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Editorial

Annually Laminated Lake Sediments—Recent Progress

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Abstract: The collection of papers entitled "Annually Laminated Lake Sediments" illustrates the recent progress made in varved sediment research and highlights the variety of methodological approaches and research directions used. The contributions cover the monitoring of modern sediment fluxes using sediment traps, geochronological and sedimentological analyses of varves, multi-proxy investigations, including geochemical and biological proxies, as well as spatiotemporal analyses based on multi-core studies supported by satellite images. The scientific issues discussed the influences of hydroclimatological phenomena on short-term changes in sediment flux, the relationships between biogeochemical processes in the water column and the formation of varves, the preservation of environmental signals in varves, and possibilities of synchronizing varved records with other high-resolution environmental archives.

Keywords: environmental monitoring; geochronology; hypoxia; pollen analysis; sediment flux; varve microfacies

Annually laminated (varved) sediments are excellent archives of the changing Earth. They store information with a high temporal resolution about past climate variability, natural rates of environmental change, and anthropogenic disturbances [1]. The fundamental advantage of varves is the possibility of establishing precise time scales along sediment cores, which provide a solid geochronological framework and builds an essential element of paleoenvironmental reconstruction. In addition to the calendar-year time control, another advantage of varves is the absence of bioturbation in these natural archives enabling the application of innovative sub-millimeter-scaled scanning techniques for the generation of high-resolution (annual, sub-annual or seasonal) proxy data series (e.g., [2–4]). However, the lacustrine environment is prone to influences from a variety of natural and human-related forcing factors, all of which influence lake systems directly (e.g., water temperature, mixing regime, water column oxygenation, biological productivity) and indirectly (e.g., vegetation cover in the catchment area, soil erosion with an influx of minerogenic particles, pollutants and nutrients) with different intensities and at different time intervals. Complex interactions within the lake-catchment system and their effects on the lacustrine deposition cause uncertainties in the interpretation of reconstructions based on proxy records from lake sediments. Disentangling these overlapping influences is one of the most difficult problems to tackle [5]. However, new findings of lakes with varved sediments [6,7] and rapid developments in monitoring and analytical techniques shed new light on the potential of varves for paleolimnological reconstructions.

The initiative for this Special Issue emerged from activities of the past global changes (PAGES) Varve Working Group that was established to coordinate activities leading to methodological developments and, at the same time, setting quality standards for varve chronologies, data management and processing, as well as integration with other high-resolution, i.e., annually resolved environmental archives [8]. The authors present recent progress reports for different directions in

varved sediment research. This is illustrated by the diversity of papers involving different methods and applied techniques, as well as different lake settings and geographical locations.

In their work, Johansson et al. [9] showed a novel technique for monitoring modern sedimentation processes in Lake Kallavesi, eastern Finland. They track the direct influence of meteorological and hydrological phenomena on short-term changes in sediment fluxes using the prototype of a high-resolution online sediment trap to obtain flux-rate information with daily resolution. In addition to typical seasonal variability, this research also provides valuable information on catchment responses to short-term and weather-related events, e.g., influences of storm tracks that cause larger sediment fluxes over several days. This new technique of sediment trapping combined with microstratigraphic analyses of varved sediment archives helps in the interpretation of paleoclimatic proxy records and improves the modeling of past weather and erosion conditions.

Salminen et al. [10] documented a multi-core investigation of spatiotemporal variations in hypolimnetic hypoxia for the past 200 years in Lake Lehmilampi, eastern Finland. They used spatiotemporal changes in varve distribution as an indicator for hypolimnetic hypoxia oscillations. This approach allowed for the recognition of several periods with hypoxia primarily related to changing climatic conditions. They conclude that more sophisticated investigations are essential for a better understanding of climatic and anthropogenic forcing behind hypolimnetic hypoxia oscillations in boreal lakes.

The potential of high-resolution pollen analysis in varve records from northern Germany was presented by Theuerkauf et al. [11]. They test whether pollen analysis with annual resolution can be used for synchronizing different varve records. The results for species that show strong annual variations in flowering, e.g., *Fagus sylvatica* and *Picea abies*, supported their chronostratigraphic potential and indeed allowed to synchronize these records. Moreover, peaks in pollen deposition correlate with minima in tree-ring widths, which provides a tool for the synchronization of these records.

Thys et al. [12] investigated the potential of sediments from Kenai Lake in south-central Alaska to archive snow avalanches. Using a precise chronology, sedimentological characteristics of varves, and satellite images, they explain how sediments are redistributed by ice floes across the lake and compare dropstone records with climate data. They present a direct link between historical snow avalanches and dropstones preserved in lake sediments, which suggests that dropstones can be used for long-term reconstructions of snow-avalanches with at least decadal resolution.

Additionally, Vegas-Vilarrúbia et al. [13] focused on the preservation of different environmental signals in varves. They synthesize results of different modern analogue studies performed for Lake Montcortès, Central Pyrenees (Spain), and discuss different limnological and biogeochemical processes that reveal seasonality in the lake and indicate different potentials for preservation in the sublayers of each varve. Advantages and limitations of such a multiproxy modern-analogue approach for investigations of lake sediments are discussed, and guidelines for future research at Lake Montcortès and beyond are proposed.

Finally, classical microstructural investigations of varves and their components were presented by Żarczyński et al. [14], who compare varve microfacies and particle-size distributions in biogenic varves of Lake Żabińskie in northeastern Poland. Although changes in particle-size distributions between different varve types were relatively small, end-member analyses allowed recognizing variabilities in the deposition of allochthonous and autochthonous sediment components. This suggests that there is room for more detailed sedimentological investigations not only in clastic but also in biogenic depositional environments. Grain size analysis of individual sediment components is suggested as a future task to improve the interpretation of end-member analysis.

All the papers in this volume demonstrate that annually laminated (varved) lake sediments are reliable recorders of past environmental change. However, the studies also highlight the complexity of the information embedded in these natural archives. Further investigations are required to improve our understanding of varves and their fascinating potential for reconstructions of natural and man-made changes in the environment, especially in modern times of ongoing global climate change.

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