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LAKE SEDIMENTS FROM THE KASHMIR HIMALAYAS: INVERTED ^{14}C CHRONOLOGY AND ITS IMPLICATIONS

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ABSTRACT. We have measured ^{14}C, ^{210}Pb and ^{137}Cs profiles in two representative cores from Manasbal Lake, Kashmir, India. The sedimentation rate derived from ^{210}Pb and ^{137}Cs in the upper part of the core is in the range of 3.4 to 5.5 mm yr^{-1}. In contrast, ^{14}C ages show an inversion at depths >20 cm. These results are attributed to the erosion of the ubiquitous 10–20-m-thick loess mantle, based on the similarity of ^{14}C ages of the inversion layer in the sediments and the paleosols present in the catchment area. Frequency-dependent mineral magnetic susceptibility (χ_{fd}), carbon to nitrogen ratios and pigment concentrations in the profile show a significant amount of allochthonous component in the lake deposits and support the conclusion that the ^{14}C dates do not reflect the chronology of the *in-situ* lake sedimentation but episodic deposition of the surrounding loess. Thus, ^{14}C serves as a useful tracer to understand source components of the sediments.

MANASBAL LAKE CORE SAMPLES AND EXPERIMENTAL PROCEDURE

Manasbal Lake (34°9′N, 74°52′E) at altitude 1584 m, is about 25 km northwest of Srinagar in the Kashmir Valley. This closed lake derives its water both from the catchment and the subterranean springs in the basin itself (Zutshi & Khan 1978). As part of the Kashmir Palaeoclimate Project (Agrawal *et al.* 1989), we took several cores, 1 m and 6 m long, from sites near the center of the lake in October 1989. The lake is *ca.* 2.8 km^2, with maximum length, 2.3 km, width, 0.5 km and water depth, 13 m. We collected cores from the area of maximum depth, using a Mackereth (1958) corer. We discuss the results of two 1-m cores (1M2, 1M7), which were located close to each other and, thus, were treated as having identical sediment sections (here after labeled 1M2-7). The 6-m core (6M3) was located 0.5 km from 1M2-7. We sampled the short cores at 1-cm and the long cores at 4-cm intervals. We measured ^{210}Pb, ^{14}C and bomb-produced ^{137}Cs activities in these samples following techniques used earlier (Agrawal, Gupta & Kusumgar 1971; Figgins 1961; Krishnaswami *et al.* 1971; Kusumgar, Lal & Sharma 1963) for dating cores. To distinguish the autochthonous from the allochthonous components, we measured the frequency-dependent magnetic susceptibility (χ_{fd}), carbon to nitrogen (C/N) ratio and pigments (carotene). The ^{210}Pb, ^{137}Cs, ^{14}C and χ_{fd} measurements were done in our laboratory, except for the pigments and C/N ratio measurements, which were carried out at the Nuclear Research Laboratory, Srinagar and the Bhabha Atomic Research Centre, Bombay. Pigments were measured spectrophotometrically (Swain 1985) and C/N ratios were determined using a CHN analyzer.

RESULTS

^{210}Pb, ^{137}Cs, ^{14}C, C/N ratio and carotene were measured in the short cores (1M2-7) and ^{14}C, C/N and χ_{fd} in the long core (6M3). We discuss these results separately for the two cores.

Core 1M2-7

Figure 1 shows ^{210}Pb and ^{137}Cs profiles. We use them as chronological markers for determining the sedimentation rates. The top 1 cm has a high ^{210}Pb activity of 5.87 ± 0.09 dpm g^{-1}, which drops to 2.39 ± 0.14 dpm g^{-1} at a depth of 14 cm and below. This gives an average sedimentation rate between 3.4 to 5.5 mm yr^{-1} within the experimental uncertainty. ^{137}Cs, on the other hand, is present only in the top 6 cm of the core, with a peak concentration at 5–6 cm, below which it suddenly drops to near zero value. Using the sedimentation rate of 5.5 mm yr^{-1} based on ^{210}Pb, the peak of

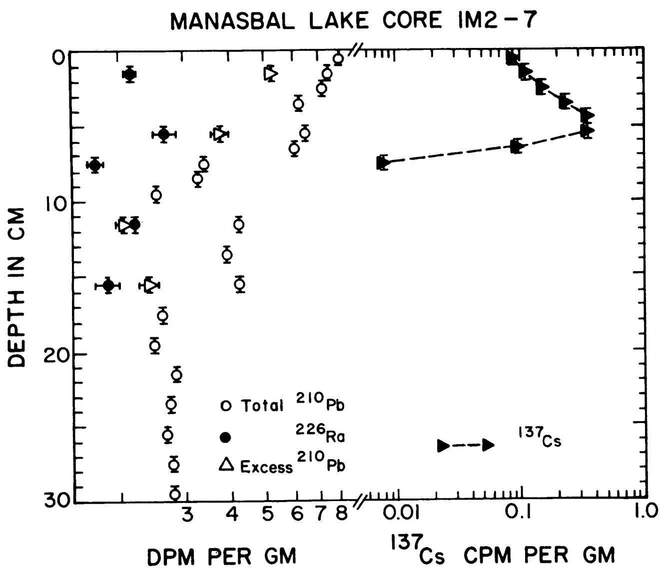

Fig. 1. ^{210}Pb and ^{137}Cs depth profiles in Manasbal Lake Core 1M2-7

^{137}Cs corresponds to *ca.* 1980. Around this time, significant ^{137}Cs fallout occurred in the Himalayas as a result of Chinese nuclear explosions at Lop Nor (41°N, 89°E), as noted by Bhandari *et al.* (1982). The high activity level of 25 dpm cm^{-2} in Manasbal Lake compared to that of 3.7 dpm liter^{-1} observed in glacial snow of Changme Khangpu (27°58′N, 88°42′E) at altitude 4800–5500 m, by Bhandari *et al.* (1982) could be a manifestation of deposition of ^{137}Cs-rich soil from the catchment area (Oldfield, Battarbee & Dearing 1983). We infer from the sedimentation rate of 5.5 mm yr^{-1} that the major ^{137}Cs peak of 1963 due to Soviet nuclear tests would occur at a depth of 15 to 20 cm. However, since these samples were used previously for other analyses, this peak of ^{137}Cs activity could not be identified.

Figure 2 shows the apparent ^{14}C ages of bulk organic matter of these sediments at different depths, which indicate that from *ca.* 19 cm downwards, the chronology of the sediments reverses. At 30 cm depth, we get a date of 2900 BP. Gradually, the sediment becomes "older" as we move up the core to 19 cm, except for one date of 1500 BP at *ca.* 5 cm. Such inversion of ^{14}C chronology can occur as the rock debris, soils, *etc.* from the catchment area get eroded and deposited into the lake. Paleosol-1 in the Kashmir loess sequence has been dated to *ca.* 5000 BP and belongs to the mid-Holocene (Kusumgar *et al.* 1986). The younger ages relate to carbon derived from the upper paleosol strata, and the older ages, to the lower levels of the same soil section, deposited above them in the lake.

As ^{137}Cs and ^{210}Pb also appear in the upper part of the lake core, it is obvious that sedimentation up to a depth of 30 cm could not be older than 55 years, even at the rate of *ca.* 5.5 mm yr^{-1}. Thus, the apparent ^{14}C measurements date the eroded matter from Paleosol-1 (Kusumgar *et al.* 1986). ^{14}C ages here serve as markers for finding the source of the sediments, rather than indicating the sedimentation rate in the lake. The only way we can use ^{14}C dating to determine the sedimentation rates in such topography is by extracting and isolating exclusive aquatic plant-derived organic fractions, such as pigments.

Figure 3 shows the C/N ratio profile. The C/N ratio is <9 up to 12 cm depth, and thereafter increases up to a depth of 27 cm, reaching a value of 13 at *ca.* 22 cm depth. Carotene variation (Fig. 3) also has a similar trend.

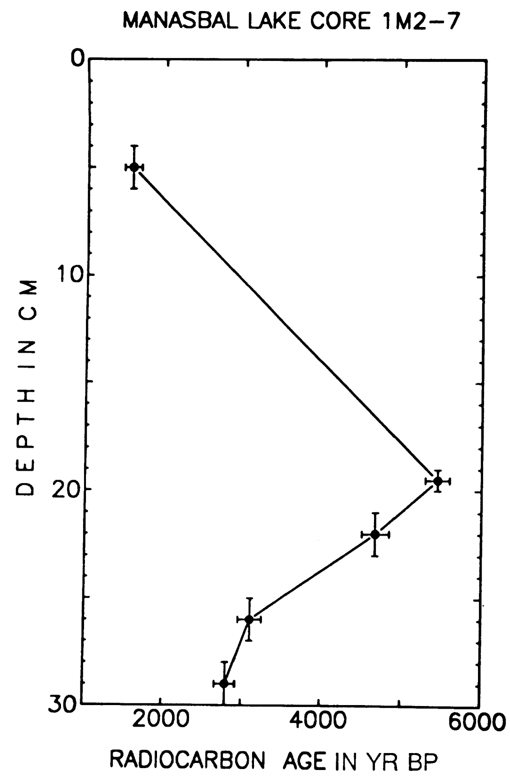

Fig. 2. ^{14}C ages *vs.* depth in Manasbal Lake Core 1M2-7

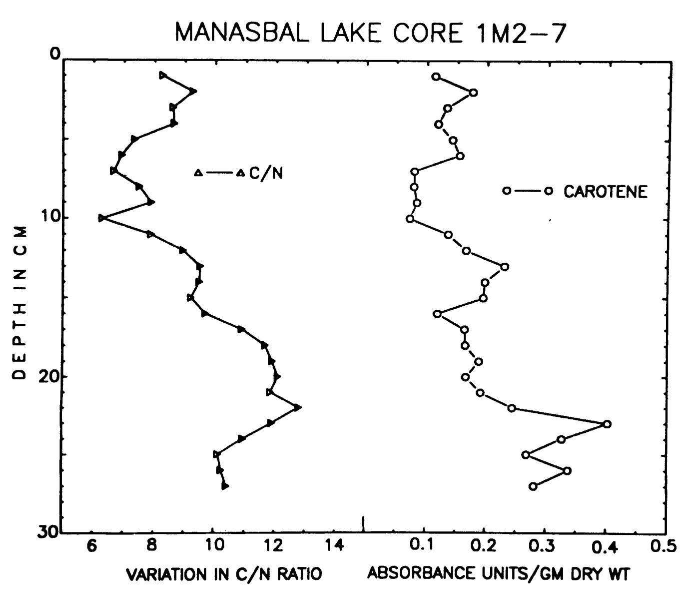

Fig. 3. Variation in C/N ratio and carotene *vs.* depth in Manasbal Lake Core 1M2-7

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C/N ratios are distinct for allochthonous and autochthonous organic materials (Nakai & Koyama 1987), as indicated below:

Source	C/N ratio
Lake water planktons (autochthonous)	~7
Land plants (allochthonous)	>30
Sedimentary rocks (allochthonous)	<5

Generally, increased terrestrial organic material is accompanied by increased carotene in lacustrine sediments. The increase in carotene is not derived primarily from land plants, but from the enhanced lake plant productivity due to the introduction of terrestrial nutrient-rich material. Thus, increased allochthonous input into the lake (Swain 1985), from *ca*. 12 cm downwards is responsible for the increase in carotene. Both the C/N ratio and carotene indicate that, from a depth of 12 cm downwards, the allochthonous source of organic input becomes dominant. This is consistent with the conclusion derived from ^{14}C ages discussed above.

Core 6M3

Figure 4 shows ^{14}C ages of bulk organic matter, C/N ratio and frequency-dependent magnetic susceptibility (χ_{fd}) of the sediments at different depths. The large sampling thickness (sampled at 4-cm intervals) did not allow the determination of sedimentation rate by ^{210}Pb and ^{137}Cs. This core (6M3) was taken at a distance of only *ca*. 0.5 km from the 1-m cores (1M2, 1M7) discussed above. Thus, it is reasonable to assume that both have undergone similar processes of sedimentation and were deposited at roughly similar rates. A uniform rate of deposition of ~5.5 mm yr^{-1}, similar to Core 1M2-7, would mean that Core 6M3 represents a time period of *ca*. 1000 years, but episodic deposition, as seen in Core 1M2-7, would alter this time scale significantly. The ^{14}C ages are 1480 years at 20-cm depth, and thereafter remain practically the same (at 1780 ± 70 and 1840 ± 100) within 1 σ between 300 to 555 cm. These ages are consistent with a steady deposition in the upper 300 cm, and indicate an episodic event of allochthonous organic material deposition from 300 to 555 cm.

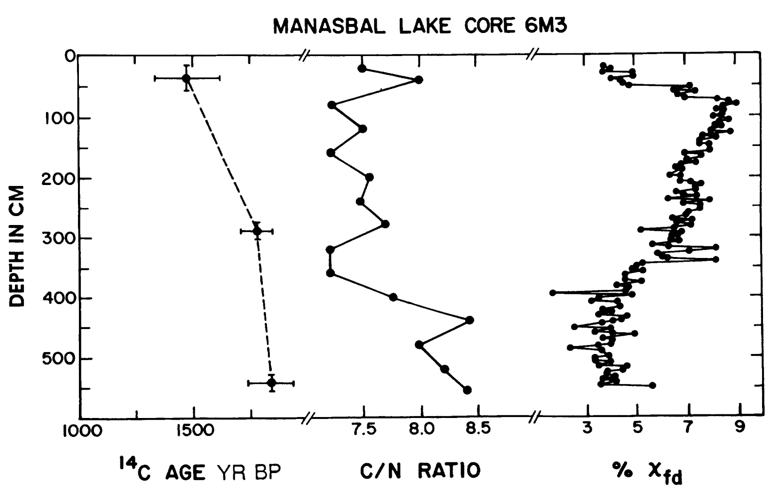

Fig. 4. Depth profile of ^{14}C ages, C/N ratio and frequency-dependent magnetic susceptibility (χ_{fd}) in Manasbal Lake Core 6M3

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The C/N ratio remains within 8 for the top 400 cm, ranging between 7.2 to 8 (Fig. 4), except at a depth of *ca.* 50 cm, where it shows an increasing trend and has a value *ca.* 8. Below 400 cm, the C/N ratio becomes >8. This indicates a predominantly autochthonous component during the upper 400-cm deposition, except for the top 50 cm and below 400 cm, where the allochthonous inputs become dominant. The frequency-dependent magnetic susceptibility (χ_{fd}) (Fig. 4) is less than 5 in the top 55 cm, whereas it ranges from 5 to 9 between 55 and 400 cm depths, and below 400 cm, it is *ca.* 4 or less. The values of <5 show the input of unweathered rock debris in the upper 55 cm and from 400 to 555 cm. The higher values of χ_{fd} from 55 to 400 cm are characteristic of fine-grain, weathered soil. Thus, the three parameters, *i.e.*, ^{14}C, C/N ratio and χ_{fd}, show concordant trends. However, the low sampling resolution of this core does not allow us to see the finer variations in C/N ratio observed in Core 1M2-7.

Conclusions

Manasbal Lake shows a reasonably high sedimentation rate that allows high-resolution study of environmental records in the Himalayas. However, in lakes with rapidly eroding carbon-rich rocks, apparent ^{14}C ages do not indicate lacustrine sedimentation rates, but only the chronology of the allochthonous material. Thus, ^{14}C ages can also help in tracing the source of allochthonous material by correlating the ^{14}C ages of lake sediments of a particular stratum and the catchment rock strata of known ^{14}C age.

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