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10 000 years of interannual sedimentation recorded in the Lake Nautajärvi (Finland) clastic–organic varves

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Abstract

Physical properties of varves formed over the last ca. 10 000 years from Lake Nautajärvi, central southern Finland provide a potential proxy record of winter precipitation and temperature via catchment runoff and erosion. The seasonal-scale varved data indicate that the winter severity and duration of summer growing season has changed considerably during the Holocene in southern central Finland. Periods of increased catchment erosion occurred at 7590–7530 BC, 7450–7400 BC, 7220–7110 BC, 7000–6000 BC, 5400–5200 BC, 4400–4000 BC, 2700–2400 BC, ca. 1500 BC to AD 500, and 1400 AD onwards. The observed changes are likely related to severe winters conditions with high net accumulation of snow between ca. 7500 BC and AD 300, whereas AD 300 onwards an increasing agricultural input is seen in the varve and pollen data. Periods that can be interpreted as indicating attenuated spring floods caused by milder and wetter winters appeared around 7000 BC and AD 1000–AD 1200, the latter corresponding with the last historically recorded warm interval in Europe, known as the Medieval Climate Anomaly.

Keywords: Varves; Lake sediments; Palaeoclimate; Medieval period; Holocene; Finland

1. Introduction

The primary strength of varved lake sediments is their visual reflection of the annual sedimentation cycle. This property allows construction of an inherent and continuous chronology on the condition that the annual nature of these couplets has been verified (Saarnisto, 1986). In addition, varves provide a unique opportunity for palaeoecological studies, as they permit a high temporal resolution and the possibility to perform accurate quantitative analysis (e.g. Renberg and Segerström, 1981).

Recently, the applications of varve records have transformed from stratigraphical and chronological analysis to the provision of high-resolution indicators of the palaeoenvironment, and particularly as a tool to study the effects of climate forcing on the physical and biological properties of sediments (Anderson et al., 1996; Zolitschka et al., 2000; Lamoureux et al., 2001; Snowball et al., 2002). For example, the

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physical characteristics of varves in proglacial lakes have been found to preserve a proxy record of the palaeoclimate due to the annual or seasonal discharge of suspended sediment from the catchment, which is correlated with air temperature (Leemann and Niessen, 1994; Hardy et al., 1996). A number of studies, therefore, have been conducted to develop routine methods that allow better and more objective measurement of the fine-scale qualities and quantities of varved sediment structures. Advancements in digital imaging (e.g. Francus, 1998; Lotter and Lemcke, 1999; Petterson et al., 1999; Saarinen and Petterson, 2001; Ojala and Francus, 2002; Tiljander et al., 2002), image filtering (e.g. Cooper, 1997; Russ, 1999; Ojala and Francus, 2002), and digital image analysis (e.g. Zolitschka, 1996; Francus, 1998; 2001; Petterson, 1999; Saarinen and Petterson, 2001; Tiljander et al., 2002) have produced a useful tool to record the physical properties of varves with a high temporal resolution.

The seasonal-scale variation of minerogenic and organic matter accumulation in Lake Nautajärvi during the last 10000±100 years was recorded using X-ray radiography and digital image analysis (X-ray densitometry; Tiljander et al., 2002). This paper aims to discuss the formation and structure of varves and primary factors controlling sediment influx into the lake. Another important task of this paper is to provide a perspective on Holocene climate variability based on a dataset of clastic–organic varves, and also to estimate the magnitude of human impact on this high-resolution sediment sequence using pollen analysis.

2. Materials and methods

2.1. Site description

Lake Nautajärvi is located in central southern Finland (61°48′N, 24°41′E) in the larger-scale drainage basin of River Kokemäenjoki and at an altitude of 103.7 m a.s.l. (Fig. 1). Deeply eroded coarse-grained granites, partly overlain by a thin till layer, cover approximately half of the drainage basin adjacent to Nautajärvi. The other half is covered by thicker Quaternary till and post-glacial silt in equal proportions formed on the distal side of the end moraine called the central Finland ice-marginal formation (Kujansuu et al., 1981).

Nautajärvi is a small (0.17 km^2) oval-shaped lake that was isolated from the Baltic Sea basin during the Lake Ancylus stage at 7675 BC (Ojala et al., 2005). The water volume is about 1.7 million m^3 and the maximum and mean water depths are 20 and 10 m, respectively. Varves are confined to water depths >18.5 m, which cover approximately 13% of the lake area. The lake is supplied by three inflows from the north and there is one southern outflow. According to limnological measurements (from the PIVET database of the Finnish environmental authorities) performed in January 1989 and 1997, Lake Nautajärvi has an inverse water stratification and anoxia (<1 mg l^{-1}) near the bottom, suggesting a dimictic nature. Conductivity (3.1–3.4 MS M^{-1}) and pH (5.8–6.0) remain fairly stable throughout the water column, whereas concentrations of Fe and Mn increase with depth from 500 to 2000 μg l^{-1} and from 100 to 500 μg l^{-1}, respectively. Total N and P in the water column are also highest near the bottom and vary between 400 and 800 μg l^{-1} and between 15 and 80 μg l^{-1}, respectively, indicating mesotrophy.

The present-day local climate is continental, with a mean annual precipitation of about 500 to 700 mm, of which approximately one third falls as snow. The annual mean temperature is ca. +3 °C, the warmest months being July (+15 to +18 °C) and the coldest January or February (−5 to −12 °C). Lake Nautajärvi is ice-covered for a period of 4 to 5 months, usually from mid-December (Alalammi, 1987). The lake is located within the Southern Boreal vegetation zone and the dominant tree species are pine and spruce.

2.2. Field and laboratory methods

Altogether, more than 30 sediment cores have been taken from the Lake Nautajärvi basin between 1997 and 2003 (Fig. 1). This study is mainly based on three long cores (A, C, AS4) taken with a gravity piston corer (Putkinen and Saarelainen, 1998) and a surface freeze core (JNA1), all taken from the deepest part of the lake. The remaining cores are referred to here only to establish a broader picture of the sedimentary environment and in the calculation of total sediment accumulation. In addition, several acoustic profiles