Editorial: Advances in Paleolimnology

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Lakes are excellent "sentinels of change" (Williamson et al., 2009) because they can provide insight into the effects and mechanisms of climate change. With the historical record offered in their sediments, they also provide natural archives for past environmental change. In many cases, the study of lake sediments (i.e., paleolimnology), and specifically the biotic and abiotic components that integrate information from the water column, catchment area, and atmosphere, can help assess baseline conditions for different physical, chemical, and biological systems (e.g., climate, nutrients, ecosystem functioning), as well as the impacts of and recovery times after disturbances of ecosystems.

Abrupt climate change has become a key issue in paleoclimate research. Understanding the processes and dynamics of rapid and high-amplitude climate shifts (e.g. ENSO, PDO, NAO/AO, Heinrich and D/O events, Younger Dryas) is crucial for a better assessment of the probability of such changes in the future, which bear risks for landscapes, ecosystems, and organisms of all sorts, including humans. "Reliable risk assessment should not exclusively be based on computer model simulations but also on accurate observational and high-resolution paleoclimate data" (S. Rahmstorf, EGU meeting Vienna, 20 April 2009). Such data, needed to refine climate models, can only be generated using state-of-the-art, high-performance analytical techniques.

Paleolimnological approaches can provide robust reconstructions of climate variability and of the sensitivity of lacustrine ecosystems to such changes (e.g., Battarbee et al., 2004; Pienitz et al., 2004; Smol, 2008). Lakes can also yield insights on the hydrological cycle and provide long records where other archives cannot (e.g., trees and ice cores). Many paleolimnological methods are now standardized (e.g., Last and Smol, 2001a; b; Smol et al., 2001a; b). However, relatively little progress has been achieved in the area of developing proxy records that provide sufficient resolution to resolve decadal- to century-scale variability over several millennia, and to understand and refine empirical climate-proxy relationships. Like other fields of environmental science, the paleolimnological community must face these challenges.

After an initial phase of predominantly descriptive studies, the paleolimnology community has been developing and improving the numerical foundations for quantitative paleolimnology (e.g., Birks, 1998), attempting to better constrain the ecological indicator value of lacustrine biotic and abiotic proxies (e.g., Eggermont et al., 2006), and using multi-proxy records to test hypotheses (e.g., Lotter and Birks 2003; Bradshaw et al., 2005). For biological proxies preserved in lake sediments (e.g., pollen, diatoms, chironomids, cladocerans, ostracods), transfer functions have been developed from calibration or training sets of modern surface sediment samples collected along environmental gradients (e.g., climate, nutrients, salinity, pH). This "calibration-in-space" approach is limited by the laborious and time-consuming analysis required. Additionally, the so-called "non-analog situations" have evoked some discussion over the past years.

With recent developments in reflectance spectroscopy scanning techniques (see contributions in this issue; Rein and Sirocko, 2002), high-resolution data acquisition has become very fast for different biogeochemical proxies and approaches. However, since lakes are biophysical systems with different configurations, transfer functions for biogeochemical sediment data cannot easily be established. The only way to transform biogeochemical sediment proxies into quantitative climate variables, therefore, is a "calibration-in-time"—a time series of well-dated abiotic sediment proxies regressed against meteorological observations (see Grosjean et al., p. 108).

This newsletter issue focuses on advances in paleolimnology, with special emphasis on recent methodological developments and their significance for research in the PAGES context.

Methodological aspects: Novel approaches and techniques

Francus et al. (p. 93) provide an overview of new X-ray fluorescence (XRF) scanning techniques that allow rapid, non-destructive acquisition of high-resolution geochemical data from sediment cores. Examples of applications include pollution detection, varve counting, and estimation of past ecosystem productivity. Brauer et al. (p. 96) present a new approach to studying annually laminated (varved) sediments, by combining microfacies analyses on thin sections with high-resolution XRF scanning on impregnated sediments. They elaborate on its potential for improved varve counting and interpretation of seasonal paleoclimate signals. Rosén et al. (p. 98) describe novel ways of extracting highly resolved information on climatic and environmental change, using non-destructive methods. They demonstrate the potential of Fourier transform infrared spectroscopy as a low-cost and effective analytical tool for the quantitative determination of biogeochemical properties from tiny sediment samples. Heiri et al. (p. 100) discuss the use of stable isotope techniques ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$) on fossil chitinous invertebrate remains for reconstructing past climate and aquatic food webs. They highlight the need to understand diagenetic processes and their impact on the chemical composition of these fossils in the sediments. The prospect of using microbial cell membrane lipids (TEX_{86} and MBT-CBT) preserved in lake sediments as paleothermometers is discussed by Weijers et al. (p. 102), who show that these compounds are promising new proxies for reconstructing past lake water and catchment air temperatures. The use of fossil DNA preserved in the sedimentary record of lakes, and the potential of this new approach to reconstruct past changes in lake ecosystems is discussed by Coolen and Gibson (p. 104). Jeziorski et al. (p. 106) highlight the "aquatic osteoporosis" problem associated with declines in aqueous calcium commonly observed in lakes, such as the Canadian Shield. They show that Ca-rich zooplankton microfossils can help assess the ecological consequences of reduced Ca availability due to acidification, forestry, and other environmental stressors. Finally, Grosjean et al. (p. 108) discuss the importance of a reliable chronological framework in paleolimnological studies and provide a new approach with regard to ^{210}Pb profiles for depth-age modeling. Moreover, they explore the as yet rarely used "calibration-in-time" approach to infer past environmental conditions.

Regional syntheses

This newsletter also provides an overview of progress made in resolving the climate history and human impacts on lakes at a subcontinental to regional scale. Several

contributions herald a PAGES initiative aimed at the high-resolution reconstruction of climate history obtained through lake records from South America, Africa, and China. Another contribution focuses on deep-sediment drilling efforts in old crater lakes. These initiatives use a number of the techniques described above, which allow for the study of global teleconnections of climate variability at timescales of 10^5 to 10^2 years, while also revealing distinct regional and/or sub-continental climate features. Such regional syntheses are crucial for establishing the spatial and temporal patterns of climate change across climatic, hydrological, and ecotonal boundaries, thereby separating climate-driven and anthropogenic impacts on ecosystems at both the site-specific and landscape scales.

Rioual and Wang (p. 110) provide a review of progress in Chinese paleolimnological studies, particularly highlighting records that trace the past dynamics of Asian monsoon systems and the Westerlies, which provide a better understanding of complex atmospheric teleconnections. Verschuren and Russell (p. 112) highlight the regionally different patterns of hydro-logical change during recent millennia, as reconstructed using novel temperature and moisture proxies in lakes across tropical Africa. They also demonstrate how paleogenetic tools can improve our understanding of climate-human-ecosystem interactions. García-Rodríguez et al. (p. 115) demonstrate the value of integrating data obtained through paleolimnological studies in Argentinean and Uruguayan Holocene lake records. They focus particularly on the links between past monsoonal activity and regional hydrological variability since late Glacial times in the Pampas. Finally, Pienitz et al. (p. 117) provide an update on progress in the recovery of long sediment records from continental sites and, in particular, large and deep crater lake basins. They highlight three projects funded through the International Continental Scientific Drilling Program and other partners.

The final contribution to this issue is a Program News by Gell et al. (p. 119). They report on the European Water Framework Directive and the important role paleolimnology can play in assessing ecological baseline conditions for lakes.

Outlook

The various contributions in this issue of *PAGES news* show that paleolimnology has reached a stage where high-precision data based on different proxies can be generated for lake records. Based on a vast amount of data gathered and standardized approaches, paleolimnologists are now in a position to document continent-to hemispheric-wide sensitive responses of freshwater systems to ongoing global change.

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For full references please consult:
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The potential of high-resolution X-ray fluorescence core scanning: Applications in paleolimnology

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A new generation of XRF core scanners allows rapid, non-destructive acquisition of high-resolution geochemical and X-radiographic data from lacustrine sediment cores, facilitating new approaches to many applications in paleolimnology, including pollution detection, varve counting, and estimation of past ecosystem productivity.

X-ray fluorescence (XRF) core scanning was developed in the late 1990s (Jansen et al., 1998) and is a powerful analytical technique: it is fast, requires no sample preparation, and it can detect most chemical elements of the periodic table down to limits of a few ppm, depending on acquisition dwell time and sample conditions. A new generation of XRF core scanners allowing high resolution analysis, with improved count rates and detection limits, has become widely available. One of these, the Itrax™ core scanner, takes high resolution radiographic and optical images at the same time as XRF measurements. It has a flat X-ray beam with a measurement area of 100 μm x 4 mm (or 200 μm x 8 mm), rather than a spot beam, so that grain-to-grain variance is averaged in the horizontal core axis, ensuring predominance of the environmental signal through depth (Croudace et al., 2006).

Practicalities

High-resolution non-destructive analyses of lacustrine sediments can be achieved with an XRF core scanner in a remarkably short time. For example, a 1.5 m-long core section can be scanned at 1 mm intervals in about 13 hours, with a dwell time of 30 seconds. Using a Mo X-ray tube, light elements such as Al and Si require long dwell time (>20 sec.), while heavier elements, such as Fe, Ca, Ti, are more easily detected with reduced dwell times. Numerous factors related to the sediment matrix, such as water content, organic matter, grain size, mineral crystallinity and porosity may have a significant impact on the production and the detection of fluorescent photons (Weltje and Tjallingii, 2008). Results are usually presented as spectral peak areas or counts per second (cps) and can be calibrated to concentration, although this may be cumbersome in some sediments because of the high variability of the matrix factors mentioned above. The use of element ratios and the plotting of XRF curves (in cps) together with discrete sample analyses obtained using destructive techniques, such as inductively-coupled plasma or other conventional techniques (Fig. 3a), are two ways to evade this issue. The Itrax™ core scanner also provides high-resolution X-radiographs that are useful for detecting invisible sedimentary structures.