



# Growth of normal faults in multilayer sequences: A 3D seismic case study from the Egersund Basin, Norwegian North Sea

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## ABSTRACT

We investigate the structural style and evolution of a salt-influenced, extensional fault array in the Egersund Basin (Norwegian North Sea) through analysis of 3D reflection seismic and well data. Analysis of fault geometry/morphology, throw distribution and syn-kinematic strata reveal an intricate but systematic style of displacement and growth, suggesting an evolution of (1) initial syn-sedimentary fault growth contemporaneous with salt mobilization initiated during the Late Triassic, (2) cessation of fault activity and burial of the stagnant fault tips, and (3) subsequent nucleation of new faults in the cover above contemporaneous salt re-mobilization initiated during the Late Cretaceous, with downward propagation and linkage with faults. Stage 3 was apparently largely controlled by salt mobilization in response to basin inversion, as reactivated faults are located where the underlying salt is thick, while the non-reactivated faults are found where salt is depleted. Based on the 3D-throw analyses, we conclude that a combination of basement faulting and salt (re-) mobilization is the driving mechanisms behind fault activation and reactivation. Even though the sub- and supra-salt faults are mainly geometrically decoupled through the salt, a kinematic coupling must have existed as sub-salt faults still affected nucleation and localization of the cover faults.

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## 1. Introduction

The structural style and evolution of normal fault arrays developing in the presence of mechanically weak detachments rich in, for example, halite (salt) or mudstone, are different to and less well understood than, fault arrays forming in the absence of such detachments. These differences arise in part due to the ability of salt and mudstone to accommodate strain and displacement by ductile flow. For example, salt- or mudstone-rich layers can: (i) act as regional detachment horizon or *décollement* (Morley et al., 2003; Jackson and Hudec, 2005); (ii) inhibit the vertical or lateral propagation of faults (e.g. Withjack et al., 1990; Pascoe et al., 1999; Maurin and Nivière, 2000; Withjack and Callaway, 2000; Richardson et al., 2005; Ford et al., 2007; Kane et al., 2010; Marsh et al., 2010); and (iii) cause full or partial geometric and kinematic decoupling of sub- and supra-detachment deformation (e.g.

Stewart et al., 1997; Withjack and Callaway, 2000; Ford et al., 2007). Hence, ductile layers may significantly affect the geometry and evolution of extensional fault arrays, resulting in marked temporal and spatial variations in structural style, fault-related folding and displacement distribution (e.g. Rowan et al., 1999; Kane et al., 2010; Marsh et al., 2010; Duffy et al., 2012). The impact of ductile layers on normal fault array evolution becomes even more complex when polyphase extension occurs, because a second phase of extension can lead to: (i) reactivation of sub-detachment, typically 'thick-skinned' faults, and triggering of 'thin-skinned' extension of the supra-detachment cover; and (ii) the growth of salt- and shale-cored structures due to thin-skinned extension of the cover, which can itself cause faulting of the overburden (e.g. 'reactive diapirism'; Vendeville and Jackson, 1992; Jackson and Vendeville, 1994; Van Rensbergen et al., 1999).

Relatively few studies have addressed the structural style and evolution of normal fault arrays forming in response to salt- or mudstone-influenced, polyphase extension (Richardson et al., 2005; Kane et al., 2010; Duffy et al., 2012). The aims of this study are to: (i) highlight the relative roles of sub-salt 'basement' reactivation and salt mobilization, on the distribution and magnitude

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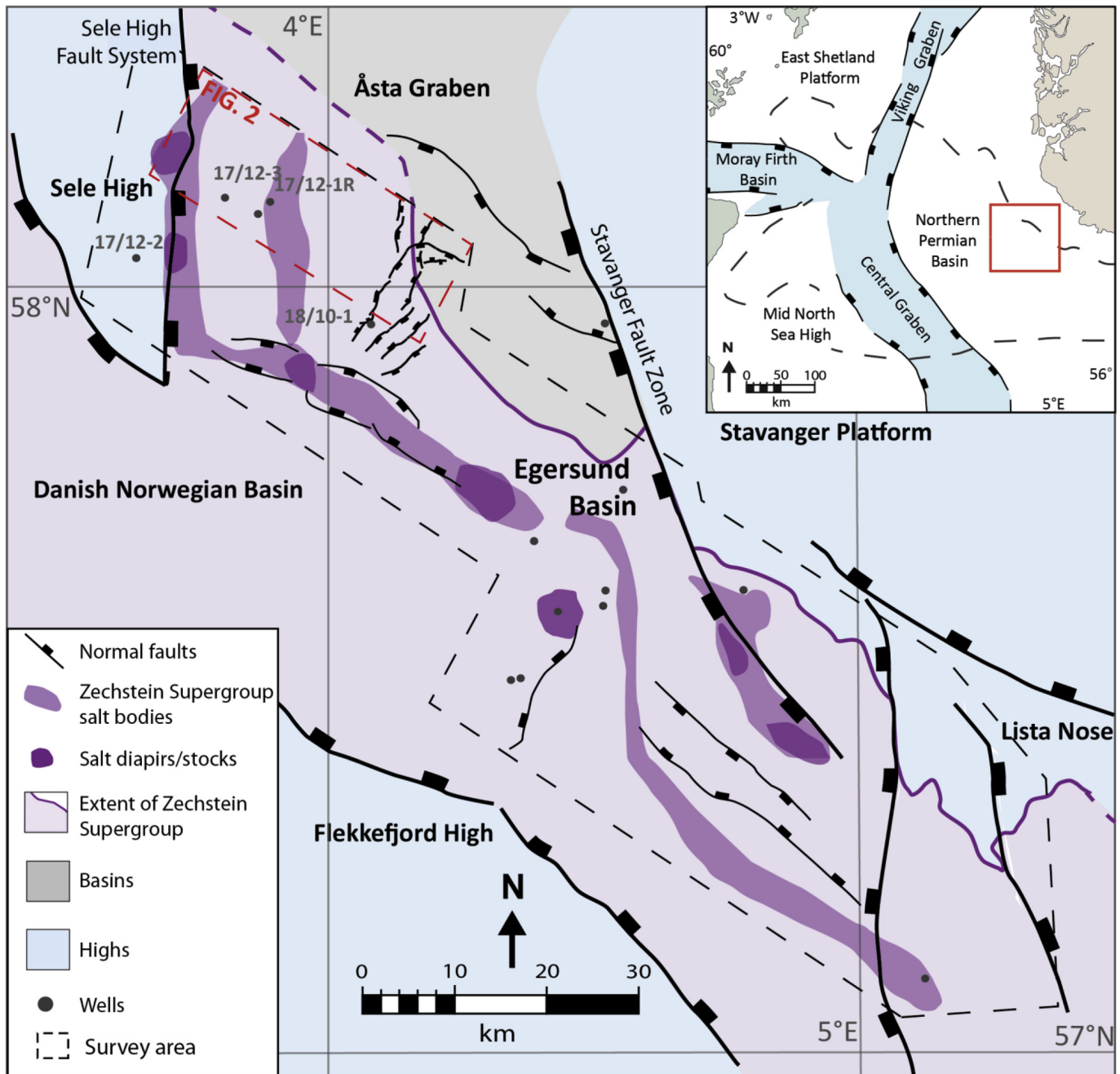
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of supra-salt 'cover' deformation; (ii) assess the impact that salt has on the magnitude of kinematic coupling between supra- and sub-salt faulting; and (iii) determine how mudstone layers influence the growth of normal fault systems in the supra-detachment sequence. To achieve these aims we use high-quality, 3D seismic reflection data (PGS MC3D-EGB2005) from the Egersund Basin, offshore Norway (Figs. 1 and 2), which allow us to constrain, in three-dimensions, the spatial relationship between, geometry and distribution of displacement on basement and cover faults, and thickness changes in coeval growth strata. Borehole data allows us to directly constrain the composition of the faulted sequence, and provide insight into the growth rate and spatial evolution of the studied fault array. Our results provide new insight into the control

of polyphase rifting and ductile layers on the temporal and spatial evolution of normal fault arrays.

## 2. Geological framework

The Egersund Basin trends NW–SE and represents the NW extension of the Norwegian Danish Basin (Fig. 1). The basin initially formed in response to Carboniferous-to-Permian rifting (Sørensen et al., 1992; Ziegler, 1992). A thick succession of continental sediments was deposited in the basin during the Early Permian (Sørensen et al., 1992). During the Late Permian, the Egersund Basin represented a sub-basin of the 'North Permian Basin' (Sørensen et al., 1992; Ziegler, 1992), which formed following the syn- to



**Fig. 1.** Location of the Egersund Basin (EGB) in the North Sea north east of the Central Graben (red square in the inset of simplified structural map of the North Sea). Structural maps and extent of ZSG is based on observations in this study with data from Millennium Atlas (Zanella and Coward, 2003) and data from the Norwegian Petroleum Directorate. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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