Infrared spectroscopy as a tool to reconstruct past lake-ecosystem changes

Method development and application in lake-sediment studies

Carsten Meyer-Jacob

Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av filosofie doktorsexamen framläggs till offentligt försvar i Lilla Hörsalen (KB3A9), KBC,
fredagen den 11 december, kl. 09:00.
Avhandlingen kommer att försvaras på engelska.

Fakultetsopponent: Dr. John F. Boyle,
Department of Geography and Planning, School of Environmental Sciences, University of Liverpool, Liverpool, United Kingdom.

Department of Ecology and Environmental Science
Umeå University
Umeå 2015

Organization
Umeå University
Department of Ecology and
Environmental Science

Document type
Doctoral thesis

Date of publication
20 November 2015

Author
Carsten Meyer-Jacob

Title
Infrared spectroscopy as a tool to reconstruct past lake-ecosystem changes: Method development and application in lake-sediment studies.

Abstract
Natural archives such as lake sediments allow us to assess contemporary ecosystem responses to climate and environmental changes in a long-term context beyond the few decades to at most few centuries covered by monitoring or historical data. To achieve a comprehensive view of the changes preserved in sediment records, multi-proxy studies – ideally in high resolution – are necessary. However, this combination of including a range of analyses and high resolution constrains the amount of material available for analyses and increases the analytical costs. Infrared spectroscopic methods are a cost-efficient alternative to conventional methods because they offer a) a simple sample pre-treatment, b) a rapid measurement time, c) the non- or minimal consumption of sample material, and d) the potential to extract quantitative and qualitative information about organic and inorganic sediment components from a single measurement.
The main objective of this doctoral thesis was twofold. The first part was to further explore the potential of Fourier transform infrared (FTIR) and visible-near infrared (VNIR) spectroscopy in paleolimnological studies as a) an alternative tool to conventional methods for quantifying biogenic silica (bSi) – a common proxy of paleoproductivity in lakes – in sediments and b) as a tool to infer past lake-water total organic carbon (TOC) levels from sediments. In a methodological study, I developed an independent application of FTIR spectroscopy and PLS modeling for determining bSi in sediments by using synthetic sediment mixtures with known bSi content. In contrast to previous models, this model is independent from conventional wet-chemical techniques, which had thus far been used as the calibration reference, and their inherent measurement uncertainties. The second part of the research was to apply these techniques as part of three multi-proxy studies aiming to a) improve our understanding of long-term element cycling in boreal and arctic landscapes in response to climatic and environmental changes, and b) to assess ongoing changes, particularly in lake-water TOC, on a centennial to millennial time scale.
In the first applied study, high-resolution FTIR measurements of the 318-m long sediment record of Lake El'gygytgyn provided a detailed insight into long-term climate variability in the Siberian Arctic over the past 3.6 million years. Highest bSi accumulation occurred during the warm middle Pliocene (3.6-3.3 Ma), followed by a gradual but variable decline, which reflects the first onset of glacial periods and then the finally full establishment of glacial–interglacial cycles during the Quaternary. The second applied study investigated the sediment record of Torneträsk in subarctic northern Sweden also in relation to climate change, but only over the recent post-glacial period (~10 ka). By comparing responses to past climatic and environmental forcings that were recorded in this large-lake system with those recorded in small lakes from its catchment, I determined the significance and magnitude of larger-scale changes across the study region. Three different types of response were identified over the Holocene: i) a gradual response to the early landscape development following deglaciation (~10000-5300 cal yr BP); ii) an abrupt but delayed response following climate cooling during the late Holocene, which occurred c. 1300 cal yr BP – about 1000-2000 years later than in smaller lakes from the area; and iii) an immediate response to the ongoing climate change during the past century. The rapid, recent response in a previously rather insensitive lake-ecosystem emphasizes the unprecedented scale of ongoing climate change in northern Fennoscandia. In the third applied study, VNIR-inferred lake-water TOC concentrations from lakes across central Sweden showed that the ongoing, observed increase in surface water TOC in this region was in fact preceded by a long-term decline beginning already AD 1450-1600. These dynamics coincided with early human land use activities in the form of widespread summer forest grazing and farming that ceased over the past century. The results of this study show the strong impact of past human activities on past as well as ongoing TOC levels in surface waters, which has thus far been underestimated. The research in this thesis demonstrates that infrared spectroscopic methods can be an essential component in high-resolution, multi-proxy studies of past environmental and climate changes.

Keywords
Fourier transform infrared spectroscopy, visible-near infrared spectroscopy, PLS regression, biogenic silica, climate change, carbon cycling, lake-water quality, geochemistry, paleolimnology, Holocene, Lake El'gygytgyn, Torneträsk

Language
English

ISBN
978-91-7601-372-4

Number of pages
25 + 4 papers