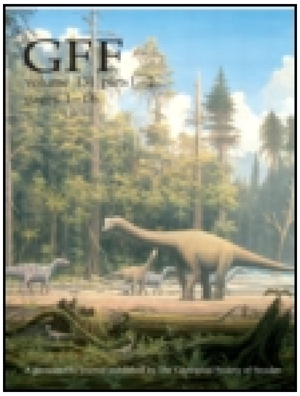

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The rise of varves

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Editorial

The rise of varves

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Varves are exceptional in many aspects: they are rare, can be used to constrain and build chronologies, and contain high-resolution records of past environment and climate. Moreover, their occurrence and reproducibility in different settings allows for an internal validation of their continuity and integrity.

Gerard De Geer of Sweden understood the value of varved sediments over a century ago. Although other geologists during his time had described rhythmic, glacial lake sediments that they interpreted as annual layers (e.g. Smith 1832; Hitchcock 1841; Upham 1884), it was De Geer who saw the potential of varves (from the Swedish word *varv*, meaning cycle), for dating the retreat of the Scandinavian ice sheet, and by extension, the late Quaternary. And it was De Geer and his students who built the so-called Swedish Time Scale, which extends from the present to over 13,000 years before present. Much of De Geer's early work was in fact published in *GFF* (e.g. De Geer 1908, 1921, 1935). However, De Geer's considerations of teleconnections (today, a hot topic in climate research), along with strong reservations from North American geologists about the implications of the varve chronology in the Connecticut River valley by Ernst Antevs (one of De Geer's *ler-jungar*; Antevs 1922, 1928), led many to doubt the annual nature of varves. Ages for the New England varves, based on the, at that time, new ^{14}C technique, as well as varves' similarities to the turbidites that Philip Kuenen was describing, convinced many that varves were not annual (for details, see Ridge and Larsen 1990; Ridge et al. 2012).

Today, the varves that De Geer (as well as Antevs) looked at are understood to be annual, and varve chronologies have been published in several areas of Europe and North America. Varve chronologies have even been correlated with the Greenland ice cores, suggesting that De Geer's consideration of teleconnections was a reasonable one (Andrén et al. 1999; Ridge et al. 2012).

Significantly, because of concern about current climate change, there has been a growing number of publications dealing with varved sediments that are currently being formed, giving rise to the term "recent varves" for those forming today, and "paleovarves" for those from earlier in the Holocene and Pleistocene. Much of the activity on these recent varves has been coordinated within the PAGES Varve Working Group (VWG).

This special issue arose from the third workshop of the PAGES VWG held in Manderscheid (Zolitschka 2012) in the German Eifel, a region famous for its Quaternary maar volcanoes and the long varved records they contain. The VWG aims at promoting the study and the use of varved records in regional and global paleoclimate reconstructions by building a community of specialists in the study of these exceptional archives, setting up methodological quality standards and establishing a specialized database. The group is open to all, and all interested scientists are encouraged to visit its web page (http://www.pages.unibe.ch/workinggroups/varves-wg). Members of the VWG contributed several papers to this special issue on varves encompassing three main topics: process studies, establishing accurate chronologies and paleoenvironmental records.

First, Maier et al. assessed the amount of compaction in recent varved lacustrine sediments, allowing for a better understanding of the changes in varve thickness through time, especially in the upper few centimeters of sediment in modern lakes. Since this interval is used to calibrate the geological record against modern environmental parameters, it is critical to include this factor when establishing quantified reconstructions of past environments. Ojala et al. monitored the settling of particles in the water column during 2 entire years within a lake containing a long varved record. The traps confirmed the annual nature of the clastic-biogenic laminations, specified the seasonal contributions of the different varve components and refined the understanding of seasonal variability of varve properties. This paper demonstrated the relevance of process studies for improving the quality of paleoclimate reconstructions.

Kinder et al. evaluated the quality of the chronology of a new 8410-year-long varve record in Northern Poland. Their chronology was tested against independent radiometric dating methods, several manual varve counts and one semi-automated counting technique. They estimated the error of the age depth model based on varve counting to approximately $\pm 1\%$. Schimmelmann et al. presented a revised chronology of the last 2000 years of the famous and partially varved marine sediment in Santa Barbara Basin, California. They based their revision on evidence from a new set of radiocarbon dates made on small fragments of terrestrial organic debris that are unaffected by variations of the marine radiocarbon reservoir age. The discrepency between the former and new chronology can be explained by the difficulty to recognize varve boundaries when the terrigenous input was low, by erosional events or by unrecognized bioturbation blurring or obliterating varve boundaries.

Chu et al. used synchrotron radiation X-ray fluorescence (XRF) to measure variations of the geochemical content of varves from a lake in Northeastern China. Variations in mental composition were linked to lithogenic and biogenic input as well as to dust and the intensity of weathering. Cyclicities in the elements indicative of the biogenic input are similar to those of El Niño Southern Oscillation and solar activity.

Work on paleovarves continues to highlight the use of matched varve sequences as a means of constructing coupled varve and glacial chronologies. Hang and Kohv continue this tradition with a new varve sequence from Estonia that furthers the chronology of glacial events dating prior to the onset of the Swedish Varve Chronology. Study of this period of early deglaciation south of the Baltic Sea is critical for assembling a more complete record of the last deglaciation of the Fennoscandian Ice Sheet. Critical to reconstructing paleovarve sequences is the development of new techniques. Rayburn and Vollmer provide a new mathematical correlation application that includes a statistical analysis and new computer program, making it accessible to the scientific community. The program will allow the rapid testing of potential matches of varve sequences and push us toward a standard for accurate matching of varve sequences. Johnson et al. use multiple parameters, including grain size and XRF scanning, to characterize two marine varve units from western Sweden that straddle the Holocene boundary and which lie above and below sediment deposited during the catastrophic drainage of the Baltic Ice Lake. The sedimentology of the varves can be attributed to grain size and provenance changes, and imply that the Baltic Ice Lake drainage lasted < 1 year.

Paleovarve analysis has advanced in the use of the varve sequences to further our understanding of Pleistocene climate as well as non-climatic events associated with deglaciation. Interpretations of climate change and deglacial events from paleovarves will require a more complete understanding of varve composition, depositional environments and non-climatic events that may influence varve thickness and composition. Mörner identifies seismites, or seismically induced marker beds, which had previously been identified as drainage events, and leads to a potential method for analyzing the chronology and frequency of seismicity. Kanamaru et al. demonstrate the use of micro-scanning techniques to further refine varve and glacial stratigraphy of cores from Saanich Inlet in British Columbia. They take advantage of backscattered scanning electron imaging and energy dispersive spectrometry analysis using a scanning electron microscope as well as micro-XRF core scans to define subtle changes in sediment texture, bedding, chemistry and density, leading to improved environmental analysis of varves and for a better understanding of climatic and environmental changes over time.

This is one of the few special issues of a scientific journal completely dedicated to varves. Will it be the last one? Of course, varve records are rare (Ojala et al. 2012). Their analysis is time consuming and sometimes frustratingly difficult. However, the emergence of non-destructive and highly efficient analytical technologies, such as XRF scanning, spectrophometry and micro-stratigraphic techniques, and the need for accurately dated records of past climate change, the increased capability of coring technologies and our improved understanding of varve formation and preservation will contribute to the rise of varves.

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