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The use of amino acid analyses in (palaeo-) limnological investigations: A comparative study of four Indian lakes in different climate regimes

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Abstract

In the present study, we report the results of comprehensive amino acid (AA) analyses of four Indian lakes from different climate regimes. We focus on the investigation of sediment cores retrieved from the lakes but data of modern sediment as well as vascular plant, soil, and suspended particulate matter samples from individual lakes are also presented. Commonly used degradation and organic matter source indices are tested for their applicability to the lake sediments, and we discuss potential reasons for possible limitations. A principal component analysis including the monomeric AA composition of organic matter of all analysed samples indicates that differences in organic matter sources and the environmental properties of the individual lakes are responsible for the major variability in monomeric AA distribution of the different samples. However, the PCA also gives a factor that most probably separates the samples according to their state of organic matter degradation. Using the factor loadings of the individual AA monomers, we calculate a lake sediment degradation index (LI) that might be applicable to other palaeo-lake investigations.

1. INTRODUCTION

Amino acid (AA) analyses yield reliable information about the state of organic matter degradation and organic matter sources in modern as well as in palaeo-sediments especially from the marine environment (Lee, 1988; Cowie and Hedges, 1994; Wakeham et al., 1997; Dauwe et al., 1999; Keil et al., 2000). This is due to the fact that specific AAs accumulate as a consequence of their production during degradation processes (e.g. microbial built-up) or their resistance to degradation processes (Lee and Cronin, 1984; Lee, 1988). They may, furthermore, be protected from degradation by incorporation into shell material or

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by sorption to mineral surfaces (Hecky et al., 1973; King, 1977; Müller and Suess, 1977; Carter and Mitterer, 1978; Hedges and Hare, 1987; Henrichs and Sugai, 1993). AA composition in marine samples is very similar in different regions, and variations depend mostly on the degradation state of organic matter. In contrast, the variations in AA composition are much larger in terrestrial influenced systems where sources of organic matter have a stronger imprint on AA spectra potentially complicating their interpretation (Meckler et al., 2004; Gaye et al., 2007; Unger et al., 2013).

Many attempts were made to summarise the degradation or source information that can be obtained by AA analyses in terms of individual indices that have universal applicability. Early information about the state of organic matter degradation gathered from AA analyses was based on the diminished concentration of AA in marine sediments with progressing sediment depth and the reduced percentage of nitrogen associated with AA (Emery et al., 1964; Kemp and Mudrochova, 1973; Whelan, 1977; Rosenfeld, 1979). Later, ratios between proteinogenic AAs and their respective degradation products or intermediates were used to assess the state of organic matter degradation (Henrichs et al., 1984; Ittekkot et al., 1984a). Also, the sensitivity of AA-based proxies to different stages of organic matter decomposition (Cowie and Hedges, 1994; Unger et al., 2005; Davis et al., 2009) and to different environmental conditions (Cowie et al., 1995; Nguyen and Harvey, 1997; Keil et al., 2000) was investigated. Based on the previous works, more complex degradation indices were invented as for example ratios of the sums of different protein and non-protein AAs (Jennerjahn and Ittekkot, 1997; Gupta and Kawahata, 2007) or the combination of the differences in molar percentage of individual AAs between samples and a reference data set, weighted on the basis of a principal component analysis (Dauwe and Middelburg, 1998; Dauwe et al., 1999). In a next step, AA-based indices were also applied to terrestrial systems (Das, 2002; Verma and Subramanian, 2002; Jennerjahn et al., 2004), and the adopted indices were tested and adapted to the different environments (Meckler et al., 2004; Ingalls et al., 2006; Menzel et al., 2013).

Early source information gathered from AA analyses was based on the preferential association of individual AAs with specific organisms, as for example bacteria (Schleifer and Kandler, 1972; Lee and Bada, 1977; Kandler, 1979), or biologically produced substances, such as chitinaceous (Degens and Mopper, 1975; Müller et al., 1986), calcareous (King, 1977; Müller and Suess, 1977; Carter and Mitterer, 1978; Ittekkot et al., 1984b), and siliceous (Hecky et al., 1973; King, 1977) matter. Ratios and sums of individual AAs were invented to characterise the dominant origin of organic matter in marine sinking particles and sediments (Ittekkot et al., 1984a; Müller et al., 1986; Lomstein et al., 2006).

Source indicators may be even better applicable in lakes than in the marine realm as terrestrial and aquatic organic matter has specific compositions (Degens and Mopper, 1975; Cowie and Hedges, 1992). Furthermore, organic matter sources can vary considerably between individual lakes due to the limited catchment areas and specific plankton assemblages related to environmental conditions (Menzel et al., 2013). However, AA analyses were only rarely applied to limnic and fluvial systems (Kemp and Mudrochova, 1973; Gupta et al., 1997; Meckler et al., 2004; Unger et al., 2005; Das et al., 2010). This is partly due to the fact that most AA-based degradation and source proxies were developed on the basis of marine samples and might not be suitable in terrestrial aquatic environments. Thus, their applicability to lake sediments needs further elaboration and potential adjustment. Therefore, we analysed the AA assemblages of sediment cores of four Indian lakes from different climatic regimes as well as samples from the vicinities of two of the investigated lakes and tested the different AA-based degradation and organic matter source indices. We identified degradation and organic matter source indices that probably show universal applicability and that are transferred to deeper sediments. Moreover, we detected factors that potentially bias the use of individual indices in lake systems, and we calculated an AA-based degradation proxy on the basis of the investigated lake sediments which should also be suitable to other (palaeo-) limnological investigations.

2. STUDY SITES

Four Indian lakes were investigated during this study (Fig. 1): The Tso Moriri in Leh district of Jammu and Kashmir state in northern India is an oligotrophic, closed alpine lake with a cold semi-arid climate and a summer (SW) monsoon precipitation maximum. Mansar Lake in Udhampur district of Jammu and Kashmir state in northern India is a subtropical tectonic lake in the Lesser Himalayas. Lonar Lake in Buldhana district of Maharashtra state in central India is an anoxic, eutrophic crater lake in the core monsoon zone. Pookode Lake in Wayanad district of Kerala state in south India is an oxic, meso- to eutrophic lake that receives some winter (NE) monsoon precipitation in addition to the SW monsoon rains. Table 1 summarises some general and environmental

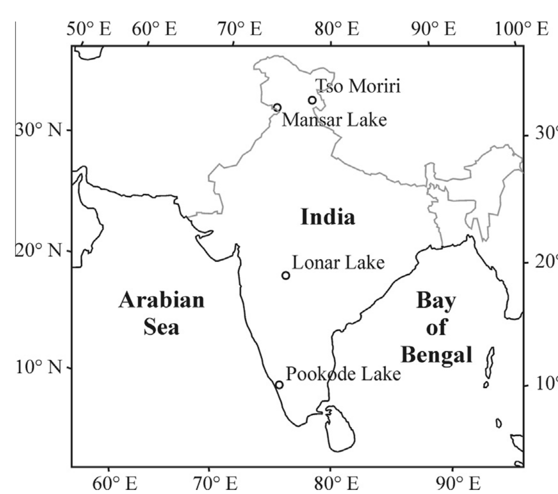

Fig. 1. Map showing the locations of the four investigated lakes.