

Preliminary Paleoclimatological Records from High Mountain Lakes in Taiwan

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ABSTRACT

A sediment core obtained from the anoxic Great Ghost Lake at an elevation of 2150 m reveals interlaminated dark and light colored sediments. The brightest sediment has the smallest mean grain size ($9.9\mu\text{m}$; the mode is $10.5\mu\text{m}$), and contains the least vanadium (5 ppm), carbon (3.5%) and sulfur (0.026%). On the other hand, the darkest sediment has the largest mean grain size ($52\mu\text{m}$; the mode is $80.7\mu\text{m}$), and contains the most vanadium (13 ppm), carbon (16.3%) and sulfur (0.15%). Non-distinctive sediments are bimodal in size distribution and the chemical properties fall between the two extremes.

The relative brightness of the sediments seems to correlate with the paleoclimate in China. The darkest sediment corresponds to the warmest temperature and wettest period while the brightest sediment corresponds to the lowest temperature and driest period.

Another sediment core collected at the 1670 m high Yuen-Yang Lake shows similar signals but has lower frequency interlamination with a 450 year periodicity which is close to the 420-year solar oscillation cycle. Preliminary studies show that several other lakes may show similar low frequency interlamination.

1. INTRODUCTION

Regional and global climatic and environmental changes are expected within the Earth system in the next 50-100 yr. due to anthropogenic activities such as release of greenhouse gases (Chen and Drake, 1986; Chen and Lin, 1986). We believe that a better understanding of those changes that occurred in the not-too-distant past, including the Little Ice Age and the preceding warmer intervals, such as the so-called "Medieval Warm Interval" should provide important insights into the rates of future changes. Indeed, the International Geosphere-Biosphere Program (IGBP) recognized this potential and made the Past Global Changes (PAGES) one of the core projects (IGBP, 1992).

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Two streams were identified by PAGES. The objective of Stream I is to reconstruct the detailed history of climatic and environmental change for the entire globe for the period since 2000 BP, with temporal resolution that is at least decadal and ideally, annual or seasonal (IGBP, 1992). PAGES recognized that a clearer illumination of the global and regional changes that have occurred in the last 2000 yr. has many merits.

For instance, the period of most reliable climate history, now limited to at most a few centuries but not even one century in Taiwan, will be extended many times; it may be possible to distinguish human-induced changes in this period from natural responses to external forcing mechanisms and internal system dynamics, allowing calibration and estimation of anticipated human impacts, and by focusing on the period of overlap between written history and natural records, Stream I research will provide a solid basis which can be used to validate and interpret data from the more distant past (IGBP, 1992).

With the above in mind, we undertook a project to study lake sediments in order to obtain high resolution records because the sedimentation rates are generally higher in lakes than in oceans. It quickly became clear to us, however, that, without exception, low elevation lakes in Taiwan are polluted; the sediments are also much disturbed. We have, therefore, concentrated our efforts on subalpine lakes (Chen *et al.*, 1988), especially Great Ghost Lake, which is known to be anoxic below the thermocline (Wang, 1989). An anoxic environment offers many advantages for studies of past changes (Lin, 1992; Overpeck *et al.*, 1992).

Several of the cores reveal clear dark/light interlamination, but these are not varves. These layers are so distinctive that we feel their relative brightness could be useful in describing the cores. The heretofore-unreported relative brightness also correlates with many physico-chemical properties of the sediments. These changes may reflect paleoclimate variations.

2. SAMPLING AND EXPERIMENT

The Great Ghost (Ta-Kuei) Lake is situated north of Yao-Bye Mt. in Moulin, Kaohsiung County at 22°58'N, 120°48'E. This 2150 m high lake (Figure 1) is one of the best preserved natural lakes in Taiwan, with little pollution because of its isolation. It takes two days to reach it by foot from the nearest road. The sediments are well preserved as the deep water of the lake is anoxic most of the year. (Wang, 1989; Chen and Wang, 1990; Wang and Chen, 1990).

The lake sits in a basin with slope averaging 25°. The drainage area is approximately 6.5 times the surface area of the lake, which reaches 40 m at the deepest part and averages 15.4 m.

The area belongs to the Miocene Lushan Formation (Ho, 1986) composed mostly of argillite and slate. The environment is humid, surrounded by forest and covered with moss. A 82-cm long core was collected in March, 1992 with a home-made gravity corer. The water depth of the sampling site was 30 m. This core was studied in detail and the results are discussed below. Two longer cores (110 cm and 210 cm) were collected subsequently but have not been examined in detail.

Another 120 cm sediment core was collected in Jan. 1992 at the 1670 m high Yuen-Yang Lake. The water depth was 4.3 m. The lake is located at 24°34'50"N, 121°23'50"E. Local strata are composed by Eocene to Oligocene slate and phyllite (Ho, 1986). The environment is also humid, surrounded by forest and covered with moss.

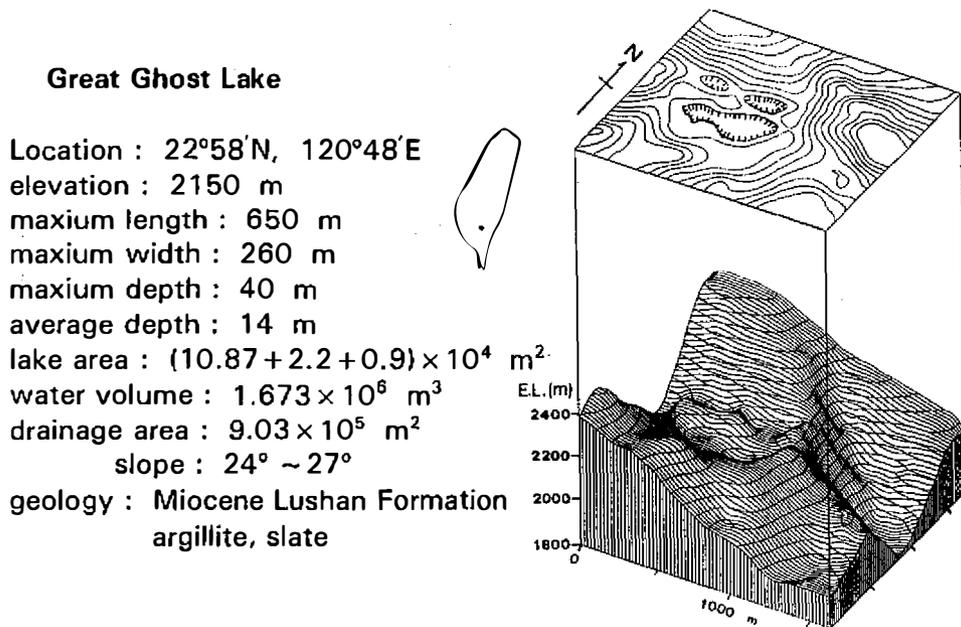


Fig. 1. The topography of Great Ghost Lake.

The cores were sealed by wax immediately after recovery and then opened at the home laboratory by cutting with a fishing line. The Relative Brightness Index (RBI) was measured by a home-made MG-X brightness counter system which essentially measures the light intensity reflected by the sediment from a cold light source. The grain size was measured by a Coulter LS-100 particle sizing system. The total carbon and total sulfur were measured by the LECO CS-244 element analysis system. Acid-leached trace metals were measured by an ICP-MS. Carbon-14 dating was done by both conventional and AMS methods.

3. RESULTS AND DISCUSSION

The 82-cm core from the Great Ghost Lake was well preserved with clear horizontal lamination. The upper 20 cm has several dark/light colored interlamination. Below 20 cm the dark, coarse sediments dominate, but 1-2 cm thick light-colored fine sediments appear at 21, 55, 66, and 77 cm depth with clear and sharp boundaries. Twigs and small fragments of leaves are frequently found beneath the light layers. This may suggest a dry or cold period causing defoliation. The fragments were then transported to the lake and were subsequently buried by fine, light-colored sediments. The boundaries are sharp, suggesting rapid or catastrophic changes on a scale of one or two years or even shorter. The longer cores indicate that approximately 4 cm was lost from the core top of the 82-cm core.

Figure 2 shows the grain-size distribution. Most particles are larger than $4\mu\text{m}$ in diameter but fewer than 10% are larger than $200\mu\text{m}$. There are three types of grain-size distributions. The darkest sediment is the coarsest and has a single mode at $80\mu\text{m}$ and a mean grain size of $52\mu\text{m}$. The lightest sediment is the finest and has a mean grain size of

9.9 μm and a single mode at 10.5 μm . The non-distinctive sediments are bimodal and are mixtures of bright and dark sediments. X-ray diffraction studies do not show any difference in the mineral types of the light and dark sediments (Figure 3).

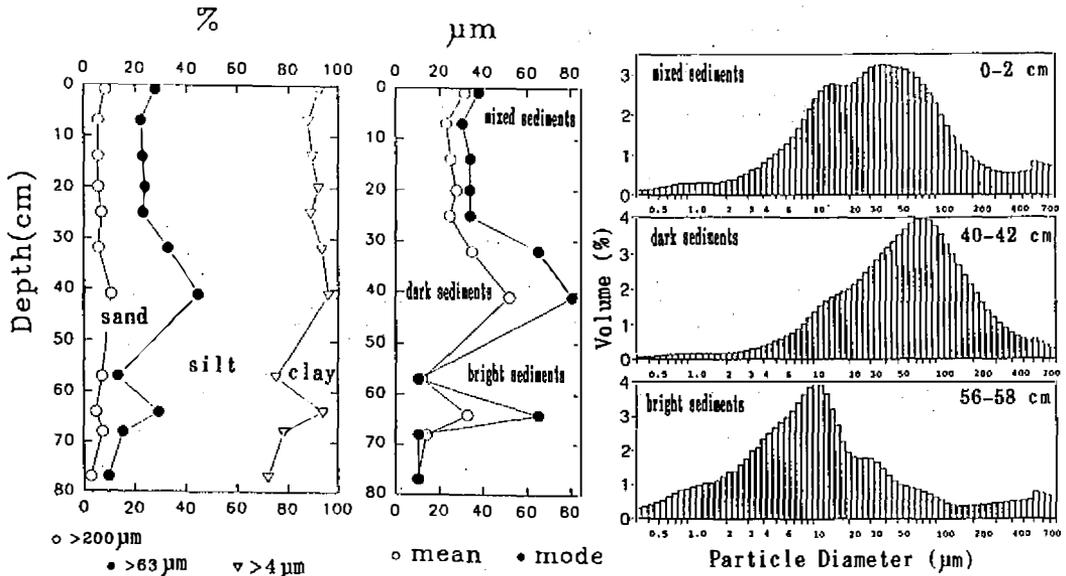


Fig. 2. The grain size distribution of sediments collected at Great Ghost Lake.

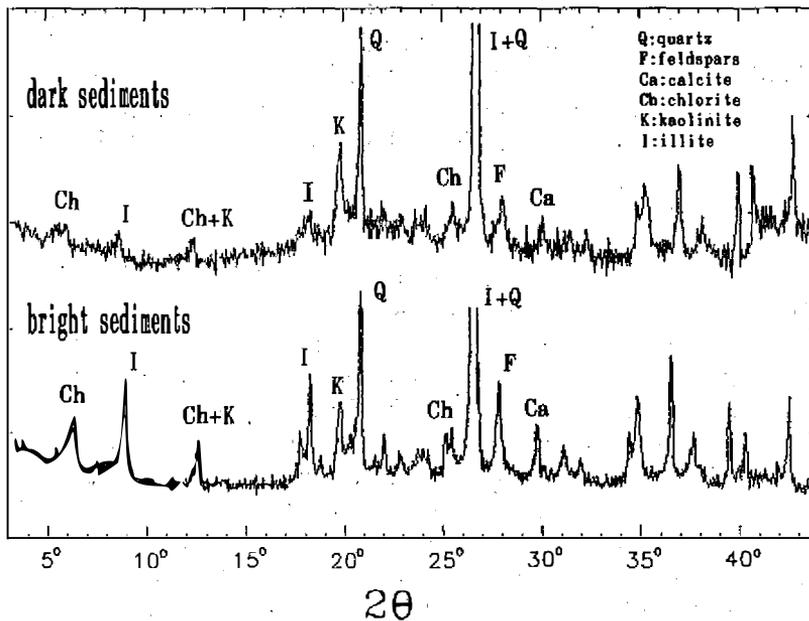


Fig. 3. X-ray diffraction records of the dark and bright sediments.

Normally finer sediments contain more organic carbon but at Great Ghost Lake the total carbon content correlates positively with both grain size and total sulfur content (Figure 4). The lightest (smallest) sediments have the lowest total carbon (3.5%) and sulfur (0.026%). The darkest (coarsest) sediments have the highest total carbon (16.35%) and sulfur (0.15%).

Figure 5 shows the RBI profile where the highest RBI correlates with the smallest grain size and the lowest carbon and sulfur contents. The lowest RBI correlates with the coarsest grain and the highest carbon and sulfur contents. It is interesting to note that the RBI seems to reflect the accumulative humidity index in Eastern China (P. Y. Zhang, 1993; personal communication). The highest RBI falls at the driest period and the lowest RBI falls at the wettest period. This may be coincidence but on the other hand may have a physical explanation, namely that the source of the bright sediments is Asian dust or that a cool period results in finer, brighter sediments.

Since the cool period in China is also the driest, dust may be transported farther and to a larger extent. As a result, finer aeolian particles settle down to form the sediments. During the warm and wet period, a smaller percentage of fine aeolian particles reaches Great Ghost Lake, resulting in coarser sediments.

The alternative hypothesis is that if the precipitation pattern in China is also valid at Great Ghost Lake then it may be argued that runoff from lighter rain transported only smaller particles to the lake from the drainage area. On the other hand, runoff from heavier rains was energetic enough to transport coarser particles to the lake. The mineralogy of all sediments is the same, which is consistent with the above argument (Figure 3).

We also compared the RBI with the 1500-year decadal paleoclimate records of Quelccaya Ice Cap in Peru. High RBI periods occur at approximately the same time that the ice cap accumulated more particles, had higher conductivity, lower $\delta^{18}\text{O}$ but higher ice accumulation, all suggesting colder, drier periods (Figure 6).

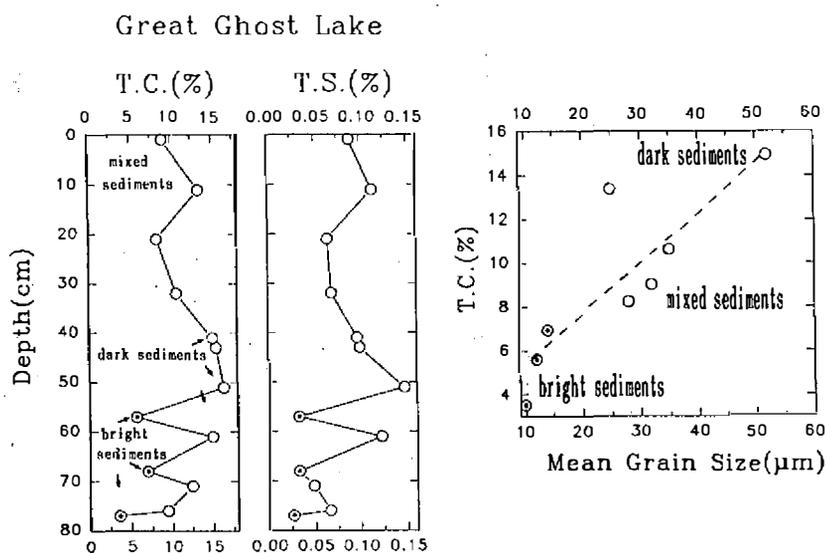


Fig. 4. Vertical profiles of total carbon (T. C.) and total sulfur (T. S.), and correlation between T. C. and mean grain size.

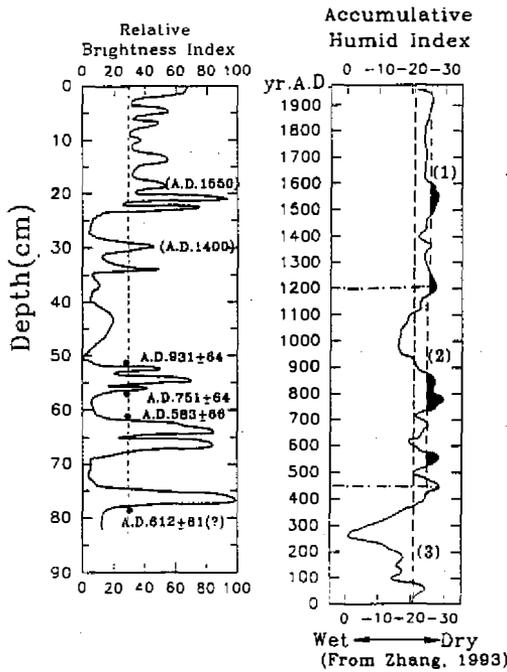
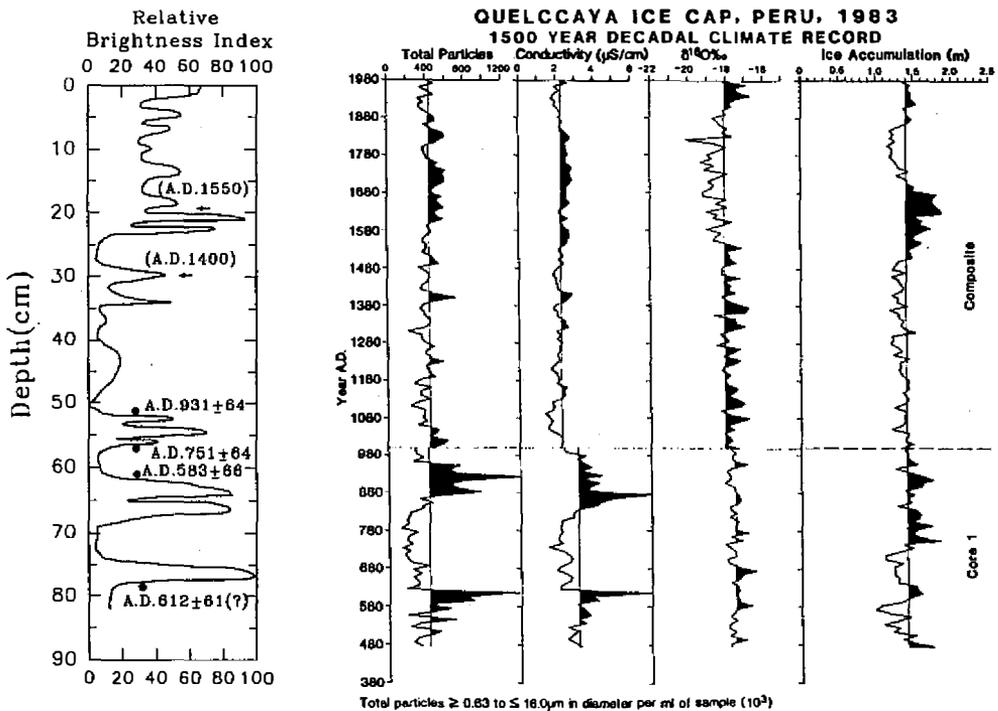


Fig. 5. Relative brightness index of sediments collected from the Great Ghost Lake and the accumulative humidity index (AHI) in China. The C-14 dates are marked. The dates in parentheses are approximate values estimated by assuming constant rate of sedimentation. The dashed line (1) is the average AHI between the present and 1200 A. D.; line (2) is the average between 1200 A. D. and 450 A. D.; line (3) is the all-time average.



(From Thompson and Thompson, 1992)

Fig. 6. RBI and Quelccaya Ice Cap records.

In order to help us to identify the sources of particles, we analyzed acid leached heavy metals. Vanadium seems to show a trend (Figure 7) which correlates with the RBI curve. Brighter sediments have lower V content and darker sediments contain more V. The significance is not yet clear except that the dusts contain low V (<1%; Arimoto *et al.*, 1989). Biological activities in the lake may concentrate V in the organic matter, thus darker sediments contain higher V.

The RBI of sediments taken from the Yuen-Yang Lake shows a lower frequency interlamination at a period of roughly 450-yr based on C-14 dating of total organic matter in the sediment (Figure 8). The period is similar to the 420-yr solar oscillation cycle (Schatten, 1988; Stuiver and Braziunas, 1989). Sediments in several other lakes, such as Ma-Lin-Ku Lake, show similar trends. This may suggest that visual assessments of the brightness provide a new approach for extracting quantitative paleoclimatic information from lake sediments. More C-14 dating and detailed study are planned to reveal the significance of this similarity.

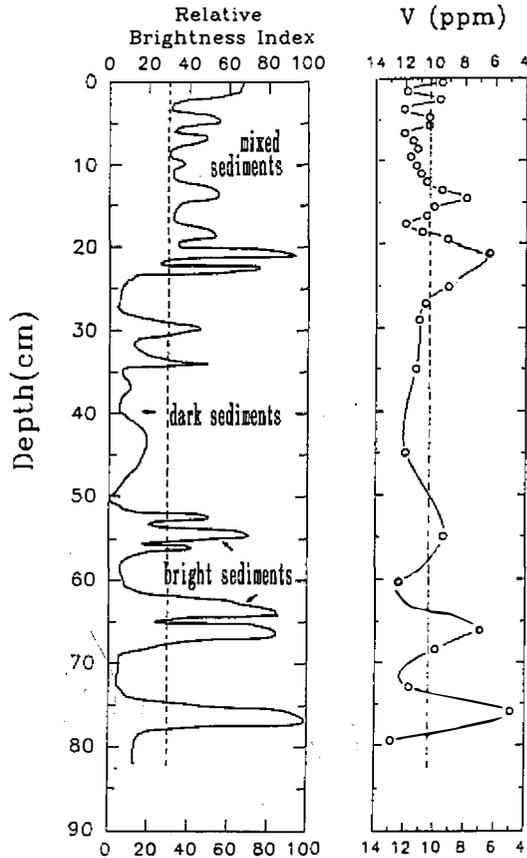


Fig. 7. RBI and acid-leached vanadium of sediments collected from Great Ghost Lake.

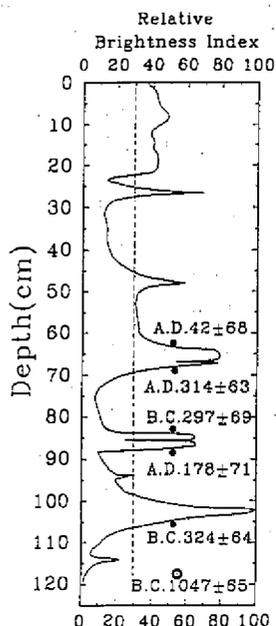


Fig. 8. Relative brightness index of sediments taken from the Yuen-Yang Lake. C-14 dates are marked.

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