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The timing of the Weichselian Pomeranian ice marginal position south of the Baltic Sea: A critical review of morphological and geochronological results

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ABSTRACT

The Pomeranian Phase of the Weichselian glaciation in northern middle Europe has been the object of investigation in various studies aiming to derive numerical ages for this specific phase. Apart from traditional ^{14}C-chronologies, surface exposure dating with in-situ produced terrestrial cosmogenic nuclides and optically stimulated luminescence dating have been applied by different authors. The ages derived are so far not consistent. Generally, cosmogenic exposure dating results in younger ages (~15 ka) and luminescence dating results in older ages (~20 ka) for the formation of the Pomeranian Phase. The apparent age gap has been subject to discussions from both, methodological and geomorphological viewpoints. We recalculated compiled exposure ages with a recent calibration data set, which reflects very recent progress in cosmogenic nuclide dating, and received results that differ significantly from the originally published ages. The newly calculated ages deviate 9–15% from the original ages from the source studies towards the older age range, thus reducing the offset between the different dating methods and supporting the theory that the onset of the Pomeranian Phase was earlier in the marine isotope stage 2. In one example from northeast Germany, good agreement between both methods results from the recalculations, corroborated also by the local geomorphology. Nevertheless, postdepositional movement of glacial boulders as well as erosion and shielding effects are hard to quantify and most probably cause an underestimation of exposure ages. The study aims to contribute to a critical evaluation of existent chronologies for the southern margin of the Scandinavian Ice Sheet.

1. Introduction

During the last decade, a number of studies have been carried out with the purpose of obtaining numerical ages for the formation of ice marginal positions (IMPs) and the subsequent ice retreat along the southern margin of the Scandinavian Ice Sheet (SIS) (Rinterknecht et al., 2005,2006,2007,2008; Heine et al., 2009; Lüthgens et al., 2010a,b, 2011a,b; Lüthgens and Böse, 2011; Rinterknecht et al., 2012; Rinterknecht et al., 2014). Especially for the Pomeranian Phase (W2 phase), a considerable data set has been developed over recent years (Fig. 1). In this paper we present numerical ages from northern middle Europe that were published by different authors, with a strong focus on the Pomeranian IMP. We critically review the ages with respect to the different dating methods, pointing out that different methods can date different geomorphic processes. In our study we recalibrated reported ages that were derived by cosmogenic exposure dating with an alternative global production rate. Finally, we compare the results of the Pomeranian IMP south of the Baltic Sea with new results from Denmark to emphasize the influence of postsedimentary landscape development in a paraglacial environment.

By the end of the 19th century, the idea of repeated glaciations of northern middle Europe, originating from Fennoscandia, started to prevail. The so-called concept of polyglaciation goes back to Penck (1879), who investigated glacial landforms in the northern German lowlands and found evidence for multiple ice advances. Thirty years later, Keilhack (1909) published the first map showing ice marginal positions and ice marginal valleys in northern middle Europe in a broader geographical context. Enormous work by a large number of researchers followed and led to a better understanding of the extent, sedimentological sequences and climatic implications of the Pleistocene oscillations of the SIS (summarized in, e.g., Böse et al., 2012; Lüthgens and Böse, 2012; Ehlers et al., 2013). The map 'Nordic glaciations in Central Europe' by Liedtke (1981) condensed the available data in a comprehensive,

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descriptive manner. At that time, the geochronological timeframe of the different oscillations of the SIS was mostly based on morphostratigraphy and radiocarbon dating of organic matter found in, under, or above glacigenic deposits. The timeframe suggested that the various Pleistocene ice advances displayed rather static behavior. Additionally, the radiocarbon method can only be used to determine indirect ages, because it is impossible to date mineral matter (i.e., glacigenic sediments) itself using radiocarbon dating (Lüthgens and Böse, 2012).

With the development of new dating techniques, it is nowadays possible to directly date glacigenic or glaciofluvial sediments. Cosmogenic nuclide surface exposure dating (in this paper referred to as *cosmogenic exposure dating*) and Optically Stimulated Luminescence (OSL) are most commonly used. Cosmogenic exposure dating utilizes the known production rates with which certain atoms accumulate in sediment or bedrock when exposed to the atmosphere (Gosse and Phillips, 2001). In OSL dating, quartz or feldspar grains are used as natural dosimeters that build up a time-dependent dose after deposition and when protected from sunlight (e.g., Rhodes, 2011).

For the determination of deglaciation ages using cosmogenic exposure dating, samples are best taken from quartz veins in glacially transported boulders or glacially eroded bedrock. When exposed to cosmic radiation after the ice retreat, cosmogenic nuclides (e.g., ^{10}Be, ^{26}Al) are produced in the mineral (Nishiizumi et al., 1993); of these ^{10}Be is most frequently used for dating purposes. One important precondition is that the sampled surface was eroded by the last glacial process that is meant to be dated. Otherwise the age will be overestimated due to inherited nuclides. Nevertheless, cosmogenic exposure dating tends to underestimate rather than overestimate ages, owing to weathering of the surface or post-depositional movement, as studies with independent age control have shown (Ivy-Ochs and Kober, 2008). The trend of age underestimation is corroborated by statistical reevaluation of the age distributions of published data sets (Heyman et al., 2011).

Age determination by the OSL method is restricted to the sand and silt grain size fractions of quartz and feldspar minerals. The important precondition is that the grains are exposed to sunlight during their transport for a time span long enough to completely bleach the grains. Postdepositional mixing should be excluded by examination of the sedimentary features of the layer to be sampled. After deposition and burial with other sediments, a luminescence signal is built up in the grains caused by natural ionizing radiation from the surrounding sedimentary body, cosmic rays, and, especially in the case of alkali feldspar minerals, also from the grains themselves (Huntley et al., 1985; Preusser et al., 2008; Rhodes, 2011).

Incomplete bleaching, which can lead to an overestimation of OSL ages, occurs in many cases in the glacial and glaciofluvial sedimentary system. It can be overcome with the single grain technique, which allows discrimination between completely and incompletely bleached grains in the measurement results (Duller, 2008; Fuchs and Owen, 2008; Thrasher et al., 2009).

2. Recalculation of reported cosmogenic exposure ages – why?

Very basically, an exposure age (T) [a] is calculated by division of the measured nuclide concentration (N) [atoms g^{-1}] by the production rate of the respective nuclide (P) [atoms g^{-1} a^{-1}] (Nishiizumi et al., 1993). In case of, e.g., ^{10}Be and ^{26}Al, N can be measured precisely by AMS (accelerator mass spectrometry) (Ivy-Ochs and Kober, 2008). But the net cosmic radiation that finally reaches the surface to be sampled depends on a number of factors, which are sometimes hard to reconstruct for past time periods. Thus P depends on factors such as elevation, latitude, longitude, shielding, erosion and inheritance (Gosse and Phillips, 2001).

Balco et al. (2008) introduced the CRONUS-Earth online calculator, a convenient tool for calculating production rates and exposure ages. The production rate is scaled by the online calculator with respect to the geographical position of each sampling site. All reported cosmogenic exposure ages cited in this study (except for Heine et al. (2009) who used a different calculation method) have been calculated with the CRONUS-Earth online calculator (Balco

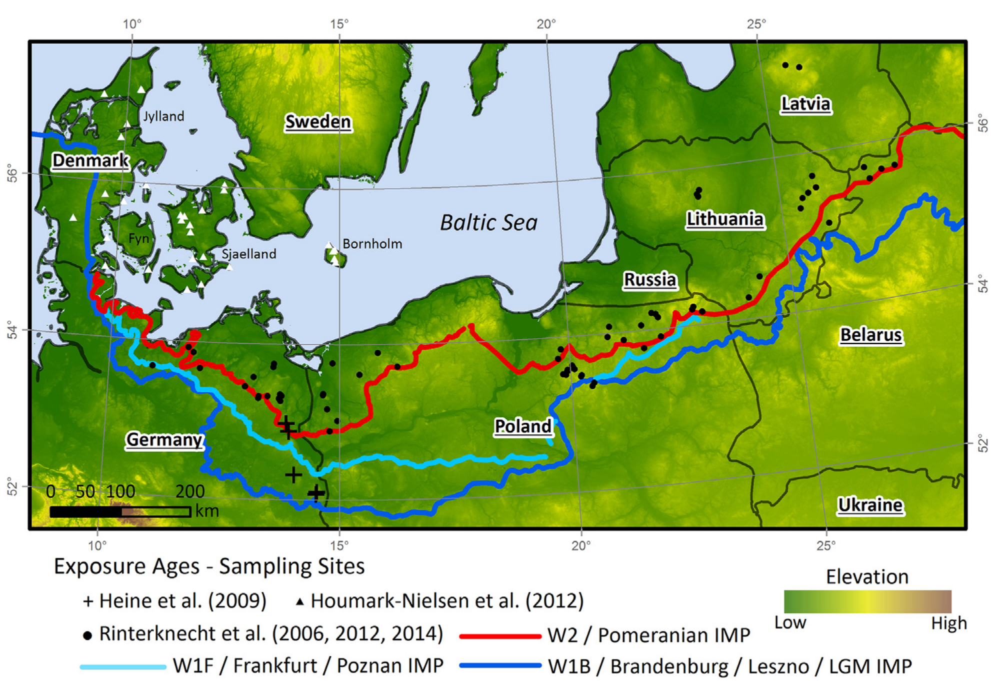

Fig. 1. Overview map of Weichselian ice marginal positions (IMPs) south of the Baltic Sea and sampling sites for cosmogenic exposure dating, which are included in this study. Ice marginal positions according to Ehlers and Gibbard (2004). Base map created on basis of 250 m SRTM data (Jarvis et al., 2008).