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Onset of N-Atlantic rifting in the Hoop Fault Complex (SW Barents Sea): An orthorhombic dominated faulting?

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ABSTRACT

The Hoop Fault Complex is one of the main fault systems in the south-western Barents Sea. This platform underwent a long extensional history under the influence of both the Atlantic and the Arctic rifts, which culminated in the Atlantic break-up in the Cenozoic. The object of this paper is the structural analysis of the late Mesozoic rifting in the Hoop Fault Complex area, based on a 10,000 km^2 3D seismic volume.

We constrained the intervals of activity of the main fault systems during the late Mesozoic rifting through the synsedimentary thickness variations, reconstructing the evolution of the strain field. In order to clarify the relationship between the strain field and the rheological layering, we compared the structures at different depths, highlighting a decoupling of shallow and deep deformations along the Triassic ductile clay-rich layers.

A transition from an orthorhombic faulting, corresponding to a 3D strain field, to an Andersonian faulting, related to a planar strain field, was observed. The change of the strain field could be driven by the evolution of the regional stress field or, alternatively, by the reactivation of deep structures. In this latter case, the structural evolution of the Hoop Fault Complex could potentially represent a general process to be extended to other rifting settings with a similar mechanical stratigraphy.

1. Introduction

Orthorhombic fault systems consist of four sets of faults developed simultaneously in a rhomboidal pattern (Fig. 1) (Reches, 1978). The robust theoretical analysis of Reches (Reches, 1978, 1983; Reches and Dieterich, 1983) and Krantz (Krantz, 1988) pointed out that this fault arrangement is required to accommodate a three-dimensional deformation, where none of the principal strains equals zero (ε_1, ε_2, $\varepsilon_3 \neq 0$). Given the 3D nature of the crust, a 3D strain is expected to be more common than planar strain (Healy et al., 2015), however few examples of orthorhombic systems have been described in recent years. This is possibly due to the difficulty of proving the simultaneous activity of different fault trends. Nevertheless, orthorhombic patterns have been described at different scales: hundreds of meters (Aydin and Reches, 1982; Carvell et al., 2014), kilometers (Krantz, 1988; Miller et al., 2007), tens of kilometers (Franceschi et al., 2014). All the previously cited examples of orthorhombic systems have been described in extensional settings, suggesting a connection between these fault arrangements and extensional domains.

In this work, an orthorhombic fault system has been observed and analyzed in an area of 10,000 km^2 across the Hoop Fault Complex (SW Barents Sea), one of the major fault zones of the Barents Shelf, which marked the transition between the stable Bjarmeland Platform (to the east) and the basinal province (to the west) during the late Mesozoic-Cenozoic rifting (Fig. 2). Thanks to the location at the transition between stable and highly subsiding areas, the sedimentary succession corresponding to the initial phase of the rift is at very shallow depth, assuring excellent seismic resolution. Furthermore, the Hoop Fault Complex is an old zone of weakness, affecting a sequence characterized by units with different rheological properties (Glørstad-Clark et al., 2010). Hence, it has been possible to study the influence of rheological layering and reactivation processes on the nucleation of orthorhombic systems.

The imaging of the structures at different levels of the stratified succession allowed for the comparison between shallow and deep deformations. In addition, we were able to define the relative activation order of the various fault systems of the late Mesozoic-Cenozoic rifting thanks to synsedimentary thickness variations highlighted in time-thickness maps. Hence, 3D seismics enabled us to address the activity of the orthorhombic system in the tectonic framework of the Barents Sea.

The development of an orthorhombic system in the Hoop Fault Complex has been seen in the light of the overall late Mesozoic structural architecture of basins and highs of the Barents Shelf, which largely reflects Caledonian weakness zones of the basement (Gernigon

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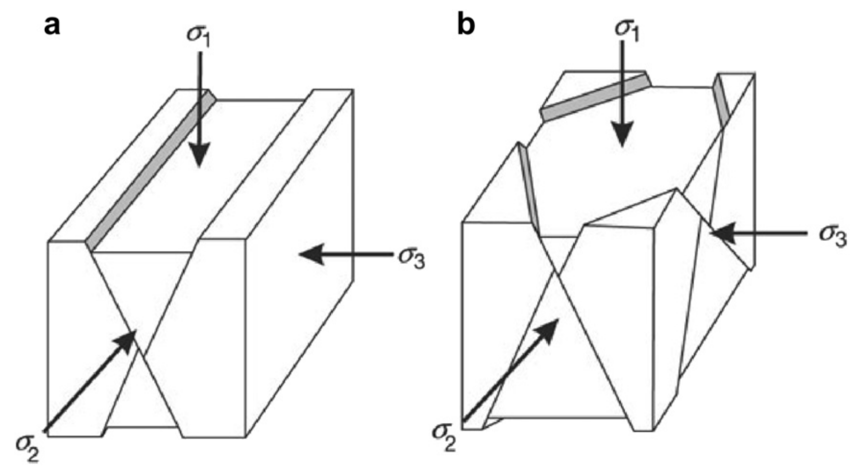

Fig. 1. (a) Andersonian fault pattern and the associated stress field (Anderson, 1951); (b) orthorhombic fault pattern and the associated stress field according to Reches (1978) (modified after Healy et al., 2006).

et al., 2014). Further, we addressed the relationship between orthorhombic faulting and the specific tectonic framework of the Barents Sea, characterized by the interaction between the Atlantic and the Arctic rifts, as well as the possible significance of this system in terms of general processes occurring during rifting. Indeed, the specific rheological layering of the Barents Sea succession and the amazing imaging possibilities disclosed by 3D seismic could highlight processes difficult to appreciate in other settings. In summary, this work addresses the following interconnected questions about orthorhombic fault systems in a rift tectonic setting:

(a). Why an orthorhombic regime might develop within opening rifts despite a pre-existing buried architecture?
(b). What is the key criterion in terms of rheological stratigraphy that leads to such a development?
(c). Which is the regional tectonism that might favour evolutions between 3D and planar strain regimes?

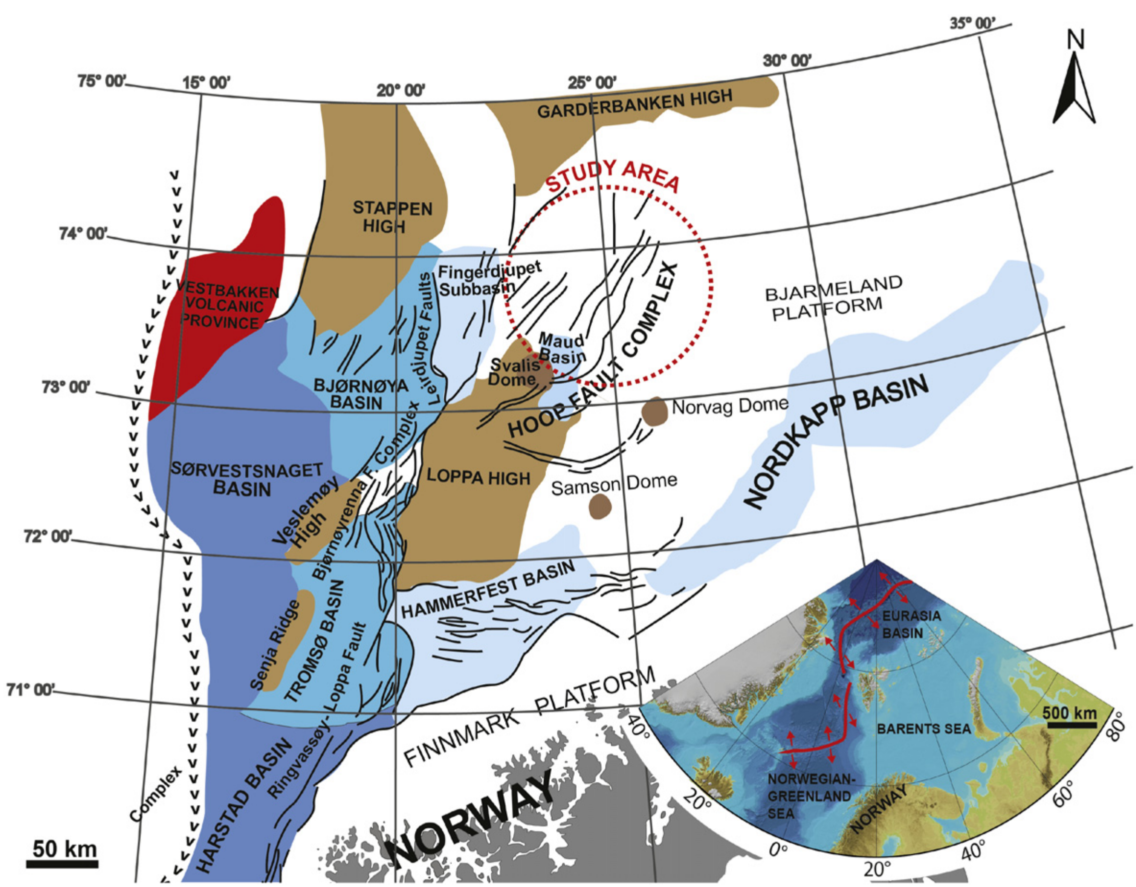

Fig. 2. Main structural elements and fault complexes of the late Mesozoic-Cenozoic rift in the south-western Barents Sea (modified after Gabrielsen et al., 1990). Red = volcanic province; brown = structural highs; blue = structural lows (the darkest the deepest); white = stable platform; V = continental margin. The red circle indicates approximately the study area of this work. The inset shows the geodynamic setting of the Barents Sea. Base map from Jakobsson et al. (2012).