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Lake-mire deposition, earthquakes and wildfires along a basin margin fault; Rønne Graben, Middle Jurassic, Denmark

Lars Henrik Nielsen [a,*], Henrik I. Petersen [a], Karen Dybkjær [a], Finn Surlyk [b]

[a] Geological Survey of Denmark and Greenland, GEUS, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
[b] Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

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ABSTRACT

Regional uplift of structural highs took place in the greater North Sea region in early Middle Jurassic times, resulting in a change from marine shelf deposition in the Early Jurassic to widespread emergence, erosion and localized deposition in grabens. The Middle Jurassic Bagå Formation exposed on the island of Bornholm in the Baltic Sea was deposited in the Rønne Graben, which forms a dog-leg pull-apart basin linking the northern and southern branches of the Tornquist Zone. The studied succession is situated on the hanging wall immediately adjacent to the main eastern graben margin fault and the footwall consists of deeply weathered granite. It is the only locality along the northern branch of the Tornquist Zone where active tectonic influence on Middle Jurassic deposition can be demonstrated in outcrop.

Small alluvial fans composed of poorly sorted washout sands and muddy debris flows with weathered granite boulders fringed the footwall scarp. Syn-depositional soft-sediment deformation and chaotic bedding structures interpreted as seismites caused by earthquake shocks are characteristic at several levels. On the hanging wall further away from the active fault the depositional environment was dominated by shallow freshwater lakes with deposition of clay. Lake deposition outpaced subsidence and open, oxygen-deficient freshwater mires were formed during periods of no or only incremental fault-movement. The mires were only occasionally isolated from clastic input due to doming and dense vegetation, resulting in accumulation of pure peat beds. The content of spores and pollen shows that the mires were covered by a vegetation of arborescent and herbaceous Filicopsida (ferns), Lycopsida (club mosses), Cycadales/Bennettitales, Ginkgoales, Caytoniales, Taxodiaceae or Cupressaceae, and Araucariaceae. Wildfires were common in the mires and also on the footwall probably followed by episodes of increased run-off and erosion of the upland.

The presence of common washout sands, debrites, seismites and abundant lacustrine flooding surfaces indicating sudden drowning of the mires was caused by abrupt movements on the fault with associated earthquakes. The succession thus provides an example of temporal changes in deposition in response to changes in tectonic conditions.

The study illustrates how regional uplift of structural highs caused a restriction of deposition to narrow grabens like the Rønne Graben. Facies patterns changed dramatically from laterally extensive uniform packages controlled by sea-level changes in the Early Jurassic to strongly localized deposition with marked facies changes controlled by faulting and earthquakes in the Middle Jurassic. The succession thus serves as an excellent example of tectonically controlled deposition under humid conditions in a continental graben.

1. Introduction

The Tornquist Zone is a long-lived, major tectonic zone separating the Baltic Shield from the subsiding sedimentary basins in northwest Europe. The non-marine Middle Jurassic Bagå Formation was deposited in the Rønne Graben, which forms a dog-leg pull-apart basin linking the northern and southern branches of the Tornquist Zone. Deposition took place on the hanging wall fault block close to the main eastern bounding fault of the Rønne Graben along the west coast of the island of Bornholm in the Baltic Sea (Figs. 1 and 2). It is the only locality in the region where direct tectonic influence on Middle Jurassic deposition can be demonstrated in outcrop.

The Bagå Formation records the local response to the regional early Middle Jurassic uplift in the greater North Sea basin, which caused a change from widespread marine shelf deposition to regional emergence, erosion and localized fault-controlled deposition. This shift in physiography changed the dominant controlling factors on deposition from regional sea-level fluctuations in the Early Jurassic to strong tectonic control in the Middle Jurassic. The influence of sea-level fluctuations on the marine Jurassic successions of northwest Europe

* Corresponding author.
E-mail address: lhn@geus.dk (L.H. Nielsen).

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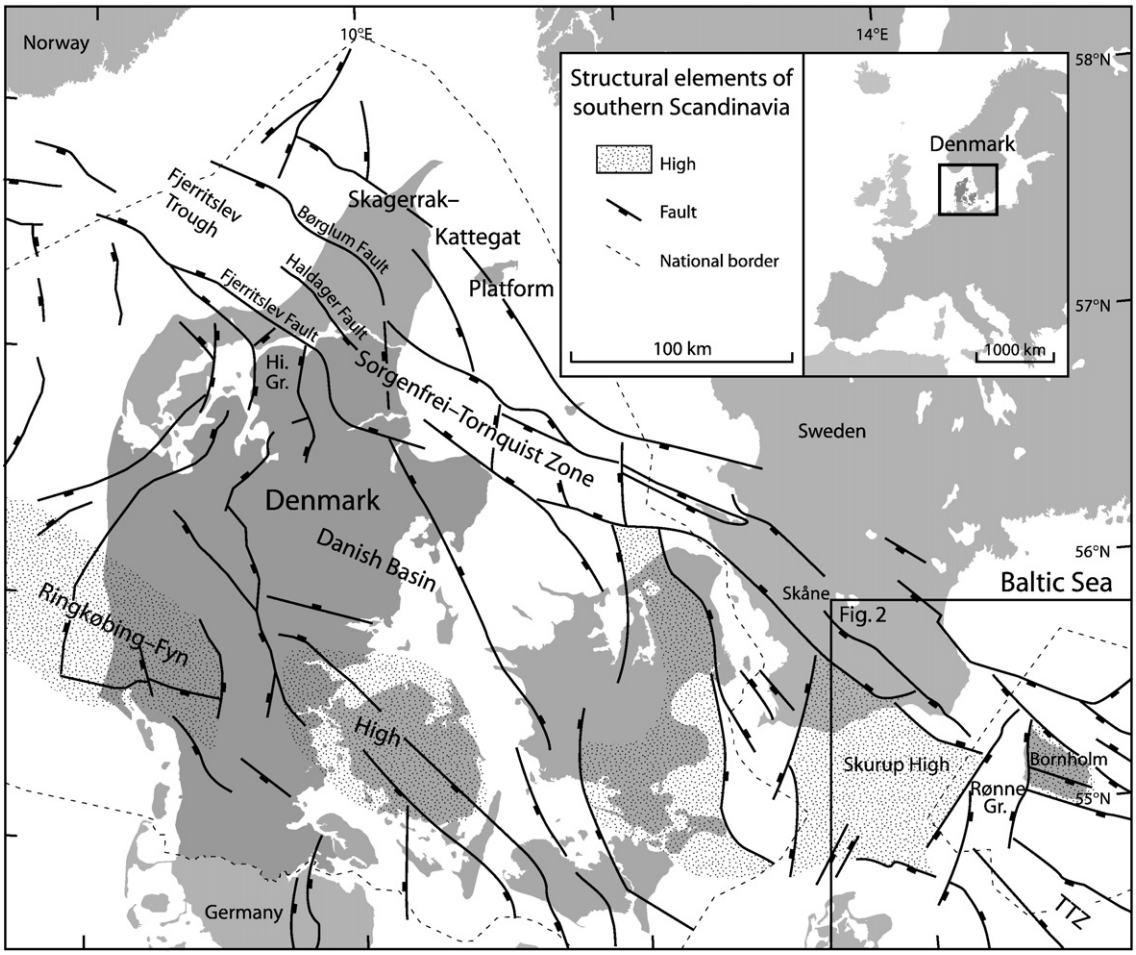

Fig. 1. Map showing the principal structural elements of the Danish Basin and the Sorgenfrei–Tornquist Zone. Bornholm is located in the western part of the Baltic Sea where the Sorgenfrei–Tornquist Zone via the Rønne Graben dog-leg passes into the Teisseyre–Tornquist Zone (TTZ). The faults were normal faults during deposition of the Bagå Formation but several have later been inverted.
Modified from Nielsen (2003).

are well documented (Rattey and Hayward, 1993; Underhill and Partington, 1993; Andsbjerg et al., 2001; Andsbjerg and Dybkjær, 2003; Johannessen, 2003; Michelsen et al., 2003; Nielsen, 2003; Surlyk and Ineson, 2003), but less focus has been placed on the factors controlling the development of local graben environments following regional uplift and emergence of structural highs.

The aim of this study is to highlight how Middle Jurassic deposition was governed by borderland uplift, restriction of areas of sedimentation to narrow grabens, episodic faulting and associated earthquakes, frequent wildfires, deep weathering of the exposed footwall block, formation of lakes and mires, and repeated lacustrine flooding. A multidisciplinary approach is applied, including sedimentology, organic petrography, and palynology. Direct evidence for syn-depositional faulting and associated earthquakes is especially emphasized.

2. Geological setting

The Rønne Graben is a large offshore pull-apart basin that also includes the westernmost fringe of the island of Bornholm where it is bordered by the Rønne–Hasle Fault (Figs. 1 and 2). It was formed in Late Carboniferous–Early Permian times as a right-stepping dog-leg connecting the northern and southern branches of the Tornquist Zone (Vejbæk, 1985; Liboriussen et al., 1987; EUGENO-S Working Group, 1988; Michelsen and Nielsen, 1993). The Rønne–Hasle Fault has been active since the Permian and the pre-Middle Jurassic vertical displacement is 2500–3000 m with 1500–1700 m in the Permian–Triassic and at least 850 m in the Early Jurassic. A 1500–1700 m thick Lower Permian–Triassic succession was deposited in the Rønne and Kolobrzeg Grabens as shown by the Pernille-1 and Stina-1 wells (Fig. 2), whereas thin successions were deposited on parts of the adjacent highs. Triassic redbeds are overlain by Jurassic clay and sand in the grabens and both Rhaetian and Hettangian deposits are identified in the offshore well-sections (Robertson, 1989a,b). In Pernille-1, the about 550 m thick Lower Jurassic Rønne Formation is overlain by Cretaceous strata, whereas the ca. 475 m thick Lower Jurassic succession in Stina-1, comprising the Rønne, Hasle and Sorthat Formations (Fig. 3) is topped by Quaternary deposits. The hiatuses are due to several phases of inversion. Seismic data from the Rønne Graben show gentle eastward thickening of the Jurassic succession towards the Rønne–Hasle Fault (Graversen, 2004), and in the eastern part of the graben the Lower Jurassic is ca. 850 m thick and the Middle Jurassic is ca. 200 m thick (Michelsen et al., 2003). Lower–Middle Jurassic deposits are exposed on the western and south-western part of Bornholm due to Late Cretaceous–Early Cenozoic basin inversion and uplift of 1200–1700 m of the hanging wall block along the Rønne–Hasle Fault (Figs. 2 and 4) (Petersen et al., 2003a; Graversen, 2004).

The Rønne–Hasle Fault controlled the position of the coastline since the Early Pliensbachian (Surlyk and Noe-Nygaard, 1986; Koppelhus and Nielsen, 1994) until the onset of terrestrial deposition