. Pollen zones are based on pollen abundance.

BERADA CORE

Berada core was raised from the Banni grassland, located in western India adjacent to marshy salt flats of the Rann of Kachchh receives ~335 mm average annual precipitation from the southwest summer monsoon (Kumar et al., 2015). The region is characterised by recurrent droughts, high soil salinity and high annual temperature seasonality, with an average summer temperature of 49 °C and winter temperature of 10 °C (Gujarat Institute of Desert Ecology (GUIDE), 1998). The vegetation in the Banni is characterized by coexisting trees, grasses, shrubs and herbs with the understory vegetation composed of salinity tolerant and intolerant herbs (~46 % of all the plant species), grasses (~19 %) and shrubs (~16 %). Trees comprise ca. 9 % of all plant species, with climbers and sedges making up the remaining 10 % (Patel & Joshi, 2011). This region has supported pastoralism for several centuries (Bharwada and Mahajan, 2012). The terrain is flat (Chowksey et al., 2010) and lacks pronounced topographic gradients. The Banni possesses fine textured soils mainly composed of laminated deposits of silt and clay and fine sand (Singh and Kar, 2001) resulting in low permeability (Singh and Kar, 2001; Kar, 2011). These factors, combined with the low elevation of the region, results in flooding and water logging across large sections of the landscape during the monsoon. Soil salinity is highly variable (1.0 to over 15.0 mmhos/cm) and the pH ranges between 6.5 and 8.5 (GUIDE, 1998). The Banni is also characterised by the presence of several undisturbed natural lakes.

Palynological studies on Berada core

A minimum of 300 pollen and spores (Total Pollen Count) were counted per sample (Table 8.2), however, a few samples were barren and non-productive. The pollen diagram (Figure 8.4) was constructed using TILIA (Grimm 1991). The recovered palyno taxa are arranged in the pollen diagram as mangroves taxa (comprising core mangroves and peripheral mangrove), shrubs, midland taxa/ubiquitous taxa (comprising terrestrial herbs, marshy/wetland taxa, algal remains, aquatic taxa, pteridophytic taxa as ferns and allies, drifted taxa or long-distance pollen taxa (from the higher reaches of the Himalaya) and NPPs (comprising dinoflagellate cysts, foraminiferal linings, fungal spores and other NPPs, if any).

The pollen diagram (Figure 8.4) has been divided into four distinct pollen zones (BRD-I, BRD -II, BRD -III and BRD -IV) based on the varying frequencies of the prominent arboreal and non-arboreal taxa to enable a more detailed description of the pollen data zone-by-zone. These pollen zones are designated with the initials 'BRD' after the name of the site of investigation Berada Core. The pollen zones numbering from bottom to top are described as below:

<u>Greenlandian to Northgrippian Stage</u>

BRD -I (40-25 m; ca. 10.2 and 7.7 kyr)

This pollen zone, covering the time bracket of ca. 10.2 to 7.7 kyr, is characterized by the presence of mangrove forest. The pollen assemblage shows that the core mangrove taxa, such as *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avicennia* sp., as well as the peripheral mangrove taxon (*Nypa*) contributed with an average sum of 50 % pollen and 0.4 % pollen, respectively. However, the midland taxa, such as *Syzygium* sp., *Holpotelea* sp. and *Casuarina* sp. have lesser values in the pollen assemblages (15% pollen) (Figure 8.4 & Table 8.2). Poaceae represent an average value of 0.2% pollen of the pollen assemblages. Cerealia has an average value of 1.3% pollen, whereas other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilsis* and *Cannabis sativa* contribute with an average sum of 5.5% pollen. Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* contribute with an average sum of 3.1% pollen. Cyperaceae and *Polygonum* spp. (marshy/wetland taxa), *Potamogeton* sp. and *Lemna* sp. (aquatic taxa), have an average sum of 4.7% pollen and 6% pollen, respectively, whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* (algal spores) contributed with an average sum of 0.1%. Monolete and trilete fern spores have an average sum of 2.6% in the pollen- rain. *Pinus* sp., *Cedrus* sp., *Picea* sp. and *Ephedra* sp. (drifted plant pollen taxa), transported from the higher altitudes (the Himalaya), are represented with an average sum of 10.6% pollen). Dinoflagellate cysts (2.8%) and foraminiferal linings (1.4%), as well as other non-pollen palynomorphs (NPPs; 0.4%) have lesser values. The fungal spores are recorded in lower frequencies (1.6%) in this zone (Figure 8.4 & Table 8.2).

Table 8.2 Showing percentage of pollen grain abundance in the samples analysed for Berada core.

Taxa/ sample number	1	6	11	18	19	29	34	42	52	59	65	69	72	78	83	88	103
Rhizophora spp	0	25	14.3	0	3.4	4.2	24.7	24.4	30.6	0	51.3	58.4	0	63.8	67.7	70.1	24.4
Bruguiera sp	0	0	0	0	0	0	6.2	2.3	0	0	0	2.6	0	2.6	3.6	3.4	2.2
Sonneratia sp	2	25	0	0	0	0.7	3.7	4.7	21.4	68.6	17.9	6.6	76.9	15.3	12.5	8	2.2
Avicennia sp	4	0	0	0	0	0	2.5	7	0	2.9	5.1	0.7	0	0	0	0	0
Aegiceras sp	0	0	0	0	0	0	0	0	1	2.9	0	0.4	7.7	2.6	1.6	0	0
Nypa	0	0	0	0	0	0	0	2.3	0	0	0	0	0	0.4	0	0	0
Casuarina	0	0	0	0	0	0	0	3.5	0	0	0	0	0	0.4	0	1.1	0
Syzygium	0	0	0	0	6.9	0	0	0	1	0	0	0	0	0	0	0	0
Azadirachta indica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Holoptelea	0	0	0	0	3.4	0	1.2	0	0	0	0	0	0	0	0	0	0
Acanthaceae	0	0	0	0	3.4	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	0	0	0	33.3	17.2	2.1	0	3.5	8.2	0	0	11.3	3.8	1.5	3.1	1.1	0
Cerealia	0	0	0	0	17.2	2.1	2.5	1.2	8.2	0	5.1	5.5	0	1.9	4.7	8	13.3
Amaranthaceae	90	50	71.4	0	3.4	90.3	22.2	8.1	0	8.6	2.6	4	0	1.9	1	0	2.2
Brassicaceae	0	0	0	0	0	0	0	0	0	2.9	0	0.4	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0	1	0	0	0.4	0	0	0	0	0
Artemisia	0	0	0	50	0	0	3.7	1.2	2	0	0	0	3.8	0.4	0.5	0	0
Alternanthera	0	0	0	16.7	0	0	0	0	0	0	0	0	0	0	0	0	0
Cannabis sativa	0	0	0	0	0	0	3.7	3.5	2	0	0	0.4	0	0.7	0	0	4.4
Malvaceae	0	0	0	0	6.9	0	1.2	1.2	1	0	5.1	0.7	0	0.4	0	0	0
Asteroidae/Tubuliflorae	0	0	0	0	0	0	2.5	0	0	0	2.6	0.7	0	0.7	0	2.3	2.2
Cichorioideae/Liguliflorae	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
Xanthium	0	0	0	0	0	0	0	1.2	1	0	0	0	0	0	0	0	0
Cyperceae	4	0	14.3	0	6.9	0	9.9	8.1	0	11.4	7.7	1.5	3.8	3	1.6	1.1	13.3
Polygonum	0	0	0	0	0	0	0	1.2	0	0	0	0	0	0	0	0	0
Zygnema	0	0	0	0	0	0	2.5	1.2	0	0	0	0	0	0.4	0	0	2.2
Spirogyra	0	0	0	0	0	0	0	1.2	0	0	0	0.4	0	0.4	0	0	0
Pseudoschizaea	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2.2
Potamogeton	0	0	0	0	3.4	0	1.2	1.2	1	0	0	0	0	0	0	0	0
Lemna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monlete fern spore I	0	0	0	0	17.2	0	0	0	2	0	0	1.8	0	0.4	0	0	6.7
Monlete fern spore II	0	0	0	0	0	0	0	0	0	0	2.6	0	0	0	0	0	0
Trilete fern Spore I	0	0	0	0	10.3	0.7	2.5	2.3	9.2	0	0	0.4	0	0	0	0	0
Trilete fern Spore II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinns	0	0	0	0	0	0	0	15.1	1	2.9	0	1.8	3.8	3	3.6	3.4	17.8
Cedrus	0	0	0	0	0	0	3.7	1.2	1	0	0	0	0	0	0	0	0
Picea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alnus	0	0	0	0	0	0	1.2	1.2	0	0	0	0	0	0	0	0	0
Ephedra	0	0	0	0	0	0	1.2	0	1	0	0	0	0	0	0	1.1	2.2
Dinoflegellate cysts	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
Foraminiferal linings	0	0	0	0	0	0	2.5	0	3.1	0	0	0	0	0	0	0	2.2
Glomus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Nigrospora	0	0	0	0	0	0	0	0	0	0	0	1.1	0	0.4	0	0	0
Alternaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helminthosporium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplodia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lesiodiplodia	0	0	0	0	0	0	0	1.2	0	0	0	0	0	0	0	0	0
Globose misofossil with long protuberances	0	0	0	0	0	0	1.2	2.3	2	0	0	0.4	0	0	0	0	2.2

Taxa/ sample number	107	112	114	118	123	127	133	136	140	141	145	149	154	1	168	172	177	178
Rhizophora spp	0	21	28	34	70	0	0	29	0	30	36	0	13	17.9	31	0	4.2	15
Bruguiera sp	33	2.1	1.3	0.5	17	0	0	2.9	0	1.3	0	0	0	2.6	4.4	0	0	0
Sonneratia sp	0	44	36	31	0	100	91	53	0	33	50	0	13	12.8	0	0	8.3	15
Avicennia sp	0	0	0	0.5	1.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Aegiceras sp	0	5.3	1.3	3.4	0	0	0	2.9	0	3.8	0	0	0	0	0	0	0	0
Nypa	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syzygium	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Azadirachta indica	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Acacia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Holoptelea	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Acanthaceae	0	0	0	0	1.9	0	0	0	0	0	1.9	0	0	0	0	0	0	0
Poaceae	0	0	0	3.9	0	0	0	0	0	0.4	1	0	0	0	4.4	0	8.3	2.9
Cerealia	0	8.4	11	4.9	3.8	0	0	5.7	25	13	2.9	0	13	25.6	19	25	0	18
Amaranthaceae	0	1.1	3.9	3.4	0	0	0	0	25	0	0	0	8.3	5.1	2.9	0	0	2.9
Brassicaceae	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0
Artemisia	0	0	0	0	0	0	0	0	0	0	0	0	4.2	0	0	0	0	0
Alternanthera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cannabis sativa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	0	5.9
Malvaceae	33	0	0	0	1.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteroidae/Tubuliflorae	0	4.2	2.6	1.5	0	0	0	1.9	0	0	0	0	0	2.6	2.9	25	4.2	0
Cichorioideae/Liguliflorae	0	2.1	0	0	0	0	0	0	0	0.8	0	0	0	2.6	0	0	4.2	0
Xanthium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperceae	0	0	0	0.5	0	0	9.1	1	0	4.2	1	0	8.3	2.6	1.5	0	38	2.9
Polygonum	0	0	0	0	0	0	0	0	0	0	0	0	0	2.6	0	0	4.2	0
Zygnema	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirogyra	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudoschizaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potamogeton	0	0	1.3	0	0	0	0	0	25	0	0	0	8.3	0	1.5	0	0	0
Lemna	0	0	1.3	0	0	0	0	0	0	0	0	33	0	0	0	25	0	0
Monlete fern spore I	0	0	2.6	1	0	0	0	1	0	2.9	0	0	0	7.7	2.9	0	4.2	0
Monlete fern spore II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trilete fern Spore I	0	1.1	1.3	1	0	0	0	0	0	1.7	1.9	0	0	0	0	0	8.3	2.9
Trilete fern Spore II	0	0	2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinns	0	9.5	7.9	13	3.8	0	0	1	0	0	2.9	33	17	15.4	10	0	8.3	8.8
Cedrus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	8.8	0	8.3	21
Picea	0	0	0	0	0	0	0	0	0	8.8	0	0	0	0	0	0	0	0
Alnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephedra	33	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinoflegellate cysts	0	0	0	0.5	0	0	0	0	0	0	0	33	4.2	0	4.4	0	0	2.9
Foraminiferal linings	0	1.1	0	0	0	0	0	0	0	0	0	0	13	2.6	4.4	0	0	2.9
Glomus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nigrospora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0
Alternaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helminthosporium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplodia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lesiodiplodia	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0
Globose misofossil with long protuberances	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0

Northgrippian Stage

BRD -II & BRD -III (25-13 m; ca. 7.7 and 5 kyr)

This pollen zone, covering the time span of ca. 7.7 to 7 kyr, show a marked decrease (40% pollen) in the existing core mangrove taxa, such as *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avicennia* sp., as well as the peripheral mangrove taxon (*Nypa*) and the midland taxa, such as *Syzygium* sp., *Holpotelea* sp. and *Casuarina* sp. (12% pollen) (Figure 8.4 & Table 8.2). Poaceae has an average value of 1.1% pollen of the total pollen assemblages. Moreover, Cerealia has also comparative decreased values and contributed with an average value of 2% pollen. Other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilsis* and *Cannabis sativa* also decreased considerably (an average sum of 2.2% pollen). Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* contribute have average values of 2.5% pollen, showing a bit decreased value. Cyperaceae and *Polygonum* spp., as well as *Potamogeton* sp. and *Lemna* sp. have an average sum of 2.5% pollen and 3% pollen, respectively), whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* have a contribution of average of 1.4%. Monolete and trilete fern spores have also diminished (average sum of 2%). *Pinus* sp., *Cedrus* sp. and *Ephedra* sp. have an average sum of 1.3% pollen. Dinoflagellate cysts (0.4%) and foraminiferal linings (1%), as well as fungal spores (1%) and other NPPs 0.3%) have lesser values in this zone too.

In the pollen zone BRD- III, encompassing a time frame of ca. 7 to 5 kyr, is again demonstrating the comparative higher values of especially the core mangrove taxa, such as *Rhizophora* spp., *Sonneratia* sp., *Bruguiera* sp., *Avicennia* sp. (average sum of 78% pollen). However, the midland taxa, such as *Casuarina* sp. and *Syzygium* sp. have made their presence felt, although in lesser values (12% pollen) (Figure 8.4 & Table 8.2). Poaceae has comparative increased frequencies and represented with an average value of 10% pollen of the pollen assemblages. Cerealia also show increased values (average value of 12% pollen). Other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., and *Cannabis sativa* contribute with an average sum of 11% pollen, showing comparative increased frequencies in this pollen zone. Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* have average 11% pollen. Cyperaceae and

Polygonum spp., as well as Potamogeton sp. and *Lemna* sp. contributed with increased values (average sum of 10% pollen) (Figure 8.4 & Table 8.2), whereas *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* have also comparative increased frequencies with an average value of 8%. Monolete and trilete fern spores increased in this pollen zone with an average value of 14% pollen. *Pinus* sp., *Cedrus* sp., *Picea* sp., *Alnus* sp., and *Ephedra* sp. also showed increasing tendency (average 2% pollen). Dinoflagellate cysts (1%) and foraminiferal linings (2%), as well as fungal spores (1%) and NPPs (0.4%) have comparative higher values.

<u>Meghalayan Stage</u>

BRD -IV (13-0 m; ca. 5 kyr to the Present)

This pollen zone, covering the time interval of ca. 5 kyr to the Present, is characterized by the decreasing trend of the core mangrove taxa, such as *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avicennia* sp., as well as the peripheral mangrove taxon (*Nypa*) (23% pollen and 0.3% pollen, respectively) till 4kyr. However, the midland taxa, such as *Casuarina* sp., *Syzygium* sp. and *Holpotelea* sp. have a bit increased values (1.8% pollen) during the said time period. Poaceae (7.1% pollen), Cerealia (average value of 3.5% pollen) (Figure 8.4 & Table 8.2) represent comparative values, whereas other cultural plant pollen taxa, especially Amaranthaceae, and *Artemisia* sp., have handsome values (46.6% pollen) in this zone. Moreover, Brassicaceae and *Alternanthera sessilsis* have comparative lesser values (22% pollen). Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae), Malvaceae and *Xanthium* have decreased values (1.7% pollen) so as the marshy taxa, such as Cyperaceae and *Polygonum* spp. (4.9%), as well as the aquatic taxa, such as *Potamogeton* sp. and *Lemna* sp. (0.8%) and the algal spores, such as *Zygnema* and *Spirogyra* (zygospores) and *Pseudoschizaea* (0.2%). Monolete and trilete fern spores also showed diminishing trend (average sum of 3% pollen) as the existing drifted pollen taxa, such as Pinus sp., *Cedrus* sp., *Picea* sp, *Alnus* sp. and *Ephedra* sp. (3%pollen). Dinoflagellate cysts, foraminiferal linings, as well as fungal spores and other NPPs almost vanished in this pollen zone.

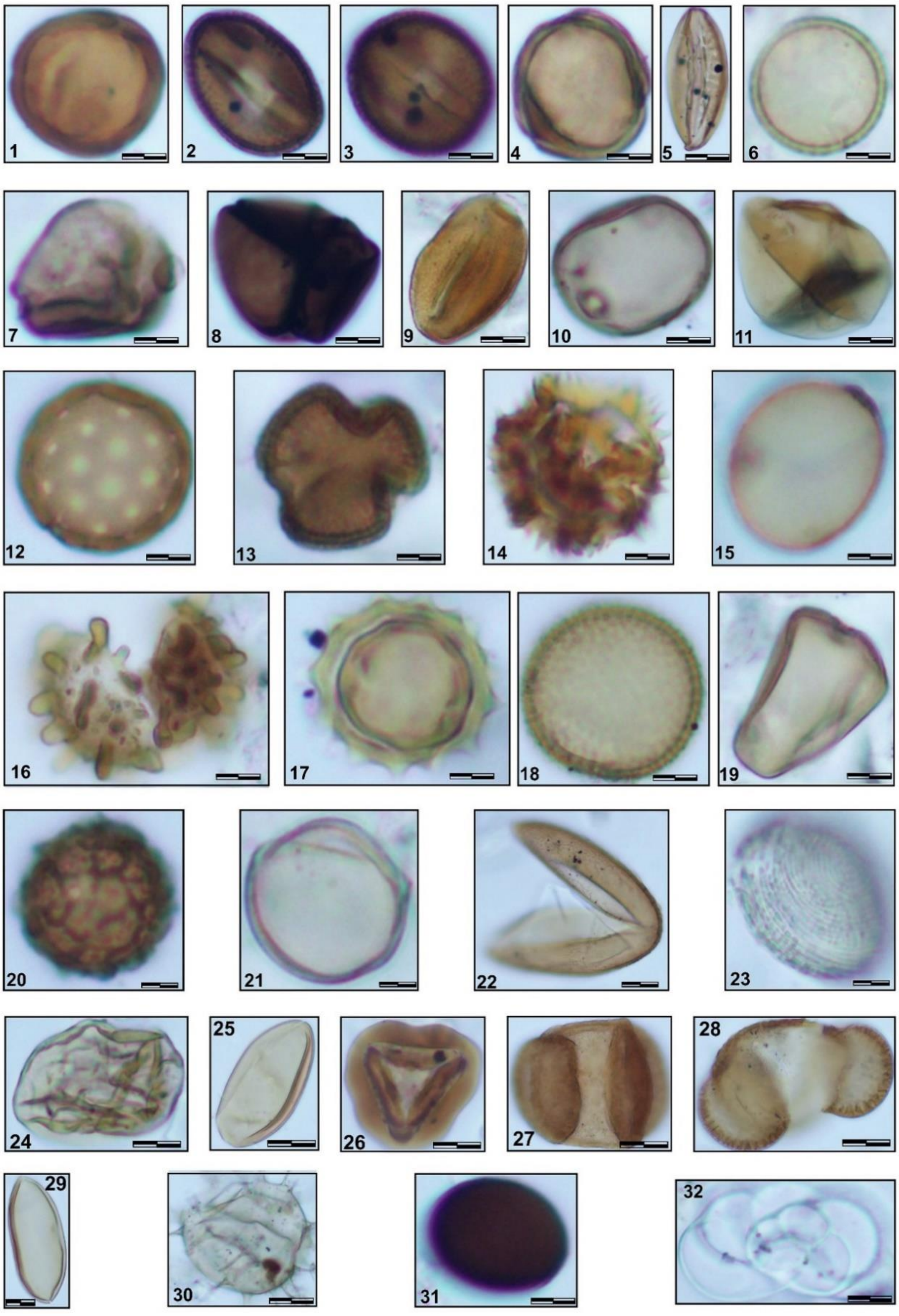

Figure 8.3: - The microphotographs shows morphology of pollens collected from the Berada core. 1. *Rhizophora spp*., 2&3. *Sonneratia* sp., 4. *Bruguiera* sp., 5 *Nypa*., 6. *Holoptelea*., 7. *Casuarina*., 8. *Syzygium*., 9. *Acanthaceae*., 10. Poaceae., 11. *Cerealia*., 12. Amaranthaceae., 13. Brassicaceae., 14. *Alternanthera*., 15. *Cannabis sativa*., 16. *Malvaceae*., 17. Asteroidae/Tubuliflorae., 18. *Xanthium*., 19. *Cyperceae*., 20. Polygonum., 21. Zygnema., 22. Spirogyra., 23. Pseudoschizaea., 24. *Potamogeton*., 25. Monlete fern spore., 26. Trilete fern Spore., 27. Pinns., 28. Cedrus., 29. Ephedra., 30. Dinoflegellate cysts 31. Nigrospora., 32. Foraminiferal linings.

Palaeoenvironmental conditions of Berada core

Pollen analytical investigation of a 51 m deep sedimentary core (Berada core) provides insights into the vegetation and climate changes since the Holocene from the Banni Plains (Banni Grassland), Gujarat, India. The pollen assemblages have demonstrated the increased presence of *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avecennia* sp., and *Aegiceras* sp. (core mangrove taxa), along with *Nypa* (peripheral mangrove taxon) and *Syzygium* and *Holoptelea* (midland taxa) between ca. 10.2 and 7.7 kyr (Pollen Zone BRD -I) (Figure 8.4), which suggest the existence of mangrove forest in the vicinity of the study area under a warm and humid climate with increased monsoon rainfall (Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008). The record of Cerealia and other cultural plant pollen taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilis* and *Cannabis sativa* suggests thet incipient cereal-based agricultural practice and other anthropogenic (human) activities around the the sampling site. The presence of *Zygnema* and *Spirogyra* (zygospores), and *Pseudoschizaea* (*Concentricystis*)- freshwater algae, as well as *Potamogeton* sp. and *Lemna* sp. (aquatic elements) indicates the presence of a lake/water body with a small swampy margin, as Cyperaceae and Polygonum spp. (marshy/wetland taxa) are present (Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008; Berkeley et al., 2009). Monolete and trilete fern spores grew locally in the moist and shady environment close to the sampling site around the study area. The encounter of conifers, such as *Pinus* sp., *Cedrus* sp., and *Picea* sp. and *Epherdra* sp. in the sediments of this zone point to the long-distance air and/or water transport from the higher reaches of the Himalaya (Khonde et al., 2107a; Khonde et al., 2017b).

The presence of dinoflagellate cysts and foraminiferal linings indicates tidal influence. Between ca. 7.7 and 7 kyr (Pollen Zone BRD -II), a reduction in the core mangrove taxa and a simultaneous presence of a few midland taxa, such as *Casuarina, Syzygium,* and *Holoptelea*, as well as comparative increase in Poaceae, suggesting a relatively lesser monsoonal condition (relatively less warm-humid conditions) around the study area (Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008). Agricultural practice and other human activities also decreased, as indicated by comparatively lesser values of Cerealia and other cultural plant pollen taxa. The dimension of lake/water body, as well as swampy area decreased, as evidenced by the decrease in the existing aquatic elements, along with freshwater algae and marshy/wetland taxa (Chen et al., 2006 Quamar et al., 2017) (Figure 8.4). Monolete and trilete fern spores grew locally during this phase in moist and shady conditions around the water body of the studied area. The record of pollen of *Pinus* sp., *Cedrus* sp., and *Ephedra* sp. indicates long-distance air and/or transport from the far-off Himalaya. Subsequently, between ca. 7 and 5 kyr (Pollen Zone BRD -III) (Figure 8.4), the core mangroves, as well as the peripheral mangrove taxa and midland taxa show a comparative increase in this phase under a warm and humid climate with increased monsoon rainfall. The agricultural practice comparatively increased in the region with increase in Cerealia and other cultural plant pollen taxa (Chen et al., 2006 Quamar et al., 2017).

A comparative increase in the number and frequencies of the existing aquatic taxa, together with freshwater algae and marshy/wetland taxa is indicative of a comparative increase in the dimension of lake/water body, as well as swampy margin. Monolete and trilete fern spores continued to thrive locally close to the lake/water body around the study area in comparative lesser values to the moist and shady conditions. The presence of the pollen of *Pinus* sp., *Cedrus* sp., and *Ephedra* sp. suggests their long-distance air and/or transport from the Himalaya. Finally, during 5 kyr to the Present (Pollen Zone BRD -IV), the mangrove taxa, as well as the midland taxa show a marked decrease in this phase under a decreased monsoonal rainfall. Further, the overall decreasing pollen assemblage from ~5 kyr (Figure 8.4), therefore, marks the initiation of the aridity that established by ~4 kyr which correlates well with the other records from the NW Indian archives. Moreover, the simultaneous record of comparative increased values of aridity-tolerant herbs, such as Amaranthaceae and *Artemisia* sp. (growing in arid and semi-arid climates), followed by Poaceae, Asteroideae, Malvaceae and *Cannabis sativa* (although in lesser values) suggest decrease in both vegetation cover and monsoonal rainfall, as well as drier climate (Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008). Negligible abundance in the pollen during past ~2 kyr suggests the degradation of mangrove forest, swampy-marshy land that probably also marks the phase of drying of Banni plain, its conversion to grassland might have started since then (Figure 8.4).

The pace of agricultural practice and other anthropogenic activities started decreasing, as the values of Cerealia and other cultural plant pollen taxa, such as Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia* sp., and

Alternanthera sp. started decreasing till 2 kyr Torricelli et al., 2006; Ellison, 2008; Khandelwal et al., 2008). The swampy margin of the existing lake also decreased, as the marshy/wetland taxa, as well as the freshwater algae and aquatic elements show decreasing trend in the pollen diagram. Monolete and trilete fern spores also decreased comparatively during this phase close to the lake around the study area in the milieu of moist and shady situation. The stray presence of Cedrus sp. and *Picea* sp., is suggestive of their long-distance air and/or water transport from the far away Himalaya (Figure 8.4).

The record of fungal spores althrough the core between 9.7 kyr and 5 kyr, although in lesser values, in general, point towards a warm and humid climate study area. Therefore, the Banni plains appear to have evolved from originally a fluvial landscape during LGM that was occupied by shallow marine sea ingression which enabled rapid growth of mangrove swamps ~10-8 kyr BP in the region peaking at ~8 kyr. As the SW monsoon improved for its strength the wet-warm conditions were established around 8-7 kyr BP while its deterioration initiated by 5 kyr as recorded in our core. Advancement of the aridity in the Kachchh region based on our core record is ~4 kyr while the Banni plains achieved its present status as a raised paleo-sea surface i.e., grassland during past ~2 kyr till present which also marks the period of withdrawal of the sea from this region (Figure 8.4).

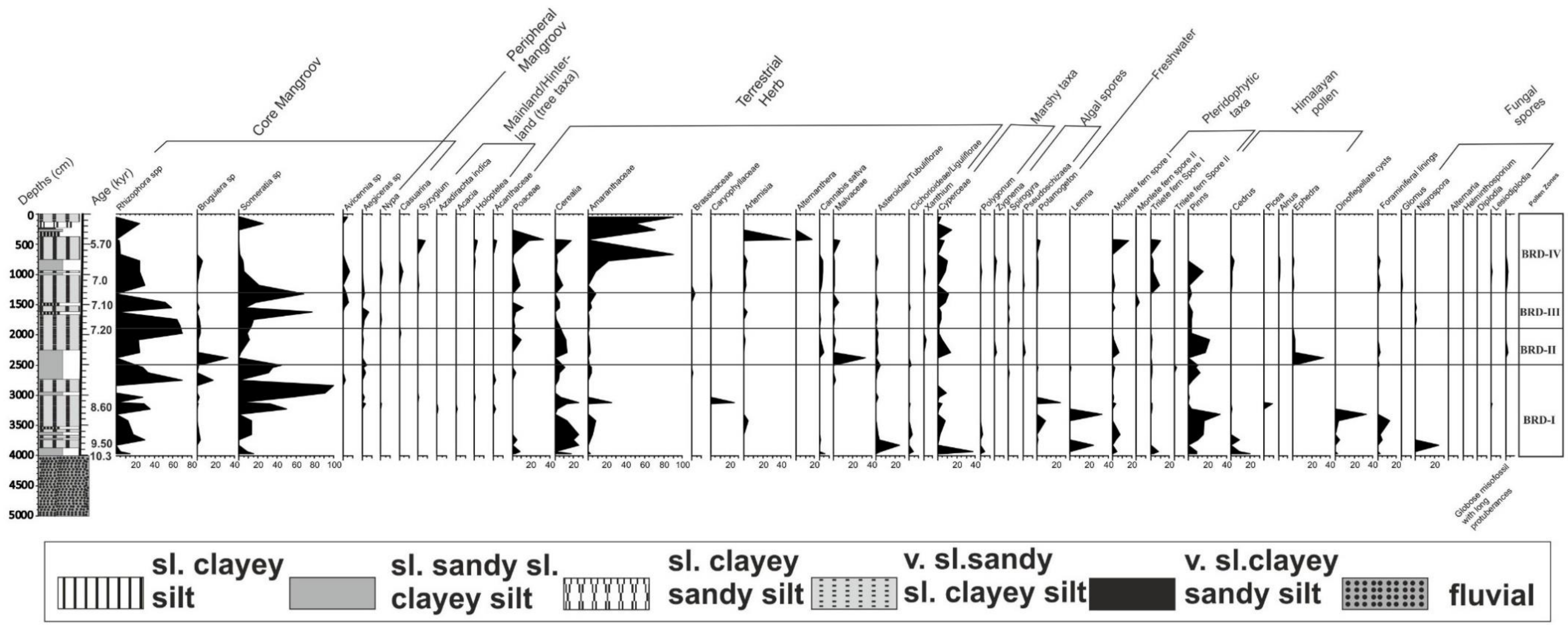

Figure 8.4. Pollen diagram represented in-depth showing percentages of main pollen taxa of Berada core. Pollen zones are based on pollen abundance