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Reconstruction of past climate of Indian subcontinent for the last 40 ka BP based on multi proxy data and correlation with global data–a review

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ABSTRACT

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The contribution attempts to reconstruct the past climate of different regions of the Indian subcontinent for the last 40 ka before present (BP) on the basis of ^{14}C dating, chemical analysis, pollen analytical studies and carbon isotope analysis($\delta^{13}C$). A correlation of data from India with other global sites is also attempted. Review of the published data shows heterogeneous climatic conditions in different parts of India. The climate in highland regions of India especially in Ladakh, Jammu & Kashmir (J & K) and neighbouring areas was alternating from dry arid to brief ameliorations during the last 31.4 ka BP (Beyond Calibration Range (BCR)). The climate in the Gangetic plain, representing humid and subtropical climate zone, was alternating from warm humid to cool humid primarily due to changes in SW monsoon in the region during the last 40.0 ka BP (BCR). The climate in arid zones in western India especially Rajasthan and parts of Gujarat was predominantly arid with a brief wet and humid climate during the above period. In semi arid zone in Nilgiris and Palni Hill regions of south India the climate was alternating from moist humid to dry arid phase. One of the tropical wet and dry climatic zones of India namely Orissa was experiencing predominantly wet and occasional dry climate. The beginning of the Holocene warming and onset of humid phase was suggested in several climatic regions of India during 11.4-7.6 ka Cal BP. Amelioration of climate was observed in different regions during 2.0 ka Cal BP as well as during the present time. It is inferred from several proxy data from diversified climatic and geographical region.

Key-words—Palaeoclimate, Multiproxy data, Indian sub-continent, Global correlation.

बहु परोक्ष आँकड़ों व भू-मंडलीय आँकड़ा सहसंबंध के आधार पर पिछले 40 हजार वर्ष पूर्व की भारतीय उपमहाद्वीय की पूर्व जलवायु की पुनर्संरचना-एक पुनर्विलोकन

बी. सेकर

सारांश

यह योगदान ^{14}C कालनिर्धारण, रासायनिक विश्लेषण, परागकण विश्लेषिक अध्ययनों तथा कार्बन समस्थानिक विश्लेषण ($\delta^{13}C$) के आधार पर पिछले 40 हजार वर्ष पूर्व की भारतीय उपमहाद्वीप के विभिन्न क्षेत्रों की पूर्व जलवायु की पुनर्संरचना हेतु प्रयास है। अन्य भू-मंडलीय स्थलों सहित भारत से प्राप्त आँकड़ों के सहसंबंध का भी प्रयास किया

गया है। प्रकाशित आँकड़ों की समीक्षा भारत के विभिन्न भागों में विषमजातीय जलवायवी स्थिति प्रदर्शित करती है। भारत के उच्चभूमि क्षेत्रों विशेषकर लद्दाख, जम्मू एवं कश्मीर तथा पड़ोसी इलाकों में जलवायु पिछले 31.4 हजार वर्षों पूर्व (अंशशोधन परिसर से ऊपर (बी.सी.आर.)) के दौरान शैलसंधि शुष्क से अल्प सुधार में प्रत्यावर्ती थी। आर्द्र व उपोष्ण जलवायु मंडल का प्रतिनिधित्व करते हुए गंगा के मैदानों में जलवायु पिछले 40 हजार वर्ष पूर्व (बी.सी.आर.) के दौरान क्षेत्र में दक्षिण-पश्चिम मानसून में परिवर्तन के कारण प्राथमिक रूप से उष्ण आर्द्र से शीत आर्द्र में प्रत्यावर्ती थी। पश्चिमी भारत में विशेषतः राजस्थान एवं गुजरात के भागों के शुष्क मंडलों में जलवायु उक्त अवधि के दौरान अल्प आर्द्र व आर्द्र जलवायु सहित प्रमुख रूप से शुष्क थी। दक्षिण भारत के नीलगिरि एवं पल्नी पहाड़ी क्षेत्रों में अद्र्ध शुष्क मंडल में जलवायु नम आर्द्र से शैलसंधि शुष्क चरण में प्रत्यावर्ती थी। भारत के उष्णकटिबंधीय आर्द्र एवं शुष्क जलवायवी मंडलों में से एक उड़ीसा प्रमुख रूप से आर्द्र एवं कभी-कभी शुष्क जलवायु का अनुभव कर रहा था। होलोसीन ताप की शुरूआत तथा आर्द्र चरण का प्रारम्भ 11.4-7.6 हजार अंशशोधन वर्ष पूर्व के दौरान भारत के कई जलवायवी क्षेत्रों में होना प्रस्तावित था। जलवायु का सुधार 2 हजार अंशशोधन वर्ष पूर्व के दौरान तथा वर्तमान में विभिन्न क्षेत्रों में देखा गया था। विविध जलवायु तथा भौगोलिक क्षेत्र के कई परोक्ष आँकड़ों से यह अनुमान लगाया गया है।

संकेत-शब्द—पुराजलवायु, बहु-परोक्ष आँकड़ें, भारतीय उपमहाद्वीप, भू-मंडलीय सहसंबंध।

INTRODUCTION

IN efforts to understand the natural variability of earth's climate system and the potential for delineating natural variability in anticipated future climate change, palaeoclimate data can play a key role by extending the baseline of environmental and climatic observations. The major events of the Quaternary Period in India are neotectonism, climate changes and human evolution and culture. These events have left their indelible imprints in a variety of materials which are preserved in rocks of geological past. Though these events are categorised stratigraphically as Pleistocene, Holocene, etc. the contemporaneity of events and the cause and effect relationships during these periods can be understood only in terms of absolute ages following radiocarbon, luminescence, U-Th series decay like techniques. The radiocarbon dating method has contributed significantly in interpreting the data based on pollen analysis, stable isotope variations or variations in elemental concentrations in sediment profile for palaeoclimatic events reliably up to 40 ka BP (BCR). The chronology built up using ^{14}C ages has been most widely applied and compared because of the ubiquitous distribution of ^{14}C in all living matter both on land and sea and standardisation of measurement techniques. Birbal Sahni Institute of Palaeobotany (BSIP) radiocarbon laboratory has been providing ^{14}C dates for most of the palaeoclimatic research in India for the last 30 years. Still there is insufficiency in palaeoclimatic data from different climatic regions of India for the last 40 ka BP (BCR). In this contribution the past climatic changes of India for the last 40.0 ka BP (BCR) have been reconstructed on the basis of available data on ^{14}C dating, pollen analysis and chemical analysis of lake and coastal sediments of different regions (Fig. 1). These data are correlated with proxy climatic data from different regions of the world which have similar monsoon and climatic system as India.

PRESENT DAY CLIMATIC SCENARIO OF INDIA

The Indian subcontinent lies between latitudes 8°4' and 37°6' N. It experiences tropical monsoon climate. Monsoon is associated with winds which stresses the air masses blowing in the region. Climatically, the Indian subcontinent is a part of the larger monsoon region which includes Thailand, Southern China, Northern Australia and the lands near Eastern Horn of Africa. The latitude, relief features and sea primarily influence present day climate of India. The plateau of Tibet which separates Southern Asia from Central Asia acts as a great transverse relief barrier. In winter, cold dry winds blowing from Central Asia are reversed north-west over China and Japan and from north or north-east over

South-East Asia. In summer, the Himalayan wall reverses the pole-ward wind direction both on the surface and upper troposphere. In the peninsular part of India the relief features such as the Vindhyan mountain system, Eastern and Western Ghats and the Aravallis in the north-west play an important role in bringing variation in the distribution of rainfall. It is not only the monsoon reversal of air flow that marks the monsoon type of climate but the monsoon effect is associated with wet condition due to their passage through the Indian ocean. The southern part of India lies near the equator and remains hot almost throughout the year and there is practically no winter season. India experiences varied and sharp climatic diversity in contrast to other part of Asia. Climatologically India can be divided into six main regions namely Highland, Humid Subtropical, Semi-Arid, Arid, Tropical Wet and Dry and Tropical Wet (Fig. 2).

PALAEOCLIMATIC SCENARIO OF INDIA SINCE 40 Ka BP

The diverse climate in different regions of India is controlled mainly by factors like differing monsoon activity, latitude, altitude and proximity to ocean. The following broad conclusions can be drawn on the basis of analysis of multi proxy climatic data from different climatic regions.

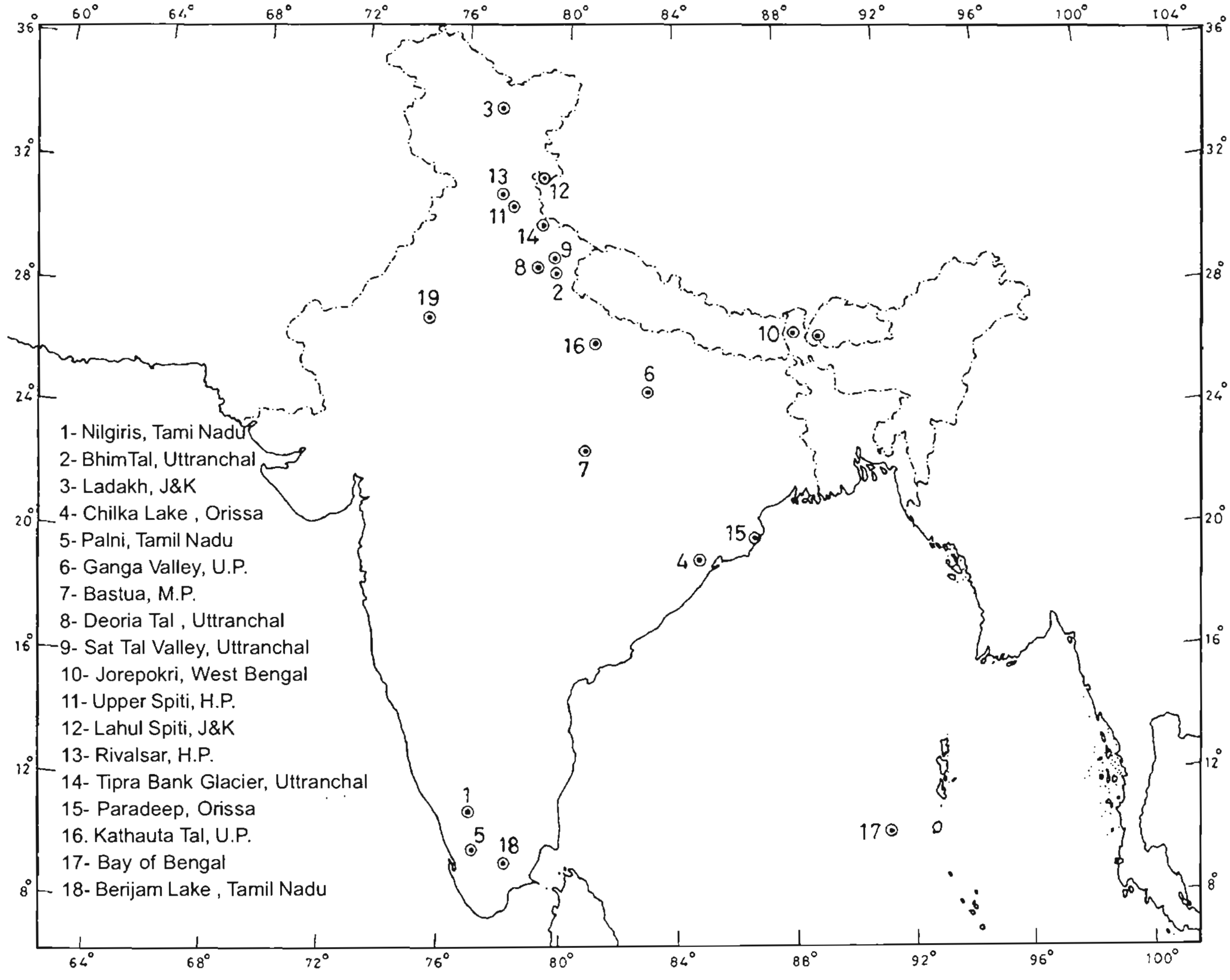

Fig. 1—Investigated locations in India.

HIGHLAND REGIONS

The overall climatic conditions of the highland regions were alternating from dry arid to brief ameliorations in climate during the last 31.4 ka BP (BCR). This has been derived from elemental, mineral content variations and palynological studies of lake sediment cores from these regions by several workers (Fig. 3). The climate was mostly cold and dry arid during 31.4-30.4 ka BP (BCR) in Ladakh and Tibet. Pollen analytical study of Tsokar lake, Ladakh has shown that the area was festooned with *Artemisia,* member of Asteraceae, Chenopodiaceae, etc., denoting the prevalence of dry alpine steppe growing under cold and dry climate (Bhattacharyya, 1989). Variations in elemental concentration of Na, K, Mg, Fe, Mn, Co and Zn in allogenic fraction of above lake sediment cores have also shown a similar deterioration of climate

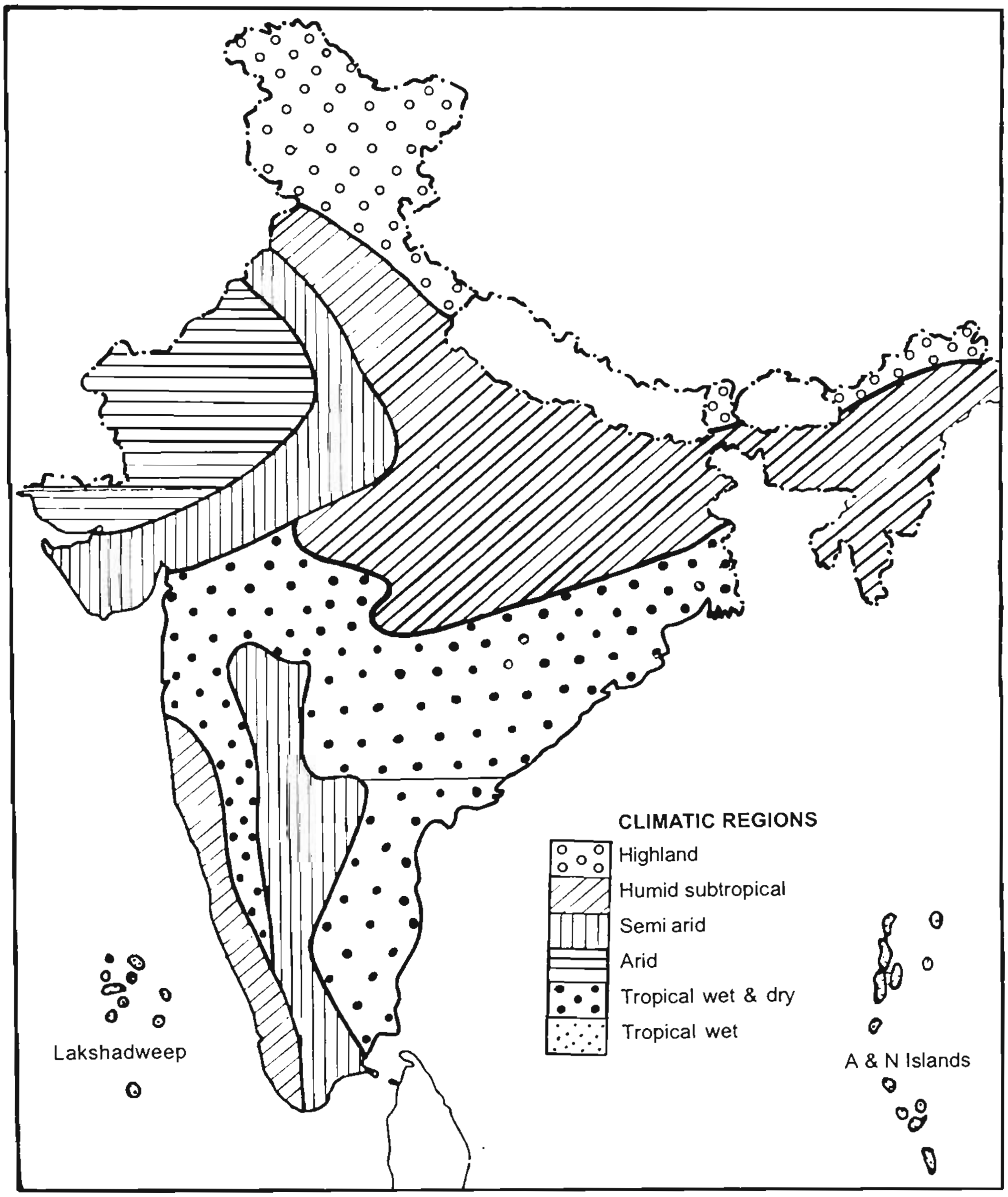

Fig. 2— Climate zones of India.

(Sekar, 2000; Sekar *et al.*, 1994). The same trend of aridity is also seen in Tibetan plateau also during this period (Yan *et al.*, 1999).

Again the climate was deteriorating in most parts of Ladakh, J & K and Central Higher Himalaya whereas climate at North Eastern Tibetan plateau was ameliorating during 28.0 ka BP (BCR)-23.6 ka Cal BP. In region around Ladakh, J & K alpine steppe elements substantially improved at the cost of *Juniperus* forest. Lithologically also the formation of thick clay layers indicate permafrost conditions leading to cold and dry environment in highlands (Meher-Homji & Gupta, 1999). Studies on varve sedimentation record at Garbyang Basin, Central Higher Himalaya reveal overall dry climatic condition during 23.6 ka Cal BP (Juyal *et al.*, 2004). Research work on loess deposition and soil formation at Alaknanda and Pindar river basins shows drier and dustier climate due to weak South West monsoon in these regions (Pant *et al.*, 2005). However, North-Eastern Tibetan plateau had grass land and meadow vegetation indicating wet climate (Yan *et al.*, 1999) around this period.

During 23.6-14.9 ka Cal BP climate was ameliorating in Ladakh, J & K (Bhattacharyya, 1989) and Central Higher Himalaya (Pant *et al.*, 2005) whereas Tibetan plateau experienced intense dry climate (Yan *et al.*, 1999). The same trend of amelioration in climate in Tsokar lake (Ladakh), J & K was also inferred during 22.4-19.6 ka Cal BP on the basis of variation of chemical data (Sekar, 2000; Sekar *et al.*, 1994). Loess deposition and soil formation studies on Alaknanda and Pindar river basins, Central Higher Himalaya have revealed a drier and dustier climate due to weak SW monsoon during 14.1-10.2 ka Cal BP (Pant *et al.*, 2005).

The beginning of the Holocene was marked by warming and onset of humid phase during 10.2-8.6 ka Cal BP. The same trend is also observed in Tibet (Yan *et al.*, 1999), Central Higher Himalaya and Garhwal Higher Himalaya. Loess deposition and soil formation studies on Alaknanda and Pindar river basins have also shown facilitation of pedogenesis of loess due to stronger SW monsoon during 10.2-4.5 ka Cal BP (Pant *et al.*, 2005). Marshy and meadow vegetation followed by dark conifer islet was reported in North-Eastern Tibet (Yan *et al.*, 1999). But Phadtare (2000) has reported the dominance of evergreen oak (*Quercus semecarpifolia*), alder (*Alnus*) and grasses in the pollen record from alpine peat at Dokriani Glacier, Garhwal Higher Himalaya which reflect a cold, wet climate with moderate monsoon precipitation. Vegetation was progressively dominated by conifers, indicating ameliorated climate with stronger monsoon around 8.6-5.7 ka Cal BP. Climate was predominantly dry arid in Central Higher Himalaya and Trans Himalaya (Mazari *et al.*, 1996) whereas in Eastern (Chauhan, 1995) and Kumaon Himalayas (Gupta & Khandelwal, 1982) there was primarily amelioration of climate during 5.7-2.0 ka Cal BP. But loess deposition and soil formation studies on Alaknanda and Pindar river basins have shown dry and dustier climate due to weaker SW monsoon during 4.5-0.9 ka Cal BP (Pant *et al.*, 2005). Vegetation was transformed into a marsh and sub-alpine with scattered islets of dark conifer in Tibet (Yan *et al.*, 1999) during 4.5 ka Cal BP. Phadtare (2000) has also reported a sharp decrease in temperature and rain fall at 4.5-3.8 ka Cal BP in Garhwal Higher Himalaya representing the weakest monsoon event of the Holocene record. However, amelioration of climate was reported in Garhwal (Sharma *et al.*, 2000) and Eastern Himalayas (Chauhan & Sharma, 1996) during the last 2.0 ka Cal BP. Same trend of the ameliorating climate is also seen in Tibet during last 2.0 ka Cal BP (Yan *et al.*, 1999). High resolution pollen and diatom evidences from a peat deposit in the Pinder Valley have also shown a synchronous and abrupt ecosystem turnover towards wetter state in the last two centuries that exceeded changes recorded over the last three millennia (Ruhland *et al.*, 2006). The above data sets indicate changing pattern of climate in the highland regions of India over the last 40 ka BP (BCR) (Fig. 4).

HUMID AND SUBTROPICAL CLIMATE ZONE

The climate in the Gangetic belt, representing humid and subtropical climate zone, was alternating from warm humid to cool humid primarily due to changes in SW monsoon during the last 40.0 ka BP (BCR) (Fig. 5). Sedimentological studies carried out at southern

Age and Range (ka BP)	Calibrated Age (ka Cal BP)	Investigated area	Material/^{14}C/ other dating method/ climatic Proxy	Climatic data & inference	Reference
31.5-30.4	BCR	Tsokar lake, Ladakh	Sediment/Conventional/Pollen study	Prevalence of dry alpine steppe, cold & dry climatic regime	Bhattacharyya, 1989
-do-	-do-	-do-	Sediment/Conventional pollen/Chemistry	Cold dry climate	Sekar, 2000; Sekar *et al.*, 1994
30.4-28.5	-do-	-do-	-do-	Low Na, K & Mg content, amelioration of climate	-do-
28.5 (BCR) -22.4	28.5 (BCR) -22.4	-do-	-do-	Cold, dry arid climate	-do-
28.0	23.6	Ladakh, J & K	Sediment/Conventional Vegetation/Climatic study	Alpine steppe at the cost of *Juniperus* forest/cold and dry climate	Meher-Homji & Gupta, 1999
20.0	23.6	Garbyang Basin, Central Higher Himalaya	Sediment/TL Dating/Varve sedimentation record	Overall dry climatic condition	Juyal *et al.*, 2004
20.0-15.0	23.6-17.9	Alaknanda & Pindar river basins	Sediment/TL Dating, Loess deposition & Soil formation	Drier & dustier climate due to weak SW monsoon	Pant *et al.*, 2005
18.9-16.4	22.4-19.6	Tsokar lake, Ladakh	Sediment/Conventional pollen/Chemistry	Amelioration of climate	Sekar, 2000; Sekar *et al.*, 1994
16.0-12.0	19.1-14.1	Alaknanda & Pindar river basins	Sediment/TL Dating, Loess deposition& Soil formation	Facilitation of pedogenesis of loess due to enhanced SW monsoon	Pant *et al.*, 2005
16.4-15.9	19.6-19.0	Tsokar lake, Ladakh	Sediment/Conventional pollen/Chemistry	Dry and arid	Sekar, 2000; Sekar *et al.*, 1994
14.9-12.6	17.8-14.9	-do-	-do-	Cold & dry climate	-do-
12.6-11.6	14.9-13.5	-do-	-do-	Amelioration of climate	-do-
12.0-9.0	14.1-10.2	Alaknanda & Pindar river basins	Sediment/TL Dating, Loess deposition & Soil formation	Drier & dustier climate due to weak SW monsoon	Pant *et al.*, 2005
11.6-10.7	13.5-12.8	Tsokar lake, Ladakh	Sediment/Conventional pollen/Chemistry	Deterioration of climate	Sekar, 2000; Sekar *et al.*, 1994
9.0-4.0	10.2-4.5	Alaknanda & Pindar river basins	Sediment/TL Dating Loess deposition & Soil formation	Facilitation of pedogenesis of loess due to stronger SW monsoon	Pant *et al.*, 2005
7.8-5.0	8.6-5.7	Dokriani Glacier, Garhwal Himalaya	Sediment/Conventional pollen study	Amelioration of climate	Phadtare, 2000
4.0-1.0	4.5-0.9	Alaknanda & Pindar river basins	Sediment/TL Dating, Loess deposition & Soil formation	Drier & dustier climate due to weak SW monsoon	Pant *et al.*, 2005
4.0-3.5	4.5-3.8	Dokriani Glacier, Garhwal Himalaya	Sediment/Conventional pollen study	Deterioration of climate; weakest monsoon	Phadtare, 2000
4.0-3.2	4.5-3.4	Deoria Tal, Garhwal Himalaya	Sediment/Conventional pollen study	Warm humid phase	Sharma *et al.*, 2000
3.2-1.7	3.4-16	Deoria Tal, Garhwal Himalaya	Sediment/Conventional pollen study	Deterioration of climate	Sharma *et al.*, 2000

3.0-1.3	3.2-1.3	Sat Tal Valley, Kumaon Himalaya	-do-	Warm & low humid	Gupta & Khandelwal, 1982
2.8-1.9	2.9-1.9	Garhwal Himalaya	-do-	Moist temperate climate	Chauhan *et al.*, 1997
2.5-1.6	2.6-1.5	Jore Pokhari, Darjeeling	-do-	Warm temperate climate	Chauhan & Sharma, 1996
2.3-1.5	2.3-1.4	Upper Spiti, H.P.	-do-	Cold dry climate	Chauhan *et al.*, 2000
2.0-1.0	2.0-0.9	Lahul-Spiti, Trans Himalaya	-do-	Cold dry climate	Mazari *et al.*, 1996
1.7	1.6	Deoria Tal, Garhwal Himalaya	-do-	Amelioration of climate	Sharma *et al.*, 2000
1.6-1.0	1.5-0.9	Jore Pokhari, Eastern Himalaya	-do-	Cool humid climate	Chauhan & Sharma, 1996
1.5-0.9	1.4-0.8	Upper Spiti, H.P.	-do-	Warm moist climate	Chauhan *et al.*, 2000
1.3-0.85	1.3-0.74	Sat Tai Valley, Kumaon Himalaya	-do-	Wet & low warm climate	Gupta & Khandelwal, 1982
1.0-0.3	0.9-0.3	Jore Pokhari, Eastern Himalaya	-do-	Warm temperate climate	Chauhan & Sharma, 1996
1.0-0.4	0.9-0.5	Lahul Spiti, Trans Himalaya	-do-	Warm moist climate	Mazari *et al.*, 1996
0.9	0.8	Upper Spiti, H.P.	-do-	Cold climatic condition	Chauhan *et al.*, 2000
0.7-0.6	0.7-0.7	Tipra Bank Glacier, Garhwal Himalaya	-do-	Warm & moist climate	Bhattacharyya & Chauhan, 1997
0.6-0.46	0.7-0.5	-do-	-do-	Cold & dry climate	-do-
0.46	0.5	-do-	-do-	Warm & moist climate	-do-
0.4	0.5	Lahul spiti	-do-	Cold & dry conditions	Mazari *et al.*, 1996
30.0-26.0	BCR	Northeastern Tibetan Plateau	Sediment/Conventional palynological & stable isotope study	Less vegetation	Yan *et al.*, 1999
26.0-18.0	BCR-21.4	-do-	-do-	Grass land & meadow vegetation	-do-
18.0-14.2	21.4-17.0	-do-	-do-	Alpine desert climate	-do-
14.2-10.0	17.0-11.4	-do-	-do-	Wet climate, grass lands & meadows with islet forests dominance	-do-
10.4-9.0	12.3-10.2	-do-	-do-	Marshy & meadow vegetation	-do-
9.4-4.0	10.6-4.5	-do-	-do-	Amelioration of climate, dark conifer islet & marshy vegetation	-do-
4.0	4.5	-do-	-do-	Marshy sub-alpine meadows	-do-

Fig. 3—Climatic records of high land regions since last 40.0 ka BP.

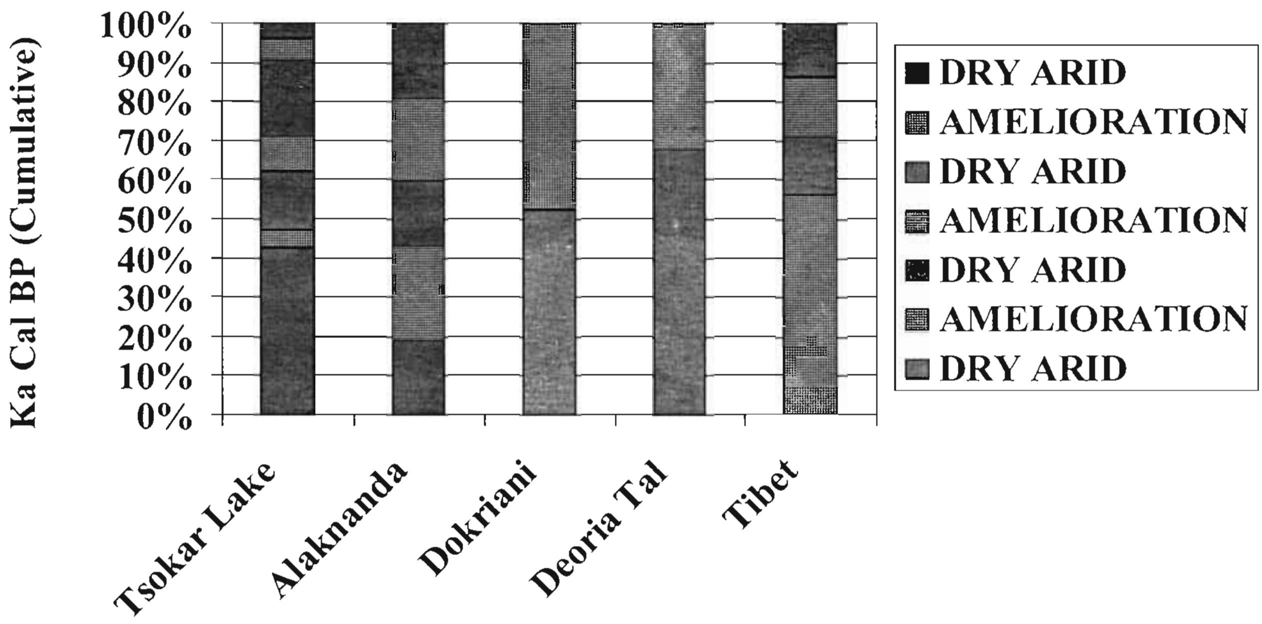

Fig. 4—Reconstruction of climate in highland regions of India and Tibet.

Gangetic plain have shown that the above region experienced warm and humid climate during 15.6-13.0, 6.8-4.5 and 4.5-2.0 ka Cal BP and cool humid climate during 13.1-10.0 and 8.9-6.8 ka Cal BP (Rajagopalan, 1992; Srivastava *et al.*, 2003). Vegetation pattern around Mansarovar lake, Lalitpur, Uttar Pradesh reveals emergence and abundance of arboreals during 2.6-1.31 ka Cal BP probably due to warm and humid climatic conditions. Arboreals declined sharply due to anthropogenic pressure later (Farooqui *et al.*, 2003). The above data sets indicate the pattern of climate fluctuation in the humid and subtropical climatic regions of India over the last 40 ka BP (BCR)(Fig. 6).

Age and Range (ka BP)	Calibrated age (ka cal BP)	Sample investigation area	Material/^{14}C/ other dating method/ Climatic Proxy	Climatic inferences	Reference
13.0-11.0	15.6-13.0	Southern Ganga plain	Calcareous sediment/ Conventional sedi-mentologieal studies	Warm & humid climate due to reestablishment of SW monsoon	Srivastava *et al.*, 2003
11.1-8.9	13.1-10.0	-do-	-do	Cool humid	-do-
8.0-6.0	8.9-6.8	Gangetic plain	Sediment/Conventional carbonate materials	A humid phase	Rajagopalan, 1992 Srivastava *et al.*, 2003
6.0-5.0	6.8-4.5	-do-	Sediment/Conventional Gangetic alluvium	Increased aridity due to weaker SW monsoon	Rajagopalan, 1992, Srivastava *et al.*, 2003
4.0-2.0	4.5-2.0	-do-	-do-	Dry phase	Rajagopalan, 1992
2.5-1.4	2.6-1.31	Lalitpur, U.P.	Sediment/Conventional pollen	Warm & humid climate, abundance of arboreal pollen	Farooqui *et al.*, 2003

Fig. 5—Climatic records of humid and subtropical climate zones.

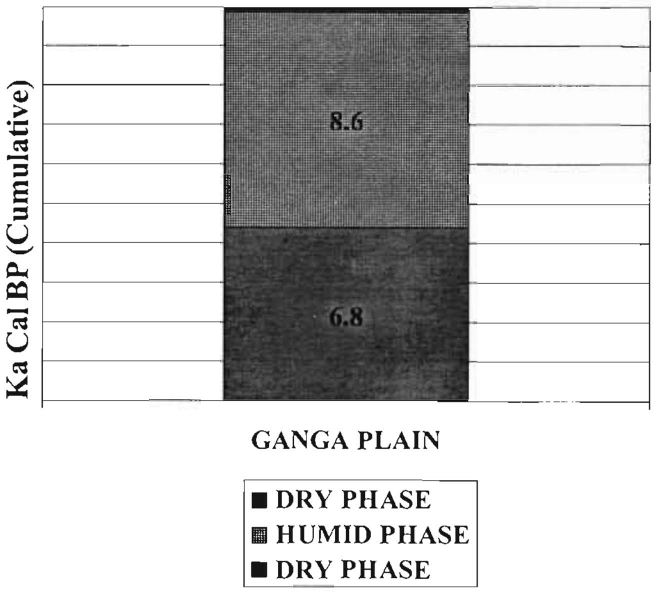

Fig. 6 — Reconstruction of climate in humid and subtropical zones.

ARID CLIMATE ZONE

The climate in western India especially in Rajasthan and Gujarat is predominantly arid with a brief wet and humid climate during the last 40 ka BP (BCR) (Fig. 7). Studies on the Quaternary climate change in the desert regions of Gujarat and Rajasthan (Allchin *et al.*, 1978) have revealed a dry phase prior to 40 ka BP (BCR) and a wet phase after 40 ka BP (BCR). Palynological data from Didwana salt lake, Rajasthan indicate a steppe vegetation between 23.6-15.6 ka Cal BP which reflect towards a weaker summer monsoon, a higher winter precipitation and hyper-arid conditions than at present (Singh *et al.*, 1990). Onset of fluvio-aeolian sedimentation after 30 ka BP (BCR) and initiation of a regionally extent aeolian sedimentation during 23.6-13.0 ka Cal BP at southern margin of Thar Desert have also indicated overall dry climatic condition (Juyal *et al.*, 2006). The rapid reduction of terrigenous matter at 16.0 ka Cal BP in the core 74KL has reflected a reduction of dust from Arabia paralleling a general increase of humidity in the peninsula. The same transition was reflected in East African Lake levels and global atmospheric methane levels due to similar monsoon forcing (Butzer *et al.*, 1972; Sirocko *et al.*, 1996) during 17.9-14.9 ka Cal BP. The Younger Dryas is barely observable in the record of up-welling (Ba) with an increase of terrigenous matter, at similar proportions of glacial times. It was either derived from Persian Gulf area or from Pakistan side by strong northeast-monsoon winds around 14.5 ka Cal BP. This inference is based on studies of deep-sea sediments from Arabian sea. During the transitional period from glacial to post-glacial conditions, the slow solar forcing seems to have induced very rapid changes in local climate over the Arabian sea. This is inferred on the basis of high resolution record of oxygen isotopes, carbonates and ^{14}C dating (Sirocko *et al.*, 1996). Didwana Salt lake, Rajasthan, changed to permanent fresh water condition during 10.2-6.8 ka Cal BP (Singh *et al.*, 1990). Sirocko *et al.* (1996) has shown humid climate in coastal regions around Rajasthan and Gujarat during 9.9-8.6 ka Cal BP on the basis of oxygen isotopes and carbonate studies. Wet climate in Didwana, Rajasthan has been observed by Sekar *et al.* (1997a, b) on the basis of pollen and chemical studies of lake sediment cores during 9.0-7.2 ka Cal BP. Deotare *et al.* (2004) has also suggested fresh water condition at Bap-Malar and Kanod, Rajasthan on the basis of multi proxy study during 8.9-6.3 ka Cal BP. The vegetation around the above region changed to savanna grass land around 8.3 ka Cal BP in which *Prosopis cineraria* formed the bulk of the tree vegetation. The presence of good number of pollen of this taxon is indicative of increase in summer and rise of winter precipitation during the mid-Holocene while their decline during the late Holocene seem to be in harmony with the declining lake level (Singh *et al.*, 1990). Enzel *et al.* (1999) has shown wet climate due to south western monsoon rains at Lukaransar, Rajasthan on the basis of multi proxy study around 7.3-5.5 ka Cal BP. But climate around Didwana lake and areas around Arabian sea changed to dry arid during 6.8-5.2 ka Cal BP (Sekar *et al.*, 1997a, b; Sirocko *et al.*, 1996). Luckge *et al.* (2001) has also observed onset of aridification around Arbian sea on the basis of geochemical evidence during 3.2-2.2 ka Cal BP and summer monsoon and high precipitation around 2.2-1.4 ka Cal BP. The above data sets indicate the fluctuation in the climate in the arid climatic zones of India over the last 40 ka BP (BCR) (Fig. 8).

Age and Range (ka BP)	Calibrated age (ka BP)	Investigated area	Material/^{14}C/other dating method/ climatic Proxy	Climatic inferences	Reference
40.0	BCR	Great Indian Desert	Sediment/Conventional palaeogeography	Dry phase	Allchin *et al.*, 1978
20.0-13.0	23.6-15.6	Didwana salt lake, Rajasthan	Sediment/Conventional palynological study	Hyper-saline conditions	Singh *et al.*, 1990
20.0-11.0		Thar Desert	Aeolian sedimentation	Overall dry climatic condition	Juyal *et al.*, 2006
N.A.	14.5	Arabian sea	Calcareous sediment/Conventional terrigenous matter	Increase in terrigenous matter	Sirocko *et al.*, 1996
N.A	16.0	-do-	-do-	Increase in humidity	Sirocko *et al.*, 1996
9.0-6.0	10.2-6.8	Didwana salt lake, Rajasthan	Sediment/Conventional palynological study	Increase summer & winter precipitation	Singh *et al.*, 1990
8.85-7.85.	9.9-8.6	Arabian sea	Calcareous sediment/Conventional oxygen isotopes	Humid climate	Sirocko *et al.*, 1993
8.1-6.3	9.0-7.2	Didwana, Rajasthan	Sediment/Conventional chemical & pollen study	Wet humid climate	Sekar & Rajagopalan, 1997a, b
8.0-5.5	8.9-6.3	Bap-Malar & Kanod	Sediment/Conventional multi proxy study	Fresh water conditions	Deotare *et al.*, 2004
6.3-4.8	7.3-5.5	Lukaransar, Rajasthan	-do-	Wet climate due to southwestern monsoon rains	Enzel *et al.*, 1999
6.0-4.5	6.8-5.2	Didwana, Rajasthan	Sediment/Conventional pollen & chemical study	Dry arid climate	Sekar & Rajagopalan, 1997a, b
5.0-3.9	5.7-4.4	Northeastern Arabian sea	Sediment/Conventional geochemical evidence	Summer monsoon activity	Luckge *et al.*, 2001
4.8	5.5	Arabian sea	Calcareous sediment/Conventional oxygen isotopes	Arid climate	Sirocko *et al.*, 1993
NA	3.2-2.2	-do-	Sediment/Conventional geochemical evidence	Onset of aridification	Luckge *et al.*, 2001
2.2-1.5	2.2-1.4	-do-	-do-	Summer monsoon & high precipitation	-do-
1.5	1.4	-do-	-do-	Modern climatic conditions	-do-

Fig. 7—Climatic records of arid climate zones.

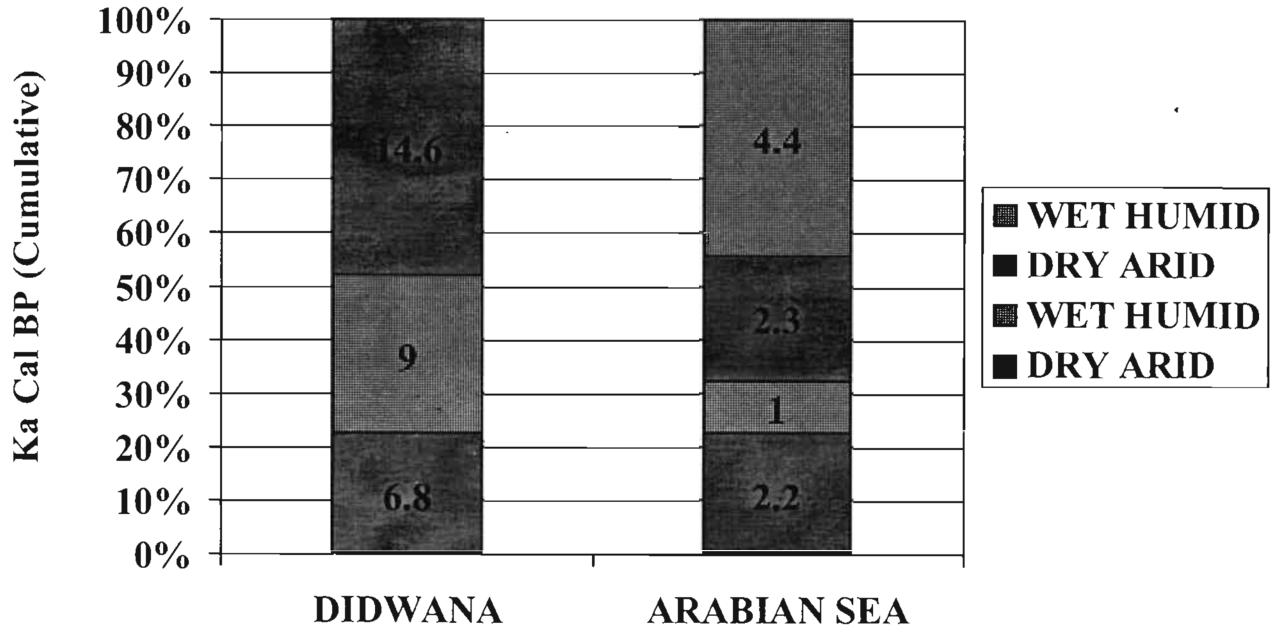

Fig. 8—Reconstruction of climate in arid zones.

SEMI ARID CLIMATE ZONE

The climate around Nilgiris and Palni Hill regions of south India were alternating from moist humid to dry arid phase during the last 40 ka BP (BCR) (Fig.9). The measurement of carbon isotope variations in peat samples has revealed moist climatic conditions during 40.0-28.0 ka BP (BCR) in regions around Nilgiris (Geeta *et al.*, 1997; Sukumar *et al.*, 1993). An arid phase been inferred in the above region from the predominance of C4 vegetation and is supported by data indicating weak summer monsoon (Geeta *et al.*, 1997; Sukumar *et al.*, 1993) during 28.5 ka BP (BCR)-20.2 ka Cal BP. Reversion to moist climate is observed around 20.2 ka Cal BP in the above region. Bera *et al.* (1997) has observed warm humid climate during 25.0 ka BP (BCR) and 11.4-5.7 ka Cal BP around Marian Shola, Palni Hills, Tamil Nadu on the basis of pollen study. The chemical and pollen studies (Sekar & Bera, 1999) denote alternating climate from cool humid during 21.4-20.1, 19.3-16.2, 6.3-5.0 and 3.5 ka Cal BP to warm and moist during the intervening periods around Berijam lake, Palni Hills. The radiocarbon dates and the Holocene sea level curve worked out for Marakkanam, Tamil Nadu indicate a gradual and slow sea level rise since 10.36-0.83 ka Cal BP indicating gradual amelioration of climate in that region (Hameed *et al.*, 2006). A less humid climate since 4.5-2.2 ka Cal BP has been observed from a study of two marine cores from inner shelf off Karwar, Karnataka, western India on the basis of decrease in pollen of evergreen trees and mangrove taxa, increase in pollen of savanna taxa and $\delta^{13}C$ values of sedimentary organic matter (Caratini *et al.*, 1994). On the basis of $\delta^{13}C$ value of -17‰ in peat deposits moist phase was found in Nilgiris area, south India during 2.0 ka Cal BP (Geeta *et al.* 1997; Sukumar *et al.*, 1993). The instrumental data in the rainfall reconstruction shows an increasing trend over coastal and north-interior Karnataka from 1.9-1.98 ka Cal BP and a dry period between 1.9-1.93 ka Cal BP which is clearly recorded as reduced width of layers and enriched level of $\delta^{18}O$ in the speleothem during this time span (Yadava *et al.*, 2004). The above data sets show the pattern of climate change in the semi arid regions during the last 40 ka BP (BCR) (Fig. 10).

Age and Range (ka BP)	Calibrated age (ka BP)	Investigated area	Material/^{14}C/ other dating method/ climatic Proxy	Climatic inferences	Reference
40.0-28.0	BCR	Nilgiris, Tamil Nadu	$\delta^{13}C$ of Peat, Conventional	Decline of $\delta^{13}C$ values in peat, increased dominance of C3 plants concurrent with a moist climate	Sukumar *et al.*, 1993; Geeta *et al.*, 1997
25.0 ka	BCR	Marian Shola, Palni Hills, Tamil Nadu	Sediment/Conventional pollen study	Warm humid climate	Bera *et al.*, 1997
20.0-17.0	23.6-20.2	Nilgiris, Tamil Nadu	Conventional stable isotope study of peat	Dominance of C4 vegetation: an arid phase	Geeta *et al.*, 1997
18.0-16.9	21.4-20.1	Berijam lake, Palni Hills, Tamil Nadu	Sediment/Conventional chemical & pollen analytical study	Cool humid climate	Sekar & Bera, 1999
17.0	20.2	Nilgiris, Tamil Nadu	Peat/Conventional stable isotopic study	Moist climate	Sukumar *et al.*, 1993; Geeta *et al.*, 1997
16.9-16.2	20.1-19.3	Berijam lake, Palni Hills	Sediment/Conventional chemical and pollen study	Warm humid climate	Sekar & Bera, 1999
16.2-14.9	19.3-17.8	-do-	-do-	Reversion to cool humid	-do-
14.5-13.5	17.4-16.2	-do-	-do-	Cool humid climate	-do-
10.0-5.0	11.4-5.7	Marian Shola, Palni Hills	-do-	-do-	Bera *et al.*, 1997
9.0-1.1	10.36-0.83	Marakkanam, Tamil Nadu	Sediment/Conventional sea level change	Moist climate	Hameed *et al.*, 2006
8.9-5.5	10.0-6.3	Berijam lake, Palni Hills, South India	Sediment/Conventional chemical & pollen analytical study	Warm humid climate	Sekar & Bera, 1999
7.0	7.8	Tropical montane forest, South India	Sediment/Conventional vegetation	Decline of tree taxa	Gupta, 1990
5.5-4.4	6.3-5.0	Berijam lake, Palni Hills	Sediment/Conventional chemical & pollen study	Cool humid climate	Sekar & Bera, 1999
4.4-3.3	5.0-3.5	-do-	-do-	Warm humid climate	-do-
3.5-2.2	4.5-2.2	Off Karwar, Karnataka	Sediment/Conventional pollen & stable isotope study	Less humid climate	Caratini *et al.*, 1994
3.3	3.5	Berijam lake, Palni Hills	Sediment/Conventional chemical & pollen study	Humid climate	Sekar & Bera, 1999
2.0	2.0	Nilgiris,South India	Sediment/Conventional stable isotope study	Moist phase	Sukumar *et al.*, 1993; Geeta *et al.*, 1997
1.9-2.0	1.9-2.0	North-interior Karnataka	Speleothem/Conventional/ Rainfall reconstruction, reduced width of layers and enriched level of $\delta^{18}O$	A dry period	Yadava *et al.*, 2004

Fig. 9—Climatic records of semi arid climate zones.

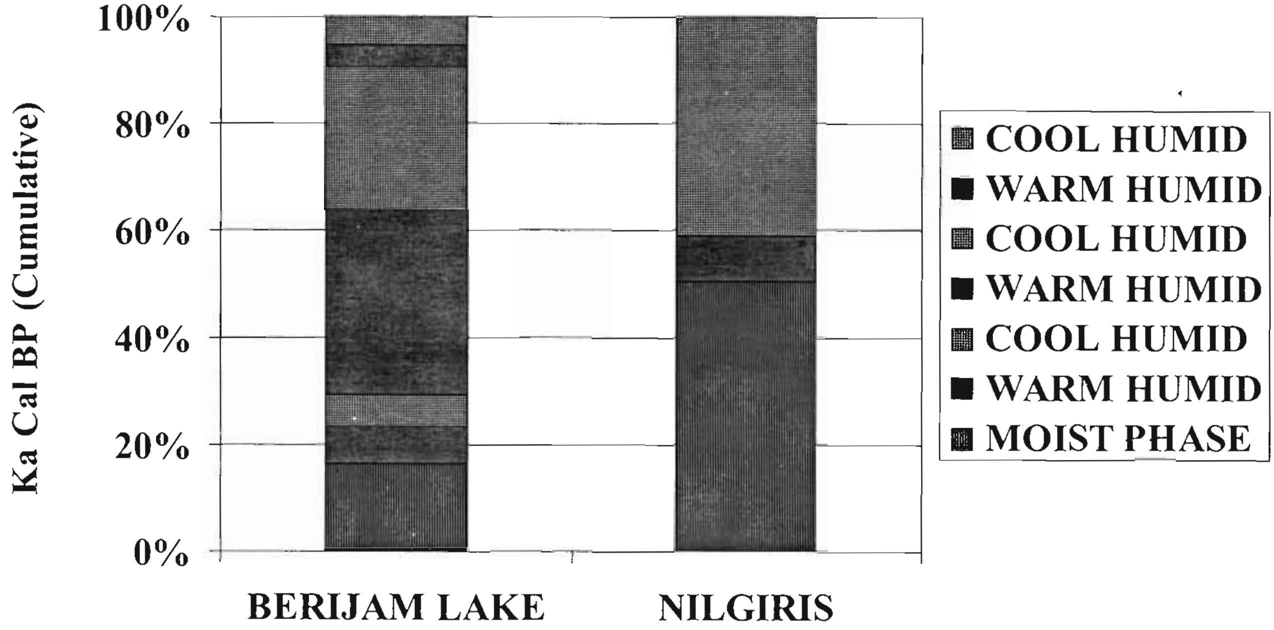

Fig. 10—Reconstruction of climate in semi arid zones.

TROPICAL WET AND DRY CLIMATE ZONES

The climate of this zone is characterised by predominantly wet and occasional dry climate. There was an amelioration of climate during 30.4-28.0 ka BP (BCR) in Chilka lake, Orissa (Fig. 11). The sediments during this period were enriched with the seeds of *Carex* and *Potamogeton* marking the expansion of lake margins. The total vegetation scenario suggests a drastic change from cold and dry to warm and humid environment with greater discharge of melt water (Gupta & Khandelwal, 1992). But Chauhan and Suneethi (2001) have observed that region around Bay of Bengal experienced deterioration of climate during 17.9-15.6 and 13.5 ka Cal BP on the basis of sedimentological study.

Succession of vegetation from grass land to shrub-savannas, tree-savannas, tropical deciduous forest and establishment of sal forest in Bastua, Sidhi, Madhya Pradesh has been observed through pollen study (Chauhan, 1995) during 8.9, 7.6-5.7, 5.2-3.3 and 1.1 ka Cal BP respectively whereas the above region was experiencing cold and dry climate during 11.4-9.6 ka Cal BP. Peat formation and submergence of forest in Bengal Basin have been recorded during 7.6-5.7 ka Cal BP (Gupta, 1981). Geochemical and palynological studies of a core from Jagmotha swamp, northeastern Madhya Pradesh indicate a cool and dry climate between 6.8-5.7 ka Cal BP representing a tree savanna type vegetation. It is followed by warm and moist climate between 5.7-3.2 ka Cal BP indicated by mixed deciduous forests in the region. Climate improved further between 3.2-1.1 ka Cal BP as evidenced by the advent of Sal tree (*Shorea*) in the forest (Yadav *et al.*, 2006). Based on the correlation of χ_{lf} with instrumental rainfall and historical records, palaeorainfall conditions have been reconstructed in terms of rainfall variations in the past 3.7 ka Cal BP. Aridity up to 2.5 ka Cal BP has been documented in the 3.7 ka TK profile which is in tune with inferences made using records from Rajasthan lakes, Nilgiri peat deposits and a western Arabian sea sediment core (Sekar & Rajagopalan, 1997a, b; Sukumar *et al.*, 1993). From 2.5 to 1.55 ka Cal BP, conditions have turned slightly humid while 2.5 ka Cal BP onwards, rainfall seems to have a crude cycle of ~1,000 years and increased towards the Present with progressively higher amplitude fluctuations (Shankar *et al.*, 2006).

Age and Range (ka BP)	Calibrated age (ka Cal BP)	Investigated area	Material/^{14}C/ other dating method/ Climatic Proxy	Climatic inference	Reference
30.0-28.0	BCR	Nalabana Island, Chilka lake, Orissa	Sediment/Conventional mangrove vegetation	Vegetation changed drastically from cold & dry to warm & humid environment	Gupta & Khandelwal, 1992
15.0-13.0	17.9-15.6	Bay of Bengal, India	Sediment/Conventional sedimentological study	Reversal to variable climate	Chauhan & Suneethi, 2001
11.5	13.5	-do-	Sediment/Conventional clay mineral assemblage, etc.	Arid climatic conditions	-do-
10.0-8.7	11.4-9.6	Bastua, Sidhi, M.P.	Sediment/Conventional pollen study	Cold dry climate	Chauhan, 1995
8.0	8.9	-do-	Sediment/Conventional/ Succession of grass lands by shrub savannas	Amelioration of climate	-do-
7.0-5.0	7.8-5.7	Bengal Basin	Sediment/Conventional pollen study	Submergence of forest	Gupta, 1981
6.7-5.0	7.6-5.7	Bastua, Sidhi, M.P.	Sediment/Conventional pollen analysis	Transformation of shrub to tree savanna	Chauhan, 1995
4.5-3.1	5.2–3.3	-do-	-do-	Tropical deciduous forest	-do-
1.2	1.1	-do-	-do-	Establishment of Sal forest	-do-
0.46-0.29	0.5-0.3	Paradip, Orissa	Sediment/Conventional chemical data	Stable landscape conditions	Sekar *et al.*, 1992
0.29	0.3	-do-	-do-	Unstable landscape conditions	-do-

Fig. 11—Climatic records of tropical wet and dry climate zones.

Ameliorating climate and stable landscape conditions were found in Paradip, Orissa during 2.0 ka Cal BP on the basis of chemical data (Sekar *et al.*, 1992). The above data sets indicate the pattern of fluctuation of climate in the tropical wet and arid climatic regions during the last 40 ka BP (BCR)(Fig. 12).

CONCLUSION

On the basis of the multiproxy data, the palaeoclimatic reconstruction of Indian subcontinent demonstrates that climate was different in different regions in India. The overall climatic conditions of the highland regions were alternating from dry arid to brief ameliorations. The climate in the Gangetic plain was alternating from warm humid to cool humid primarily due to changes in SW monsoon in the region during the last 40.0 ka BP (BCR). The arid climate zone especially in Rajasthan and parts of Gujarat in western India was predominantly arid with a brief wet and humid period. The semi arid climatic zone around Nilgiris and Palni Hill regions of south India, climate was alternating from moist humid to dry arid phase. The tropical wet and dry climatic zone around Orissa was characterised by predominantly wet and occasional dry climate. The beginning of the Holocene warming and onset of humid phase was observed in several climatic regions during 11.4-7.6 ka Cal BP. Again ameliorating condition appeared during 2.0 ka Cal BP as well as in present time covering larger part of India as evidenced from analyses of several proxy data from diversified climatic and geographical regions. The above conclusions are in broad agreement with climatic records of global sites having similar climatic system. However, there is still meagre data available for some of the climatic zones like tropical wet zone as compared to other zones.

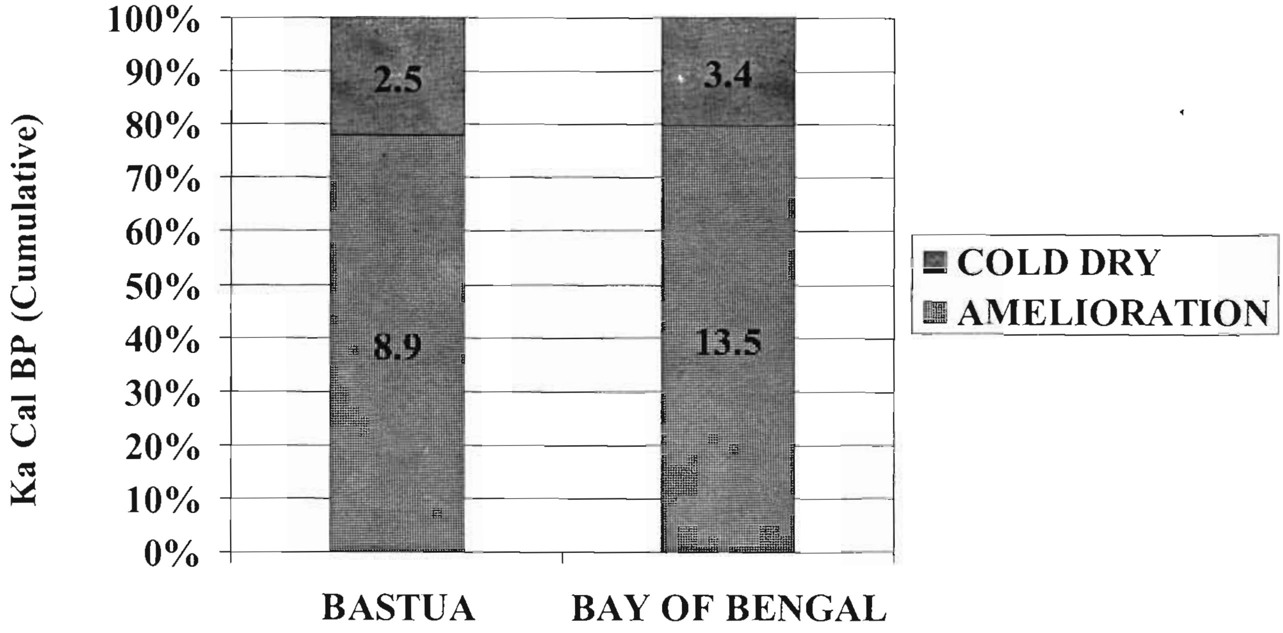

Fig. 12—Reconstruction of climate in tropical wet and dry zones.

Further work in data-deficient areas will throw more light towards refining the past climatic scenario of India on both temporal and spatial aspect.

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REFERENCES

Allchin B, Goudie AS & Hegde KTM 1978. The prehistory and palaeogeography of the Great Indian Desert. Academic Press, San Francisco, New York, London.

Bera SK, Farooqui Anjum & Gupta HP 1997. Late Pleistocene/Holocene vegetation and environment in and around Marian Shola, Palni Hills, Tamil Nadu. Palaeobotanist 46 : 191-195.

Bhattacharyya A 1989. Vegetation and climate during the last 30,000 years in Ladakh. Palaeogeography Palaeoclimatology Palaeoecology 73 : 25-38.

Bhattacharyya A & Chauhan MS 1997. Vegetational and climatic changes during recent past around Tipra Bank Glacier, Garhwal Himalaya. Current Science 72 : 408-412.

Butzer KW, Issac GL, Richardson J & Wasbourn-Kamau C 1972. Radiocarbon dating of East African Lake levels. Science 175 : 1069-1076.

Caratini C, Bentaleb I, Fontugne M, Morzadec-Kerfourn MT, Pancal JP & Tissot C 1994. A less humid climate since ca.3500 yr BP from marine cores off Karwar, Western India. Palaeogeography Palaeoclimatology Palaeoecology 109 : 371-384.

Chauhan MS 1995. Origin and history of tropical deciduous Sal (*Shorea robusta* Gaertn.) forests in Madhya Pradesh, India. Palaeobotanist 43 : 89-101.

Chauhan MS & Sharma Chhaya 1996. Late Holocene vegetation of Darjeeling (Jore-Pokhari), eastern Himalaya. Palaeobotanist 45 : 125-129.

Chauhan MS, Sharma Chhaya & Rajagopalan G 1997. Vegetation and climate during Late Holocene in Garhwal Himalaya. Palaeobotanist 46 : 211-296.

Chauhan MS, Mazari RK & Rajagopalan G 2000. Vegetation and climate in upper Spiti region Himachal Pradesh during Late Holocene. Current Science 79 : 373-377.

Chauhan Onkar S & Suneethi J 2001. 18 ka BP records of climatic changes, Bay of Bengal: Isotope and sedimentological evidences. Current Science 81 : 1231-1234.

Deotare BC, Kajale MD, Rajaguru SN, Kusumgar S, Jull AJT & Donahue JD 2004. Paleoenvironmental history of Bap-Malar and Knod playas of western Rajasthan, Thar Desert. Proceedings of the Indian Academy of Science (Earth and Planetary Sciences) Special Issue on Quaternary History and Palaeoenvironmental record of the Thar Desert in India 113 : 403-425.

Enzel Y, Ely LL, Mishra S, Ramesh R, Amit R, Lazer B, Rajaguru SN, Baker VR & Sandler A 1999. High resolution environmental change in the Thar Desert, NW India. Science 284 : 125-128.

Farooqui A, Farooqui SA & Sekar B 2003. Vegetation pattern since 4000 yrs. BP in Lalitpur, India : Mansarovar Lake. *In* : Anupama K & Achyuthan Hema (Editors)—Proceedings of the International PAGES workshop on Late Quaternary environment change : Emerging issues : 247-249.

Geeta Rajagopalan, Sukumar R, Ramesh R, Pant RK & Rajagopalan G 1997. Late Quaternary vegetational and climatic changes from tropical peats in southern India- an extended record up to 40,000 years BP. Current Science 73 : 60-63.

Gupta HP 1981. Palaeoenvironments during Holocene time in Bengal Basin, India as reflected by palynostratigraphy. Palaeobotanist 27 : 138-160.

Gupta HP 1990. Sholas in south Indian montane : past, present and future. *In* : Jain KP & Tiwari RS (Editors)—Proceedings of Symposium Vistas in Indian Palaeobotany. Palaeobotanist 38 : 394-403.

Gupta HP & Khandelwal A 1982. Late Holocene palynology from the lake in Sat Tal Valley, district Naini Tal, Kumaon Himalaya, U.P. Geophytology 12 : 313-321.

Gupta HP & Khandelwal A 1992. Mangrove development at Nalabana island, Chilka lake- a palynological interpretation. *In* : Venkatachala BS, Jain KP & Awasthi N (Editors)—Proceedings of Birbal Sahni Birth Centenary Palaeobotanical Conference. Geophytology 22 : 235-238.

Hameed A, Achyuthan H & Sekar B 2006. Radiocarbon dates and Holocene sea-level change along the Cuddalore and Odinur Coast, Tamil Nadu. Current Science 91 : 362-367.

Juyal N, Pant RK, Basavaiah N, Yadava MG, Saini NK & Singhvi AK 2004. Climate and seismicity in the Higher Central Himalaya during the last 20 kyr : evidences from Garbyang Basin, Uttaranchal, India. Palaeogeography Palaeoclimatology Palaeoecology 213 : 315-330.

Juyal N, Chamyal LS, Bhandari S, Bhushan R & Singhvi AK 2006. Continental record of the southwest monsoon during the last 130 ka: evidence from the southern margin of Thar Desert, India. Quaternary Science Review (in press).

Luckge A, Rolinski Doose H, Khan AA, Schulz H & Rad von U 2001. Monsoonal variability in the northeastern Arabian Sea during the past 5000 years : geochemical evidence from laminated sediments. Palaeogeography Palaeoclimatology Palaeoecology 167 : 273-286.

Mazari RK, Bagati TN, Chauhan MS & Rajagopalan G 1996. Palaeoclimatic record of last 2000 years in Trans-Himalayan Lahaul-Spiti region. *In* : Mikami T, Matsumoto E, Ohta S & Sweda T (Editors)—Proceedings of the 1995 Nagoya IGBP-Pages/PEP II Symposium : 262-269.

Meher-Homji VM & Gupta HP 1999. A critical appraisal of vegetation and climate changes during Quaternary in the Indian Region. PINSA B65 : 205-244.

Pant RK, Basavaiah N, Juyal N, Saini NK, Yadava MG, Appel E & Singhvi AK 2005. A 20-ka climate record from Central Himalayan loess deposits. Journal Quaternary Science 20 : 485-492.

Phadtare NR 2000. Sharp decrease in summer monsoon strength 4000-3500 cal Yr B.P. in the Central Higher Himalaya of India based on pollen evidence from Alpine peat. Quaternary Research 53 : 122-129.

Rajagopalan G 1992. Radiocarbon ages of carbonate materials from Gangetic alluvium. *In:* Singh IB (Editor)—Terra Incognita, Geology Department, Lucknow University : 45-48.

Ruhland K, Phadtare NR, Pant RK, Sangode SJ & Smol JP 2006. Accelerated melting of Himalayan snow and ice triggers pronounced changes in a valley peatland from northern India. Geophysical Research Letters 33 : 1-6.

Sekar B 2000. Interpretation of past climatic changes around Tsokar Lake, Ladakh for the last 33 ka on the basis of chemical data. Palaeobotanist 49 : 519-527.

Sekar B & Bera SK 1999. Reconstruction of past climatic changes around Berijam Lake, Palni Hills for the last 17.7 kyr BP based on chemical analysis and ^{14}C dating. Gondwana Geological Magazine 14 : 51-55.

Sekar B & Rajagopalan G 1997a. Chemical analysis and ^{14}C dating of lake sediments and their significance for the interpretation of the past climatic changes. *In* : Das SN & Thakur RS (Editors)—Proceedings of IGBP Symposium on Changes in Global Climate due to Natural and Human activities : 173-175. Allied Publishers Limited.

Sekar B & Rajagopalan G 1997b. Environment and climate around Didwana lake, Rajasthan during the last 8100 years B.P. *In* : Proceedings of Quaternary Geology of South Asia, First Regional Geosas Workshop, Anna University, Chennai : 232-239.

Sekar B, Rajagopalan G & Bhattacharyya A 1994. Chemical analysis and ^{14}C dating of a sediment core from Tsokar lake, Ladakh and its implications on climatic changes. Current Science 67 : 36-39.

Sekar B, Rajagopalan G, Nautiyal BD & Dube BK 1992. Chemical analysis of a sediment core from Paradip, Orissa and its application to environmental reconstruction for 450 years. Current Science 63 : 371-372.

Shankar R, Prabhu CN, Vijaya Kumar GT & Sekar B 2006. Reconstruction of palaeoclimate and human-induced changes from Lake/ Tank-bed sediments from Karnataka, India. Journal of Geological Society of India 68 : 447-459.

Sharma Chhaya, Chauhan MS & Rajagopalan G 2000. Vegetation and climate in Garhwal Himalaya during last 4000 years. Palaeobotanist 49 : 501-507.

Singh G, Wasson RJ & Agrawal DP 1990. Vegetational and seasonal changes since the last full glacial in the Thar Desert, northwestern India. Review of Palaeobotany & Palynology 64 : 351-358.

Sirocko F, Sarnthein M, Erlenkeusar H, Lange H, Arnold M & Duplessy JC 1993. Century scale events in monsoonal climate over the past 24000 years. Nature 364 : 322-324.

Sirocko F, Gabo Schoenberg D, McIntyre A & Molfino B 1996. Teleconnections between the subtropical monsoon and high altitude climates during the last deglaciation. Science 272 : 526-529.

Srivastava P, Singh IB, Sharma S, Shukla UK & Singhvi AK 2003. Late Pleistocene-Holocene hydrologic changes in the interfluve areas of the central Ganga Plain, India. Geomorphology 54 : 279-292.

Sukumar R, Ramesh R, Pant RK & Rajagopalan G 1993. A $\delta^{13}C$ record of late Quaternary climate change from tropical peat in southern India. Nature 364 :703-706.

Yadav DN, Chauhan MS & Sarin MM 2006. Geochemical and pollen proxy records from northeastern Madhya Pradesh : an appraisal of Late Quaternary vegetation and climatic change. Journal of Geological Society of India 68 : 95-102.

Yadava Madhusudan G & Ramesh Rangaswamy 2004. Rainfall variation of Peninsular India reconstructed from a 331 year-old Speleothem. Pages News 12 : 5-6.

Yan G, Wang FB, Shi GR & Li SF 1999. Palynological and stable isotope study of palaeoenvironmental changes on the northeastern Tibetan plateau in the last 30,000 years. Palaeogeography Palaeoclimatology Palaeoecology 153 : 147-159.