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Radionuclide dating of recent sediment and the validation of pollen-environment reconstruction in a small watershed reservoir in southeastern China

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ABSTRACT

A 76 cm sediment core was collected from the Huangdong Reservoir (southeastern China). The radionuclides ^{137}Cs and ^{210}Pb and sediment grain size analysis were applied to establish the chronology and modern sedimentation rates. The chronology established by the ^{137}Cs time markers was consistent with the Constant Flux Constant Sedimentation (CFCS) model and the known time of dam construction (1960 AD) recognized from the curve of sediment grain size at the depth of 54 cm. The results show that the sedimentation rate of the Huangdong Reservoir is relatively high, implying that soil erosion and water loss were strong. The sedimentation rate before the construction of the reservoir was approximately 1.5 cm/a, which belongs to the fluvial flooding deposit. The rate decreased to approximately 1.0 cm/a during the reservoir deposition (since 1960s). Pollen and micro-charcoal analysis were performed to test the reliability of pollen-based environment reconstruction, including vegetation cover, deforestation, planting and fire disasters. The results of pollen and micro-charcoal indicated that the herbs (primarily Gramineae), ferns (such as *Dicranopteris*) and several trees (mainly *Pinus*) varied following chorography or historical records. We discovered that the most important indicators for local forest-cover changes are pollen concentration and the AP/NAP value (ratio of arboreal pollen to non-arboreal pollen). Human impact on forests is manifested by a sharp decrease in pollen percentage of trees and absolute pollen concentration. Forest fire events were recorded by the peaks of charcoal concentration and the C/P value (ratio of charcoal concentration to pollen concentration). For example, the massive deforestation and intensive fires during the Great Leap Forward movement and the Cultural Revolution are reflected by pollen and micro-charcoal spectra. This work testifies that radionuclide use as a dating method is applicable in southern China, and the ^{137}Cs method has demonstrated its reliability in the small reservoir setting in spite of low absolute values. The environmental proxies, such as grain size, pollen, and charcoal, are sufficiently sensitive to reveal local ecosystem changes caused by natural disasters or human activity.

1. Introduction

Lake and reservoir sediments contain rich information regarding local natural and human-influenced environmental changes, which potentially provides material that allows us obtain a temporal resolution as high as 1–10 years or even less because of the generally high sedimentation rate. During the past several decades, a large number of high-resolution sediment studies of multidisciplinary proxies exhibited successful results related to environmental reconstruction, which are valuable if only a reliable age model is established (Díaz Acencio et al., 2009; Tylmann et al., 2013). Several short-lived radiometric dating methods have been used to determine the modern sediment age. For example, the reliability of the ^{137}Cs method has been demonstrated in a large number of studies of lacustrine environments, whether sediment accumulation rates are uniform or non-uniform (Arnaud et al., 2006). ^{137}Cs is a man-made radionuclide created by the global fallout (particularly in the Northern Hemisphere) of particles from nuclear weapons and nuclear leakage accidents. The ^{137}Cs radionuclide has a half-life of 30.17 yr and has been redistributed globally as fallout since the onset of atmospheric nuclear weapons testing in the 1950s. Within the sediment horizons, two clear time markers, 1954 and 1963 (corresponding to the onset and the peak fallout of ^{137}Cs), are identified at most depositional sites (Ritchie and McHenry, 1990). The fallout of ^{137}Cs from the 1986 Chernobyl accident was primarily observed at sites in Europe and the western former USSR and has been used as a time marker for the sediments deposited in that year (Chu et al., 2005; Wieland et al., 1993). The atmospheric nuclear experiment in China in 1975 and the Chernobyl accident in the pre-Soviet Union potentially influenced the

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distribution of several zones in China (Zeng et al., 2009), such as Chenghai (Xu and Wan, 2001), Erhai Lake, Hongfeng Lake (Wan, 1999), Dong Lake (Yang et al., 2004) and Taihu (Liu and Wu, 2006). ^{210}Pb, with a half-life of approximately 22.3 yr, has been widely used for sediment dating and determining the sedimentation rates over the time scale of the last 100–150 years (Koide et al., 1972; Lu and Matsumoto, 2005; Robbins et al., 2000). However, the general assumption of the commonly used Constant Flux Constant Sedimentation (CFCS), Constant Initial Concentration (CIC) and Constant Rate of Supply (CRS) dating models is not always fulfilled in nature, which may result in unreliable chronologies (Smith, 2001). Despite a careful choice of the model, ^{210}Pb-based geochronologies should be validated by at least one different tracer that provides an unambiguous, independent time-marker such as ^{137}Cs (Anderson et al., 1987; Reinikainen et al., 1997; Smith, 2001). The two radionuclides can be combined to reduce the uncertainty in dating (Benninger et al., 1997).

As the recipient of the migrating materials in the watershed, sediments of lakes or reservoirs record abundant information concerning local human activities, climate disasters and vegetation succession. Pollen assemblages (Kutzbach et al., 1996; Leopold et al., 1982), grain size (Halfman and Thomas, 1984; Noren et al., 2002) and charcoal (Inoue et al., 2012; Long et al., 1998; Walsh et al., 2010) measurements are widely used in global lake sediment studies. Using pollen assemblages from lake or reservoir sediments, which are indicators of vegetation patterns in a watershed, past vegetation and environmental changes can be reconstructed. Pollen-based quantitative reconstructions are now well-developed and are becoming an important method in quantitative paleoclimate reconstruction (Seppä and Birks, 2002). Through the analysis of pollen assemblages and sediment charcoal in lakes or reservoirs, high resolution variation and abrupt events are easily compared with written historical documentation describing environmental changes, such as fires, deforestation, and agricultural developments, such as plantations, flooding and erosion (Liu et al., 2007). Previous studies have demonstrated that the lake sediment well revealed the past environment change and history of human impact on vegetations (Atherden and Hall, 1999; Cole and Mitchell, 2003; Dark, 2005).

In this paper, we elected to study a small and relatively closed reservoir in southeastern China, which has a notably limited watershed region. The ^{210}Pb and ^{137}Cs radionuclides and sediment grain size have been used to confirm the time scale and sedimentation rate. In parallel, pollen analysis was conducted to reveal the relationship between pollen-charcoal and local ecosystem changes. The local recorded land-use history helps to evaluate the reliability of environmental interpretation based on pollen and charcoal changes in the study region.

2. Study area

To establish the sediment age of lake sediment correctly and to perform pollen-based environmental reconstruction of the source area, we selected the Huangdong Reservoir, a small reservoir with limited watershed area. This reservoir is located near Liangjing village, which is middle-north of the Huiyang District of Huizhou City, Guangdong Province (Fig. 1). The catchment surface of Huangdong Reservoir is about 7 km^2. The reservoir covers a water area of approximately 0.8 km^2 with a total storage water capacity of 6 million m^3 (Chen and Tian, 2010). According to local chronicles, dam construction was officially completed and began to store water in 1960. The study area has a subtropical monsoon climate with annual precipitation reaching 2000 mm and a mean annual temperature of 22 °C. The reservoir is surrounded by mountains on three sides, and the dam is located at its northwest side.

The soil in the region is a kind of primarily lateritic red soil. The soil is acidic (pH $\approx$ 5), with low content of organic matter and relatively abundant elements of Fe and Al (Yang and Liu, 1994; Yang and Zhu, 2007). The soil texture is hard, cohesive with poor permeability. The local vegetation is composed of planted forests, secondary bushes and economic plantations. Due to a strong human disturbance, broadleaved natural evergreen trees have been greatly reduced in this environment. The most widespread forest is the aerial seeding pine forest (*Pinus massoniana*), accompanied by a wide distribution of *Dicranopteris dichotoma*, *Erigeron acer*, *Ageratum conyzoides*, *Rhodomyrtus tomentosa*, *Toxicodendron succedaneum*, *Ilex asprella* and others. Local economic fruit forests primarily include *Litchi chinensis*, *Dimocarpus longan*, *Mangifera indica*, *Musa paradisiaca*, *Citrus maxima* and *Chaenomeles speciosa*. The paddy fields and vegetable plots are located south of the reservoir, and the principal crops of this area are *Oryza sativa*, *Brassica campestris*, *Solanum melongena* and swamp morning glory. In the wasteland and wetland near the reservoir, herbs and aquatics are popular, such as *Setaria viridis*, *Miscanthus floridulus*, *Thysanolaena latifolia*, *Imperata cylindrica*, and *Cyperus rotundus*.

3. Materials and methods

A vegetation field survey was conducted in July 2010. With the help of field investigation and remote-sensing images, the ecotypes of the watershed region of Huangdong Reservoir are divided into five major types: pine forests, secondary bushes, fruit and economic forests, rice paddy fields and wetlands (Fig. 1c). Northeast of the reservoir, 76 cm of undisturbed core (HD) was obtained using a Russian corer. The GPS position of the sampling site is 22°57′16″N, 114°34′10″E (Fig. 1c), and the water depth of the coring site is 7.2 m.

To establish the chronology of the core, 26 subsamples for ^{137}Cs, total ^{210}Pb and ^{226}Ra measurements were taken. All wet sediment samples were placed in a pre-weighted plastic box with a volume of 2 cm^3 and were dried at 100 °C. Next, the dried samples were ground into a fine powder in a mortar and sent to State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences for radioactivity measurement. The total ^{210}Pb, ^{226}Ra and ^{137}Cs were measured using a high resolution, low-background and low energy γ-ray spectrometer and a high pure germanium semiconductor (EG&G ORTEC Instruments Ltd., USA). Radioactivity levels of ^{210}Pb were determined via gamma emissions at 46.5 keV. ^{226}Ra was determined with the 295 keV and 352 keV γ-rays emitted by its daughter nuclide ^{214}Pb after 3 weeks storage in sealed containers to allow radioactive equilibrium. ^{137}Cs radioactivities were measured with the 662 keV photopeak. The standard sources and sediment samples of known activity, provided by the Institute of Atomic Energy of China, were used to calibrate the absolute efficiencies of the detectors. This analytical process allowed us to measure ^{137}Cs and ^{210}Pb isotopes with detection limits of below 2 and 10 Bq kg^{-1}, respectively. Counting times of ^{137}Cs and ^{210}Pb were typically in the range 50,000–86,000 s, giving a measurement precision between approximately $\pm$5% and $\pm$10% at the 95% level of confidence, respectively. Supported ^{210}Pb in each sample was assumed to be in equilibrium with the in-situ ^{226}Ra, and unsupported ^{210}Pb ($^{210}Pb_{ex}$) activities were determined from the difference between the total ^{210}Pb and the supported ^{210}Pb activity (Arnaud et al., 2006; Bao et al., 2010; Lu and Matsumoto, 2005; Zhang et al., 2006).

Sediment grain size was measured with a Mastersizer 2000 laser grain-size analyzer that was manufactured by the Malvern Company. A total of 38 samples were taken at 2 cm intervals from the HD core. The procedure involves the following steps: (1) 10 ml of 30% H_2O_2 was added to a beaker containing 1–2 g of reservoir sediments to remove organic material; (2) 10 ml of 10% HCl was added to the sample for approximately 10 min to remove carbonates; (3) the sample residue was washed three times in water and later dried at 100 °C; (4) the sample was dispersed for approximately 15 min in an ultrasonic vibrator and then transferred to the laser grain-size analyzer (modified protocol of Konert and Vandenberghe, 1997; Xiao et al., 1995). The grain size grading system of the core was based on the Udden–Wentworth scale (Wentworth, 1922): sand (>63 μm), silt (4–63 μm) and clay (<4 μm). The percentages of sand-size, silt-size and clay-size fractions, as well