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Spatial variability and the controlling mechanisms of surface sediments from Nam Co, central Tibetan Plateau, China

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ABSTRACT

Sixty-six surface sediments were retrieved from Nam Co, central Tibetan Plateau, to evaluate the spatial variability of their distributions and controls across the entire lake. Grain size distribution, total carbon, total nitrogen, total sulfur, ^{210}Pb and ^{137}Cs activities, and carbon and oxygen isotopes of carbonate of the bulk sediments were analyzed, and the correlations among these variables, as well as water depth, were calculated. The results showed distinct spatial variability for all variables. The grain size distribution provides adequate information to reflect water energy levels within the lake. Based on these factors, the accumulation zone of Nam Co was distinguished from the erosional and transportation zones. The results indicate that the deep area (>80 m) of the central main basin and the centre of the eastern small basin serve as the accumulation zones in Nam Co. Water depth is the most important factor influencing the distribution of the surface sediments because all variables show different distribution patterns in shallow and deep areas. Additionally, river input, sediment focusing, grain size effects, and heterogeneous physicochemical features of the lake water, as well as possible currents within the lake, also play different roles that affect surface sediment characteristics. Water depth noticeably affects grain size and the δ^{13}C and δ^{18}O values of carbonate sediment, implying that these proxies could be used as indicators of lake level change. These findings are of significance for palaeoenvironmental interpretations when using these proxies.

1. Introduction

Sediment is not evenly distributed over the bed of most lakes, and various factors exist that influence the depositional processes in lakes (Sly, 1978; Downing and Rath, 1988; Anderson, 1990a). Theoretically, fine sediment particles are more prone to be distributed in deep water areas, whereas coarse materials dominate shallow regions due to the different energy levels within a lake with distance from sediment input point (Håkanson, 1982). As a result, a lake can typically be divided into three sedimentary zones: an erosional zone, a transportation zone, and an accumulation zone (Håkanson and Jansson, 1983). Based on some early studies, the term "sediment focusing" was introduced to describe the phenomenon that, in general, allows for more material to accumulate in deeper than in shallower areas of lakes. As a result, models have been constructed to predict the sediment focusing and redistribution in small lakes (e.g., Hilton, 1985; Hilton et al., 1986).

Many studies have evaluated the spatial variability of surface sediments in lakes with regard to aspects such as heavy metal distribution and sediment transport (Moore, 1980; Onyari and Wandiga, 1989), diatom assemblages (Anderson, 1990b, 1990c; Zalat and Vildary, 2005), geochemical records or fossil-fuel-derived pollutants (Hilton and Gibbs, 1984; Rose et al., 1998; Korsman et al., 1999), and pollen distribution (Debusk, 1997; Zhao et al., 2006). Vogel et al. (2010) analyzed the composition of recent sediments in Lake Ohrid (Albania/Macedonia) and suggested that sedimentation in this lake is controlled by geological catchment features, anthropogenic land use and water currents. In Laguna Potrok Aike, southern Patagonia, Argentina, the lake's wind-driven internal currents are believed to be the main influence on the surficial sediment distribution pattern (Kastner et al., 2010). Some mechanisms affecting sedimentary processes have also been distinguished, such as turbidity currents from delta foreslopes that affect deep water depositional pattern (Lamoureux, 1999). Reynoldson and Hamilton (1982) suggested that wind action could disturb bottom sediment, resulting in homogeneous sediments, whereas other studies suggested wind was a forcing factor for uneven sediment distribution patterns (Odgaard, 1993; Whitemore et al., 1996). Bacterial oxidation (Hilton and Gibbs, 1984), benthic animals' activity (Downing and Rath, 1988), industrial distribution and land use conditions (Boyle

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et al., 1998; Rose et al., 1998; Gälman et al., 2006) are all influencing factors that can affect the distribution of sediments.

Nam Co, the second largest lake in Tibet (Tibet Autonomous Region, China), has been considered an important site for both palaeoenvironmental changes and modern limnological studies in the past several years. Focusing on recent and long-term environmental changes, several cores have been retrieved from Nam Co, and palaeoenvironmental records or lake level fluctuations have been reconstructed for the Holocene period or more recent stages (Zhu et al., 2008, 2010a; Daut et al., 2010; Frenzel et al., 2010; Mügler et al., 2010; Li et al., 2011a; Kasper et al., 2012, 2013; Doberschütz et al., 2014). Wang et al. (2009) completed a survey of lake bathymetry and modern water physicochemical conditions. These studies have provided useful information for understanding the environmental evolution and the modern status of Nam Co. However, investigations of this lake are still insufficient with respect to the modern sedimentation patterns and related processes. Li et al. (2011b, 2012) and Wang et al. (2012a) illustrated the spatial distribution of rare earth elements, monohydrocalcite and organic matter and argued for their utility in palaeoenvironmental change studies. Nevertheless, the water energy level of Nam Co and the controlling factors of sediment distribution were still not sufficiently discussed.

The present study focuses on the spatial variability of surface sediments in Nam Co based on their physical and chemical properties like grain size, organic and inorganic carbon component, total sulfur, radionuclide activities (^{210}Pb, ^{137}Cs) as well as oxygen and carbon isotopes of carbonate. The main aim is to map lake surface sediments and to elucidate the controlling mechanisms on sediment distribution patterns. Moreover, the environmental significance of different proxies commonly used for lake palaeoenvironmental reconstruction will be discussed.

2. Materials and methods

2.1. Study area

Nam Co is a closed lake formed by Himalayan tectonic activity. It is located in the central part of the Tibetan Plateau (90°16′–91°03′E, 30°30′–30°55′N, Fig. 1) at an altitude of approximately 4718 m a.s.l. The lake and its drainage area were 1920 km^2 and 10,610 km^2, respectively, in the 1970s. Thus, the replenishment coefficient (the ratio of drainage area to lake area) of Nam Co is 5.53 (Guan et al., 1984). The rivers sourced by precipitation and meltwater from modern glaciers in the Nyainqentanglha range to the southeast of Nam Co form the main water supply. More than 60 rivers flow into the lake during the summer season, and most of them are distributed along the western and southern shores (Wang et al., 2010). The largest rivers originate from the Nyainqentanglha range to the southwest, whereas almost no rivers flow in from the north (Fig. 1).

The bathymetric survey showed a large and flat deep-water area in the central part of the lake, where the water depth is >95 m and the deepest recorded point is ~99 m (Wang et al., 2009, Fig. 1). Based on the calculated area from remote sensing images and water depth data, the water volume is estimated to be 783.23 × 10^8 m^3 and 863.77 × 10^8 m^3 for the years 1971 and 2004, respectively. Over the same period, the lake area increased from 1920 km^2 to 2015.38 km^2

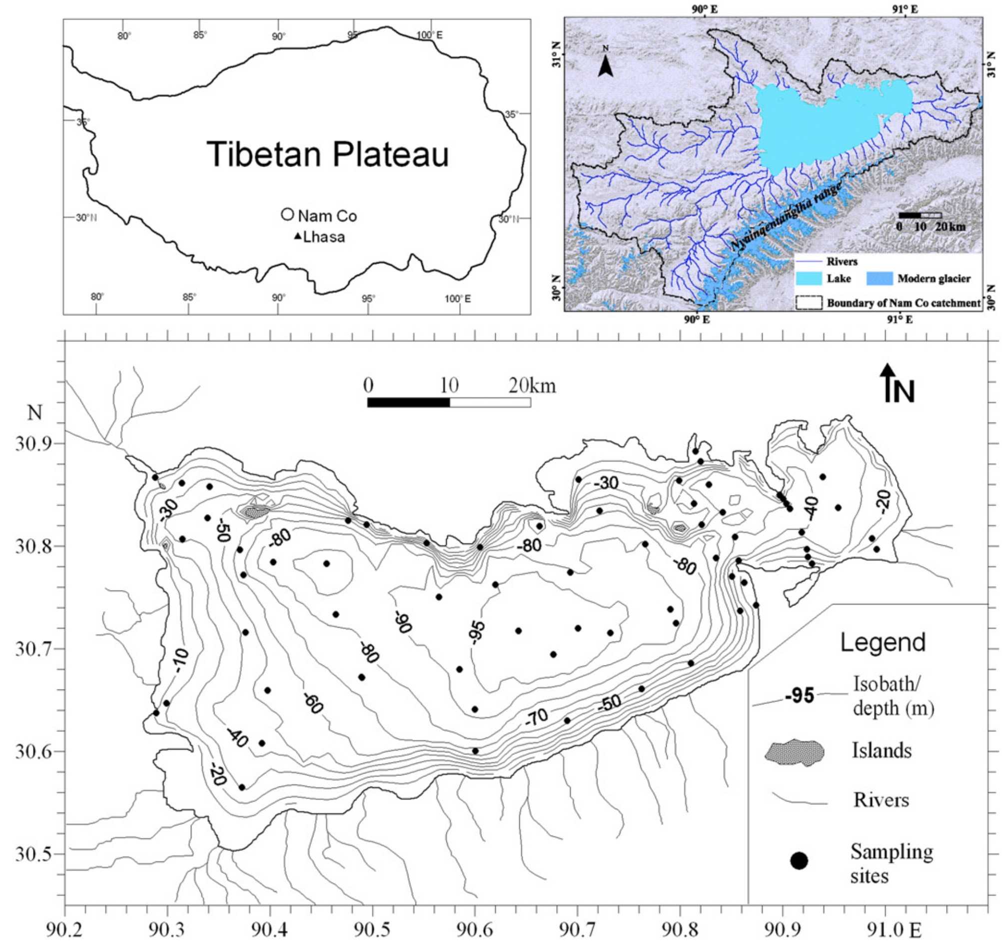

Fig. 1. Map of Nam Co showing the isobaths, the surface sediment sampling sites, and some main river inflows. The upper small maps show the location of Nam Co in the Tibetan Plateau and the catchment.