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Varves and megavarves in the Eberswalde Valley (NE Germany) — A key for the interpretation of glaciolimnic processes

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ABSTRACT

Rhythmic sediments were investigated on the 'main terrace' (36 m a.s.l.) of the Toruń–Eberswalde ice-marginal valley near Eberswalde (NE) Germany. The 'main terrace' is correlated with the Pomeranian phase of the Weichselian glaciation, during which most of the fluvial sedimentation in the ice-marginal valley took place. Two rhythmically laminated lithofacies associations are distinguished on the 'main terrace' in two outcrops, at Eberswalde and Macherslust, respectively: (1) a horizontally-laminated silt and clay unit (lithofacies association Th, Mh); and (2) a thick, horizontally-laminated silt with, additionally, a horizontally-laminated clay (lithofacies association Th, (Mh)), both deposited in quite deep depressions of subglacial origin. Both depressions were formed by high-concentration flows that resulted from ice melting. The presence (at Macherslust) of up to 45 cm thick varves/'megavarves', which are unique for Quaternary sediments in an ice-marginal valley and even for glaciolimnic sediments ('classic' varves) in general, sheds light on depositional conditions in ice-marginal valleys and in glaciolimnic environments. The thick varves can be considered as a diagnostic criterion for glaciolimnic deposits derived from repeated high-discharge conditions of currents that probably had a hyperconcentrated character.

1. Introduction

The Toruń–Eberswalde (Noteć–Warta) ice-marginal valley forms the largest valley in the Polish–German northern plains (Fig. 1). It was formed during the Late Weichselian, and is oriented parallel to the then existing ice front. The Eberswalde Valley is a part of the Toruń–Eberswalde ice-marginal valley. It is oriented E–W, at least 500 km long, and incised into glaciofluvial sands and gravels of outwash plains, and locally it is incised into a till plain of the Brandenburger–Leszno phase of the Weichselian glaciation. The valley drained water from both proglacial streams which ran from the ice-sheet in the North and probably extraglacial rivers coming from the South.

The role of fluvial processes in the development of this ice-marginal valley was discussed by Kozarski (1966, 1988), Carls (2005), Börner (2007), Weckwerth (2010, 2011), Weckwerth et al. (2011) and Pisarska-Jamroży and Zieliński (2011). Börner (2007, 2009a, 2009b) described stages of the Eberswalde Valley development, with burying of the valley by coarse-grained gravel and sands of an outwash plain up to 47 m a.s.l., followed by erosion of the deposits by meltwater streams. This resulted in the formation of the 'main terrace' at 36 m a.s.l. Schirrmeister (1998) reported remnants of glaciolimnic deposits in this terrace; he described them, on the basis of Krebetschek's (1997) IR-OSL dates (17.0 ± 4.4 ka), as older than the Pomeranian phase. Studies by Lüthgens et al. (2011) dated the sediments by OSL to 14.7 ± 1.0 ka, and the present author who obtained two OSL ages of 14.6 ± 6.5 ka and 12.18 ± 4.5 ka. All ages imply that these terrace sediments are correlatable with the Angermünde–Chojna subphase of the Pomeranian phase.

Sediments excavated in two outcrops in the Eberswalde Valley 'main terrace' were investigated by several researchers. In the first outcrop, at Eberswalde, Schirrmeister (1998) found 101 varves in a 103 cm high profile; he interpreted them as deposited by settling from suspension. The second outcrop, at Macherslust, contains a 'megavarves' (the term 'megavarves' is introduced here; megavarves are varves thicker than 10 cm) that have been interpreted as deposited in a small lake by melting of blocks of buried dead-ice (cf., Marcinek and Schultz, 1995; Schirrmeister, 1998, 2004).

The main objectives of the present contribution are (1) to reconstruct, on the basis of detailed lithofacies analysis, the depositional conditions of the glaciolimnic sediments, (2) to unravel the origin of the 'megavarves' at Macherslust which may shed new light on glaciolimnic sedimentation; (3) to evaluate the depositional conditions of sands that accumulated at a significant distance from the ice-sheet margin, at both Eberswalde and Macherslust; (4) to reconstruct the development of deformations in both glaciolimnic successions; and (5) to consider whether an earlier valley existed which evolved into an ice-marginal valley.

2. Geological setting and geomorphology

The Eberswalde Valley (which is on average 8 km wide, but only 3.5 km in the study area) was a uniform landform during the Pomeranian

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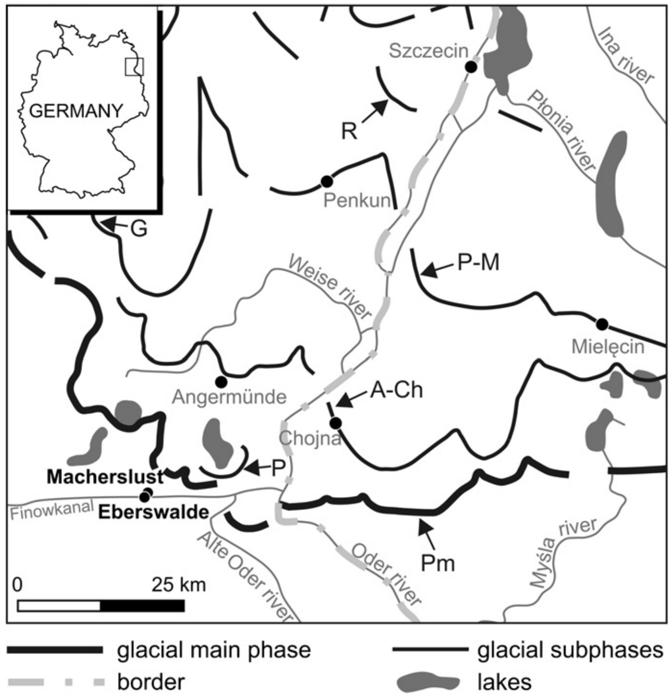

Fig. 1. Study area in the Eberswalde Valley and adjacent regions reached by the ice during the Pomeranian phase. Pm = Pomeranian phase, A-Ch = Angermünde–Chojna subphase, P = Parsteiner subphase, P-M = Penkun–Mielęcin subphase, G = Gerswalde subphase, R = Rosenthal subphase.
Modified from Kliewe and Kozarski, 1979; Liedtke, 1981.

phase of the Weichselian glaciation (Figs. 2, 3). The study area was overridden by glacial ice during two major Weichselian ice advances. Northeast of the Eberswalde Valley, end-moraine ridges occur that were formed during the maximum ice extent of the Pomeranian phase; in the south and west moraines of the Brandenburger–Leszno phase are present. Outwash and till plains are locally covered by Late Weichselian aeolian sands (Fig. 2). Nowadays, the Eberswalde Valley is occupied by secondary rivers and canals, glaciolimnic silts and sands of the Pomeranian phase, peat areas, and limnic and fluvial sediments deposited between and the Preboreal and the late Subatlantic.

In the valley, three terraces have been distinguished: (1) a terrace at 47 m a.s.l., which was formed during accumulation of the main sandur of the Pomeranian phase; (2) a terrace at 40 m a.s.l., which is related with a small sandur, which accumulated on top of the previous sandur; and (3) the lowest and 'main terrace', at 36 m a.s.l., which formed during the multi-phase recession of the ice-sheet margin related to the Angermünde–Chojna subphase of the Pomeranian phase (Gärtner et al., 1995; Börner, 2007). The outcrops at Eberswalde and Macherslust are both located in glaciolimnic sediments of the 'main terrace'. Locally, the glaciolimnic sediments were covered by peat or by glaciofluvial sands and gravels of outwash plains (Figs. 2, 3).

3. Methods

Standard sedimentological analyses using laser diffraction and thin-section analyses have been performed. OSL dating was done for the Macherslust succession. The grains of 4–11 μm were obtained by wet sieving. The quartz grains were etched with HF (40%) for 60 min. Determination of the equivalent dose was carried out by OSL-SAR.

The lithofacies are coded following Miall (1978), with a slight modification in order to obtain a higher descriptive resolution for fine-grained lithofacies (Table 1). Miall (1978) used the textural symbol *F* for both silts and clays, which is unsatisfactory in the case of granulometrically different fine-grained sediments, as present in glaciolimnic deposits. Two additional textural symbols, *T* for silt and *M* for mud/clay were therefore introduced by Zieliński and Pisarska-Jamroży (2012). The most frequent and most characteristic lithofacies are combined into lithofacies associations, e.g. Th, Mh. Less frequent lithofacies are indicated with their code between brackets, e.g. Th, (Mh).

Table 1
Sedimentary lithofacies code used in this study.
Modified from Miall, 1978.

Code	Texture	Structure
Mh	Mud/clay	Horizontal lamination
Th	Silt, medium to coarse	Horizontal lamination
Sh	Sand, fine to medium	Horizontal lamination
Sm	Sand, fine to medium	Massive

The grain size of the sediments is indicated according to the Udden–Wentworth scale (Udden, 1914; Wentworth, 1922). The results obtained from grain-size analyses are presented in a Passega C-M diagram (Passega, 1964; Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011), where the values of the first percentile, *C*, are plotted against the median grain diameter, *M*.

In addition to standard sedimentological analyses, the Markov chain statistical analysis was used to determine the sequence of sedimentary processes; this analysis, which was done following common usage (cf., Nemec, 1981; Doktor and Gradziński, 1985), was used in order to decide if any non-random vertical lithofacies superposition is present at any of the study sites.

4. The Eberswalde and Macherslust sedimentary successions

Two rhythmically-laminated lithofacies associations are distinguished. The first association (in Eberswalde) contains horizontally-laminated silt and clay: Th, Mh; the second association (in Macherslust) consists of a horizontally-laminated silt with, additionally, horizontally-laminated clay: Th, (Mh). Subordinate deposits in both associations are sandy lithofacies.

4.1. Horizontally-laminated silt and clay at Eberswalde

4.1.1. Description

The visible thickness of lithofacies association Th, Mh is 2 m (34–36 m a.s.l.; Fig. 4), but in drillings it reaches 17 m (15–32 m a.s.l.). The association is composed of silt and clay with horizontal lamination (lithofacies Th, Mh) and, less common, horizontally-laminated sand (lithofacies Sh). The silty lithofacies make up over 55%, whereas the clayey lithofacies constitute almost 40%; the sands form the remaining part. All lithofacies form sheet-like beds from a few millimetres to 3.5 cm thick. The lower and upper boundaries of the lithofacies are mostly sharp and non-erosional, but sometimes they are deformed. A characteristic feature of lithofacies association Th, Mh is its rhythmic organization. Two types of rhythmites are distinguished: Th ⇨ Mh and Sh ⇨ Mh of ~4 cm thick (Fig. 5A). Grain-size analysis indicates that the silt lithofacies cover the whole grain-size spectrum; similarly sand lithofacies contain fractions from very fine to coarse sands (Figs. 6, 7; Table 2). The Passega diagram (Fig. 8) shows two fields of sediments, the first one with silty and clayey lithofacies and the second one with sandy lithofacies.

The northern part of the outcrop contains soft-sediment deformation structures: folds (e.g., kink folds, kink bands), flexures and normal faults (Fig. 4). The normal faults, which tend to have offsets of 0.5–1 cm, have planes usually dipping 30°–55° to the NNW. The vergence of the folds is 45°–55°, also to the NNW. The laminae of the Th, Mh association show a dip of approximately 5°–45° toward the North (the beds are more inclined in the northern part of the outcrop).

4.1.2. Interpretation

The Th, Mh lithofacies association represents 'classic' (glaciolacustrine) varves intercalated by sands. The rhythmites appear similar