Pact 41 - I.1 : André F. Lotter and Michael Sturm

The Study of Environmental Dynamics by Means of Laminated Sediments: Results from Switzerland

INTRODUCTION

Annually laminated sediments provide a unique tool for the study of past environmental changes on an absolute time-scale. The potential of these lacustrine deposits is exceptional because they allow the highest time resolution possible in sediment studies. By distinguishing single years or even seasons it becomes possible to link present day ecology with palaeoecology or *vice versa* on a micro-scale (see e.g. Delcourt *et al.*, 1983; Jacobson, 1986). Past events of short duration such as fires, floods, forest clearances and other short-term human impact on the environment can be traced and the biotic responses to these environmental disturbances such as succession or competition can be studied on a precise and long time-scale.

At the International Geological Congress held in Stockholm in 1910 De Geer introduced the term *varve* to the scientific literature: « The Swedish word varv (old spelling: hvarf), means as well a circle as a periodical iteration of layers. An international term for the last sense being wanted it seems suitable to use the transcription varve, in Engl. and Fr., while in German it might be written Warw. » (De Geer, 1912). De Geer's original description of varves was related just to physical sedimentation processes of glacial and/or periglacial lakes influenced by allochthonous particles. Ever since, more than 2000 scientific papers on varves have been published, covering as different fields as sedimentology, geochemistry, palaeobotany, palaeophysics, geochronology, geomagnetics, assessment of methods etc. within a variety of different environmental conditions (e.g. Zeuner, 1958). Hence, it is not surprising, that a description of the origin of varves became increasingly more complex than it was in the days of De Geer.

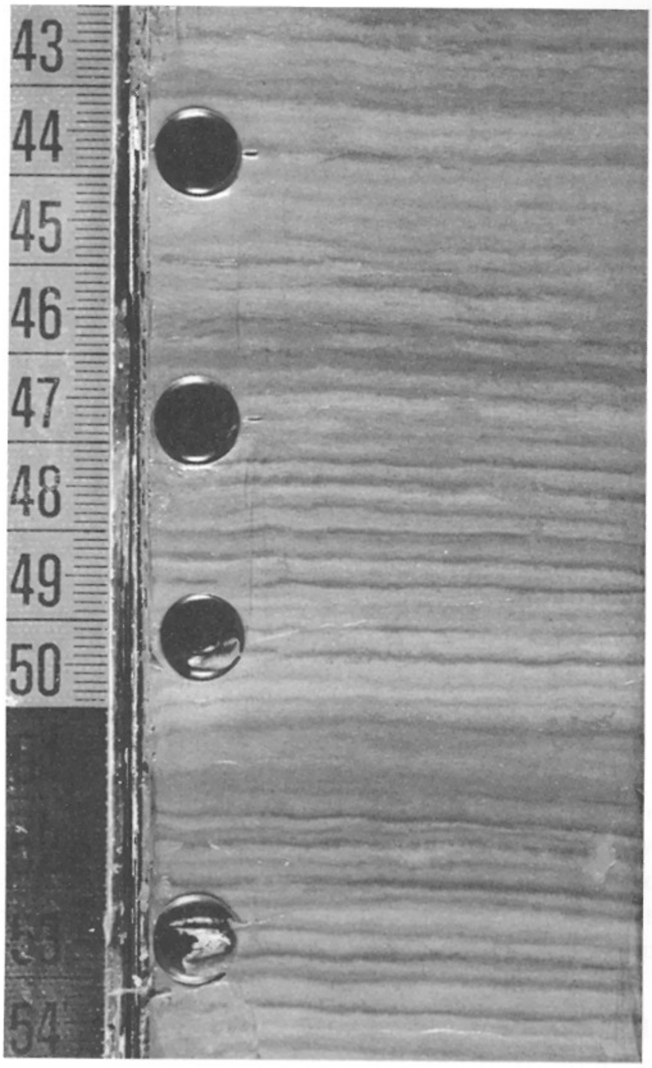

Fig. 1. Physical (clastic varves) from oligotrophic Brienzersee, Switzerland. Each year is represented by a dark sand/silt layer (spring/summer), which grades upwards into a light silt/clay layer (autumn/ winter). Scale in cm.

As early as 1920 varves of a different origin were described from Swiss lakes (Nipkow, 1920). Biological and chemical processes are responsible for the formation of this kind of varve. They are indicative of eutrophied lakes with a minimum of allochthonous input. But the occurrence of varves has not only be reported from modern and Quaternary freshwater environments. Varves have also been described from salt/soda-lakes (Kempe and Degens, 1978), modern marine basins (Anderson *et al.*, 1990) and from Tertiary and Precambrian sites (Taylor *et al.*, 1990).

When using the term varve it seems adequate to define the corresponding environmental conditions in order to avoid confusion. In this paper we use a simplified version of O'Sullivan's (1983) varve-classification in distinguishing:

– physical (clastic/allochthonous) varves from
– bio-chemical (autochthonous) varves.

Physical (clastic/allochthonous) varves

The deposition of physical varves (Fig. 1) takes place in tributary-controlled lakes with high clastic particle-loading (Sturm, 1979). These oligotrophic lakes are normally stratified during summer and usually well flushed and aerated down to the sediment/water interface. They have short water renewal times (<1 year) and high sedimentation rates (>>1 kg/m^{2}y), the latter minimizing bioturbating effects by benthic organisms. The yearly lamination appears to be grain-size dependent; spring/summer is represented by a coarse layer of sand/silt, whereas autumn/winter is characterized by the deposition of a distinct clay layer. The amount of organic matter is small (mostly residues of leaves and wood fragments) and the chemical composition of clastic varves reflects the chemistry of the lake's catchment.

Bio-chemical (autochthonous) varves

Bio-chemical varves (Fig. 2) are deposited in lakes with very low clastic particle-loading. Having only small tributaries these lakes have much longer water renewal times (> 1 year) and lower sedimentation rates (< 1 kg/m^{2}y). The lakes show strong thermal and sometimes chemical stratification, and may develop meromictic conditions during years of poor physical mixing. Most of these lakes are meso- to eutrophic and exhibit anaerobic conditions at the sediment/water interface, which usually prevents bioturbation by benthic organisms.

Autochthonous bio-chemical processes in the water column during the course of a year are responsible for the formation of suspended particles (Sturm, 1984) and are reflected by the composition of the individual varve (Kelts and Hsü, 1978; Lotter, 1989). The assimilation processes of the first phytoplankton bloom of the year cause a significant increase in pH and a dramatic decrease in the high levels of PO_4-P in the lake water; the latter having up to this event prohibited the precipitation of vast amounts of calcium-carbonate from the $CaCO_3$-oversaturated lake water (Kunz and Stumm, 1984). This sudden formation of large calcite-crystals (40-60 μm) is documented in the biochemical varves of hardwater lakes by the distinct light layer (spring/summer). Ongoing summer conditions in the lake are characterized by subsequent precipitation of small, but numerous calcites (< 5 μm). The next phytoplankton-bloom (e.g. pennate diatoms) then forms the base for the dark, organic rich autumn/winter-layer of an individual varve.

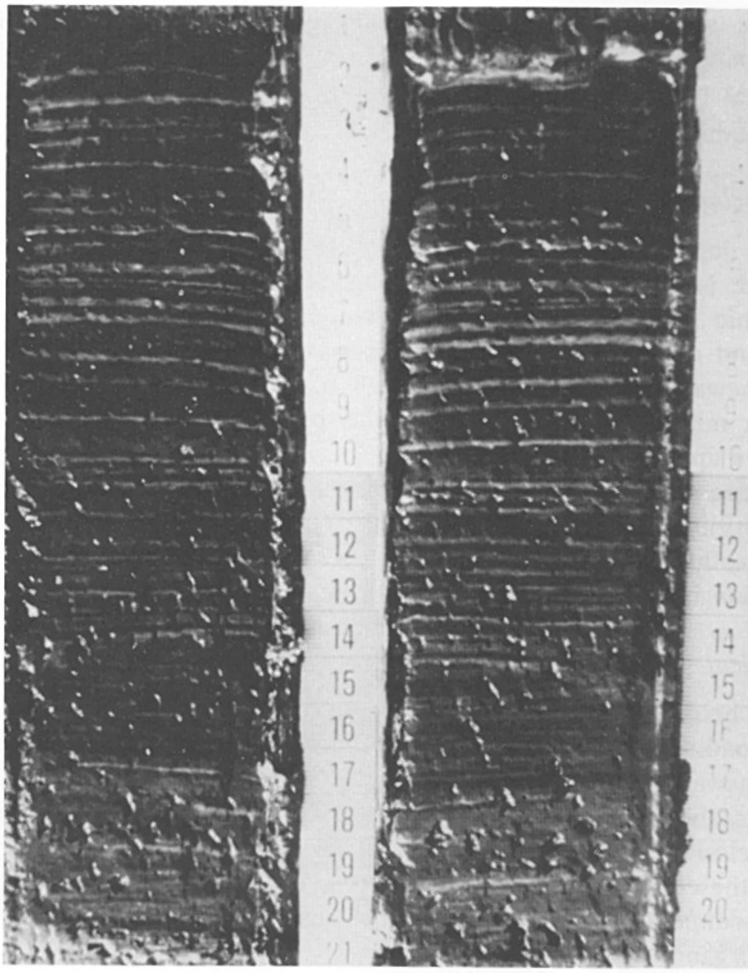

Fig. 2. Bio-chemical varves from eutrophic Greifensee, Switzerland. Each year is represented by a light layer of calcite (spring/summer) and a dark layer of organic material (autumn/winter). Scale in cm.

Swiss varve studies

The first studies on laminated sediments in Switzerland go back to the last century: early conceptual work has been published by Heer (1865). Heim (1909) was the first to report on the occurrence of annual layers in the Molasse of Oehningen. In the 1920's Nipkow (1920, 1927) discovered and described the annually laminated sediments in Zürichsee and Baldeggersee. Niessen and Sturm (1987) have discovered a close correlation between the grain size of the calcite crystals and the P-concentration in the lake water. The formation of these varves is mainly due to man made eutrophication and anoxic conditions in the bottom water of these lakes (see

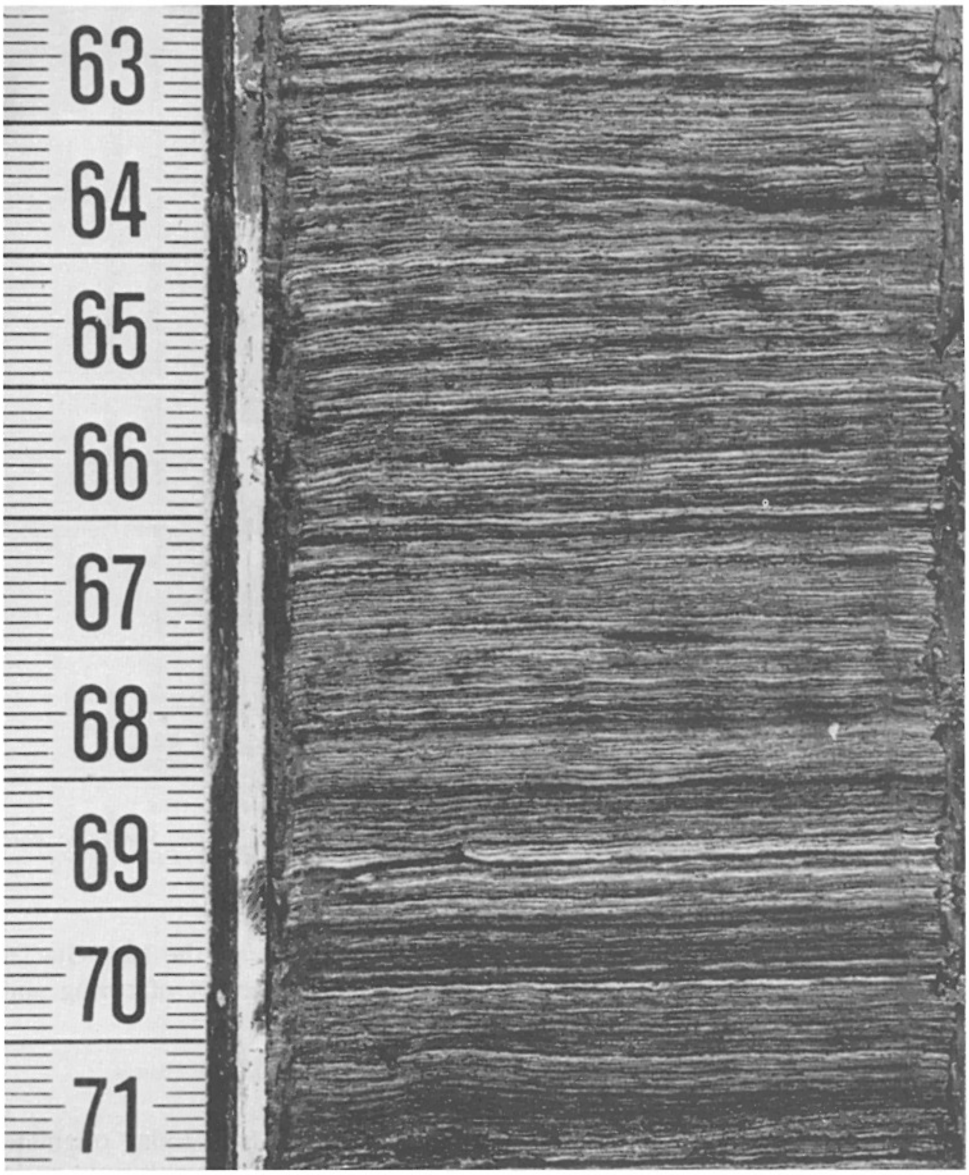

Fig. 3. Part of the Holocene varved deposits of Soppensee. Scale in cm.

also Kelts and Hsü, 1978). Nipkow (1927) was among the first to realize the potential of the absolute timescale these sediments provide ; he subsequently used it to investigate the dynamics in the life cycle of planktonic diatoms.

Early pioneering work on geochronology and vegetation history using bio-chemical varves was carried out by Welten (1944) at Faulenseemoos.

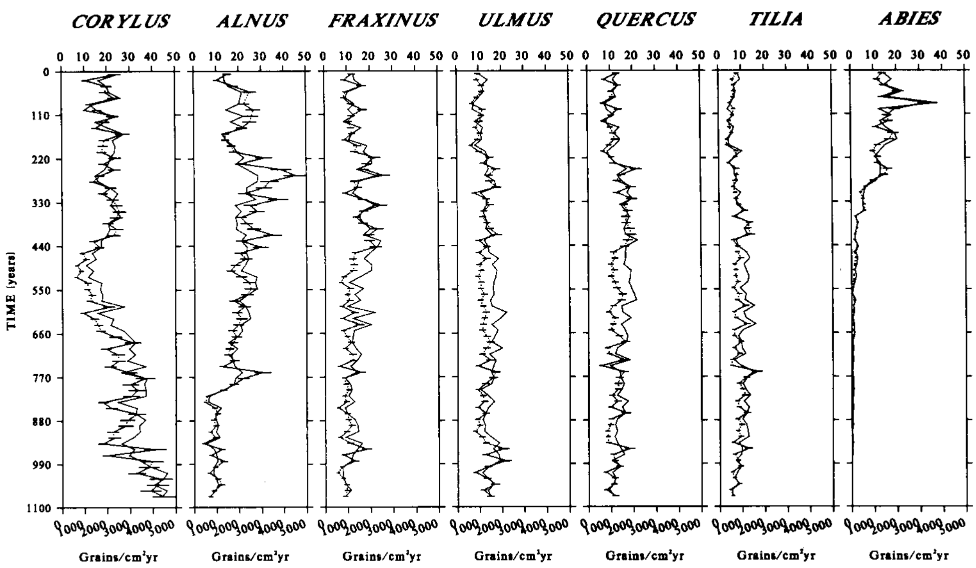

Fig. 6. High resolution pollen diagram of Soppensee core SO86-14. The 72 contiguous samples each contain 15 years (for exact location see Fig. 5). Only selected AP taxa are shown. Solid lines represent pollen percentages (100 % = ΣAP + ΣNAP, top scale), whereas the dashed lines represent influx values (bottom scale). Note that the y-axis is a time-axis.

of rates of change (Ammann and Lotter, 1989 ; Zbinden *et al.*, 1989). However, these problems can be overcome by a radiocarbon independent chronology assessed by varve counts on sediment thin-sections (Fig. 4 ; Lotter, 1991b ; Lotter *et al.*, 1991).

Pollen analysis revealed the standard Holocene vegetation succession for the Central Swiss Plateau (Fig. 5 ; Lotter, 1988). The sediment of Atlantic age above and below the *Abies* (fir) expansion has been sampled and analyzed in contiguous 15 year intervals using a *Segerström-harp* (Segerström and Renberg, 1986). This section includes a highly dynamic phase in vegetation history, namely the invasion and expansion of fir and its competition with the species of the « mixed oak forest ». Within this period the well-known elm decline occurs and it has been argued that the cause of this event is infraspecific competition, human impact or/and a pathogene disease (see e.g. Troels-Smith, 1955 ; Heitz-Weniger, 1976 ; Moore, 1984). Due to the high temporal resolution of the datapoints it is, at first sight, difficult to correlate the coarsely sampled diagram (Fig. 5 : 5 cm sample intervals) with the contiguously sampled section of the same core. A close correlation between pollen percentage and influx values is illustrated in Fig. 6.

The establishment phase in the *Abies* curve, characterized by long-distance dispersal and low population density includes *ca* 500 years and meets the expectations (Watts, 1973). On the high-resolution time-scale (Fig. 6) the *Ulmus* (elm) decline is only gradual. The largest step in this influx-decrease of elm pollen occurred within a time-span of 50-60 years (Fig. 6). Judging from the pollen data human impact is not likely to be the cause of this decrease in *Ulmus* and *Quercus* (oak) at Soppensee, but it seems to be the result of an increasing light competition with the shade tolerant *Abies*.

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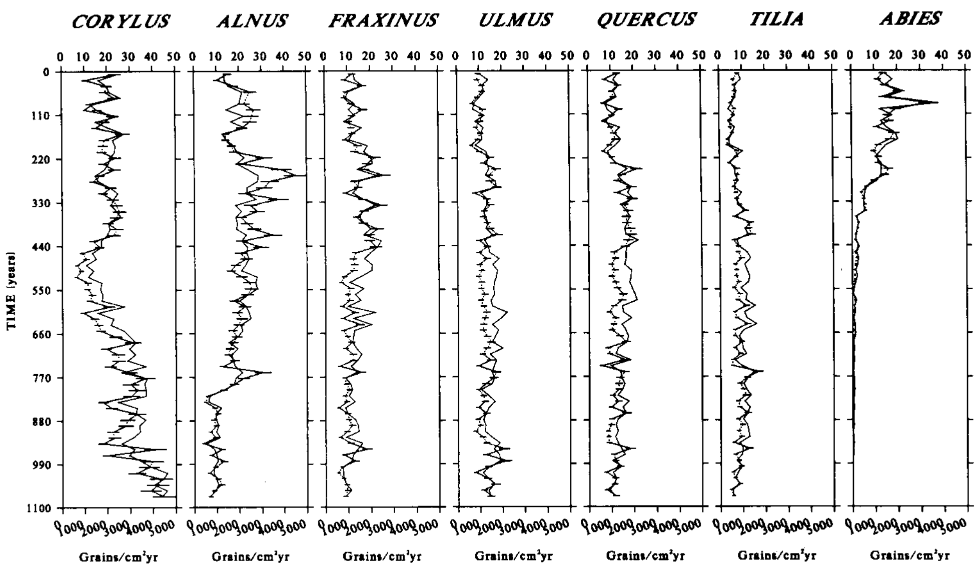

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