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Geometry and architecture of faults in a syn-rift normal fault array: The Nukhul half-graben, Suez rift, Egypt

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ABSTRACT

The geometry and architecture of a well exposed syn-rift normal fault array in the Suez rift is examined. At pre-rift level, the Nukhul fault consists of a single zone of intense deformation up to 10 m wide, with a significant monocline in the hanging wall and much more limited folding in the footwall. At syn-rift level, the fault zone is characterised by a single discrete fault zone less than 2 m wide, with damage zone faults up to approximately 200 m into the hanging wall, and with no significant monocline developed. The evolution of the fault from a buried structure with associated fault-propagation folding, to a surface-breaking structure with associated surface faulting, has led to enhanced bedding-parallel slip at lower levels that is absent at higher levels. Strain is enhanced at breached relay ramps and bends inherited from pre-existing structures that were reactivated during rifting. Damage zone faults observed within the pre-rift show ramp-flat geometries associated with contrast in competency of the layers cut and commonly contain zones of scaly shale or clay smear. Damage zone faults within the syn-rift are commonly very straight, and may be discrete fault planes with no visible fault rock at the scale of observation, or contain relatively thin and simple zones of scaly shale or gouge. The geometric and architectural evolution of the fault array is interpreted to be the result of (i) the evolution from distributed trishear deformation during upward propagation of buried fault tips to surface faulting after faults breach the surface; (ii) differences in deformation response between lithified pre-rift units that display high competence contrasts during deformation, and unlithified syn-rift units that display low competence contrasts during deformation, and; (iii) the history of segmentation, growth and linkage of the faults that make up the fault array. This has important implications for fluid flow in fault zones.

1. Introduction

Fault zone architecture, defined as the three-dimensional spatial arrangement of structural elements such as zones of fault rock (e.g. gouge or cataclasite), lenses of wall rock incorporated into the fault zone, and damage zones fringing the fault zone (Hancock, 1985; Wilson, 2008), is both temporally and spatially variable. Such variability results from fault zones cutting different rock types (e.g. Yielding et al., 1997), bifurcation of faults during their evolution (e.g. Childs et al., 1996a), the growth and linkage of fault segments through time (e.g. Cartwright et al., 1995; Cowie et al., 2000; Gawthorpe et al., 2003), and the variation in local stress environment along the fault (e.g. at restraining or releasing bends; Sibson, 1986).

In rift basins, it would be expected that the architectural characteristics of faults will change significantly as faults initiate in basement or in lithified pre-rift units, propagate vertically into unlithified syn-rift units, break the surface, and propagate laterally to link with adjacent fault segments (e.g. Heynekamp et al., 1999; Sigda et al., 1999; Gawthorpe and Leeder, 2000; Sharp et al., 2000a, b; Rawling et al., 2001; Gawthorpe et al., 2003). Several publications have addressed the influence of lithology ('mechanical stratigraphy': Erickson, 1996) on the geometry and architecture of faults and fault-related folds (e.g. Withjack et al., 1990; Dominic and McConnell, 1994; Pascoe et al., 1999; Cardozo et al., 2005; Jackson et al., 2006; Schöpfer et al., 2006, 2007), but the influence of the degree of lithification of the protolith on fault geometry and architecture is not well understood. The temporal evolution of the faults, coupled with the changing nature of the rocks being faulted (i.e. lithified pre-rift units followed by poorly lithified syn-rift units) should lead to significant spatial variation in fault architecture in the final fault array. However, it is rarely possible to make

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observations of fault geometry and architecture over half-graben scale (several km^2) syn-depositional fault arrays in the field. Indeed, despite great interest in the issue of how faults affect fluid flow in the crust, relatively few field descriptions of faults are available in the public domain. In this study we present observations of an exceptionally well exposed fault array and associated syn-rift and pre-rift strata in the Nukhul half-graben of the Suez rift, Egypt (Fig. 1). There are two sets of observations. The first set comprises observations of the geometry and architecture of an intra-block normal fault (the Nukhul fault) at different localities along strike. The second comprises observations of a set of minor normal faults within the footwall damage zone of a major block-bounding fault (the Baba-Markha fault) at both pre-rift and syn-rift level. Our field observations are placed in the context of a half-graben scale terrestrial LIDAR dataset (see Section 3), in which key stratigraphic horizons and faults can be mapped very accurately. This allows a reconstruction of the evolution of the half-graben and in particular the vertical and lateral propagation of faults (Wilson et al., 2009). Our purpose in this paper is as follows:

(i) to describe the geometry and architecture of the fault array in the Nukhul half-graben;
(ii) to discuss how the temporal evolution of the fault array, in terms of vertical and lateral propagation and linkage of faults, has affected the geometry and architecture of the fault array, and;
(iii) to discuss how lithology (including state of lithification) has controlled the geometry and architecture of the fault array.

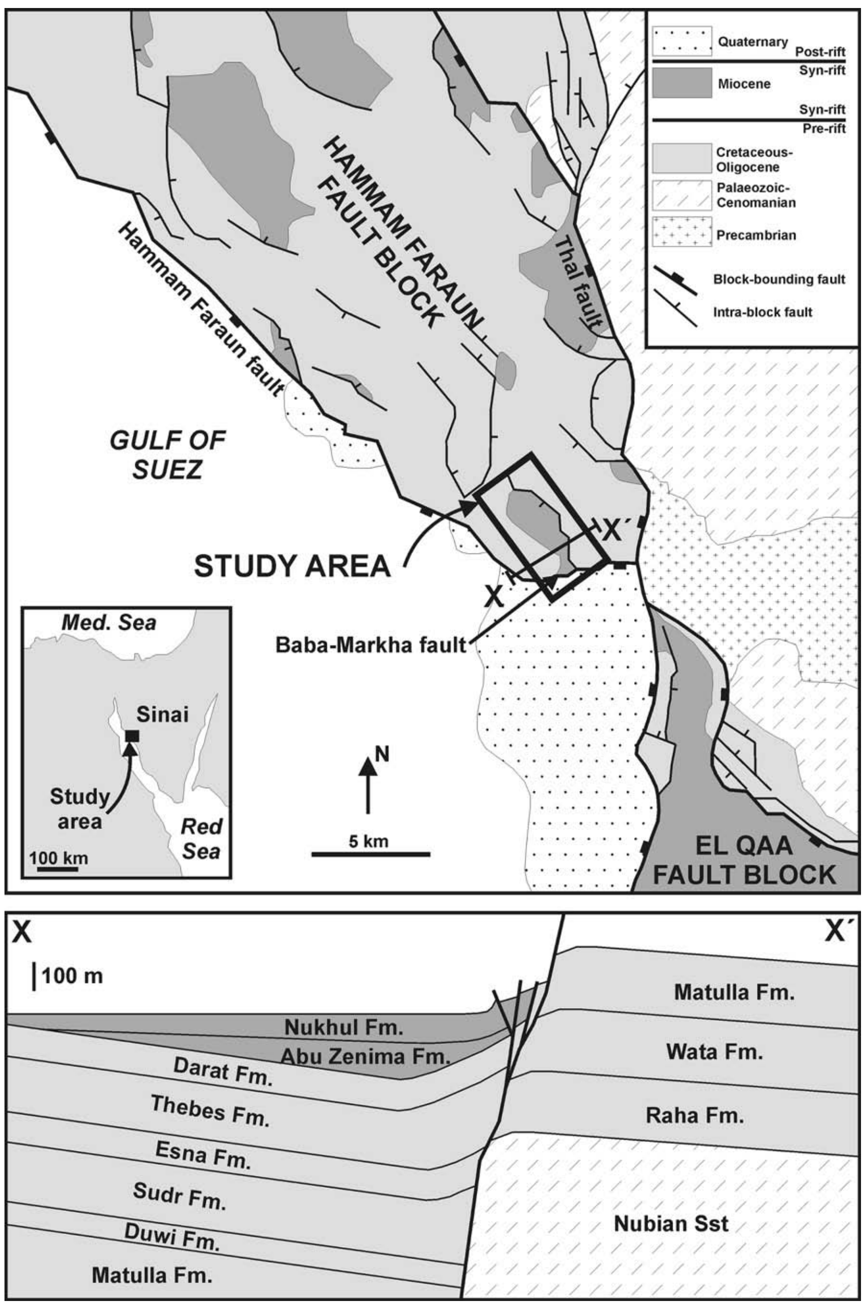

Fig. 1. Simplified geological map of the Hammam Faraun and El Qaa fault blocks, Suez rift, showing the location of the study area. The cross section shows the geometry of pre-rift and syn-rift units in the half-graben bounded by the Nukhul fault. Modified after Moustafa and Abdeen (1992), Jackson et al. (2006) and I.R. Sharp (unpublished).