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VARVES AND SOLAR VARIABILITY (LAKE HOLZMAAR, EIFEL, GERMANY)

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ABSTRACT. Annually-laminated sediments from Lake Holzmaar are a high resolution archive of palaeoenvironmental changes in the Eifel region (Germany). During a selected time window of the early Holocene, organic sedimentation is mainly controlled by biological productivity and seems to depend on temperature and solar radiation. Applying a non-linear phase-oriented analysis to varve thickness measurements, 11-, 88- and 208-year solar periodicities were detected.
We therefore propose to use these sediments as a proxy for solar activities. Additionally, we suspect planetary revolution and lap frequencies in this record, which might indicate a relationship between solar-activity variations and solar-system dynamics.

KEYWORDS: Lacustrine sediments, Varves, Solar forcing, Eifel, Germany.

RESUME. Chronologie des varves et variations solaires dans le Holzmaar. Les sédiments à laminations annuelles du lac Holzmaar représentent une archive de haute résolution des changements du paléoenvironment dans la région de l'Eifel (Allemagne). Pendant un certain laps de temps du debut de l'Holocène la sédimentation est contrôlée principalement par la productivité biologique et dépend apparemment seulement de la température et des radiations solaires. Après avoir appliqué une transformation en phase non-linéaire orientée aux épaisseurs mesurées des varves, nous avons obtenu les périodicités solaires de 11, 88 et 208 ans. Nous proposons dès lors d'utiliser les sédiments comme proxy pour des activités solaires.
De plus, nous pensons avoir détecté, dans cet enregistrement, les fréquences convoluées des révolutions planétaires. Ceci devrait indiquer une relation entre les variations de líactivité solaire et la dynamique du système solaire.

MOTS-CLES: Sédiments lacustres, Varves, Solar forcing, Eifel, Allemagne

1. INTRODUCTION

For more than 15 years international and multi-disciplinary research has been carried out on the organic and clastic varved sediments from European maar lakes (Fig. 1). Best records were recovered from mesotrophic to eutrophic lakes of the Eifel region, western Germany (Holzmaar, Meerfelder Maar) and at Monte Vulture in the Basilicata region, southern Italy (Lago Grande di Monticchio). Numerous cores from every site have been investigated using a variety of methods (cf. Negendank & Zolitschka, 1993). Important results of these studies are varve chronologies which have been established for the last 22,500 varve years at Lake Holzmaar (Zolitschka 1990, 1991; Brauer, 1994; Brauer *et al.*,1994) and, based on a varve-related sedimentation rate chronology, for the last 76,300 varve years at Lago Grande di Monticchio (Zolitschka & Negendank, 1996). For the site of Holzmaar the varve chronology was confirmed by dendro-calibrated AMS-14C-dates (Hajdas, 1993; Hajdas *et al.*, 1995).

According to the original definition, annually laminated sediments deposited in proglacial lakes are determined as varves (De Geer, 1912). Today, various types of varves (clastic, organic, evaporitic) are distinguished (O'Sullivan, 1983; Saarnisto, 1986; Anderson & Dean, 1988). In some cases their formation and hence their varve thickness variations are related to climatic conditions (Leonard, 1986; Leemann & Niessen, 1994; Itkonen & Salonen, 1994;

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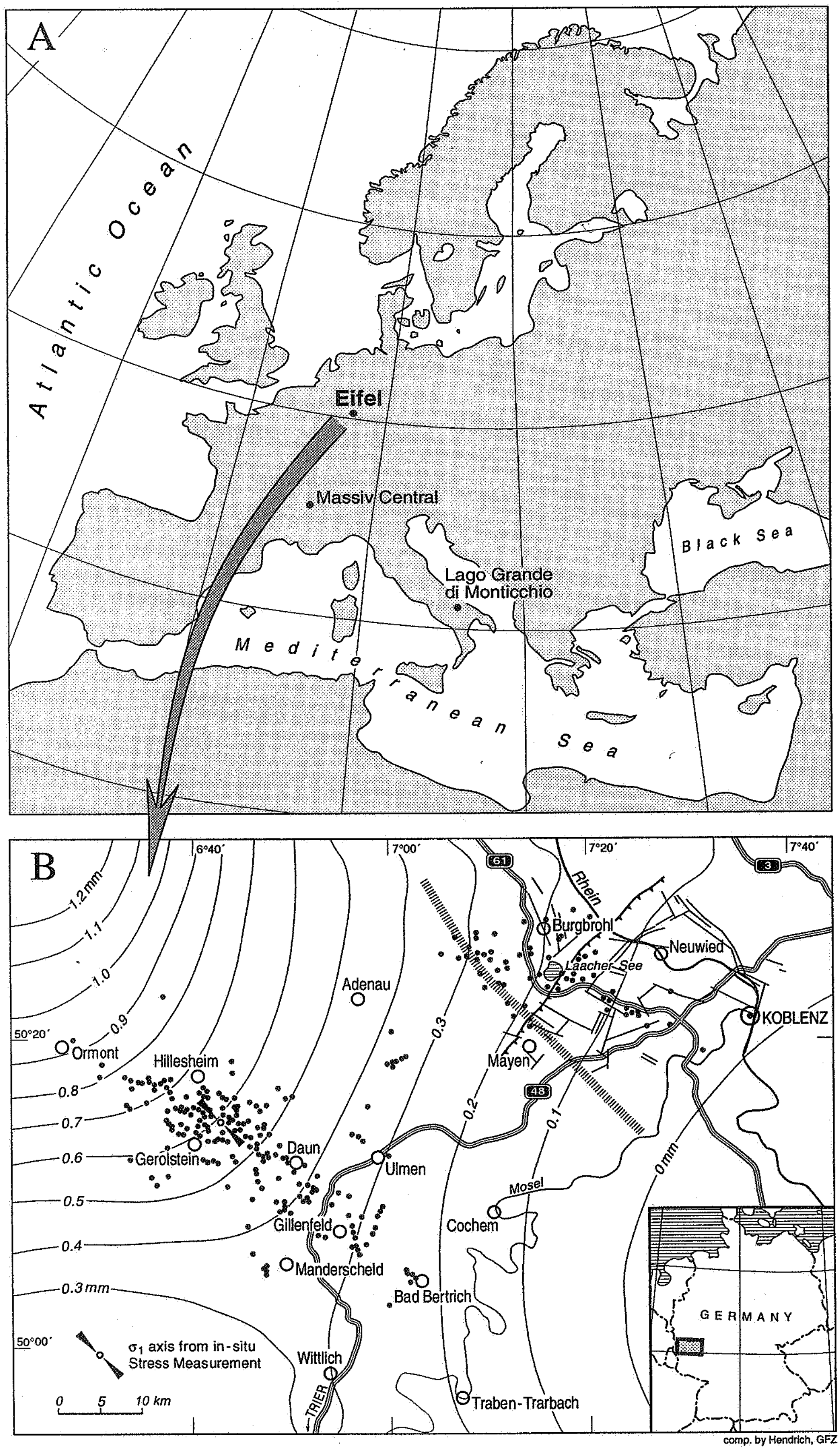

Figure 1A. Location of investigated maar lakes in Europe.
Figure 1B. Distribution of eruptive centers of the Quaternary West and East Eifel Volcanic Fields, the recent crustal movements in this area and the + 1 axis from in situ stress measurements parallel to the main alignment of the Westeifel Volcanic Field (in Refs. Mertes & Schmincke, 1983).

Hardy *et al.*, 1996). Mixed varve types are most common reflecting the interrelationship of biological and geological systems within the lake. Deposits of Eifel maar lakes show three types of laminated sediments depending on specific palaeoclimatic and palaeoenvironmental conditions (Negendank *et al.*, 1990; Negendank & Zolitschka, 1993):

- Weichselian clastic laminites (silt/clay couplets) are reported from Meerfelder Maar and Holzmaar (Brauer, 1994; Brauer *et al.*, 1994),
- Late Glacial to Holocene siderite laminites occur in the sediments of Meerfelder Maar, Holzmaar, Weinfelder Maar, and Gemuendener Maar (Brauer & Negendank, 1993; Zolitschka, 1990),
- Late Glacial and Holocene diatomaceous gyttjas were deposited in Holzmaar, Meerfelder Maar and Schalkenmehrener Maar (Negendank 1988; Negendank *et al.*, 1990; Poth & Negendank, 1993; Zolitschka, 1990; Heinz *et al.*, 1993; Rein, 1996).

In the first part of this paper we describe the composition of the sediments. In the second part the focus is directed towards spectral analyses of varve thickness measurements from a selected time window.

2. LAKE HOLZMAAR SEDIMENTS

Small crater lakes of phreatomagmatic origin e. g. maar lakes like Lake Holzmaar, are exceptional sediment traps due to their basin morphology. In these lakes very often annually laminated sediments are formed and preserved. Such varve sequences provide high-resolution proxy data for palaeoenvironmental studies. During most of the Weichselian, with a dominating open tundra-like vegetation, clastic deposition prevailed, whereas autochthonous lacustrine production is the dominant source of deposition during interglacial climatic conditions with dense vegetation and stabilized soils. During the Late Glacial and the early Holocene adjustment of the environment to changing palaeoclimates - from glacial to interglacial conditions with several more or less pronounced fluctuations, e.g. the Younger Dryas - caused a mixing of allochthonous and autochthonous deposition resulting in organo-clastic sediments. Deforestation through human cultivation started as early as 7300 cal. BP during the Neolithic and was most intense since 2750 cal. BP with the onset of the Iron Age (Zolitschka, 1992). These processes again caused the deposition of more minerogenic sediments.

The sediment sequence from Lake Holzmaar covers a period of 22,500 varve years. It is subdivided in two parts: Pre-Bølling grey silt/clay laminae and Late Glacial to Holocene black to olive-brown organic laminae with variable minerogenic contributions (Fig. 2).

2.1. CLASTIC SEDIMENTS

The Weichselian sediments of pre-Bølling to Last Glacial Maximum age (13,800 - 22,500 varve years BP) predominantly consist of allochthonous minero-genic components with quartz and clay minerals. Detrital carbonates and dark mineral phases as well as basaltic rock fragments are subordinated. Silt/clay laminations comprise different facies types. These include two different periglacial varve types, turbidites, and detrital layers. Dropstones are ubiquitous.

The majority of the silt/clay-laminae represents true varves, as suggested by comparing thin section analyses of the complete sequence with models of seasonally controlled deposition (Gilbert, 1975; Leonhard, 1986). The predominant varve type is a couplet composed of a thick silt layer, which sometimes contains fine sand and a thin but clearly recognizable clay top. This varve type represents the classic spring/summer - winter succession. The process of sedimentation is suspension fallout from snowmelt discharge in spring when the soil was still frozen. Several subtypes are discernable due to different sublaminations within the silt layer. A second coarse grained varve type relates to increased runoff. This is characteristic only for the transition period shortly before the Late Glacial warming which is indicated by the onset of organic autochthonous deposition. Generally, this varve type consists of alternating layers of fine silt-clay and coarse silt-sand.

Additionally, spectral analysis of a time series of 1050 Weichselian varve thickness measurements (from 19,850 to 20,900 varve years BP) indicates several periodicities of assumed solar origin (Brauer *et al.*, 1994) with the 88-year Gleissberg cycle as the dominant one. Such a periodicity is believed to be characteristic for varves which mainly depend on temperature variations like clastic varves (Anderson & Koopmans, 1963) and would not be recognizable in this time series, if laminations were not of annual origin (Anderson, 1993).

2.2. TEPHRA LAYERS

Two distinct isochrons mark the Late Glacial/Holocene transition in all of the Eifel maar lakes: Laacher See Tephra (12,560 varve years BP), which is the product of a catastrophic Plinian pumice eruption covering Central and Northern Europe with ash deposits, and Ulmener Maar Tephra, a regional eruption that occurred at 11,000 cal. BP (Zolitschka *et al.*, 1995).

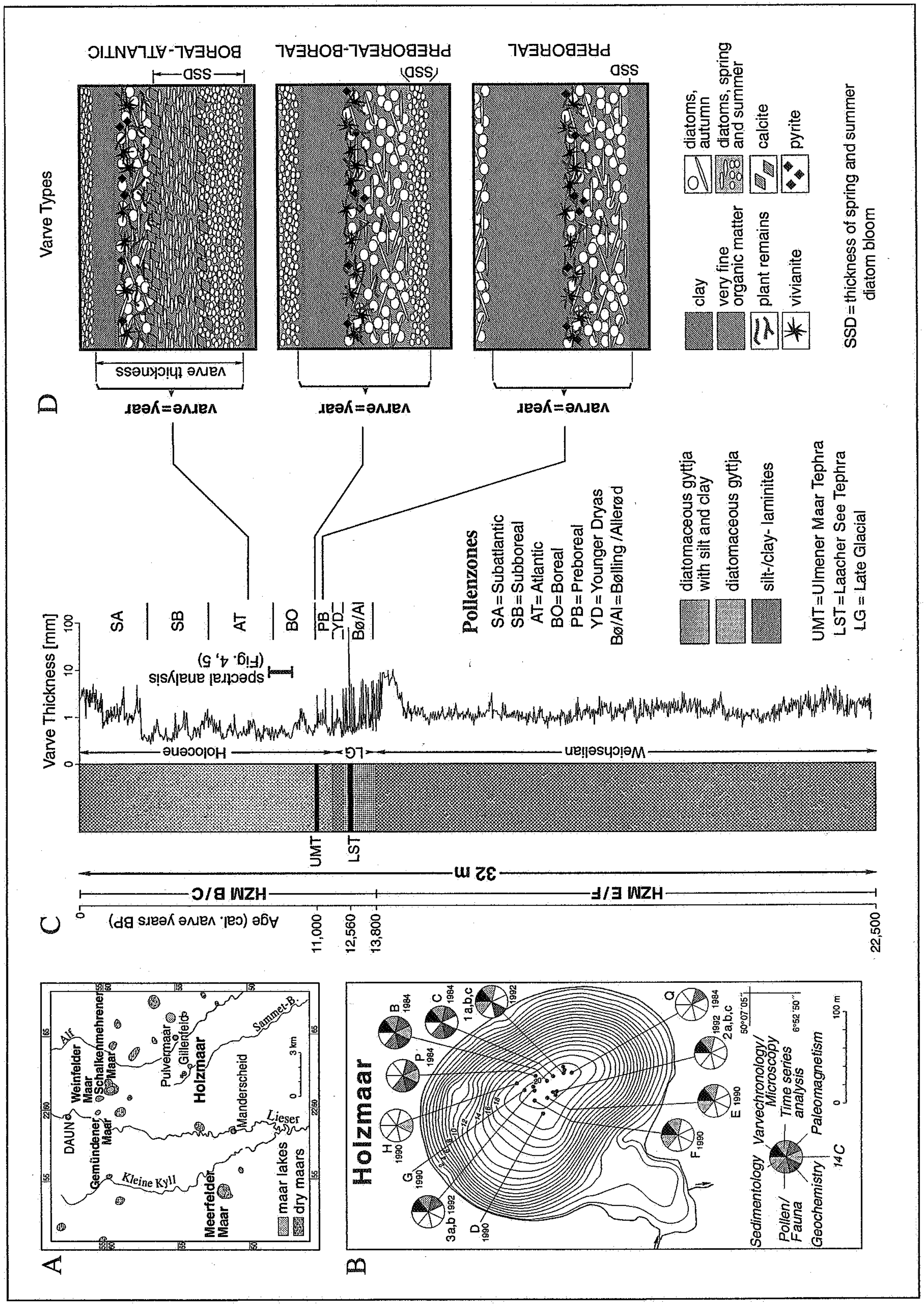

Figure 2. Lake Holzmaar in the West Eifel Volcanic Field (A) and coring sites (B) with indicated analyses for each core. Standard profile (HZM B/C and E/F) with tephra layers, biozonation and varve thickness variations (C) and three characteristic varve types of the Preboreal, Preboreal-Boreal and Atlantic biozones (D).

2.3. ORGANIC SEDIMENTS

Due to climatic conditions Late Glacial to Holocene sediments consist mainly of the remains of autochthonous production within the lake and are composed of annually- laminated diatomaceous gyttja, although, according to unstable environmental conditions during the Late Glacial to early Holocene (13,800 varve years BP - 10,000 cal. BP) and during the late Holocene (since 2750 cal. BP), increased minerogenic components are discernible. Especially, sediments deposited during the Younger Dryas biozone (12,300 varve years BP - 11,600 cal. BP) are characterized by brown colour and higher amounts of silt and clay.

The majority of the sediments represents grey organic laminae and has been demonstrated to be varves by a certain succession of diatoms and pollen grains (Zolitschka, 1991). A wide range of different varve types can be observed along the profile from the Late Glacial to the present. Three main varve types from the early Holocene show several sublaminations resulting from (climatically induced) changes in biological activity (Fig. 2). In general, diatom blooms diminish with colder climates during periods of increased clastic sedimentation due to higher rates of erosion in the catchment area, like during the Younger Dryas biozone.

During the late Boreal and the early Atlantic biozone (10,030 - 8900 cal. BP) formation of varves is dominated by algal blooms, because the catchment is stabilized by a mixed oak forest (Usinger & Wolf, 1991) and human activities disturbing this system are still of no importance. Thus minerogenic deposition via runoff can be almost excluded. Each varve consists of spring-, summer-, autumn- and winter layers beginning with central planktonic diatoms followed by pennate planktonic diatoms and then changing to littoral central and pennate diatoms with organic detritus. SEM-micrographs demonstrate the internal structure of these varves (Fig. 3). Sublaminations are often composed of only one diatom species (Fig. 3B, C, D). In some cases Chrysophycean cysts occur at the base or within one sublayer (Fig. 3E).

2.4. VARVE CHRONOLOGY AND VARIATIONS IN VARVE THICKNESS

Organic and clastic varves of the entire sequence have been counted from top to base. Additionally, thickness variations were determined by measuring the thickness of each varve 3 - 5 times and then calculating the average thickness (Fig. 2C). According to varve counts the base of the varve chronology of Lake Holzmaar is dated to 22,500 varve years BP, controlled by AMS-14C data since the Late Glacial (Hajdas *et al.*, 1995). Varve thickness variations along the profile (Fig. 2C) can be divided into 5 sections:

1. Weichselian sediments of the Last Glacial Maximum (22,500 - 14,300 varve years BP) with some variation in varve thickness (mean = 1.4 mm; maximum = 6.6 mm; minimum = 0.4 mm).
2. Extremely thick varves prior to the Bølling biozone from 14,300 to 13,800 varve years BP (mean = 6.0 mm; maximum = 17.0 mm; minimum = 0.5 mm).
3. Late Glacial to early Holocene sediments (13,800 varve years BP - 9500 cal. BP) with generally decreased varve thickness but with large variations (mean = 1.06 mm; maximum = 5.0 mm; minimum = 0.18 mm) documenting times of major climatic change.
4. Main part of the Holocene (9500 - 2750 cal. BP) with low and less variable varve thickness values (mean = 0.55 mm; maximum = 1.5 mm; minimum = 0.19 mm).
5. The youngest part of the record (since 2750 cal. BP) with anthropogenic influences causing again an elevated level of varve thickness data with high variations (mean = 1.78 mm; maximum = 8.0 mm; minimum = 0.45 mm).

3. NON-LINEAR SPECTRAL ANALYSIS OF A SEQUENCE OF 1130 VARVES

For the beginning, spectral analysis of varve thickness measurements was carried out in the time window of 10,030 to 8900 cal. BP (late Boreal to early Atlantic pollen zones). At that time the vegetation consisted of a stable mixed oak forest which reduced erosion in the lake surroundings and minimized allochthonous sedimentation. Also, this period is located prior to the onset of neolithic human activities excluding any anthropogenic influences on depositional processes. In summary, selecting this time period restricts the analysis to diatom-dominated varves and excludes distortions caused by large-scale climatic changes before and human influences after. These organic deposits are thought to contain a solar signal, because their formation and thickness variation, provided the nutrient level is fairly constant, should mainly be controlled by temperature and radiation. With low and barely variable sedimentation rates (mean varve thickness = 0.45 mm; maximum = 1.4 mm; minimum = 0.18 mm) these varves are also best suited for spectral analyses (Fig. 2).

In a biological system in equilibrium with its abiotic environment, fluctuations of the most important abiotic factors, water temperature and light, are expected to influence biological production non-linearly around an optimum for temperature and radiation (Pianka, 1983). Consequently, non-linearly-transformed fluc-

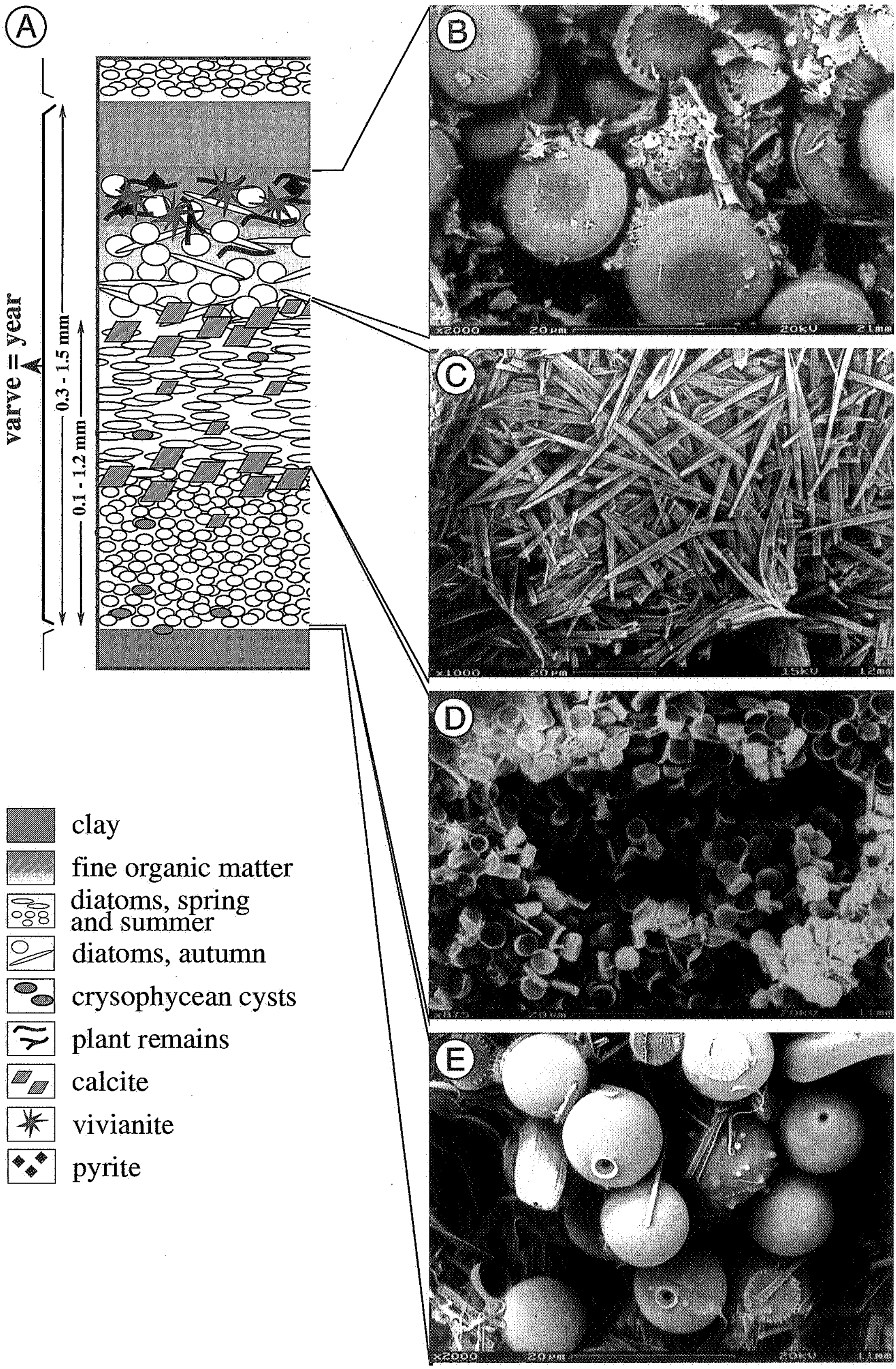

Figure 3. Typical varve of the Boreal-Atlantic biozone with sublaminations deposited during spring (D, E), summer (C), autumn and winter (B).
A: One varve with seasonal sublayers and indicated thickness of the whole varve and of spring and summer diatom blooms.
B: *Cyclotella radiosa* ; C: *Nitzschia sp.*; D: *Stephanodiscus sp.;* E: Chrysophycean cysts.

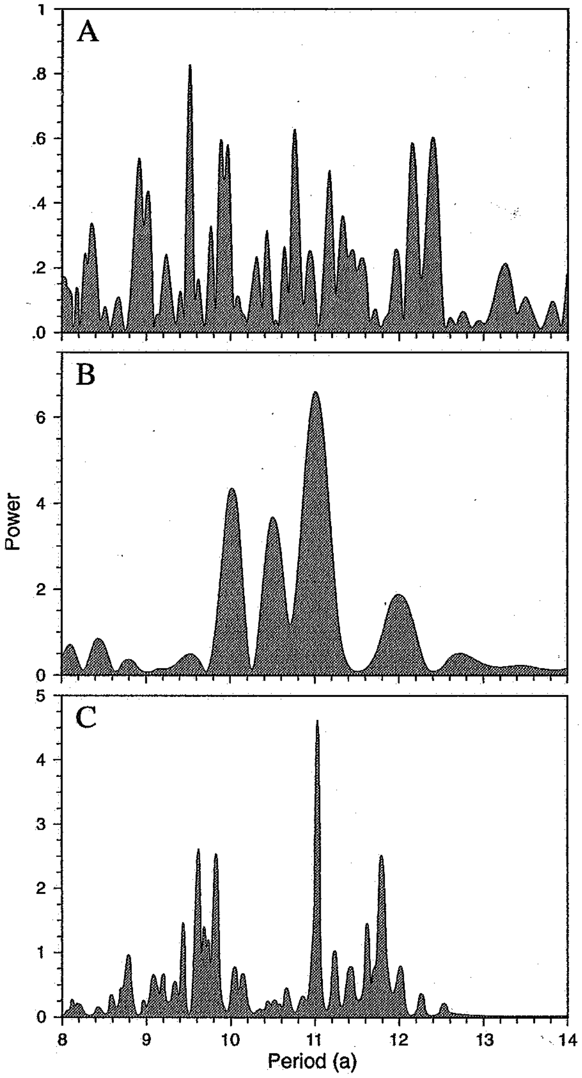

Figure 4. Sunspot cycles in Lake Holzmaar varves, in comparison with real sunspot data. A) Spectrum of varve thickness variations. B) Spectrum of sunspots between 1700 and 1992. C) Reconstructed solar spectrum of varve thickness variations by nonlinear transformations.

tuations of these abiotic factors will influence lamination thickness through biological production. If this is the case, spectral characteristics of these fluctuations are destroyed and a reconstruction of solar signals requires the application of a technique for non-linear spectral analysis. For the sediments from Lake Holzmaar a local phase quality-oriented method has been developed (Sanchez & Vos, 1994; Vos, in prep.).

Fig. 4A shows the spectrum in the time domain around the 11-year solar cycle for the original varve thickness time series. There is no significant similarity to the spectrum of the mean yearly sunspot values from 1700 - 1992 (Fig. 4B). Applying the local phase quality-oriented method with an interval length of 110 years, a spectrum with a dominant peak at 11-years is obtained (Fig. 4C). We interpret this coincidence of the reconstructed 11-year cyclicity from Lake Holzmaar sediments with the same periodicity determined from sunspot data as influence of solar fluctuations (irradiance) on organic productivity and varve formation in this lacustrine setting. Moreover, these are evidences for the relevance of non-linear biological transfer functions in such a system.

To detect longer periodicities changes in varve thickness variability have been analyzed. A set of variability time series is obtained by applying moving absolute deviations from the local mean varve thickness data with different window lengths. For each time series a spectrum was obtained and processed as proposed by Sanchez & Vos (1994). Fig. 5 shows the areas of higher spectral density for the chosen set of time series of increasing window length. In addition to the 88- and 208-year periodicities known from Holocene radiocarbon variations (Stuiver *et al.*, 1991; Stuiver & Braziunas, 1993), a set of planetary frequencies (revolutions and laps of Uranus, Neptune and Pluto) have been detected. Those planetary fingerprints suggest a possible relationship between solar activities and solar-system dynamics.

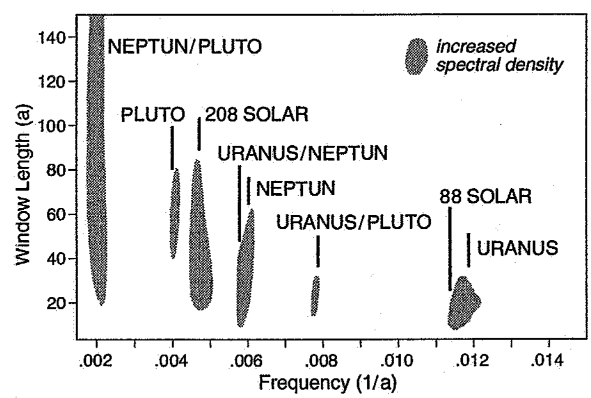

Figure 5. Sideric revolution times of planets and their laps.

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