CHINESE GEOGRAPHICAL SCIENCE
Volume 12, Number 3, pp. 249 – 253, 2002
Science Press, Beijing, China

RELATIVE BRIGHTNESS INDEX AND IT'S CLIMATIC SIGNIFICANCE FROM LACUSTRINE SEDIMENT OF NAPAHAI LAKE, NORTHWESTERN YUNNAN PLATEAU, CHINA

YIN Yong[1], FANG Nian-qiao[2], HU Chao-yong[3], NIE Hao-gang[2], QING Zun-li[2]
(1. The Key Laboratory of Coast & Island Development, Nanjing University, Nanjing 210093, P. R. China; 2. China University of Geosciences, Beijing 100083, P. R. China; 3. China University of Geosciences, Wuhan 430074, P. R. China)

ABSTRACT: Information on the palaeoenvironment from Late Pleistocene to Holocene in northwestern Yannan Plateau has been deduced from a study of a 28. 81m-long core taken from Napahai Lake. The results from Relative Brightness Index (RBI) as well as those from the lithological analyses of bulk sediments, total organic carbon and granulometric analyses have been used to reconstruct the environmental and climatic evolution of the area. The ages were provided by three ^{14}C datings. The record suggested a climate fluctuation between warm-dry and cool-wet from ca. 57 to 32ka B. P., which led a shallowing and swamping of the lake. The water level again increased quickly at ca. 32ka B. P., reached it's peak during LGM (Last Glacial Maximum, ca. 18-20ka B. P.) and remained relative high until ca. 15ka B. P. The high water level at LGM is attributed to cold-wet conditions. The area experienced an abrupt and unstable climatic changes during the transition period from 15 to 10ka B. P. with a dominated littoral environment. A warm-dry climate led to the contraction of the lake during the Holocene and reed-swamps became dominant. After a minor wet-cool pulse during the Late Holocene, the modern climate became to be established.

KEY WORDS: Relative Brightress Index; total organic carbon; particle size; palaeoclimate; Napahai Lake

CLC number: P532　　Document Code: A　　Article ID: 1002-0063(2002)03-0249-05

1 INTRODUCTION

Reflectance spectroscopy technique is a rapid, non-intrusive analytical technique based on the characteristic absorption of light by the constituents of detected substance. Relative Brightness Index (RBI) is a parameter of quantifying the amount of light returned from the sample(MIX *et al.*, 1991). Reflectance spectroscopy has been widely used in mineralogy (HUNT, 1977; GAFFEY 1986) and remote sensing since the 1970s (CLARK and ROUSH, 1984; BISHOP *et al.*, 2001). It has been used to determine the character of marine, desert and lacustrine sediments and soil, loess, and to correlate core logs(WANG and GAO, 1984; AGRESTI *et al.*, 1986; BISHOP *et al.*, 1996). For example, since 1990 the Ocean Drilling Project (ODP) has been equipped with a spectrometer on board laboratory to measure the RBI of sediments for environmental and climatic interpretation(MIX *et al.*, 1991).

A applied reflectance spectroscopy study of Chinese Loess Plateau shows that the RBI of loess has a good correlation with magnetic susceptibility, particle size, TOC (Total Organic Carbon) content, ferric and calcium oxides and can be used as a proxy indicator of palaeoclimate (GAO *et al.*, 1990). Another successful example is the palaeoclimatic reconstruction using Relative Brightness Index (RBI) in mountain lakes of Taiwan (LOU *et al.*, 1997; LOU and CHEN, 1997). The RBI is found to have a good relationship with sediment constituents, especially with sediment hue. The dark color layers exhibit lower RBI values indicating

Received date: 2002-04-29
Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 49672135)and National Key Project for Basic Research (No. G1998040800).
Biography: YIN Yong (1964 –), male, a native of Wuxi, Jiangsu Province, senior engineer, post-doctor research fellow of the Key Laboratory of Coast & Island Development, Nanjing University. His research interests include climate change and monsoon. E-mail: yinyong@nju.edu.cn

warm-wet conditions and vise-versa, the light color layers exhibit high RBI values indicating cold-dry conditions (LUO *et al.*, 1997; LUO and CHEN, 1997). This paper presents a palaeoenvironmental and palaeoclimatic reconstruction based on RBI measurements as well as TOC content and particle size data obtained from a continuous and carbon-dated lacustrine core from the dried bed of Napahai Lake, Yunnan Province. It suggests a wet-cold LGM and a warm-dry Holocene in northwestern Yunnan Plateau.

2 ENVIRONMENTAL OUTLINE

Napahai Lake (27.5°N, 99.5°E) is located in the hinterland of the Hengduan Mountains, northwestern Yunnan Plateau. The climate of the area is controlled by Indian Ocean Monsoon. The average monthly temperature of the area is about −3.8°C in January and about 13.2°C in August, with lowest temperature of −15°C in January and highest of 30°C in August respectively. The annual average temperature is estimated at about 5.4°C and the annual average precipitation is around 600mm. The rainfall is concentrated on rainy season from July to October, accounting for 84.8 percentage of annual precipitation (ZHENG, 1988).

The lake developed at an altitude of 3300m. It is believed to have formed by long-term solution of calcareous strata (WANG and DOU, 1998). The lake area has rapidly contracted since the Late Pleistocene and now mostly dries up and is covered with terrestrial herbaceous plants and aquatic plants in lake center. The present area of the lake is less than 5km^2 and its maximum depth is less than 0.5m.

Because of lack of rivers, the inflow of the lake is from surface runoff, precipitation and groundwater seepage. According to the survey around the catchment, water level of Napahai Lake in wet season is several times that in dry season (WANG and DOU, 1998).

3 METHODS

A 28.81m-long core was drilled on the northeastern flank of the basin. Samples (165) were taken at 20cm intervals throughout the core for analysis.

Samples were oven-dried at 60°C for 12 hours and then grinded into powder with an agate pestle. Sample preparation for the spectral measurements involved pouring the ground material into a sample dish of 12mm in diameter and 3mm in depth. For each sample, the dish was tapped gently on a hard surface to settle the particles without smoothing, so that a natural surface texture was presented. Reflectance spectra were measured in a Hitachi-577 spectrometer in the Testing Center of China University of Geosciences (Wuhan). The light is divided into spectral components by a monochromator and detected by a photomultiplier tube. In the case of study, we used yellow and violet band monochromatic light sources. To eliminate transmission effects of the instrumentation, reflectance from the sample is compared to reflectance from a white standard. The result is a unitless quantity termed relative reflectance. Relative standard deviation is less than 5%. RBI data in spectral area of 440nm band and 560nm band were obtained and they showed a good correlation.

Samples for ^{14}C dating were based on humic materials at 3.75m, 4.05m and 16.6m depth. Their respective measured ^{14}C ages were 11 220 ± 130a B.P., 13 820 ± 130a B.P. and 35 270 ± 1140a B.P. Ages for other layers could be interpolated and extrapolated (Fig. 1).

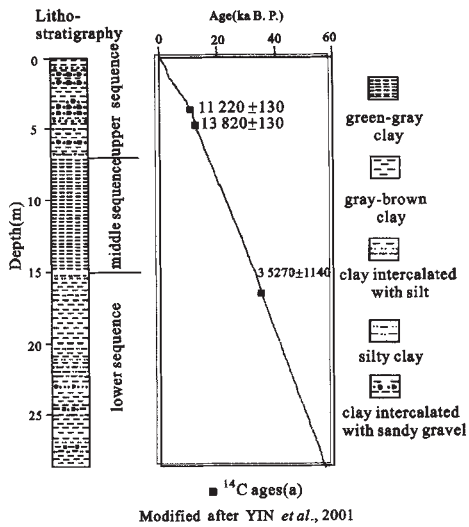


Fig. 1 Litho-stratigraphy of the core and profile of ages against depth from Napahai Lake

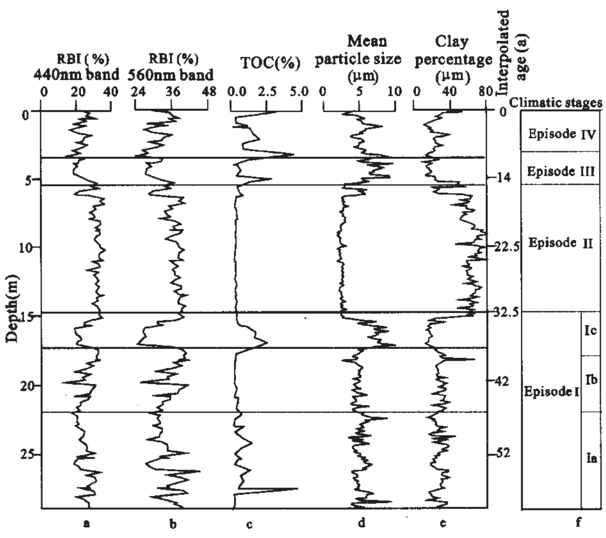
4 RESULTS ANALYSIS

4.1 Core Material

The core is composed of a continuous accumulation of gray-yellow and gray-brown clay intercalated with a few layers of silt, fine sand and pebbles. Three major units were observed from bottom to top (Fig. 1): 1) The base of the sequence (28.81 − 14.99m) mainly consists of gray-green and gray-brown clay intercalated with silty clay, silt and pebbles of 2 − 5mm in diameter. It contains molluscs shells and plant detritus, suggesting a littoral environment interrupted by a swampy environment on the top of the sequence. 2) Laminated, homogeneous and olive-green clay with lower content of organic carbon and free of coarse sediments are presented between 6.06m and 14.99m possibly formed in deeper water setting. 3) The upper unit (0 – 6.06m) is composed of gray-olive and gray-dark clay intercalated with yellowish-brown sandy gravels, with plant detritus and humic-bearing layers (possibly peat material) on the top, middle and bottom of it (YIN *et al.*, 2001). Diatoms with high diversity in species and low abundance have been observed at 1.59m depth.

4.2 RBI Variations and It's Palaeoclimatic Significance

RBI values as well as TOC content and mean particle size are plotted against depth in Fig. 2. Two sets of RBI values of samples in 440nm wavelength (violet band) and 560nm wavelength (yellow band) respectively are shown in Fig. 2a and Fig. 2b, and they show a good correlation. TOC values reach their peaks at the base, middle and top of the core, and range from 0.05% to 4.5% with an average of 0.65% (Fig. 2c). Mean grain size ranges from 1.8μm to 4.6μm with average of 2.5μm (Fig. 2d). Samples from the lower and upper part of the core contain more coarse fractions than those from middle part of the core.



(a) Relative Brightness Index of 440nm band; (b) Relative Brightness Index of 560mm band (c) Total Organic Carbon; (d) Mean grain size; (e) Clay content of less than 5μm in diameter; (f) Climatic stages

Fig. 2 RBI, TOC, grain size, clay percentage and climatic stages from Napahai Lake

Spectral signatures of a substance are controlled by chemical elements, mineral constituent, grain size, water content and surface physical signature (GAO *et al*, 1990). In the case of the material from Napahai Lake, the RBI of bulk sediments has a close relationship with TOC content, mean grain size and clay content (less than 5μm). Furthermore, the RBI has a negative correlation with TOC content with a coefficient of –0.43 and has a positive correlation with clay content (<5μm in diameter) with a coefficient of 0.52.

The mechanism of RBI values against environmental changes can be tentatively explained as below. During lowing water stages and swamping of the lake area, peat layers and plant debris are concentrated on the deposits, and this results in TOC content increasing and darkening the hue of the sediments. During higher water stages, the amount of aquatic and peat layers decline and so may the TOC content. In our core, the increase of RBI values correlates with TOC content and clay content decreasing, therefore identifying low level water stages. Conversely, the decrease of RBI values corresponds to TOC decreasing and clay content increasing, indicating water body rise (Fig. 2). So we predicated that temperature rise and drop induce humidity drop and rise respectively in the region. The pollen data of Heqing basin in the same region (YANG *et al.*, 1998) supports our hypothesis.

4.3 Climatic Changes During the Last 57ka

According to RBI, TOC and particle size data, the major climatic changes of Napahai Lake may be interpreted as follows (Fig. 2).

(1) A warm/dry and cool/wet fluctuation episode from ca. 57 to 32ka B.P.

The climatic indicators show great change especially for RBI, suggesting climate instability during these times. The low RBI value coincided with high TOC content and coarse particle size, indicating water level declining, and warm/dry climate. The high RBI value coincided with low TOC content and fine particle size, inferring water level increasing and cold/moist climate (Fig. 2). Three sub-episodes can be detected according to the fluctuation of RBI, TOC content and grain size data. Sub-episode Ia and sub-episode Ic were characteristics of temperate/dry in contrast to a cool/moisture climate developed in sub-episode Ib. Minor pulses of cool/moist in smaller amplitude were observed in sub-episode Ia. Numerous gastropod shells as well as ferric bands occurred at 15.5m, 17.1m, 18.5m, 20m, 24.2m, 26.3m and 27.5m depth support the interpretation that littoral environment characters the interval.

(2) A cold/humid episode from ca. 32 to 15ka B. P.

The abrupt increase in RBI value was attributed to TOC content declining and clay content increasing in response to water level rise (Fig. 2). Little variation in RBI, TOC and particle size (mean and medium) indicated a stable sedimentary environment. Several millimetric silty clay bands alternating with clay bands were observed around 6. 6 – 7. 9m and 9. 7m. They indicated that there was a deep lake environment in Napahai Lake. We thought that the water level rise resulted from the humidity increase according to the pollen data of Heqing basin in the region (YANG *et al.*, 1998) and the lake level statistic data of western China (YU *et al.*, 2001) .

(3) Temperature rise and climate instability from ca. 15 to 0ka B. P.

A good correlation was observed between drop of RBI value and increase in TOC content and sand percentage (Fig. 2), which reflected the increase in temperature and decrease in humidity. The cool/wet pulse reflected the instability of the climate in the transitional period between 15 to 10ka B. P., which was consistent to global atmosphere changes. We thought that a littoral environment replaced former deep lake environment due to a great drop in water level.

(4) Holocene period from ca. 10 to 0ka B. P.

The abrupt decrease in RBI value, the increase in TOC content, the decrease in average particle size and the increase in clay content took place in early to middle Holocene (Fig. 2). It strongly suggests the temperature inclining and humidity declining. And as a result, reed swamp developed within Napahai Lake. A wet/cool pulse of minor amplitude was indicated by the increase in RBI value and decrease in TOC content before the establishment of modern conditions around ca. 3ka B. P. After that, a temperate/dry climate dominates the research area shown by abrupt increase of TOC on the top of the core (Fig. 2) .

5 DISCUSSION AND CONCLUSION

The stages of climatic evolution recorded in lacustrine sediments of Napahai Lake correlate in part with oxygen isotopes stages of the North Atlantic. This indicates that the climate of this area since the Late Pleistocene has been controlled by global climate changes.

The climatic fluctuation recorded in Napahai Lake area from 57 to 32ka B. P. was similar to those identified by pollen analysis in Heqing Basin (YANG *et al.*, 1998) and Tengchong basin in northwestern Yunnan Province (QIN *et al.*, 1992), which had some similarities with oxygen and carbon isotope records from the Arabian Sea (VAN CAMPO, 1982).

Napahai Lake experienced a higher water level, with temperature declining and moisture increasing drastically between 32 and 15ka B. P. The proxy record shows that the drastically cooling in the area occurred before oxygen isotope stage II (Fig. 2). Pollen data from Heqing Basin document that distinct cooling may have started from 27ka B. P., thus before the LGM (YANG *et al.*, 1998). The record suggests that during LGM the water levels of Napahai Lake remained high and the regional climate was cold and humid . Our results support the hypothesis of LI(1990) and the interpretation of lake profiles by HAN and ZHONG (1991), who proposed wet-cold conditions during the LGM in northern Xinjiang. They also support the hypothesis of YU *et al.* (2001), who proposed a wet-cold climate during LGM in western China based on the lacustrine data.

The increasing humidity associated with decreasing temperature during LGM contrasted with the East Asia Monsoon regime and the north Europe case. This behavior may be attributed to the plateau geomorphology of the studied area, and the atmospheric circulation and climatic changes that occur with altitude in northwestern Yunnan Plateau. As a result of cooling at high latitudes during LGM, the meridional temperature gradient and baroclinity of the north continent could have been steepened (PACHUR *et al.*, 1995). They forced westerly migrating toward south(YU *et al.*, 2001) and promoted the penetration of the cold air-masses (PORTER and AN, 1995), so that a more intense atmospheric circulation was likely. An increased mass exchange between cold/dry air from the northern continent and the water vapor from the north Indian Ocean induced intense cyclonic precipitation in the studied area.

The rise in temperature that occurred around ca. 15ka B. P. is in phase with the abrupt increase of Methane recorded in Greenland Ice Cores (CHAPPELLAZ *et al.*, 1993) and carbon dioxide in Vostok ice core in Antarctic (PETIT *et al.*, 1999).

The climatic indicators of Napahai suggest that the lake environment experienced a major change around 12 to 10ka B. P. We have ascribed primarily to dry/warm conditions, but the effect of tectonics cannot be totally ruled out (WANG and DOU, 1998). Our results support the hypothesis of LI (1990) and HAN and ZHONG (1991), who proposed warm-dry climate during the Holocene in northern Xinjiang. Also, this period was synchronous with a regression event recorded in many lakes of northwestern Yunnan Plateau since the Late Pleistocene (WANG and DOU, 1998).

ACKNOWLEDGMENTS

We are grateful to Prof. WANG Su-min for his critical review of the manuscript. We are also grateful to Prof. I. Peter Martini for his critical review and providing critical comments on the manuscript.

REFERENCES:

AGRESTI D G, MORRIS R V, NEWCOMB J A *et al.*, 1986. Spectral properties of selected soils from the dry valleys of Antarctica[J]. *Lunar Planetary Science*, 17: 3 – 4.

BISHOP J L, KOEBERL C, KRALIK C *et al.*, 1996. Reflectance spectroscopy and geochemical analyses of lake Hoare sediments, Antarctica[J]. *Geochimica et Cosmochim Acta*, 60: 765 – 785.

BISHOP J L, LOUGEAR A, NEWTON J *et al.*, 2001. Mineralogical and geochemical analyses of Antarctic lake sediments: A study of reflectance and Mossbauer spectroscope and C, N, and S isotopes with applications for remote sensing on Mars [J]. *Geochimica et Cosmochim Acta*, 65: 2875 – 2897.

CHAPPELLAZ J, BLUNIER T, KINTS S *et al.*, 1993. Synchronous changes in atmospheric CH4 and Greenland climate between 40 and 8 kyr B. P. [J]. *Nature*, 366, 443 – 445.

CLARK R N, ROUSH T L, 1984. Reflectance Spectroscopy: Quantitative analysis techniques for remote sensing applications[J]. *J. Geophys. Res*. 89: 6329 – 6340.

GAFFEY S J, 1986. Spectral reflectance of carbonate minerals in the visible and near infra-red (0. 35 to 2. 55 microns): Calcite, aragonite, and dolomite[J]. *Am. Mineral*, 71: 151 – 162.

GAO Wan-yi, SUN Dong-huai, LUO Xiu-yue, 1990. Preliminary study on reflectance spectroscopy of loess[A]. In: LIU Dong-sheng (ed.). *Loess, Quaternary Geology and Global Changes (First Volume)*[C]. Beijing: Science Press, 101 – 108. (in Chinese)

HAN Shu-ti, ZHONG Wei, 1991. *Discussion on Late Pleistocene Climate Around Bailikun Lake, Northern Xinjiang, China* [M]. Dep. Geo. Univ. Xinjiang, 122 – 137. (in Chinese)

HUNT G R, 1977. Spectral signatures of particulate minerals in the visible and near infrared[J]. *Geophysics*, 42: 501 – 513.

LI Ji-jun, 1990. The patterns of environmental changes since the Late Pleistocene in northwestern China[J]. *Quat. Sci.*, 3: 197 – 204. (in Chinese)

LOU Jian-Yu, CHEN Zhen-tong Arthur, 1997. Climatic and environmental changes during last 4000 years recorded in mountain lake of Taiwan[J]. *Science in China (D Series)*, 27 (4): 366 – 372. (in Chinese)

LOU Jian-Yu, CHEN Zhen-tong Arthur, WANN Jen-kang, 1997. Paleoclimatological records pf the Great Ghost Lake in Taiwan [J]. *Science in China (D Series)*, 40 (3): 284 – 292.

MIX A C, RUGH W, PISIAS N G *et al.*, 1991. Color reflectance spectroscopy: a tool for rapid characterization of deep sea sediments[A]. In: MAYER L, PISIAS N, JANECEK T *et al.* (eds.). *Proc. ODP init Repts*[C], 138: 67 – 77.

PACHUR H J, WUNNEMANN B AND ZHANG Hu-cai, 1995. Lake evolution in the Tengger Desert, northwestern China, during the last 40, 000 years[J]. *Quaternary Research*, 44: 171 – 180.

PETIT J R, JOUZEL J, RAYNAUD D *et al.*, 1999. Climate and atmospheric history of the past 420 000 years from the Vostok ice core, Antarctica[J]. *Nature*, 399: 429 – 436.

PORTER S C, AN Z S, 1995. Correlation between climate events in the North Atlantic and China during the last Glaciation[J]. *Nature*, 375: 305 – 308.

QIN Yong, FEI An-wei, JIN Kui-li *et al.*, 1992. Late Pleistocene sporopollen assemblages and evolution of palaeovegetation, palaeoclimate and palaeoenvironments in Tengchong basin, western Yunan[J]. *Marine Geology & Quaternary Geology*, 12(1): 109 – 118. (in Chinese)

VAN CAMPO E V, 1982. Climatic conditions deduced from a 150-kyr oxygen isotope-pollen record from the Arabian Sea [J]. *Nature*, 296: 56 – 59.

WANG Su-min, DOU Hong-shen, 1998. *Chinese Lakes*[M]. Beijing: Science Press, 580. (in Chinese)

WANG Yi-mo, GAO Peng-xun, 1984. The analysis of reflective spectrum of desert in Hexi corridor[J]. *Journal of Desert Research*, 4(1): 29 – 34. (in Chinese)

YANG Xiang-dong, WANG Su-min, TONG Guo-bang *et al.*, 1998. The late Pleistocene pollen record in the lake sediments from ancient Heqing lake and its significance for palaeoclimate [J]. *Quaternary Sciences*, 10(4):335 – 343. (in Chinese)

YIN Yong, FANG Nian-qiao, HU Chao-yong *et al.*, 2001. Palaeoenvironemtal evolution deduced from organic stable compositions of Napahai Lake sediments, northwestern Yunnan, China[J]. *Lake Sciences*, 13(3): 289 – 295. (in Chinese)

YU Ge, XUE Bin, WANG Su-min *et al.*, 2001. Preliminary study on LGM climate simulation and the diagnosis for East Asia [J]. *Chinese Science Bulletin*, 46: 364 – 368. (in Chinese)

ZHENG Du, 1988. A comparative study on physico-geographic conditions between the Himalayas and Hengduan mountainous regions[J]. *Mountain Research*, 6(2):137 – 161. (in Chinese)