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3D seismic characterisation of an array of blind normal faults in the Levant Basin, Eastern Mediterranean

Catherine Baudon*, Joe A. Cartwright

3D Laboratory, School of Earth, Ocean and Planetary Sciences, Cardiff University, Main Building, Park Place, Cardiff CF10 3AT, UK

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Abstract

The geometry, throw distribution and kinematics of an array of blind normal faults were investigated using a high resolution 3D seismic dataset located in the Levant Basin, offshore Israel, to establish criteria allowing true blind faults to be distinguished from minor synsedimentary faults. A detailed analysis of throw distribution on the fault planes shows that the displacement exhibits a crudely concentric pattern about a maximum region located centrally on a fault plane, as expected for ideal blind faults. However, vertical displacement profiles do not exhibit classical linear or triangular profiles but are mostly flat-topped or hybrid in type. Comparison of unrestricted blind faults to those that interacted with a mechanical boundary or another structure suggests that such interactions significantly modify the throw spatial distribution on a fault plane. To distinguish small synsedimentary faults from blind faults, we use a combination of three criteria to assess whether a fault grew by blind propagation: (1) plunging upper-tip region and complementary pattern in the throw contours, (2) presence of upper-tip propagation fold, and (3) absence of stratigraphic evidence that the fault interacted with the free surface.

Keywords: Blind fault; Throw distribution; Fault propagation; Fault growth; Lithological effects; Mechanical stratigraphy

1. Introduction

The analysis of displacement distribution on fault surfaces has provided significant insights into the nucleation and propagation of faults (e.g. Childs et al., 1993; Dawers and Anders, 1995). The early work was based on the characteristics of an ideal blind normal fault defined as a fault that does not intersect a free surface (Watterson, 1986). In this ideal model, displacement decreases from a maximum located at the centre of the fault plane to a tip line of zero displacement. In the absence of significant mechanical heterogeneity and if displacement accrued over the entire fault plane at each slip event, the tip line is elliptical. Ideal blind faults grow by radial propagation with no migration of the point of maximum displacement, which is also the nucleation site of the fault (Watterson, 1986; Barnett et al., 1987).

This model has also been modified to include the role of segment linkage (Peacock and Sanderson, 1991; Cartwright et al., 1995; Dawers and Anders, 1995; Wojtal, 1996), the influence of mechanical heterogeneity (Peacock and Zhang, 1994; Mansfield and Cartwright, 1996; Gross et al., 1997; Wilkins and Gross, 2002) and mechanical interactions with other structures during propagation (Nicol et al., 1996; Maerten et al., 1999).

Numerous studies published data from normal faults considered as mostly post-sedimentary (e.g. Walsh and Watterson, 1987, 1988a; Gillespie et al., 1993; Watterson et al., 1998). However, few published descriptions exist for displacement distribution on entire fault planes from seismic data (Table 1). Another issue of interest is that the displacement patterns of small synsedimentary faults that have slow and regular displacement rates can be remarkably similar to those of ideal blind faults, adding to the complexity of interpretation (e.g. Petersen et al., 1992; Childs et al., 1993; Nicol et al., 1996).

* Corresponding author. NARG, SEAES, The University of Manchester, Oxford Road, Williamson Building, Manchester M13 9PL, UK. Tel.: +44 (0)161 275 0778; fax.: +44 (0)161 306 9361.
E-mail address: catherine.baudon@manchester.ac.uk (C. Baudon).

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Table 1
Blind faults with entire fault plane in the literature from seismic data

Source	Data	Measurements	Dimension	D_{max}
Barnett et al., 1987	Offshore UK North Sea (2D seismic)	52 vertical displacement measurements on 4 mapped reflectors	$L \sim 1220$ m	45 ms
Walsh and Watterson, 1991	Offshore oilfield (2D seismic)	62 displacement measurements on 4 mapped reflectors 100 m spacing between seismic lines	$L = 1800$m	60 m
Nicol et al., 1996	Gulf Coast (3D seismic)	106 throw readings on 5 horizons Estimation of tip lines positions by extrapolation of throw gradients	$L = 1500$ m $H \sim 1500$ m	42 ms = 53 m
Nicol et al., 2003	South Australia (3D seismic)	3 throw contour plots of restricted faults	Various	Various

This paper investigates a system of small normal faults using high resolution 3D seismic data to propose criteria for determining if a fault is truly blind. This question is important for those involved in dating the duration of faulting, since the dating of blind faults differs from the dating of synsedimentary faults due to the absence of growth sediments.

The examples of blind faults in this paper are located in the Levant Basin in the eastern Mediterranean. The faults show varying degrees of interaction with neighbouring faults, and varying relationships with the mechanical stratigraphy, thus allowing their effects on throw accumulation to be calibrated.

2. Regional setting

The study area is located in the Levant Basin in the eastern Mediterranean (Fig. 1). The basin formed by rifting during the Early Permian to the middle Jurassic during the evolution of the Neo-Tethys Ocean (Garfunkel, 1998). Located at the zone of interaction between the Anatolian, African and Arabian plates, its evolution is influenced by the Dead Sea Transform to the East, the Gulf of Suez to the SW, the Cyprian Arc to the NW, Taurus mountains and Bitlis suture to the North (Tibor and Ben-Avraham, 2005). A motion change in the Late Cretaceous between African and Eurasian plates led to a compressive stress-regime and induced a change in the depositional systems (Tibor and Ben-Avraham, 1992; Druckman et al., 1995). In the Late Miocene, a major desiccation of the Mediterranean region, the Messinian Salinity Crisis, led to the deposition of thick evaporites in the basin floor regions (Tibor and Ben-Avraham, 1992), pinching out laterally against basin margins as a function of structure and relict topography (Bertoni and Cartwright, 2006).

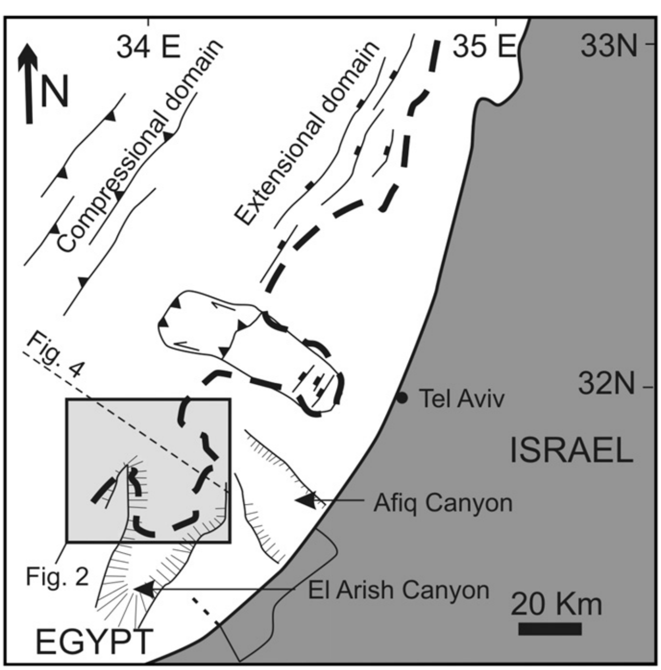

Fig. 1. Location map of the study area (grey square situates Fig. 2), offshore Israel. The dashed line represents the margin of the Messinian evaporites.

The Pliocene–Quaternary succession above the Messinian unconformity is the focus of this study. During the Pliocene, a major transgression led to the deposition of an important accumulation of clay-rich marls, sandstones and claystones mainly derived from the Nile Delta (Tibor and Ben-Avraham, 1992; Frey Martinez et al., 2005). Abrupt tilting of the margin beginning in the mid-late Pliocene resulted in two scales of gravity-driven deformation, thin-skinned sliding and slumping of slope units (Frey Martinez et al., 2005) and more substantial gravitational collapse rooted in the thick Messinian evaporites (Garfunkel and Almagor, 1987; Netzeband et al., 2006; Cartwright and Jackson, 2008). This latter deformation produced an updip extensional domain at the pinch-out of the Messinian evaporites, and a downdip contractional domain in the basin floor region (Gradmann et al., 2005). The extensional domain is characterised by a series of downslope and upslope dipping extensional faults (Fig. 1).

The study area is located in the southern part of this extensional domain, where the depositional edge of the Messinian evaporite basin defines a 'salt salient' from the interplay between the Messinian base levels and the relict topography of a series of pre-Messinian submarine canyons (Bertoni and Cartwright, 2006). The study area involves one of these canyons (called the El Arish) and the extensional domain is bounded by Messinian evaporite pinch-out around this canyon salient (Bertoni and Cartwright, 2006).

3. Database, methods and limitations

The main database for this study is a high-resolution 3D seismic survey located in the southern part of the Levant Basin