Quaternary Science Reviews 114 (2015) 167–181

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Late Pleistocene–Holocene vegetation and Indian summer monsoon record from the Lahaul, Northwest Himalaya, India

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ARTICLE INFO

Article history:
Received 13 September 2014
Received in revised form
29 January 2015
Accepted 31 January 2015
Available online 7 March 2015

Keywords:
Indian summer monsoon
Palynology
Himalaya
Carbon isotopes
Medieval Warm Period
Little Ice Age

ABSTRACT

The high resolution Holocene paleomonsoon records from Northwest (NW) Himalaya are limited. The carbon isotope ($\delta^{13}C$), Total organic carbon (TOC) and pollen analysis were therefore carried out from a peat-lake sediment sequence developed in alpine meadows of the Chandra valley, Lahaul, NW Himalaya, in order to reconstruct centennial to millennial scale vegetational changes and Indian summer monsoon (ISM) variability during the Holocene. The chronology of peat-lake sediments is constrained with 9 AMS ^{14}C dates. The recovered non-arboreal pollen (NAP) suggested that during Holocene alpine desert-steppe, meadows and shrubs growing along the stream had developed in the Lahaul valley whereas arboreal pollens (AP) e.g. *Pinus*, *Quercus*, *Cedrus* and *Ulmus* presently growing in the southern hill slopes of Pir Panjal range indicated moisture carrying monsoonal air flow from the South. The increased $\delta^{13}C$ and low TOC values between ~12,880 and 11,640 calibrated years before present (cal yr BP) suggested weakening of ISM and low organic carbon production corresponding to the Younger Dryas (YD) cold event. The gradual depletion in carbon isotope ratio from ~11,640 to 8810 cal yr BP indicated enhanced precipitation in the Chandra valley in response of increased ISM strength in early Holocene. The short spell of cold and dry climate with gradual decrease in ISM intensity between *ca* 10,398 and 9778 cal yr BP is closely linked with Bond event-7. The other prominent cold-dry events recorded in present study are (i) ~8810 to 8117 cal yr BP roughly corresponding to global 8.2 ka cold event, (ii) ~4808 to 4327 cal yr BP closely preceding the global 4.2 ka cold-arid period, and (iii) ~1303 to 1609 cal AD corresponding to Little Ice Age (LIA) event. The expansion of thermophillous broad leaved taxa viz. *Betula utilis*, *Alnus nepalensis*, *Quercus semicarpifolia* and *Juglans regia* and effective growth of meadow vegetation such as grasses, Caryophyllaceae and *Artemisia* along with marshy elements i.e. *Polygonum* and Liliaceae between ~6732 and 3337 cal yr BP marked warm and wet Holocene climate optimum (HCO) period. The warm and moist climate from ~1158–647 cal yr BP corresponded with global Medieval Warm Period (MWP).

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1. Introduction

Study of the Indian summer monsoon (ISM) during the Holocene has great bearing to the understanding of rise and fall of agriculture-based civilizations in South Asia owing to associated rainfall (Gupta, 2004; Ponton et al., 2012; Leipe et al., 2014a, b; Dixit et al., 2014a). Numerous studies have been carried out using marine proxy records of the Arabian Sea (Overpeck et al., 1996; Schulz et al., 1998; Sarkar et al., 2000; Gupta et al., 2003, 2005; Staubwasser et al., 2003; Chauhan et al., 2010) and Bay of Bengal (Rashid et al., 2011; Ponton et al., 2012) to determine ISM wind strengths whereas only few continental records from India are available (Enzel et al., 1999; Prasad and Enzel, 2006; Demske et al., 2009; Dixit et al., 2014a; Prasad et al., 2014; Leipe et al., 2014a and references therein). The marine and terrestrial records differ in timeframe (~12–10 cal ka BP) for the intensification of the monsoon in the early Holocene (Sirocko et al., 1993; Overpeck et al., 1996; Schulz et al., 1998; Staubwasser et al., 2002; Fleitmann et al., 2003, 2007; Gupta et al., 2003; Leipe et al., 2014a). The influence

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http://dx.doi.org/10.1016/j.quascirev.2015.01.032
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of winter westerlies adds more uncertainties to interpret results of ISM variability in terrestrial records (Enzel et al., 1999; Prasad and Enzel, 2006; Sinha et al., 2006; Dixit et al., 2014b).

The recent studies suggested strengthening of ISM in the early Holocene (~11–7 ka) (Fleitmann et al., 2003; Gupta et al., 2003; Demske et al., 2009; Wünnemann et al., 2010; Prasad et al., 2014) and weakening of ISM after 7 ka with repeated occurrences of dry phases (Overpeck et al., 1996; Gupta et al., 2003; Fleitmann et al., 2007; Demske et al., 2009). Although centennial to millennial scale changes in the Indian monsoon similar to those in the North Atlantic are pervasive, two major events of dry phases or drought at 8.2 ka and 4.2 ka have widely been reported from the marine records (e.g. Alley et al., 1997; Bond et al., 1997; Staubwasser et al., 2003; Gupta et al., 2005) but only from few terrestrial records (e.g. Sinha et al., 2005; Leipe et al., 2014a, b; Dixit et al., 2014a,b). The abrupt weakening of the ISM during 4.2 ka is believed to have triggered major drought in the Indian subcontinent that led to the demise of the Indus valley civilization (Staubwasser et al., 2003; Dixit et al., 2014a) and migration of populations to the East towards Ganga plains (Gupta et al., 2006) as well as adoption of new agricultural practices (Leipe et al., 2014a). Both external and internal forcing have been implicated to ISM variability on centennial or millennial time scales, however, solar insolation has been suggested as a major forcing factor through its influence on Inter Tropical Convergence Zone (ITCZ) (Neff et al., 2001; Gupta et al., 2005; Wang et al., 2010). The Indian Ocean Dipole, El Nino-Southern Oscillation (Saji et al., 1999; Webster et al., 1999) and Indo-Pacfic warm pool (Prasad et al., 2014) also influence ISM on annual to multiannual time scales (Gupta et al., 2010).

Compared to the marine records, continental records of monsoon variability are sparse from lakes in India owing to poor time control, different proxy response time and spatial variability in precipitation. The knowledge is even sparser in the Himalayan region. This limits our understanding of ISM variability and its impact on cultures at community levels (Prasad and Enzel, 2006; Ponton et al., 2012; Leipe et al., 2014a). In this study, we reconstruct changes in the late Pleistocene and Holocene vegetation linked to ISM variability at centennial to millennial scale using palynology, carbon isotope (δ^{13}C) and total organic carbon (TOC) data from a peat-lake sequence developed in the high altitude alpine meadow near the Chandra Tal area (~4302 m a.s.l, 33°79′40.5″ N, 78°34′27.4″ E), Lahaul, Himachal Pradesh, NW Himalaya.

2. Regional setting

2.1. Geology and geomorphology

The Lahaul Himalaya is located at an altitude of ~3500 to 5000 m a.s.l. in the Tethyan Himalayan zone and is ~16 km wide from Zanskar to southern Tibet (Burrard et al., 1933). The northern boundary of the Tethyan Himalaya coincides with the Indus Tsangpo Suture Zone (Gansser, 1980) whereas the southern boundary is represented by tectonic contact of the High Himalayan Crystalline Zone commonly referred as the South Tibetan Detachment System (Searle and Godin, 2003). The two NW- SE trending Pir Panjal and the Greater Himalaya mountain ranges traverses the Lahaul. The landscapes of the region have been shaped by glacial and fluvial activities during the Quaternary period (Fig. 2b and c) (Owen et al., 1996; Adams et al., 2009). Owen et al. (2001) identified five glacial stages in the Lahaul valley determining the present day geomorphic setting of the region viz. (1) Chandra glacial stage (not dated), (2) Batal glacial stage (~15.5–12 ka), (3) Kulti glacial stage (~11.4–10 ka), (4) Sonapani I (~mid Holocene but no absolute dating), and (5) Sonapani II (glaciations culminated at later part of nineteenth century).

2.2. Modern climate and vegetation

Fig. 1 shows the location of study area in the south Asian monsoonal settings. The precipitation gradient in the Lahaul region varies from south to north. The elevated Pir Panjal range blocks low monsoonal clouds preventing their northward penetration. Therefore, southern front of the Pir Panjal range receives higher monsoonal rainfall while area lying to its northern front (Lahaul, Zanskar and Ladakh) is rain shadow zone and most of precipitation in the Lahaul occurs as snow during winter (Mamgain, 1975; Owen et al., 1995; Yadav et al., 2006). The ground is usually covered with snow for more than six months in a year (mid October to early April). The vegetation growth starts in June when snowmelt provides sufficient moisture which becomes prominent in August (during ISM precipitation between July and September) and deteriorates in late September/October (Aswal and Mehrotra, 1994). The southern flank of Pir Panjal range consists of dense forest (Fig. 2a), characterised by broad leaved forest (*Quercus semicarpifolia*, *Myrica esculanta*, *Juglans* and *Ulmus wallichiana*) and coniferous forest (*Pinus wallichiana*, *Cedrus deodara*, *Picea smithiana*, *Abies pindrow*) along with sub-Alpine forest (*Alnus nepalensis* and *Betula utilis*). Whereas, north of Pir Panjal range consists less than 16% of total forest area and is dominated by sedges, grasses and alpine herbs (e.g. Amaranthaceae, Chenopodiaceae, Caryophyllaceae, Polygonaceae, Rananculaceae, Saxifragaceae, Asteraceae, *Artemisia*, *Ephedra* and *Thalictrum*) (Oleg and Stainton, 1984; Aswal and Mehrotra, 1994).

2.3. The Chandra peat bog

The Chandra peat bog is developed in a small pond (lake) of ~60 m diameter in ~500 m long scenic alpine meadows developed over the Batal glacial stage in the Lahaul Himalaya (Fig. 2d) (Rawat et al., 2012). The alpine meadow has grown between the Chandra Tal and left bank of the Chandra River. No stream or paleo-stream is observed for water supply to the lake and therefore water source is only from snowmelt and/or occasional rainfall in the lake catchment. The lake shows a small rivulet–outlet creating internal incision and removal of sediments and plant deposits from the central submerged part (Fig. 2d). This phenomenon is due to the development of lake over an elevated very gentle slope. The low sediment input in the lake is from snow-melt/rainfall eroded restricted catchment of shingle type material within the same bedrock from physical weathering. The sampling was carried out from a major peat strandline in the present periphery of the lake and is outlined in Rawat et al. (2012).

3. Material and methods

3.1. Lithology of the Chandra Peat Trench (CPT)

To obtain maximum depth of peat profile, the CPT section was trenched up to ~75 cm depth. The lower limit of the studied profile was determined at ~53 cm depth after first appearance of pebbly sediments in trenched section. The complete sequence of peat was present from surface to ~38 cm depth and underlying lake sediments from ~38 to 53 cm depth were organic matter rich clay and mud sediments (Fig. 3). The significant colour variations from light brown to dark brownish black with depth indicate peat maturity with time. The samples were collected at ~1 cm interval for high resolution pollen and isotopic analysis. The details of peat profile i.e. colour and sediments are summarized in the litho-column (Fig. 3).

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