Structural setting and kinematics of Nubian fault system, SE Western Desert, Egypt: An example of multi-reactivated intraplate strike-slip faults

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A B S T R A C T

Detailed surface geological mapping and subsurface seismic interpretation have been integrated to unravel the structural style and kinematic history of the Nubian Fault System (NFS). The NFS consists of several E-W Principal Deformation Zones (PDZs) (e.g. Kalabsha fault). Each PDZ is defined by spectacular E-W, NW and ENE dextral strike-slip faults, NNE sinistral strike-slip faults, NE to ENE folds, and NNW normal faults. Each fault zone has typical self-similar strike-slip architecture comprising multi-scale fault segments. Several multi-scale uplifts and basins were developed at the step-over zones between parallel strike-slip fault segments as a result of local extension or contraction. The NFS may extend for thousands kilometers in length and hundreds of kilometers in width (McKenzie and Jackson, 1983; Schreurs, 2003). The NFS consists of several E-W Main Deformation Zones (MDZs) (e.g. Kalabsha fault). Each MDZ is defined by spectacular E-W, NW and ENE dextral strike-slip faults, NNE sinistral strike-slip faults, NE to ENE folds, and NNW normal faults. Each fault zone has typical self-similar strike-slip architecture comprising multi-scale fault segments. Several multi-scale uplifts and basins were developed at the step-over zones between parallel strike-slip fault segments as a result of local extension or contraction. The NFS may extend for thousands kilometers in length and hundreds of kilometers in width (McKenzie and Jackson, 1983; Schreurs, 2003).

1. Introduction

The architecture of strike-slip faults is typically complex with several fault segments of different lengths dislocated by step-over zones. The strike-slip structural family, particularly step-over zones are of great economic importance; providing many hydrocarbon kitchens and traps (Escalona and Mann, 2003; Hinsch et al., 2005; Lan et al., 2016). Contractional step-over zones may be a superior location of hydrocarbon accumulation within regional basins (e.g. Escalona and Mann, 2003; Hinsch et al., 2005; Lan et al., 2016). Strike-slip faults control the distribution of many destructive earthquakes (e.g. Hinsch et al., 2005). Contractional and extensional step-over zones along active strike-slip faults may act as stress barriers preventing earthquake propagation or may be a good nucleation for a major earthquake. Moreover, strike-slip faults have direct control on the distribution of ore deposits (e.g. Pinheiro and Holdsworth, 1997).

Strike-slip faults occur usually in large and distributed shear zones, which extend for thousands kilometers in length and hundreds of kilometers in width (Mckenzie and Jackson, 1983; Schreurs, 2003). The NFS is a system of E-W faults that extends hundreds of kilometers from the River Nile to the central part of the southern Western Desert of Egypt (Fig. 1). All previous studies concerning the NFS are regional syntheses and did not emphasize on the detailed structural architecture of this system and still many debates arise about its mechanism and kinematics. The structural pattern and evolution of this fault network was the subject of study of many works related to the tectonic history of the region as well as its potentiality for seismicity (Issawi, 1968; Guiraud et al., 1985, 2001, 2005; Sehim, 1993; Schandelmeier and Reynolds, 1997; Klitzsch, 1986; Abdeen et al., 2000; Hogan et al., 2013; Tewksbury et al., 2009, 2010, 2017a,b, 2012). The most prominent structural trends in the Nubian Desert are the E-W and N-S trends which are strike-slip faults of dextral and sinistral sense of movement respectively (Woodward-Clyde Consultants., 1985). Issawi (1968) suggested that the E-W and N-S fault trends are dip-slip faults. According to Guiraud et al. (1985) the E-W trending faults are part of the so-called Guinean–Nubian E-W trending lineaments that extend across the entire African continent (Fig. 1). The tectonic origin and timing of the onset of deformation along the NFS is the subject of ongoing debate (e.g. Issawi, 1968; Guiraud et al., 1985, 2001; Thurmond et al., 2004; Guiraud et al., 2005; Hogan et al., 2013; Said et al., 2016; Tewksbury et al., 2017). A leading viewpoint suggests that NFS structures were related to the differential opening between the central and southern Atlantic ocean (Sehim, 1993; Guiraud et al., 1985), far field stresses associated with Red Sea opening (Abdeen, 2001) or due to the convergence between Africa and Eurasia (Guiraud et al., 2001 and 2005). Some interpretations suggest prolonged basement swell was responsible for development of the structural pattern in the Nubian Desert (Thurmond...
et al., 2004). Therefore, the main objective of this study is to investigate the geometry and evolution of the NFS by integrating surface geological mapping, and subsurface seismic interpretation. The excellent exposures and lack of vegetation provide a 3D view of the NFS which allow study its architecture and kinematics at several scales. The area of study is located in the Nubian Desert which represents the southeastern part of the Western Desert of Egypt and the extreme eastern part of the Great Sahara Desert. The latter includes the southern part of Egypt and the northern part of Sudan which are marked by the well exposed NFS (Fig. 1).

2. Geological set up and stratigraphy

The NFS is a complex network of multi-trend fault swarms (Issawi, 1968; Klitzsch, 1986; Klitzsch and Squyres, 1990). The clustering and multi-directional strikes of these faults are responsible for the jagged outline of the Sin El Kaddab tableland plateau which occupies the central part of the study area. Indeed, weathering and erosional processes have preferentially followed these multiple trends forming embayments, promontories, and dry ravines along the plateau’s perimeter.

The Sin El Kaddab tableland plateau is composed of Late Cretaceous to Early Eocene clastics and carbonate sediments. The plateau extends from its eastern escarpment (west of the Nile) to Darb El Arbain escarpment to the west (Issawi, 1968) (Fig. 2). Sin El Kaddab Plateau is surrounded by Nubian plains from the east, west and south (Fig. 2). The average elevation of the Nubian plain is 200 m above sea level and is covered by Late Cretaceous clastics. To the south, the Nubian swell dominates the southern part of the study area. The Nubian swell is defined as an east-west trending structural high in southern Egypt and northern Sudan and is composed of Precambrian crystalline basement (Thurmond et al., 2004). It is mainly composed of granitic gneiss and witnessed numerous intensive tectonic episodes, resulting in different structural styles (Bernau et al., 1987). The main pronounced structural elements of this belt are the E-W to ENE oriented foliation and mylonitic zones and NE oriented dyke swarms (Bernau et al., 1987; Huth and Franz, 1988). These mylonitic zones correspond to E-W oriented shear zones that might be attributed to the accretion of the Arabian Nubian shield on the eastern margin of the great Sahara Metacraton during the Late Neoproterozoic thermo-tectonic event of the Pan African orogeny. The first considerable reactivation of these Late Proterozoic shear zones

Fig. 1. Generalized tectonic map of the NE Africa and Arabia modified after Guiraud et al., 2001. Location of the study area is outlined by the red box. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
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