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Discriminating between subglacial and proglacial lake sediments: an example from the Dänischer Wohld Peninsula, northern Germany

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ABSTRACT

Subglacial lakes are common features of contemporary ice masses. However, they are rarely identified in the geological record. This is due to the difficulty in discriminating between subglacial and proglacial lake sediments; a proglacial origin is typically preferred as the 'simplest' explanation. We hypothesise that numerous deposits currently interpreted to record proglacial lake sedimentation may actually have a subglacial origin. Here we try and find ways of distinguishing proglacial from subglacial lake sediments by investigating three sites along the Dänischer Wohld Peninsula, northern Germany, which have been interpreted to record both proglacial and subglacial sedimentation. We identify two major phases of ice activity and associated lake formation during the Late Weichselian glaciation. (1) Proglacial lake formation at ~23 ka in front of the advancing Baltic Ice Stream. This lake was subsequently overridden and the sediments glaciotectonised as ice continued to advance to its maximum extent. (2) Retreat of ice back into the Baltic Basin at ~19 ka and formation of a proglacial lake that persisted for ~4 ka. We suggest that subglacial lake activity may have occurred at two of the sites between 23 and 19 ka. This is based on the presence of aggrading sediment deposits characterised by stratified/laminated diamictons and interbedded tabular to channelized sorted sediments, the juxtaposition of relatively undeformed waterlain sediment and subglacial till, absence of glaciotectonic thrusting and folding or of fining/coarsening successions and the geomorphic association with tunnel valleys to the south of the study area. The style of sedimentation and deformation provided the greatest insight into the discrimination of proglacially vs subglacially deposited glaciolacustrine sediments. The luminescence signal palaeodose distributions also offers a potentially powerful means of fingerprinting sediment transport pathways of young glacial systems.

1. Introduction

Glaciolacustrine sediments are commonly observed in the geological record and have classically been interpreted to record proglacial (ice-marginal or ice-fed) lake formation (e.g. Rust and Romanelli, 1975; Eyles, 1987; Eyles et al., 1989; Larsen et al., 2006; Livingstone et al., 2010; Carrivick and Tweed, 2013). If the geographic context for these sediments in relation to a former ice margin is suitable for lake impoundment, or where other lines of evidence exist – such as lake shorelines and/or deltas – then such an interpretation is robust. It is common, however, to find glaciolacustrine sediments without ancillary support for a proglacial origin, and we raise the question; in some of these cases could the sediments have been deposited in a subglacial lake? We suggest that breaking the automatic interpretation from glaciolacustrine sediments to the existence of a proglacial lake is timely because subglacial lakes are now known to be commonplace beneath contemporary ice masses (e.g. Wright and Siegert, 2011), and are predicted to exist beneath palaeo-ice sheets (Evatt et al., 2006; Livingstone et al., 2013). Given that they must surely have existed, it is sensible therefore to hypothesise that many glaciolacustrine sediments previously interpreted as proglacial might actually have a subglacial origin. If we can distinguish the signature of subglacial lake sediments we could glean important spatial and geological evidence on: (i) meltwater drainage, ice flow and ice streams; (ii) their relation to palaeo-floods, ice dynamics and sub-

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Milankovitch-scale climate events; and (iii) long-term Quaternary climate change (Livingstone et al., 2012).

Despite recent attempts to formulate diagnostic criteria based on our current knowledge of subglacial lake processes (e.g. Bentley et al. 2011; Livingstone et al. 2012; Ravier et al., 2014a), there is still no incontrovertible method for distinguishing their geological signature from that of proglacial lakes and therefore for demonstrating their former existence. So, despite putative examples of palaeo-subglacial lakes (e.g. Gjessing, 1960; McCabe and Ó Cofaigh, 1994; Rebesco et al., 1998; Munro-Stasiuk, 1999; van Rensbergen et al., 1999; Christoffersen et al., 2008), a proglacial lake origin is typically preferred as the 'simplest' interpretation for glaciolacustrine sediments.

We explore this conundrum using the glacigenic succession of the Dänischer Wohld Peninsula, northern Germany, in an attempt to advance our skill in the discrimination of proglacially vs subglacially deposited glaciolacustrine sediments. The sediments exposed along this Peninsula have been variously interpreted to record deposition in subglacial and proglacial lake environments (Piotrowski, 1992, 1994a,b, 1997; Hart et al., 1996, 1997; Piotrowski et al., 1997; Piotrowski and Tulaczyk, 1999). Our aim is to test these two conflicting models using a range of techniques, including geomorphological mapping, sedimentological and stratigraphic investigations, and Optically Stimulated Luminescence (OSL) dating.

2. Location and glacial context

The Dänischer Wohld Peninsula is part of Schleswig–Holstein, northern Germany and is located between deeply incised bays of the southwestern Baltic Sea at Eckernförde and Kiel (Figs. 1 and 2). An up to 25 m high sea cliff has exposed a remarkable record of intercalated glacigenic facies deposited during the Weichselian glaciation subdivided by Piotrowski (1996) into the lower and upper sedimentary complexes. The succession is interpreted to record either: (1) a single advance of ice out of the Baltic Basin, which

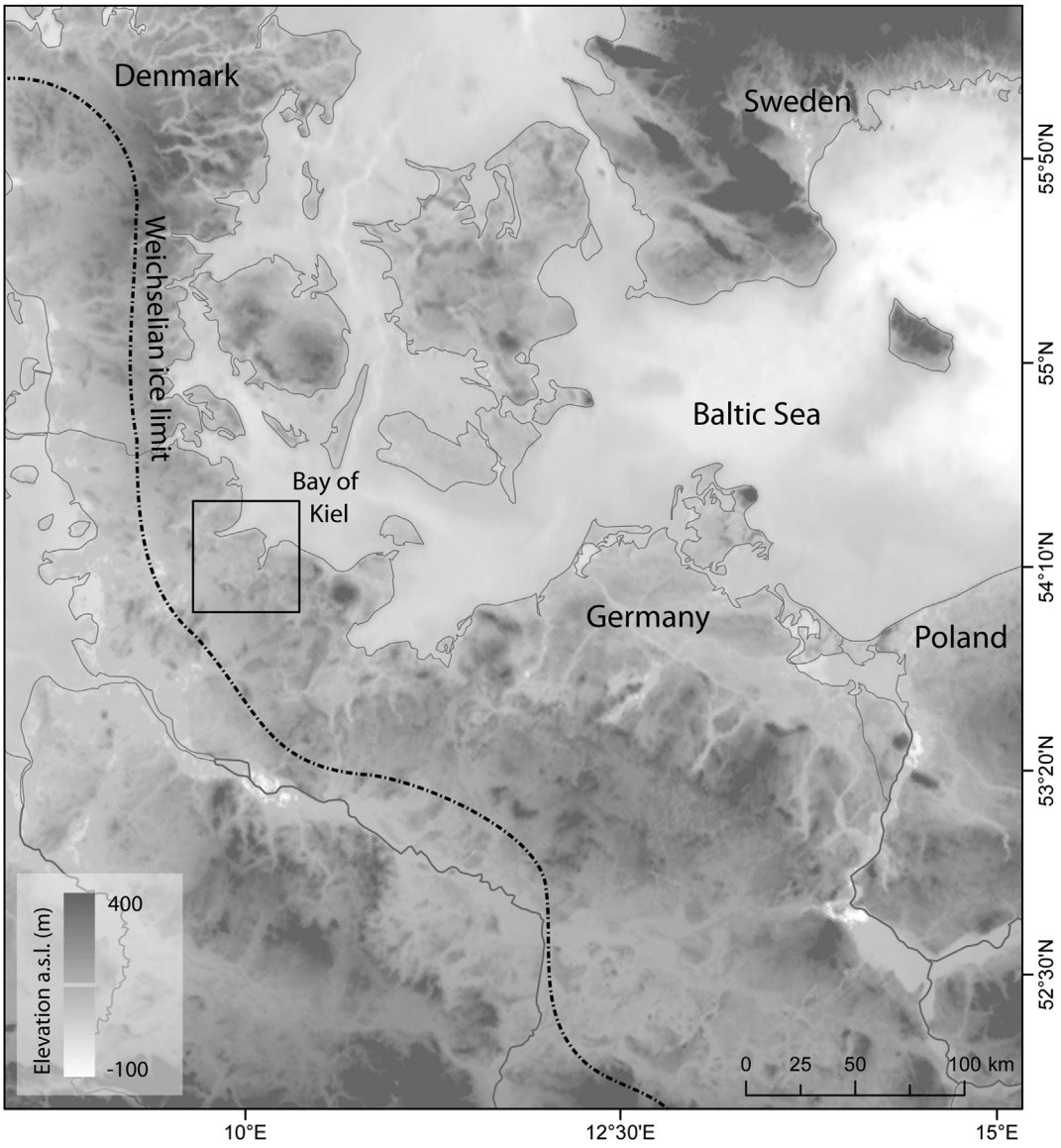

Fig. 1. Location map of the Dänischer Wohld Peninsula, northern Germany. Inset box relates to Fig. 2.