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Balancing sub- and supra-salt strain in salt-influenced rifts: Implications for extension estimates

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ABSTRACT

The structural style of salt-influenced rifts may differ from those formed in predominantly brittle crust. Salt can decouple sub- and supra-salt strain, causing sub-salt faults to be geometrically decoupled from, but kinematically coupled to and responsible for, supra-salt forced folding. Salt-influenced rifts thus contain more folds than their brittle counterparts, an observation often ignored in extension estimates. Fundamental to determining whether sub- and supra-salt structures are kinematically coherent, and the relative contributions of thin- (i.e. gravity-driven) and thick-skinned (i.e. whole-plate stretching) deformation to accommodating rift-related strain, is our ability to measure extension at both structural levels. We here use published physical models of salt-influenced extension to show that line-length estimates yield more accurate values of sub- and supra-salt extension compared to fault-heave, before applying these methods to seismic data from the Halten Terrace, offshore Norway. We show that, given the abundance of ductile deformation in salt-influenced rifts, significant amounts of extension may be ignored, leading to the erroneous interpretations of thin-skinned, gravity-gliding. If a system is kinematically coherent, supra-salt structures can help predict the occurrence and kinematics of sub-salt faults that may be poorly imaged and otherwise poorly constrained.

1. Introduction

1.1. Structural styles in salt-influenced rifts

The structural style and evolution of rifts that contain rheological heterogeneities, such as relatively thick salt (e.g. Hodgson et al., 1992; Stewart et al., 1996, 1997; Pascoe et al., 1999; Corfield and Sharp, 2000; Richardson et al., 2005; Kane et al., 2010; Duffy et al., 2013; Wilson et al., 2015; Jackson and Lewis, 2016), may significantly differ from those forming in predominantly 'brittle' crust (Fig. 1) (e.g. Gawthorpe and Leeder, 2000; Whipp et al., 2014; Duffy et al., 2015). During the early stages of basement-involved extension in salt-influenced rifts, salt may inhibit the upward propagation of sub-salt faults (Fig. 1b), mechanically decoupling them from, but being responsible for, associated forced folds in supra-salt strata (e.g. Stearns, 1978; Withjack et al., 1990; Maurin and Niviere, 1999; Duffy et al., 2013); such decoupling thus leads to differing structural styles or a geometric disparity, above and below the intra-stratal detachment (Jarrige, 1992). With increasing displacement, sub-salt faults may breach the folds and hard-link with overlying, supra-salt faults (Koyi and Petersen, 1993; Harvey and Stewart, 1998; Withjack and Callaway, 2000; Richardson et al., 2005; Kane et al., 2010). As extension continues, the degree of vertical coupling increases and the geometric disparity between the fault populations decreases between sub- and supra-salt strata (Pascoe et al., 1999; Dooley et al., 2003; Marsh et al., 2010). Salt-influenced rifts therefore typically contain a greater degree of folding than those lacking an intra-stratal detachment; the contribution of these folds in accommodating extensional strain, especially within supra-salt strata, is often ignored.

1.2. Kinematic coherence

Despite exhibiting different structural styles, sub- and supra-salt fault systems may form at the same time and accommodate similar amounts of extension ('kinematic coherence' sensu Walsh and Watterson, 1991) (Fig. 2). Field and seismic studies have shown that kinematic coherence can be maintained between sub- and supra-salt fault systems over relatively long spatial (10^{-1}–10^{3} m;

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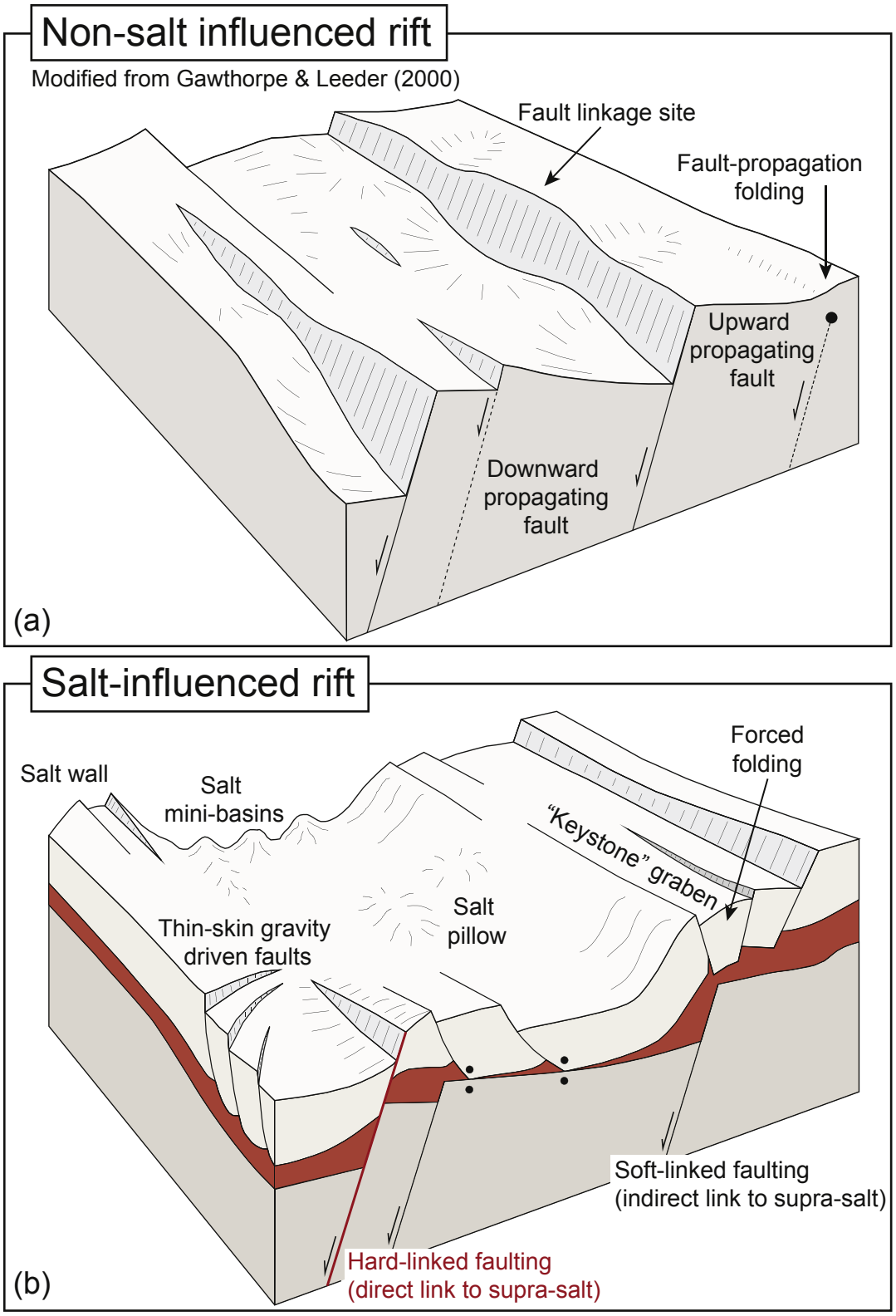

Fig. 1. Comparison of (a) non-salt influenced rifts (modified from Gawthorpe and Leeder, 2000), and (b) salt-influenced rift systems, documenting the large variation and increased complexity in structural style laterally and vertically associated with salt.

(Walsh and Watterson, 1991; Childs et al., 1996; Giba et al., 2012; Long and Imber, 2012; Lewis et al., 2013) and temporal scales (Walsh et al., 2003; Jackson and Larsen, 2009; Jackson and Lewis, 2016). The characteristics of such kinematically coherent systems are: (i) sub- and supra-salt extension should balance (e.g. Richard, 1991; Stewart et al., 1996; Harvey and Stewart, 1998); (ii) hard-linked faults may exist between the supra- and sub-salt units (e.g. Richard, 1991; Childs et al., 1993; Koyi, 1993); (iii) individual