Palaeogeography, Palaeoclimatology, Palaeoecology 426 (2015) 1–9

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Topsoil C/N ratios in the Qilian Mountains area: Implications for the use of subaqueous sediment C/N ratios in paleo-environmental reconstructions to indicate organic sources

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ARTICLE INFO

Article history:
Received 14 July 2014
Received in revised form 21 February 2015
Accepted 24 February 2015
Available online 5 March 2015

Keywords:
C/N ratios
Organic matter sources
Topsoil
Paleo-environmental reconstruction
Qilian Mountains

ABSTRACT

Sediment carbon/nitrogen (C/N) ratios can play an important role in reconstructing lacustrine and coastal paleo-environments, because significantly different C/N ratios result from aquatic phytoplankton *versus* organic matter derived from terrestrial plants. However, researchers have not yet taken into account the fact that topsoil organic matter is another important terrestrial organic source for lacustrine and coastal sediments. A study of topsoil C/N ratios from the Heihe and Shiyang River drainage basins, located in the Qilian Mountains on the northeast margins of the Tibetan Plateau, shows that topsoil C/N ratios can be as low as those of subaqueous sediments. 80.4% of total topsoils in the Heihe River drainage basin, and 67.7% of total topsoils in the Shiyang River drainage basin, have C/N ratios below 12, while 18.8% of all samples in the Heihe river drainage basin, and 29.2% of all samples in the Shiyang river drainage basin, possess C/N ratios between 12 and 20. Traditionally, researchers have considered that low C/N ratios indicate subaqueous deposition; however, these sediments are terrestrial and most of the organic matter is derived from land plants. Furthermore, topsoil C/N ratios from both the Heihe and Shiyang river drainage basins correlate significantly with altitude and local vegetation. Our results indicate that not all C/N ratios of terrestrial organic matter (including plants and soil organic matter) equal 20 or more. Nor can one distinguish subaqueous sediment organic sources solely on the basis of C/N ratios; low subaqueous sediment C/N ratios may not simply result from a greater proportion of aquatic plants *versus* terrestrial organic matter, but also from low end-member terrestrial organic matter C/N ratios which are lowered by the addition of soil organic matter with its own low C/N ratios.

1. Introduction

C/N ratios have been widely used to distinguish between the algal and land plant origins of sedimentary organic matter in lacustrine or coastal environments (Hatcher et al., 1982; Prahl et al., 1994; Yamamuro, 2000; Goñi et al., 2003; Smittenberg et al., 2004; Xiao et al., 2008; Zhu et al., 2009; Tue et al., 2011). Fresh organic matter from aquatic algae, which are protein-rich and cellulose-poor, commonly have molar C/N values between 4 and 10, whereas vascular land plants, which are protein-poor and cellulose-rich, usually create organic matter with C/N ratios of 20 and greater (Meyers, 1994). The proportions of sediment organic matter that originate from these two general sources can consequently be distinguished by their characteristic C/N ratios. Researchers generally conclude the following for C/N ratios of sediment organic matter: 1) C/N ratios ranging from 4 to 10 indicate that most of the organic matter in lacustrine or coastal sediment comes from aquatic phytoplankton; 2) C/N ratios with values of 20 and greater imply that land plants provide essentially all of the organic content in the sediment; and 3) C/N ratios varying from 10 to 20 suggest that lacustrine or coastal organic matter results from a mixture of aquatic and land plants, but is dominated by vegetation with terrestrial origins (Meyers, 1994).

Studies of global soils, however, have generally found low topsoil C/N ratios (Nguyen and Goh, 1992; Makarov et al., 1997; Liu et al., 2003; Chen and He, 2004; Chen et al., 2004; Han et al., 2005; Wang et al., 2006; Kirkby et al., 2011; Li et al., 2011). These findings upset the presumed C/N ratio difference between organic matter of terrestrial, and organic matter of subaqueous origin, thus invalidating the use of sediment C/N ratios for indicating organic sources. More studies of

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http://dx.doi.org/10.1016/j.palaeo.2015.02.038
0031-0182/

modern sediment C/N ratios are therefore needed to provide critical information for the improving of paleo-environmental sediment interpretation using C/N ratios. This study determined C/N ratios from modern topsoils in the Qilian Mountains in order to test the reliability of using sediment C/N ratios to distinguish organic sources.

2. Study area

The Qilian Mountains lie on the northeastern margins of the Tibetan Plateau, southwest China. The Heihe River and the Shiyang River rise on the northern slopes of the Qilian Mountains. They flow through every vertical vegetation zone in this temperate, arid mountainous region, and finally disappear in the Badain Jaran Desert and the Tengger Desert respectively (Fig. 1). Bedrocks in the study area are generally sandstone, conglomerate, mudstone and clay (Gansu Provincial Bureau, 1989). The southern sectors of these drainage systems fall under the influence of a cool, semi-arid climate, whereas a temperate, arid climate influences their middle and northern portions. Westerlies dominate the Heihe River drainage basin (HRDB), while southwesterly and southeasterly monsoons influence the Shiyang River drainage basin (SRDB). Consequently, precipitation decreases and the snow line rises from the eastern to the western arm of the mountain range. Mean annual precipitation (MAP) increases with altitude, while mean annual temperature (MAT) decreases with altitude (Wang et al., 2001). More information about MAP and MAT in the study area is shown in Fig. 1.

In the HRDB and SRDB, the south–north distribution of modern vegetation depends strongly on elevation, as follows: 1) the 'perennial snow and ice zone' (>4500 m a.s.l.) has essentially no vegetation; 2) the 'alpine cushion-like vegetation zone' (4500–4000 m a.s.l.) contains mostly *Arenaria serpyllifolia* L., *Androsace brachystegia*, *Saussurea medusa Maxim*, *Saussurea involucrate*, and *Lagotis brevituba Maxim*; 3) the 'alpine meadow zone' (4000–3500 m a.s.l.) features mainly *Artemisia*; 4) the 'alpine shrub zone' (3500–3100 m a.s.l.) includes plants like *Salix cupularis* and *Caragana jubata*; 5) the 'alpine steppe/forest zone' (3100–2800 m a.s.l.) is characterized by *Picea crassifolia* and *Sabina przewalskii* covering the shady slopes of the 'mountain forest grassland zone', and *Thalictrum L.*, *Epilobium angustifolium Linn.* and *Hedysarum multijugum* growing on the sunny slopes; 6) the 'mountainous grassland zone' (2800–2300 m a.s.l.) includes grasses, dotted with *Populus davidiana*, *Lycium chinense*; and 7) the 'desert steppe zone' (2300–2000 m a.s.l.) and '*gobi*-sand desert zone' (<2000 m a.s.l.) contain some scattered xerophytic plants, such as *Nitraria* spp. (Huang, 1997; Wang et al., 2002).

3. Materials and methods

Modern topsoils were collected from the open terrain along the main streams of the Heihe and Shiyang rivers. In the mountains, topsoils were taken from mountain slopes located on one side of the valley, and in the plains, sampling was conducted in open areas near the river, with

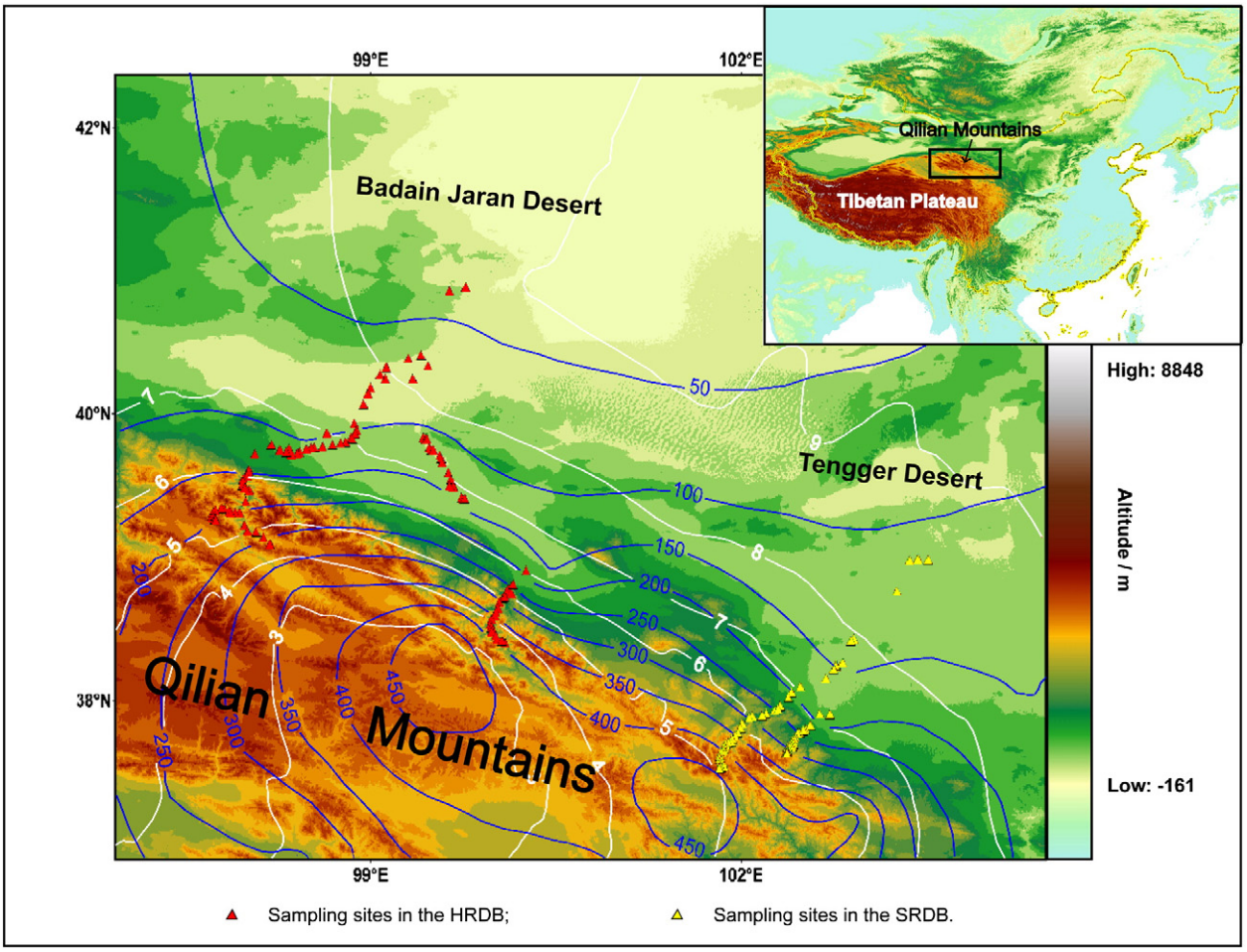

Fig. 1. Map showing location of the northern Qilian Mountains and sampling sites in the HRDB and SRDB. Blue contours indicate mean annual precipitation (mm) and white contours indicate mean annual temperature (°C). Data are cited from http://www.giss.nasa.gov.