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Late Quaternary climate changes reconstructed from mineral magnetic studies from proglacial lake deposits of Higher Central Himalaya

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ABSTRACT

High-resolution palaeoclimate data spanning ~29 ka to ~10 ka are reconstructed using sedimentological and mineral magnetic properties from two proglacial lake varved deposits in the higher central Himalayas. Mineral magnetic parameters such as magnetic susceptibility (χ) and reverse field S-ratio show high frequency low magnitude oscillations suggesting abrupt fluctuations in the ambient climate. Two prominent decreases in magnetic parameters indicate major cooling events that are dated to 18 and 11 ka respectively. The former corresponds to the Last Glacial Maximum (LGM) whereas the latter relates to the Younger Dryas (YD) cooling. In view of the fact that these events are global in nature, we envisage that the higher Central Himalayan climate was influenced by the northern hemispheric glaciation. This is the first direct evidence for LGM and YD from the higher central Himalaya.

INTRODUCTION

Expansion and contraction of continental ice sheets have modulated the global climate during the Quaternary. At regional scale the mountain glaciers had profound effect on the terrestrial climate especially the Himalaya and Tibetan plateau which have influenced the southwest monsoon in the region (Ruddiman & Kutzbach 1989; Molnar et al. 1993). In the higher Himalaya, proglacial deposits such as moraines and lakes respond too readily to a slight increase or decrease in temperature. The proglacial lakes are genetically related to the proximity of the valley glaciers, hence, they respond in accordance with the glacier advancement and retreat. The relict counter parts of the proglacial environment have been used to reconstruct the periods of extreme temperature depression during the glacial episodes (Bradely 1999).

In the mountainous region especially the Himalaya, the Quaternary climatic history is based on the mapping of lateral moraines. However, the study is limited by (i) poor preservation and fragmentary nature of the deposits and (ii) problem of dating due to lack of suitable dating material. Thus, it limits the usage of moraine as a palaeoclimatic index. Compared to this, the lacustrine sediments preserve a continuous record of climate change in the sensitive proglacial environment (Dahl & Nesje 1996). In view of this, we have investigated two relict lake sediments from higher central Himalaya using mineral magnetic technique. Radiocarbon and luminescence dating techniques provided chronological control to the climatic events. Barring few studies from the lesser Himalayan lakes (Kotlia et al. 1997; 2000), there are no records of continuous climate changes during the Late Quaternary times from the higher Himalaya. The present study is an attempt to fill this gap by searching for continuous palaeoclimate records in the two relict lake deposits of the higher Himalaya.

STUDY AREA AND CLIMATE

Two basins viz. the Goting (30°49′30″N; 79º49′E) and Garbyang (30°5′30″N; 80°50′20″E) investigated in the present study are located in the higher central Himalaya of Chamoli and Pithoragarh districts of Uttranchal (Fig.1). Garbyang basin lies in a transitional zone between dry steppe (Tibetan plateau) and the sub-humid (Himalayan) climate zone. The SW monsoon is the dominant source of precipitation in the Garbyang basin which accounts for 80% of the total precipitation, and part of it falls as snow over

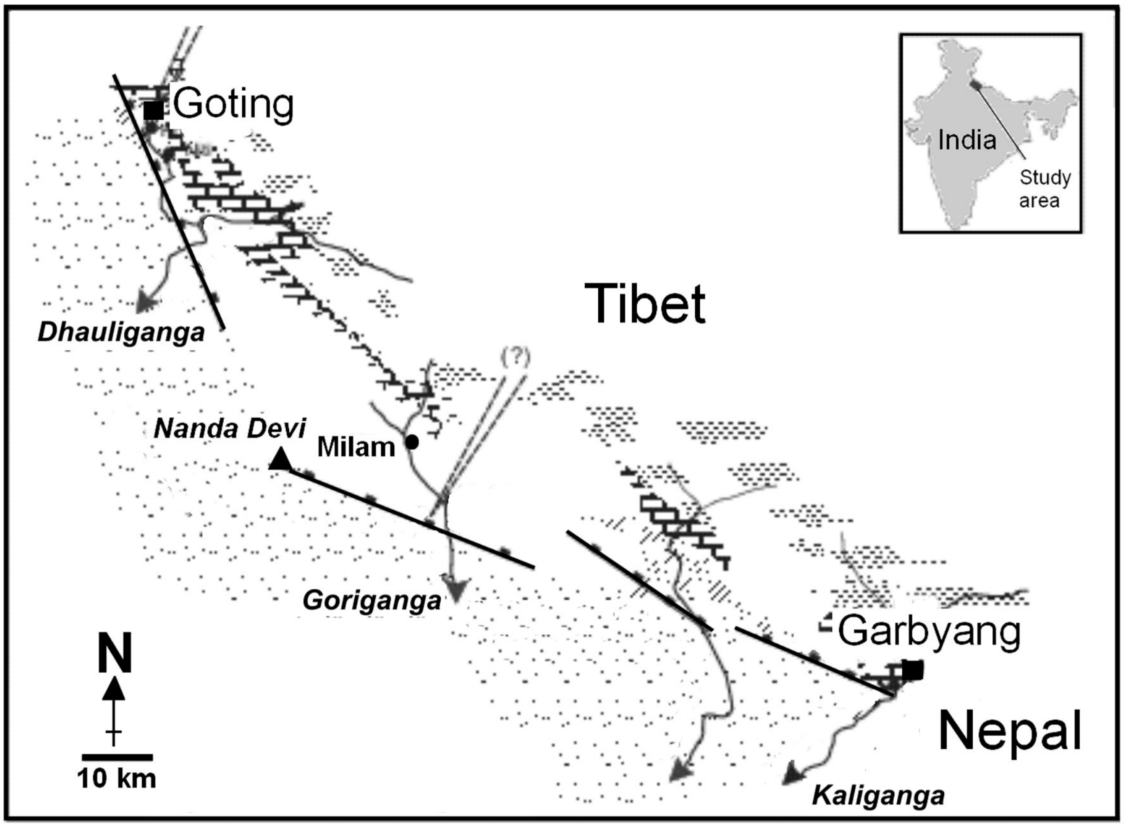

Figure 1. Study area showing the Goting (30º49′30″N; 79º49′E) and Garbyang (30°5′30″N; 80°50′20″E) proglacial lake deposits.

the glaciers (Hasnain 1999). During November to February, the westerly disturbances (winter monsoon) contribute the remaining 20% of the precipitation. Compared to this, the role of SW monsoon in Goting basin is subordinate, instead, the basin represents the dry steppe climate of the adjoining Tibetan plateau.

SEDIMENTOLOGY

The incised relict lake sediments at Garbyang (Fig. 2a) occur along the right flank of the Kali river and at Goting they occur as vertical pinnacles in the Dhauli Ganga basin. In exposed section at Garbyang, cm to mm thick planar laminae could be seen. The sedimentary structure of the beds and the proximity of terminal moraines of the succeeding advance at ~3600 m altitude suggest that deposition took place in a proglacial lacustrine environment. However, occasional presence of sand layers, thick carbonaceous laminae, faulted strata and occasional dropstones (Fig. 2d) suggest that deposition was not altogether monotonous. The entire lacustrine succession is capped by 3-5 m thick outwash gravel.

In freshly exposed sections at both the sites, the beds appear as stacked bundles of thin horizontal streaks of variable thickness ranging from mm to cm scale (Fig. 2b). Closer examination of the layers at Garbyang reveals that individual units comprise a couplet of dark and a light-coloured band of fine silty-clay (Fig. 2c). The light coloured streaks had a powdery texture and the dark bands contain organic debris. At places, prominent black coloured or yellow rust coloured streaks intercalate the succession. Another characteristic feature is the occurrence of 'dropstones' of varying sizes (Fig. 2d). The largest dropstone seen was 10 cm across the horizontal axis at Garbyang whereas in Goting towards the base melt-out debris was found. In addition to this, at places thick (~5 cm) organic rich layers interspersed the sequence (especially in the middle part of the succession).

Petrology of the varves was carried out to reconstruct the depositional environment and its seasonal variability. Sharp contact between the seasonal layers was observed under the microscope. Two superimposed contrasting bands, the upper greyish brown fine clay (dark band) and the lower

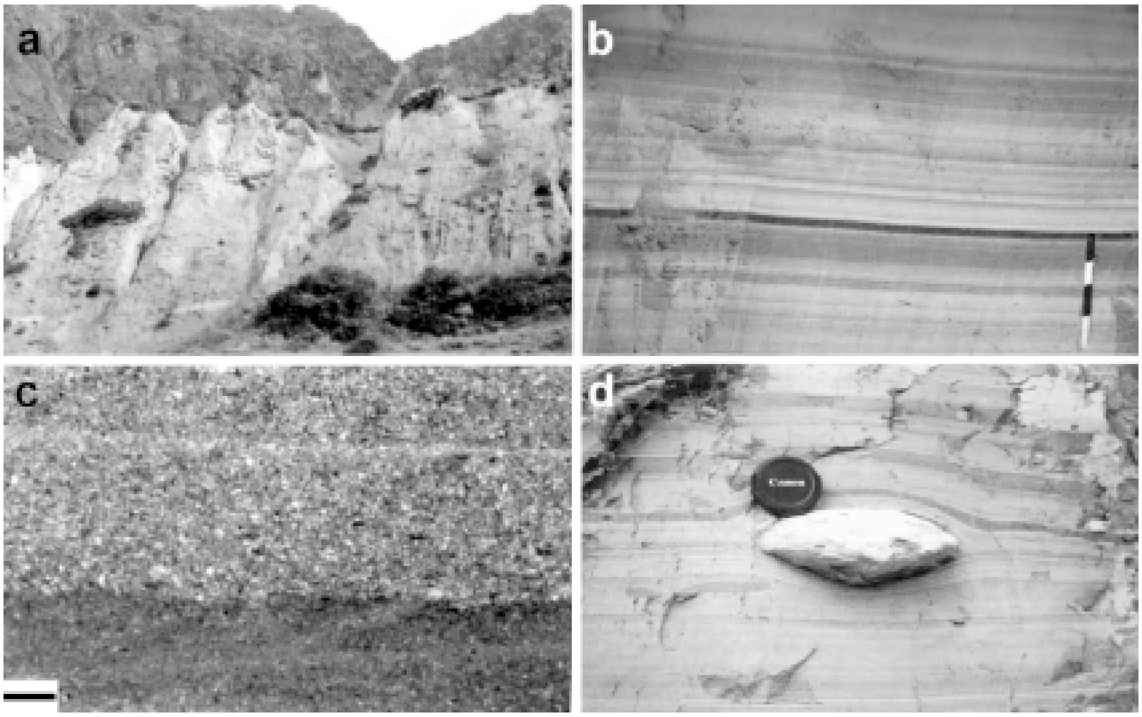

Figure 2a-d. a) Garbyang section; b) Light, dark and internally laminated varves from Goting (scale is in cms); c) Light and dark colour bands as observed in thin section and d) Dropstone embedded in varves (diameter of lens cap is 5 cm).

greyish yellow (light band) fine silt were seen. The matrix showed calcareous cement with concordant calcareous laminae. The silt laminae contained quartz and calcite that are embedded in calcareous matrix. Calcareous silt showed microsparite and disoriented mica flakes. The dark coloured lamina additionally contains thick clouds of organic debris.

STRATIGRAPHY

Garbyang

Three broad litho units can be discerned in the upper 30 m of the sequence (Fig. 3) that was investigated in the present study.

Unit-1 Measured bottom upward the lower part of the profile (30-16.6 m) has a consistent varved succession of planar laminar beds typically 0.2 cm to 0.5 cm thick. Each lamina comprised thin alternating dark and light colour streaks. A 1.70 m thick sand body punctuated the varve sedimentation towards the bottom. A thick (~7 cm) dark sticky mud deposit towards the upper part of the Unit-1 (13.40 m) indicated temporary hiatus in the varve sedimentation. Three faulting events separated by planar beds occur between 30 and 16.6 m.

Unit-2 This unit overlays Unit-1 and continues from 16.60 m – 6.0 m. Unit-2 is dominated by dark coloured planar sticky muds that frequently intercalated the varves (Fig. 2b). The thickest mud horizon measured 7 cm. The varves become thicker in the middle part of this unit with thickness varying from 0.5 cm to 3 cm. However, the grain size of the individual layers remained similar to that of varve dominated Unit-1.

Unit-3 This unit between 6.0 m and 1.6 m is characterized by three distinct features; (i) less frequent carbonaceous bands with decreasing organic carbon content (imparting brownish grey hue to the laminations) (ii) broken laminae in the lower part of the succession and (iii) an increase in the calcium carbonate and sandy-silt contents toward the top.

Goting

The incised section exposed towards the left flank of Goting basin has lower part (~10 m) concealed under the slump whereas the upper 15 m is truncated. Towards the top ~10 m thick outwash gravel mark the termination of lacustrine sedimentation. The section (Fig. 3) can be divided into two major units.

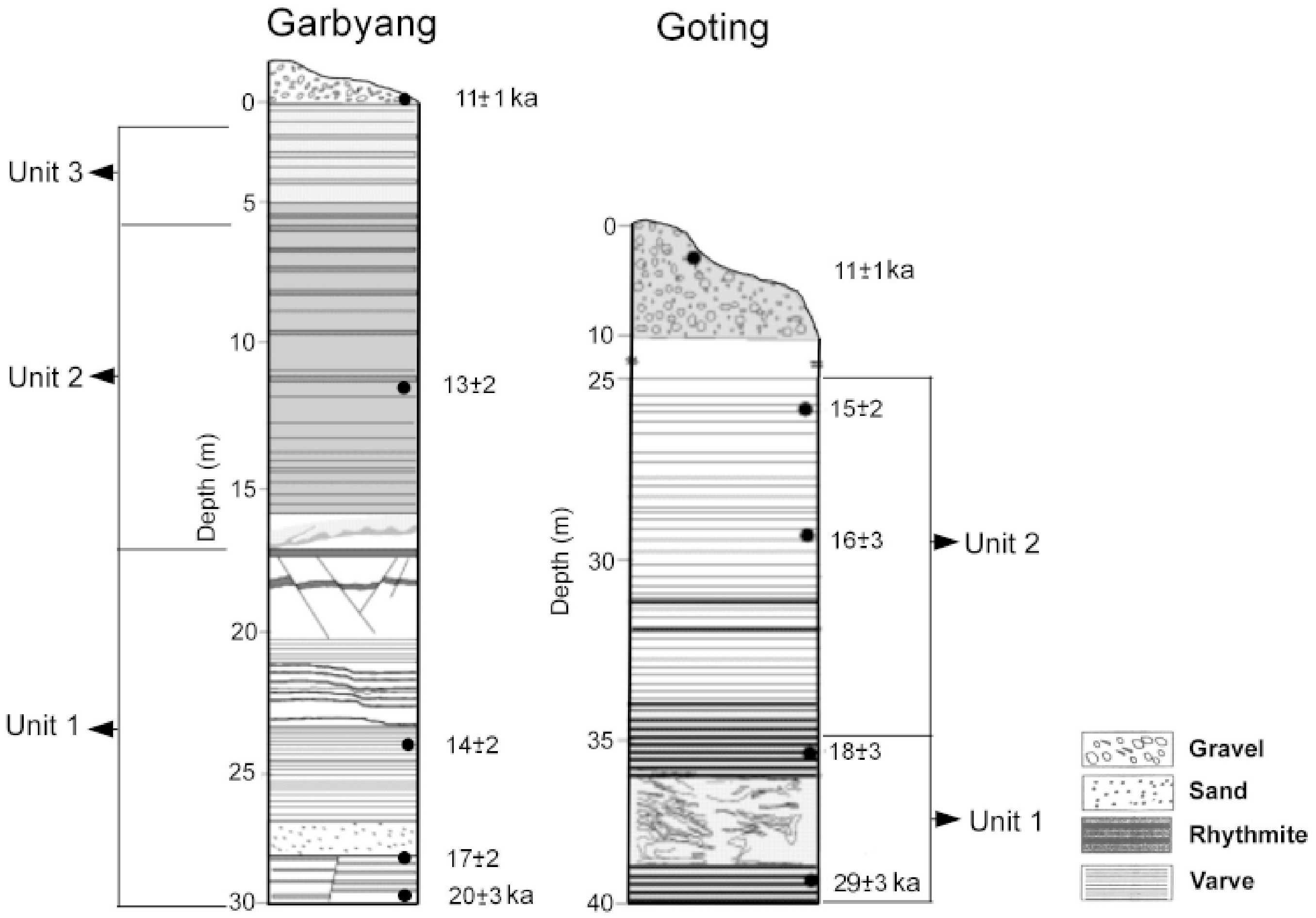

Figure 3. Stratigraphy and luminescence chronology of Garbyang and Goting deposits.

Unit-I Between depth 40 and 35 m (in composite stratigraphy), presence of thicker laminations (~2-5 cm) dominated by fine silty clay with frequent occurrence of ice rafted debris is seen. At places thick organic rich laminations are also encountered. Sequence in this part is more like rhythmite in character suggesting relatively high meltwater discharge. Besides, this horizon also shows evidences of palaeoseismic activity in the form of seismites.

Unit-II This unit lies between 35 m and 25 m depth (truncated top) and sediments are dominantly varvite in character. They show alternating bundles of internally laminated ash gray, and fine silty limonitic horizons appearing regularly at 5-8 cm intervals. A single varve consists of millimetre to sub-millimetre scale couplet of a dark and light-coloured lamina, composed exclusively of fine silt and clay and devoid of any coarse silt. Usually the laminae have fused together and difficult to discern the annual layers in a hand specimen, however under the microscope they are well differentiated.

Depositional environments

Based on the texture and sedimentary structure, it can be suggested that deposition occurred in a calm water environment with fluctuating melt-water discharge. Dominance of varve with subordinate rhythemites and ice rafted debris (dropstone and melt-out) indicates prevalence of proglacial lacustrine environment. In such environment, the lakes are thermally stratified during the summer with warm water in the upper part (epilimnion) and colder water in the lower part (hypolimnion). The upper warm layer remains in exchange with the atmosphere. A cold glacial melt water with suspended sediment gives rise to heavy density current flow during summer and deposited at the lake bottom as underflow. These layers are light coloured and relatively coarse grained. During winters, melt-water and the allochthonous sediment supply decreases, thermal stratification disappears and the lake becomes well mixed. Stokes sedimentation of the fine suspended particles then take place. Besides this, freezing of the surface water cuts off any exchange between lake water and the atmosphere. Consequently, available dissolved oxygen is gradually depleted at the expense of CO_2 thereby enhancing the preservation of organic content as dark and very fine-grained lamina.

Occurrence of dropstones- a diamictic lithology produced by ice rafting in suspension deposits on the lake bottom. The situation implies breaking of ice front that requires marginal rise in the ambient temperature. Since sedimentary succession is dominated by varves and rhythmite and does not show any significant compositional variation, it suggests that conditions during their deposition should have remained essentially glacial.

The rhythmites along with ice rafted debris may be indicative of enhanced runoff that may indicate mild climatic oscillations during their deposition (Barry 1992). Similarly, the varve sedimentation towards the upper part would suggest reduction in meltwater discharge possibly caused by decrease in the temperature. These observations find support in the magnetic data as discussed below.

MINERAL MAGNETISM

Magnetic properties of natural materials depend on the formation, transport, deposition and transformation of magnetic minerals controlled by the environmental condition and geomorphic process (Oldfield 1991; Verosub & Roberts 1995; Basavaiah & Khadkikar, this volume). In the present study, two climate sensitive magnetic parameters were used. The first is the magnetic susceptibility, which is a measure of concentration of magnetic minerals and is expressed as a mass specific (χ) value. It is measured with a KLY-2 Kappabridge (Agico). The second is magnetomineralogical 'S' ratio. It is a quantitative measure of the absolute value of the Isothermal Remanent Magnetization (IRM) after exposure to a reverse field of 300 mT divided by the SIRM acquired at 1.5 T (Verosub & Roberts 1995); simplified here as $IRM_{-300mT}/SIRM_{1.5T}$ (all IRM_{-300mT} values are opposite to SIRM).

A total of 1175 samples collected at 2 cm interval at Garbyang and about 200 samples collected at Goting were analyzed for magnetic susceptibility and S-ratio. To further characterize magnetic mineralogy of the sediments, thermal demagnetization behaviour of SIRM using a MMTD60 Furnace (Magnetic Measurements) was also analyzed on few samples. In the Garbyang sediments (Juyal et al., in press), it is observed that wet climate conditions are characterized by titanomagnetite while more haematite occurs during dry periods.

Catchment lithology, more specifically the primary magnetic mineral content, determines the overall type and concentration of magnetic minerals in lake sediments (Oldfield et al. 1983). To delineate changes in magnetic mineralogy of the sediments, a joint analysis of magnetic susceptibility and S-ratio was used. Variation in χ indicates changing concentration of magnetic minerals while the S-ratio provides a measure of the relative proportions of higher coercivity haematite to lower coercivity (titano-) magnetite. Relatively higher values of χ and S-ratio indicate a close relationship between the erosional processes and increasing detrital (titano-) magnetite concentration (Williamson et al. 1998). It has been suggested that fluctuation of χ in lacustrine sediments is modulated by the climate (Verosub & Roberts 1995). However, a direct climatic connection needs consideration on the influence of changes in lake chemistry that is modulated by fluctuating fresh water influx and has strong influence on the type and concentration of magnetic mineralogy (Williamson et al. 1998; Wang et al. 2001). Magnetic parameters especially χ are affected by dilution caused by precipitation of diamagnetic carbonate and aquatic growth of organic matter while S-ratio does not. Therefore, a combination of these two can effectively be used to make inferences about a number of environmental processes, sediment flux and erosion in lake catchments. However, under anoxic condition, ferrimagnetic magnetite and titanomagnetites are susceptible to chemical dissolution (Robinson 1986; Lean & McCave 1998; Williamson et al. 1998) leading to mineralogical modification of detrital mineralogy.

Variations in values of χ and S-ratio demonstrate changes at centennial and millennium scale and present an asymmetrical saw-tooth pattern at Garbyang (Fig. 4). The χ values range between 6 and 10 (10^{-8} m^3kg^{-1}) and S-ratio from ~0.2 (more haematite) to 0.9 (more titanomagnetite). The important aspect of χ and S-ratio records is their cyclicity and the change takes place apparently at regular interval throughout the entire sampled section at Garbyang. This regularity at Garbyang (Fig. 4) is seen punctuated by two major climate trends apparently coinciding with the Last Glacial Maximum (LGM; ~18 ka) and the Younger Dryas (YD; ~11 ka) cooling events. LGM can also be inferred at Goting.

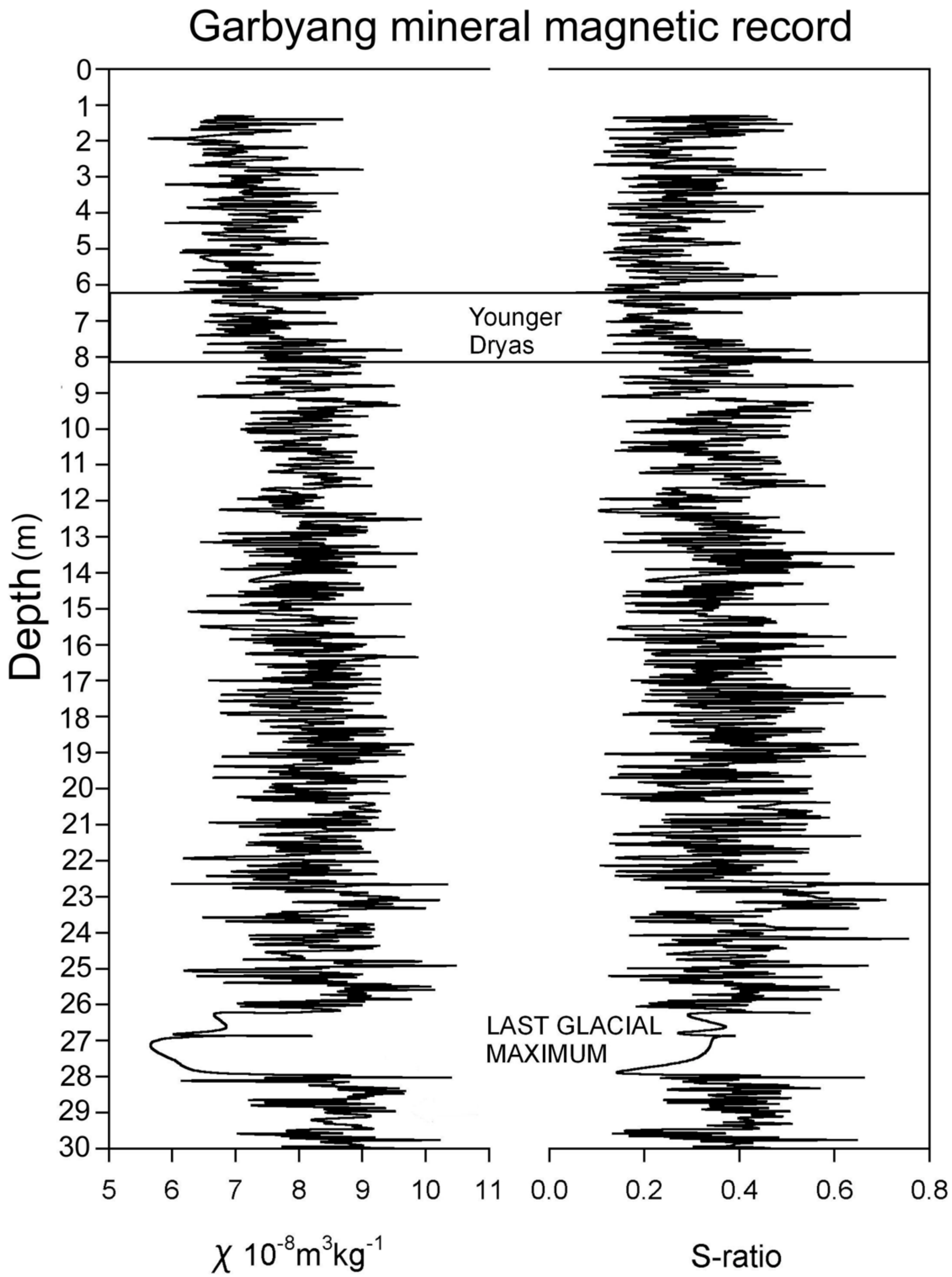

Figure 4. Magnetic susceptibility (χ) and magnetomineralogical S-ratio (IRM$_{-0.3T}$/SIRM) plots of Garbyang varve deposits. Note low values at LGM (18ka) and YD (11ka) in a saw-tooth pattern (see text).

CHRONOLOGY

Radiocarbon dating on organic carbon and Infra Red Stimulated Luminescence (IRSL) dating on fine grain feldspar are used to ascertain the chronology of the sequence at Garbyang and Goting (Fig. 3). Since catchment lithology of Garbyang and Goting is dominated by Tethyan carbonate, the radiocarbon ages have been found to suffer from variable amount of dead carbon contamination (hard water effect). Hence, the interpretation is based on the IRSL ages. Luminescence and radiocarbon dating details are discussed in Juyal et al. (in press). In Garbyang the upper 30 m of lacustrine succession was sampled that yielded an IRSL age of 20 ka whereas the exposed lower horizon at Goting is dated to 29 ka. The topmost sample at Goting gave an age of 15 ka though it has a truncated succession. However, at Garbyang a near complete record is preserved that is directly overlain by the outwash gravel. The uppermost sample was dated to 13 ka and an inferred age based on constant rate of sedimentation suggests that the deposition continued till around >11 ka, following which outwash gravel was deposited. A direct age of 11 ka on outwash gravel was obtained at Goting. In view of the stratigraphic consistency of the succession at Garbyang and Goting (both indicate termination of the lacustrine environment with the deposition of outwash gravel) it can be suggested that proglacial lake environment was terminated around 11 ka.

DISCUSSION

At Garbyang, a low in χ is seen between 30-26 m at the bottom. Also S-ratio is relatively low. This part is dominated the presence of varves with low organic matter. Thereafter, though the intermittent varve sedimentation continued, the χ and S-ratio (Fig. 4) show higher values with low amplitude high frequency changes up to 14 m (unit-1 and lower part of unit-2). Towards the upper part of unit-2, the laminae thickness increases. A drop in χ and S-ratio corresponding to this unit (between 8.0 m and 6.0 m) is followed by a rising trend towards the top (unit-3). This rise is of a lesser amplitude as compared to units-1 and 2 and also a further minimum appears between 3.0 and 2.0 m.

Based on sedimentology and IRSL ages in Garbyang basin, it can be suggested that low χ and S-ratio values at the bottom indicate the onset of LGM, i.e. cold climate. This event is dated to 18 ka, followed by a warmer phase with low magnitude high frequency oscillations prevailed between 18 and 13 ka (Fig. 4). The climate again reverted back to cold condition and is succeeded by a warming trend towards the top. Subdued discharge during cold dry conditions, led to the deposition of finely laminated varves. Though the varve sedimentation continued in relatively warm condition, increased sediment supply and productivity resulted in a shift from varve to rhythmites (upper part of unit-1 and lower part of unit-2). Increased sedimentation facilitates rapid burial of organic matter, hence its preservation (Meyers & Ishiwatari 1995). This process also deposited high concentration of detrital titanomagnetite and restricted the dilution of ferrimagnetic minerals by organic carbon. Low amplitude high frequency fluctuation in magnetic data of unit-1 and the lower part of unit-2 suggest rapid and frequent fluctuations in terrigenous input and lake productivity during the deposition, which are climatically governed. Towards the upper part of unit-2 increasing organic rich laminations indicate prevalence of anoxia. Under such condition, ferric iron is unstable and magnetite in particular is susceptible to dissolution (Lean & McCave 1998). Low values of χ and S-ratio between 8.0 m and 6.0 m indicate eutrophic condition due to reduced meltwater discharge suggesting a cooler event.

Since the sediment characteristics between 16.6 m and 1.6 m are uniformly similar, a linear sedimentation rate could be reasonably assumed for estimating the timing and duration of this cooling event. Thus, an interpolated age of 12 ka is obtained for height 8.0 m and 11 ka for height 6.0 m, which coincides with the timing of Younger Dryas- a major postglacial cooling after Heinrich event-1 (Adams et al. 1999; Bond et al. 1993; Alley 2000). Dated between 12,900 and 11,500 years ago, it was shown that the Younger Dryas event resulted in the weakening of NE trending Gulf stream in Atlantic ocean with consequent cooling (Adams et al. 1999). IRSL age of the outwash gravel at Goting (11±1 ka) with identical geomorphological setting and stratigraphy to that of Garbyang provided an age bracketed between 13±2 ka and 11±1 ka. Chronological evidence of postglacial cooling related to Younger Dryas from Indian sub-continent are scanty except for reports of changes in the hydrological regime in Thar desert (Kar et al. 2001). In view of this, the present evidence is significant suggesting inter hemispheric nature and near synchronicity of the cooling event.

Sedimentological evidences at Goting indicate the prevalence of two distinct climatic regimes. Presence of thicker organic rich silty laminae (rhythmites) and frequent occurrence of ice rafted debris in the lower unit-I suggest enhanced sediment supply and higher surface water temperature. The overlying varve dominated unit-II indicates cooler condition. These

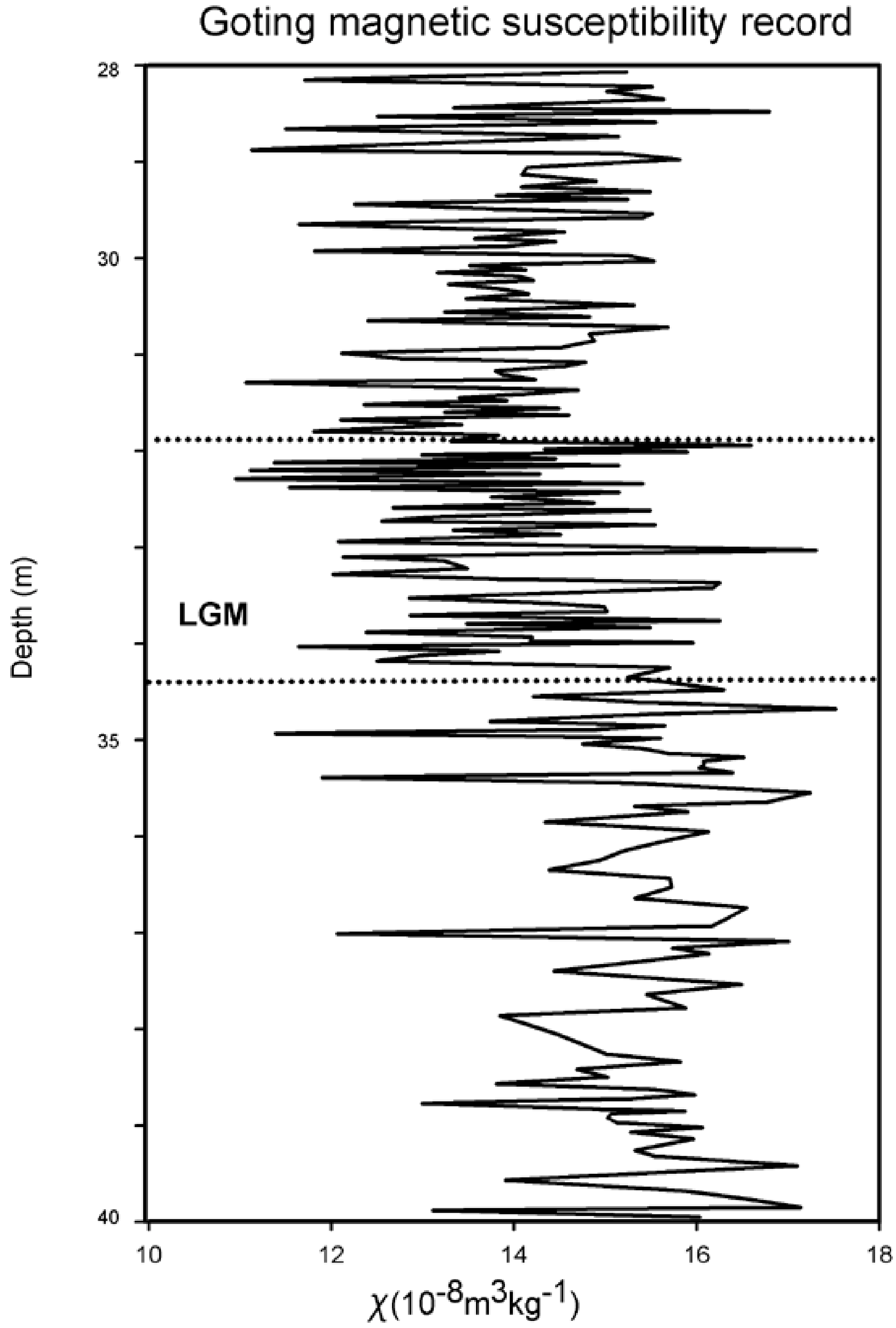

Figure 5. Magnetic susceptibility (χ) of Goting varve deposits. Note a marked low representing LGM in a saw tooth pattern (see text).

observations find support in the magnetic susceptibility data as well.

Enhanced magnetic susceptibility in the Goting record (Fig. 5) during the deposition of unit-I indicates high sediment flux dominated by titanomagnetite. IRSL age brackets this unit between 29 and 18 ka. Since sediment flux in a proglacial lake is controlled by the meltwater discharge, it is reasonable to assume that during 29 ka to 18 ka, higher solar insolation led to enhanced glacial melt in the region. Evidences towards enhanced melting are also supported by sedimentological data. Overall climatic deduction on the basis of sedimentological and magnetic susceptibility indicates a relatively warm condition with less frequent oscillation prevailed between 29 ka and 18 ka. At around 18 ka a prominent decrease in χ is observed (~depth 34 m) a signature peculiar to LGM and continues beyond 16 ka (depth 32 m). However, these fluctuations though of smaller magnitude, have higher frequency compared to unit-I. This suggests that though the climate was significantly cooler compared to Unit-I, it was punctuated by frequent warm oscillations.

Based on this model, it can be inferred that climatic instability during the period 18±3 ka to <15±2 ka prevailed in the region. Horizon corresponding to the Younger Dryas cold event is not located at Goting due to the truncated nature of the upper sequence where deposits younger than 15±2 ka are non-existent. Finally, the upper-most outwash gravel that has been dated to 11±1 ka indicate commencement of Holocene wet phase in the region.

The interesting feature of the magnetic data in Garbyang varved sediments is the asymmetrical saw-tooth shape pattern of susceptibility and S-ratio up to 13 ka and beyond (Fig. 4). However, the low values in the plot seldom revert back to the 18 ka level. High frequency fluctuations in χ and S-ratio between 18 ka and 13 ka indicate the climate frequently oscillated between warmer and cooler conditions. The sharp rise in χ and S-ratio corresponds to warmer intervals and gradual decrease towards cooler phases. Such features are typical of a glaciated terrain (ice sheet) where snow cover affects regional and global climates. In such areas minor changes in environmental condition (e.g. slightly warmer summer) can cause snow to disappear rapidly, resulting in a change of albedo due to exposed land-cover giving a greater warming effect (Adams et al. 1999). Hence it can be said that sudden changes in χ (associated with warm and cold intervals) could be the manifestation of a runaway decadal scale changes in snow reflectivity over the Tibetan plateau that lies north of Garbyang basin and was known to have profound effects on global climate (Ruddiman & Kutzbach 1989). Between 12 and 11 ka (interpolated age), an abrupt drop in susceptibility and S-ratio (Fig. 4) indicates that the lacustrine sediments did register the postglacial cooling. Coincidentally the timing corresponds to the Younger Dryas period (Adams et al. 1999; Alley 2000) associated with North Atlantic climatic perturbation (Bond et al. 1993). Following this, climate appears to have improved gradually and with full establishment of Holocene climate and catastrophic melting of valley glaciers resulted into the deposition of the topmost gravel that is dated to 11 ka. Evidences similar to this are also obtained from the Bay of Bengal where a magnitude increase in sediment load was found between 11 and 7 ka. This has been attributed to enhanced discharge in the Ganga-Brahmaputra system (Goodbred Jr. & Kuehl 2000).

In the adjoining Goting basin, lacustrine succession shows an overall concordance in the variation in magnetic susceptibility data with subtle differences in terms of absolute magnitude (Fig. 5). Relatively high values of magnetic susceptibility are located between 29 ka and 18 ka (~40 m – 35 m). Following this, a marked decrease is seen till 16 ka and beyond (~34.5 m – 32.0 m). This major shift in χ pattern at 18 ka may likely be interpreted as the onset of LGM supplementing the Garbyang magnetic record. In addition to this, sediments older than 18 ka show high amplitude but low frequency fluctuations, which are succeeded by high frequency oscillations of low amplitude after 18 ka (~32 m – 28 m).

Evidence of regional cooling and weak southwest monsoon has been suggested for less extensive valley glaciation during 22 to 16 ka in the Central Himalaya (Benn & Owen 1998). Our observations also suggest the absence of glacial moraine intercalation with lake deposits at Garbyang and Goting. This implies that valley glaciers remained much above the limit of penultimate glaciation (~60 ka) between 21 and 17 ka. Similar evidences have been reported from east and west Tibet indicating overall cold and dry condition (Schafer et al. 2002). However, the period was dominated by fine structure of low magnitude high frequency climatic instability in the lacustrine record. Such fluctuations during low summer insolation and global ice volume suggest millennial scale climatic controls, independent of orbital scale forcing (Grigg & Whitlock 2001). Due to large uncertainty associated with the IRSL ages, short-term fluctuations as seen in magnetic data would require improved dating techniques with small uncertainity.

CONCLUSIONS

Sedimentology and magnetic mineral study allow us to draw the following inferences.

1-Proglacial lacustrine environment responded to the solar forcing and the concordance of major climatic events such as the Last Glacial Maximum and Younger Dryas cooling events indicate that climate in the region responded to ice sheet dynamics of northern latitude.

2-Mineral magnetic evidences for the presence of globally known LGM and YD in the Himalayan lake deposits have established a lead in the palaeoclimatic studies of the Indian monsoons in general and the Himalayas in particular.

3- Following the Last Glacial Maximum, low magnitude high frequency climatic oscillations were seen suggesting local forcing factors possibly caused by fluctuating ice cover in the region (Tibetan plateau)

4- Beginning of Holocene was marked by the sudden increase in meltwater discharge leading to the disappearance of lacustrine environment and the deposition of out-wash gravel in the region

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REFERENCES

Adams, J., Maslin, M. & Thomas, E., 1999. Sudden climate transitions during the Quaternary, Prog. Phys. Geog., 23, 1-36.

Alley, R., 2000. The Younger Dryas cold interval as viewed from central Greenland, Quat. Sci. Rev., 19, 213-226.

Barry, R.G., 1992. Mountain, weather and climate, Routledge, London, 402 p.

Benn, D.I. & Owen, L.A., 1998. The role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation: review and speculative discussion, J. Geol. Soc. London, 155, 353-363.

Bond, G.C., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J. & Bonani, G., 1993. Correlations between climate records from North Atlantic sediments and Greenland ice, Nature, 365, 143-147.

Bradley, R.S., 1999. Palaeoclimatology: reconstructing climate of the Quaternary, Academic press, London, pp. 595.

Dahl, S.O. & Nesje, A., 1996. A new approach to calculating Holocene winter precipitation by combining glacier equillibrium line altitude and pine-tree limits: a case study from Hardongerjokulen, Central South Norway, Holocene, 6, 381-398.

Goodbred Jr. S. & Kuehl, S.A., 2000. Enormous Ganga-Brahmputra sediment discharge during strengthened early Holocene monsoon, Geology, 28, 1083-1086.

Grigg, L.D. & Whitlock, C., 2001. Evidence for millennial-scale climate change during Marine Isotope Stages 2 and 3 at Little Lake, Western Oregon, U.S.A., Quat. Res., 56, 10-22.

Hasnain, S.I., 1999. Himalayan Glaciers: Hydrology and Hydrochemistry, Allied Publishers, New Delhi. pp. 203.

Juyal, N., Pant, R. K., Basavaiah, N., Yadava, M. G., Saini, N. K. & Singhvi, A. K., 2003. Climate and seismicity in the Higher Central Himalaya: evidences from Garbyang basin, Uttranchal, India, Palaeogeogr. Palaeoclimatol. Palaeoecol, in press

Kar, A., Singhvi, A.K., Rajaguru, S.N., Juyal, N., Thomas, J.V., Banerjee, D. & Dhir, R.P., 2001. Reconstruction of Late Quaternary Environment of the Lower Luni Plain, Thar desert, India, J. Quat. Sci., 16, 61-68.

Kotlia, B.S., Bhalla, M.S., Sharma, C., Rajagopalan, G., Ramesh, R., Chauhan, M.S., Mathur, P.D., Bhandari, S. & Chacko, S.T., 1997. Palaeoclimatic conditions in the upper Pleistocene and Holocene Bhimtal-Naukuchiatal lake basin in south-central Kumaun, North India, Palaeogeog. Palaeoclimat. Palaeoecol., 130, 307-322.

Kotlia, B.S., Sharma, C., Bhalla, M.S., Rajagopalan, G., Subrahmanyam, K., Bhattacharyya, A. & Valdiya, K.S., 2000. Palaeoclimatic conditions in the late Pleistocene Wadda Lake, eastern Kumaun Himalaya (India), Palaeogeog. Palaeoclimat. Palaeoecol., 162, 105-118.

Lean, C.M. & McCave, I. N., 1998. Glacial to interglacial mineral magnetic and palaeoceanographic changes at Chatham Rise, SW Pacific Ocean, Earth Planet. Sci. Lett., 163, 247-260.

Meyers, P.A. & Ishiwatari, R., 1995. Organic matter accumulation records in lake sediments, In: Lerman, A., Imboder, M. D., Gat, R.J., (Eds.), Physics and Chemistry of Lakes, Springer-Verlag, Berlin, pp. 279-328.

Molnar, P., England, P. & Martinod, J., 1993. Mantle dynamics, uplift of Tibetan Plateau and Indian monsoon, Rev. Geophys., 31, 357-396.

Oldfield, F., Barnosky, C., Leopold, E.B. & Smith, J.P., 1983. Mineral Magnetic studies of lake sediments, Hydrobilogia, 103, 37-44.

Oldfield, F., 1991. Environmental magnetism- A personal perspective, Quat. Sci. Rev., 10, 73-85.

Robinson, S.G., 1986. The Late Pleistocene palaeoclimatic record of North Atlantic deep-sea sediments revealed by mineral magnetic measurements, Phys. Earth Planet. Int., 42, 22-57.

Ruddiman, W.F. & Kutzbach, J.E., 1989. Forcing of Late Cenozoic Northern Hemisphere climate by plateau uplift in southern Asia and west America, J. Geophys. Res., 94, 409-427.

Schafer, J. M., Tschudi, S., Zhao, Z., Wu, X., Ivy-Ochs, S., Wieler, R., Baur, H., Kubik, Peter, W. & Schluchter, C., 2002. The limited influence of glaciation in Tibet on global climate over the past 170 000 yr., Earth Planet. Sci. Lett., 194, 287-297.

Verosub, K.L. & Roberts, A.P., 1995. Environmental magnetism: past, present and future, J. Geophys. Res., 100, 2175-2192.

Wang, H., Liu, H., Cui, H. & Abrahamsen, A., 2001. Terminal Pleistocene/Holocene palaeo-environmental changes revealed by mineral-magnetism measurements of lake sediments for Dali Nor area, southeastern Inner Mongolia Plateau, China, Palaeogeog. Palaeoclimat. Palaeoecol., 170, 115-132.

Williamson, D., Jelinowska, A., Kissel, C., Tucholka, P., Gibert, E., Gasse, F., Massault, M., Taieb, M., Van Campo, E. & Wieckowski, K., 1998. Mineral-magnetic proxies of erosion/oxidation cycles in tropical marr-lake sediments (Lake Tritrivakely, Madagascar): palaeoenvironmental implications, Earth Planet. Sci. Lett., 155, 205-219.