Palaeogeography, Palaeoclimatology, Palaeoecology 279 (2009) 172–185

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Late glacial and Holocene vegetation, Indian monsoon and westerly circulation in the Trans-Himalaya recorded in the lacustrine pollen sequence from Tso Kar, Ladakh, NW India

Dieter Demske [a], Pavel E. Tarasov [a,*], Bernd Wünnemann [b], Frank Riedel [a]

[a] Free University of Berlin, Institute of Geological Sciences, Palaeontology, Malteserstr. 74-100, House D, 12249 Berlin, Germany
[b] Free University of Berlin, Institute of Geographical Sciences, EDCA, Malteserstr. 74-100, 12249 Berlin, Germany

ARTICLE INFO

Article history:
Received 10 February 2009
Received in revised form 7 May 2009
Accepted 10 May 2009

Keywords:
Late glacial
Holocene
Pollen record
Vegetation reconstruction
Climate dynamics
Indian monsoon
Westerly winds
North-western India

ABSTRACT

Palynological investigation of a 410 cm long core section from Tso Kar (33°10′N, 78°00′E, 4527 m a.s.l.), an alpine lake situated in the arid Ladakh area of NW India at the limit of the present-day Indian summer monsoon, was performed in order to reconstruct post-glacial regional vegetation and climate dynamics. The area was covered with alpine desert vegetation from ca. 15.2 to 14 kyr BP (1 kyr = 1000 cal. years), reflecting dry and cold conditions. High influx values of long-distance transported *Pinus sylvestris* type pollen suggest prevailing air flow from the west and northwest. The spread of alpine meadow communities and local aquatic vegetation is a weak sign of climate amelioration after ca. 14 kyr BP. Pollen data (e.g. influx values of *Pinus roxburghii* type and *Quercus*) suggest that this was due to a strengthening of the summer monsoon and the reduced activity of westerly winds. The further spread of *Artemisia* and species-rich meadows occurred in response to improved moisture conditions between ca. 12.9 and 12.5 kyr BP. The subsequent change towards drier desert-steppe vegetation likely indicates more frequent westerly disturbances and associated snowfalls, which favoured the persistence of alpine meadows on edaphically moist sites. The spread of Chenopodiaceae-dominated vegetation associated with an extremely weak monsoon occurred at ca. 12.2–11.8 kyr BP during the Younger Dryas interstadial. A major increase in humidity is inferred from the development of *Artemisia*-dominated steppe and wet alpine meadows with Gentianaceae after the late glacial/early Holocene transition in response to the strengthening of the summer monsoon. Monsoonal influence reached maximum activity in the Tso Kar region between ca. 10.9 and 9.2 kyr BP. The subsequent development of the alpine meadow, steppe and desert-steppe vegetation points to a moderate reduction in the moisture supply, which can be linked to the weaker summer monsoon and the accompanying enhancement of the winter westerly flow from ca. 9.2 to 4.8 kyr BP. The highest water levels of Tso Kar around 8 kyr BP probably reflect combined effect of both monsoonal and westerly influence in the region. An abrupt shift towards aridity in the Tso Kar region occurred after ca. 4.8 kyr BP, as evidenced by an expansion of Chenopodiaceae-dominated desert-steppe. Low pollen influx values registered ca. 2.8–1.3 kyr BP suggest scarce vegetation cover and unfavourable growing conditions likely associated with a further weakening of the Indian Monsoon.

1. Introduction

The province of Ladakh in the Trans-Himalayan region of NW India (Fig. 1) is situated in the rain shadow of the Great Himalayan Range and only occasionally receives moisture transported with the Indian summer monsoon. Moisture brought from the Mediterranean region with the winter westerly winds strongly decreases towards the east and southeast. The geographical location of the area explains well its present-day arid to hyper-arid climate (e.g. Bookhagen et al., 2005) and dry steppe vegetation (e.g. Klimeš, 2003).

Evidence for both a strengthening and a weakening of the Indian monsoon during the late Quaternary is found in marine sediment cores (e.g. Sirocko et al., 1993; Gupta et al., 2003; Staubwasser and Weiss, 2006) and in stalagmite records (e.g. Sinha et al., 2005; Fleitmann et al., 2007). Late Quaternary stalagmite and lake status records (e.g. Harrison et al., 1996; Bar-Matthews and Ayalon, 2004) also provide evidence of the changing precipitation and/or water balance in the Mediterranean region, suggesting shifts in the extension and latitudinal position of the westerly-associated storm tracks. The results of climate simulation are in line with the fossil

* Corresponding author. Tel.: +49 30 83870280; fax: +49 30 83870745.
E-mail address: ptarasov@zedat.fu-berlin.de (P.E. Tarasov).

0031-0182/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.palaeo.2009.05.008

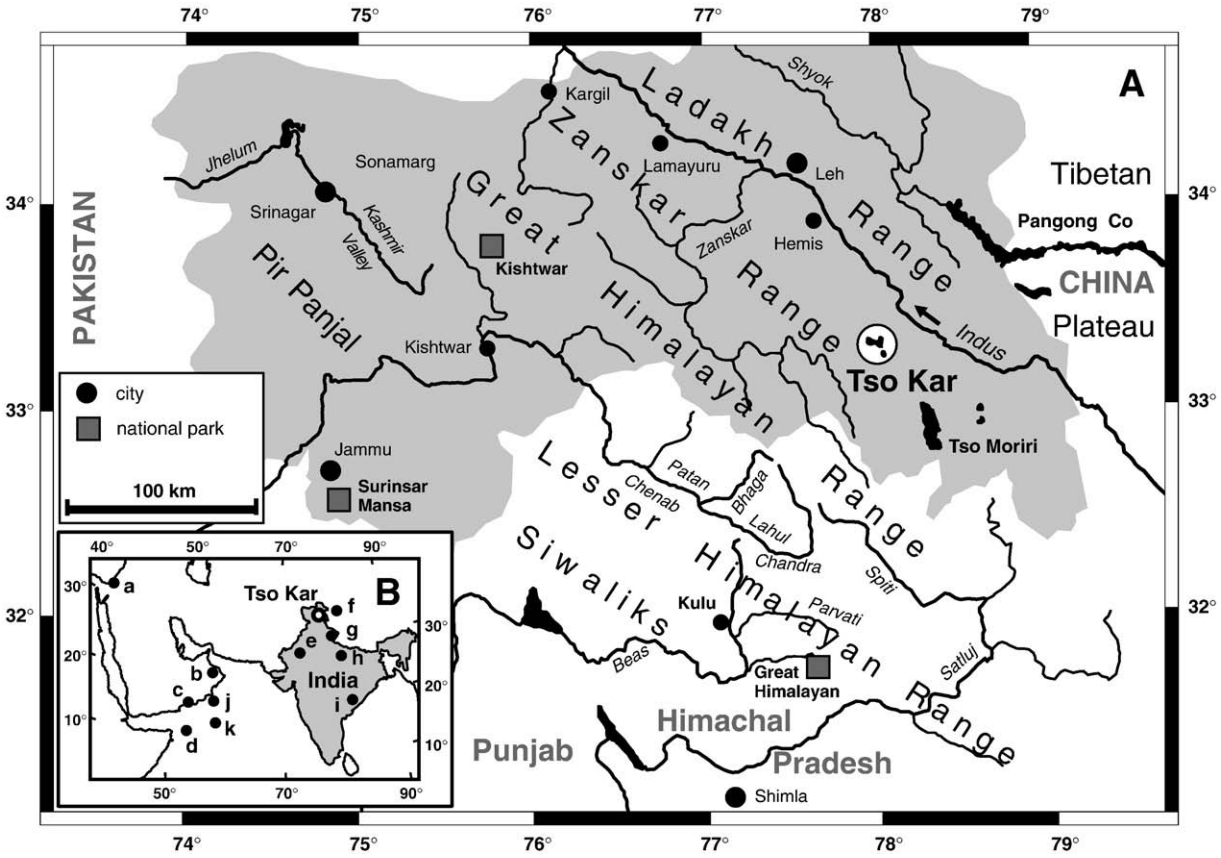

Fig. 1. A—Map of NW India with adjacent regions showing locations of the Tso Kar basin (an open circle) in Ladakh and the Pangong Co site (Van Campo et al., 1996) discussed in this paper. Shaded area indicates Jammu and Kashmir. B—Sketch map showing Tso Kar and sites referred to in the discussion section, including (a) Soreq Cave (Robinson et al., 2006), (b) Hoti Cave, (c) Qunf/Defore Caves and (d) Dimarshim Cave, Socotra (Fleitmann et al., 2007), (e) Didwana, Lunkaransar and Sambhar palaeolakes (Singh et al., 1990; Enzel et al., 1999; Sinha et al., 2006), (f) Sumxi Co (Van Campo and Gasse, 1993), (g) Timta Cave (Sinha et al., 2005), (h) Lake Sanai, Ganga Plain (Sharma et al., 2006), (i) Gupteswar/Dandak Caves (Yadava and Ramesh, 2005), (j) marine RC core series (Overpeck et al., 1996; Gupta et al., 2003) and (k) marine core 74KL (Sirocko et al., 1993).

records (e.g. Kutzbach et al., 1993; Kageyama et al., 2001), thus providing a physical background for the reconstructed climate and environmental changes.

Earlier research in Ladakh and adjacent regions has demonstrated the availability of sedimentary archives suitable for the reconstruction of the late Quaternary environments and climate (e.g. Fort et al., 1989; Bhattacharyya, 1989b; Pant et al., 2005; Phartiyal et al., 2005). A few available pollen records spanning the late glacial and Holocene intervals represent the palaeoclimatic history of regions adjacent to Ladakh, e.g. northern Himachal Pradesh (Chakraborty et al., 2006) and the western part of the Tibetan Plateau (Van Campo and Gasse, 1993, 1996), and focus on the gradual insolation-induced changes in the summer monsoon circulation. Pioneering studies on sediment cores from Tso Kar (Bhattacharyya, 1989b) and Lamayuru palaeolake (Ranhotra et al., 2007) cover longer intervals, but are coarsely resolved in time.

Our current study aims at (1) presenting a new pollen record from radiocarbon-dated lake sediments of Tso Kar (33°10′N, 78°00′E, 4527 m a.s.l.) in Ladakh spanning the last ca. 15.2 kyr; (2) using this record for a reconstruction of local and regional vegetation history; and (3) tracing post-glacial summer monsoon and westerly dynamics in the NW Himalaya.

2. Regional setting

2.1. Topography

Tso Kar is situated in the Rupshu Area of the Ladakh Province, which belongs to the state of Jammu and Kashmir in NW India (Fig. 1). In the region the highest mountain chains, including the Ladakh, Zanskar, Great Himalayan and Pir Panjal Ranges, reach above 6000 m in elevation and generally have a NW–SE orientation. The Zanskar Range is situated southwest of the lake basin and the Ladakh Range is located further north. Geologically, the Rupshu Area belongs to the Tso Moriri crystalline complex and is located near the Indus Suture Zone, which runs along the Indus valley (Philip and Mazari, 2000). While siliceous rocks dominate in the east, more calcareous rocks are present in the Tso Kar basin (Wünnemann et al., 2008).

2.2. Lake basin

Tso Kar is a terminal alpine lake with a surface area of 16.7 km^2 and a catchment area of 1042 km^2. The average water depth is 1–1.5 m. The water is hypersaline and salt crusts occur at the north-western and eastern shores (Rawat and Adhikari, 2005). An ice cover up to 50–60 cm thick forms during the winter. Several relatively small cirque glaciers situated to the southwest and southeast provide melt-water feeding the lake. Additional supply comes from the melting snow and rainwater and from several freshwater springs. At present the glaciers are of limited extensions and fed by snowfalls associated with the air brought by the westerly winds in winter, but mostly from monsoon-associated precipitation during summer time (Wünnemann et al., 2008).

2.3. Modern climate and atmospheric circulation patterns

The climate of Ladakh is characterised by cold winters, moderately warm summers and arid to hyper-arid conditions with a mean annual