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Neotectonic faulting and the Late Weichselian shoreline gradients in SW Norway

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Abstract

The Younger Dryas (YD) maximum highstand shoreline in SW Norway has traditionally been considered as being slightly concave, gradually steepening in the direction of uplift. This phenomenon is attributed to geoidal and isostatic effects near the former ice-sheet margin. On the basis of isolation basin data from the region, we have reconstructed this shoreline, and a Bølling-Allerød (B-A) lowstand shoreline, along three profiles in SW Norway. Along all profiles there are shore levels which, within the error limits estimated, cannot be captured by a single straight (or curved) shoreline. The anomalous shore levels occur near major fault zones and are interpreted to reflect differential uplift rates on opposite sides of faults, superimposed on the general glacio-isostatic tilting of the region. The inferred faulting is consistent with observations previously reported as neotectonic 'claims' in the region and shed new light on the deformational structures observed in seismic profiles of the fjord sediments. Excluding the anomalous shore levels, a straight shoreline with gradient ca. 1.1 m/km provides the best and most consistent representation of the YD shore levels along the three profiles. The B-A lowstand shoreline is constrained by fewer data points, but is approximately parallel-dipping the highstand shoreline. Our reconstructions imply a less steep YD maximum highstand shoreline compared to previous reconstructions, where gradients up to 1.4 m/km have been inferred. This may imply that the ice load effect on the lithosphere in SW Norway during the YD is less than previously assumed.

Keywords: Neotectonic faulting; Shoreline gradients; Isostasy; Younger Dryas; Isolation basins; SW Norway

1. Introduction

Neotectonic faults, which in the present study refer to tectonic faults that carry components of postglacial displacements, are well known in the northern and central parts of Fennoscandia (Kujansuu, 1964; Lundqvist and Lagerbäck, 1976; Lagerbäck, 1979; Olesen, 1988; Tolgensbakk and Sollid, 1988; Dehls et al., 2000; Mörner, 2004; Olesen et al., 2004). In these areas, neotectonic faults up to 150 km long with scarp heights up to 30 m are documented. In southern Norway, several observations associated with neotectonic faulting have been reported, but very few conclusive evidence

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of outcropping postglacial fault-rupture has been found (Olesen et al., 2004). One exception is the Berill Fault in the northwestern part of S Norway which has scarp heights up to 3 m and which almost certainly is a neotectonic fault (Anda et al., 2002).

Neotectonics may have significant impact on the record of glacio-isostatic uplift and sea level changes. Few, if any, of the shorelines that formed and were subsequently uplifted after the deglaciation in SW Norway can be "observed" in the sense that they can be followed as unbroken lines for long distances in the landscape. The uplift gradients of these raised shorelines therefore have to be determined on the basis of correlation of discrete shore-level data points, i.e., a site-to-site correlation of individual, stratigraphically or morphologically defined palaeoshore levels. Neotectonic faulting is a source of uncertainty in this respect since a few metres of vertical displacement could potentially result in a shoreline gradient that locally diverges significantly from the regional uplift trend. This is particularly the case for the Late Weichselian shoreline gradients in the region. These gradients are determined on the basis of shore-level data points from a relatively narrow coastal belt, a few tens of kilometers wide, between the present coastline and the moraines considered as the Younger Dryas (YD) moraines in the region (e.g., Anundsen, 1985; Lohne et al., in press). The short distance renders it difficult to determine whether or not the regional uplift pattern is adequately represented by the observed data points, i.e., to distinguish local gradients from regional trends.

The Late Weichselian shoreline gradients represent an important parameter in the geophysical modelling of glacio-isostatic adjustment processes, as well as in theoretical reconstructions of the YD peripheral ice-sheet profile (e.g., Fjeldskaar, 1997, 2000). Clearly, if local gradients that are conditioned by faulting are applied in geophysical modelling this could, among others, lead to incorrect ice-thickness estimates. Of particular importance in this respect is the gradient of the YD (main) shoreline. In SW Norway this shoreline, hereafter referred to as the YD maximum highstand shoreline, was formed at the end of a regionally recorded relative sea-level (RSL) rise termed the YD transgression (Anundsen, 1985). The observed data points for this shoreline were previously found to fit into a geophysical model giving a shoreline with curvilinear, concave-upwards shape, a feature attributed to geoidal and isostatic effects near a steep, parabolic- or elliptic-like ice profile (Fjeldskaar and Kanestrøm, 1981; Anundsen, 1985). The apparent consistency between theory and observations represented an important argument for interpreting the YD maximum highstand shoreline as being slightly curved.

In the present study, the YD maximum highstand shoreline is reconstructed along three profiles near Boknafjorden and Hardangerfjorden, SW Norway, on the basis of sea level data mainly derived from isolation basin studies. Along the same profiles, we have also reconstructed, albeit in less detail, the Bølling-Allerød (B-A) maximum lowstand shoreline, which is the shoreline that formed immediately prior to the YD transgression. The three shore-level profiles form, together with seismic reflection data and measurements on recent crustal movements, the basis for our detection of neotectonic fault activity in the region. Finally, we discuss the implications of such activity for the reconstruction of the region's uplift history and the YD peripheral ice-sheet profile.

2. Regional setting

The present study from SW Norway concentrates on the areas surrounding Hardangerfjorden and Boknafjorden (Fig. 1). The region is situated within the SW part of the Scandinavian Caledonides and may be broadly subdivided into three tectonic units: (1) Precambrian basement of mostly 'un-Caledonized' crystalline bedrock; (2) a dècollement zone of mostly metasedimentary rocks that developed during the Early Palaeozoic Caledonian orogeny; (3) the Caledonian thrust nappes. In the area north of Boknafjorden, the Bergen Arc Shear Zone and the Hardangerfjord Shear Zone constitute major structural discontinuities, both representing extensional basement shear zones of Devonian origin (Fossen, 1992). Similar extensional basement shear zones, although smaller and less well defined, are also indicated in the Stavanger–Boknafjorden area (Fig. 1) (Hurich and Kristoffersen, 1988; Fossen, 1992).

N–S trending tectonic lineaments occur with a high density along the coast and form one of the most prominent lineament zones of Norway, the Bergen Zone, stretching northwards from Stavanger to Nordfjord (Gabrielsen and Ramberg, 1979; Gabrielsen et al., 2002) (Fig. 3). The zone incorporates a system of deep-seated faults and fractures along which basaltic dykes of Permo-Triassic age occur (Fossen and Dunlap, 1999). In the offshore area, close to the SW Norwegian coast, the N–S trending Øygarden Fault Complex of Permo-Triassic origin is a dominating structure (Fig. 1) (Færseth et al., 1995; Færseth, 1996). This is a deep zone of weakness marking the eastern margin of the northern North Sea basin. Two other well-defined groups of lineaments in the region are the NE–SW trending Hardangerfjord lineament population, consisting mainly of fractures that are strike-parallel with the Hardangerfjord Shear Zone, and