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Oppositely dipping thrusts and transpressional imbricate zone in the Central Eastern Desert of Egypt

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ABSTRACT

This paper documents the 40–60 km wide ENE–WSW trending Mubarak–Barramiya shear belt (MBSB) in the Central Eastern Desert of Egypt by examining its structural styles, kinematics and geometry. Our study revealed the existence of prevalent dextral and minor sinistral conjugate shear zones. The MBSB is metamorphic belt (greenschist–amphibolite) characterized by at least three post-collisional (740–540 Ma) ductile Neoproterozoic deformation events (D_1, D_2 and D_3) followed by a brittle neotectonic deformation (D_4). D_1 event produced early top-to-the-northwest thrust displacements due to NW–SE shortening. D_2 produced discrete zones of NNW-trending upright folds and culminated in initiation of major NW-trending sinistral shear zones of the Najd Fault System (NFS, at c. 640–540 Ma ago) as well as steeply dipping S_2 foliation, and shallowly plunging L_2 lineation. NW-to NNW-trending F_2 folds are open to steep and vary in plunge from horizontal to vertical. D_2 deformational fabrics are strongly overprinted by D_3 penetrative structures. D_3 is characterized by a penetrative S_3 foliation, steeply SE- to NW-plunging and shallowly NE-plunging stretching lineations (L_3), asymmetric and sheath folds (F_3) consistent with dextral sense of movement exhibited by delta- and sigma-type porphyroclast systems and asymmetric boudinage fabrics. D_2–D_3 represent a non-coaxial progressive event formed in a dextral NE- over NW-sinistral shear zone during a partitioned transpression in response to E–W-directed compression during oblique convergence between East and West Gondwana developed due to closure of the Mozambique Ocean and amalgamation of the Arabian–Nubian Shield in Cryogenian-early Ediacaran time.

1. Introduction

The East African Orogen (EAO) is an accretionary orogen that extends from Arabia to East Africa and into Antarctica and related to closure of the Mozambique Ocean, which formed in association with the breakup of Rodinia ~800–900 Ma (Stern, 1994). The Mozambique Belt is the southern part of the EAO and comprises mostly pre-Neoproterozoic crust with a Neoproterozoic–early Cambrian tectonothermal overprint (Bingen et al., 2009). The Mozambique Ocean closed during a protracted period of island-arc and microcontinent accretion between ~850 and 620 Ma (Fritz et al., 2013). The Arabian–Nubian Shield (ANS) is the northern part of the EAO and composed mainly of juvenile Neoproterozoic crust (e.g. Stern, 1994, 2002; Johnson and Woldehaimanot, 2003; Johnson et al., 2011). This crust was generated when arc and back arc crust developed within and around the margins of the Mozambique Ocean.

The late Proterozoic (Pan-African, 900–550 Ma) Arabian–Nubian Shield (ANS) forms the suture between East and West Gondwana at the northern end of the East African Orogen (EAO). The Arabian–Nubian Shield was caught between fragments of East and West Gondwanaland as these collided at about 600 Ma (Meert, 2003). The ANS includes Middle Cryogenian–Ediacaran (790–560 Ma) sedimentary and volcanic terrestrial and shallow-marine successions unconformable on juvenile Cryogenian crust (Johnson et al., 2013). The ANS extends from Jordan and southern Israel in the north to Eritrea and Ethiopia in the south and from Egypt in the west to Saudi Arabia and Oman in the east. The Nubian Shield is separated by the Red Sea from its counterpart, the Arabian Shield. The ANS consists of gneisses, granitoids, and various meta-volcanic and metasedimentary rocks.

The Precambrian basement of the Eastern Desert of Egypt is the northwestern extension of the Arabian–Nubian Shield (ANS). The Central Eastern Desert (CED) is characterized by two distinctive tectonostratigraphic units. The lower unit comprises high-grade metamorphic gneisses, migmatites, schists and amphibolites and is commonly referred to as the structural basement (El-Gaby

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et al.,1990; Loizenbauer et al., 2001). The upper unit includes low-grade metamorphosed ophiolite slices (serpentinites, pillow lavas, metagabbros), arc metavolcanics, arc metasediments and is commonly referred to as structural cover or the Pan-African nappes (e.g. El-Gaby et al.,1990; Fritz et al., 1996; Abd El-Rahmana et al., 2012). Both the two units were intruded by syn-tectonic calc-alkaline granites and metagabbros–diorite complex. The later stage of the crustal evolution of the CED is characterized by the eruption of the Dokhan volcanic suite which is associated with the formation of molasse-type Hammamat sedimentary rocks that were deposited in non-marine, alluvial fan/river environments (Grothaus et al., 1979; Abd El-Wahed, 2010; Bezenjania et al., 2014). These crustal rocks were intruded by a series of late to post-tectonic granites. The syn-tectonic granite in the CED has a magmatic emplacement age of 606–614 Ma (Loizenbauer et al., 2001; Andresen et al., 2010) whereas, the late to post-tectonic granites were emplaced at ca. 590–550 Ma (Hassan and Hashad, 1990; Rice et al., 1993).

The presence of a series of gneiss domes or core complexes (e.g. Meatiq, Sibai, El- Shalul, Hafafit) in the CED is a subject of controversy over whether gneiss domes and migmatites represent a pre-Neoproterozoic crust or exhumed Neoproterozoic rocks. The process forming the gneiss domes and the surrounding shear zones is still a matter of debate. Gneiss domes have either been interpreted as: (1) antiformal stacks formed during thrusting (e.g., Greiling et al., 1994), (2) core complexes during orogen-parallel crustal extension (e.g., Fritz et al., 1996; Bregar et al., 2002; Abd El-Wahed, 2008), and (3) interference patterns of sheath folds (Fowler and El Kalioubi, 2002). Geochronology suggests that extension and exhumation of gneiss domes commenced around 620–606 Ma (Fritz et al., 2002; Andresen et al., 2009). Another controversy is about the role of sinistral shearing and transpression related to the Najd Fault System (NFS) in the exhumation of these gneiss domes and in deformation styles of the CED. The Najd Fault System (NFS) consists of brittle–ductile shears in a zone as much as 300 km wide and more than 1100 km long, extending across the northern part of the Arabian Shield. Nowadays, sinistral shearing along the NW-trending shear zones of the NFS has been used to explain the tectonic history of the Central Eastern Desert of Egypt (e.g. Fritz et al., 1996, 2002, 2013; Bregar et al., 2002; Shalaby et al.,2005; Abd El-Wahed, 2008, 2010; Abd El-Wahed and Kamh, 2010). Also, deformation along the NFS is genetically linked with deposition and deformation of Hammamat sediments (Abd El-Wahed, 2010) and emplacement of syntectonic granitoids (Fritz et al., 2013).

The CED is characterized mainly by the prevalence of a NW-trending tectonic fabric marking the NW–SE sinistral shear zone of the NFS (Abd El-Wahed and Kamh, 2010). The directions of nappe transport reported from the CED vary from top to the NE (e.g. Elbayoumi and Greiling, 1984), top to the NW (e.g. Ries et al., 1983; Greiling, 1987), top to the SE (e.g. Kamal El Din et al., 1992), and top to the SW (e.g. Abdeen et al., 2002; Abdelsalam et al., 2003). Currently, sinistral and dextral transpression involving oblique convergence has been utilized to explain the deformation styles in the Central Eastern Desert of Egypt (Fritz et al., 1996, 2002, 2013; Loizenbauer et al., 2001; Makroum, 2001; Bregar et al., 2002; Helmy et al., 2004; Shalaby et al., 2005; Abd El-Wahed, 2008, 2010; Abd El-Wahed and Abu Anbar, 2009; Shalaby, 2010; Abd El-Wahed and Kamh, 2010; Zoheir and Lehmann, 2011; Zoheir and Weihed, 2013). Abd El-Wahed And Kamh (2010) arranged the deformation events in the CED of Egypt as follows: (1) D_1 linked to NNW-directed thrusts; (2) D_2 related to NE- and SW-directed thrusts; (3) D_3 attributed to sinistral movement along the NW-trending shear zones of the NFS; (4) D_4 associated with dextral movement along NE-trending shear zones; and (e) D_5 later events.

The central part of the CED is marked by a huge NE-trending shear belt (up to 110 km in length) that occupies the area between Wadi Barramiya and Wadi Sha'it to the west (up to 60 km in width) and extends through the whole width of the Central Eastern Desert to include the area between Wadi Mubarak and Wadi Ghadir on the Red Sea coast (up to 120 km in width) (Fig. 1). There is a great controversy about the origin and the deformation styles in the Mubarak–Barramiya shear belt due to its discordant to the NW-trending tectonic fabric marking the CED. The transpression-related NW-trending sinistral shear along the NFS is superimposed by the dominant dextral transpression along NE–SW trending shear zones (Shalaby et al., 2005; Abd El-Wahed and Kamh, 2010). This dextral shearing is characterized by the development of NNE- to NE-trending cleavage, strike–slip duplex, NNE- and NE-trending folds, and NNW-directed thrusts (Abd El-Wahed and Kamh, 2010).

This study examines the structural and tectonic evolution of the post-accretionary deformational belts in the Arabian–Nubian Shield using new structural data from the Mubarak–Barramiya shear belt (MBSB) and published data for other belts. The main aims of this contribution were to:(i) establish the geometrical features and the detailed structural analysis of the entire MBSB, (ii) examine the role of sinistral and dextral transpression during the dominant deformation events in the shear belt and (iii) establish architecture of the transpressional belt and the kinematics of deformation. We focused on four areas from the Mubarak-Barramiya shear belt (Fig. 1), where kinematic criteria for dextral sense of shear have been recognized, in contrast to sinistral sense of shear to the north and the south of the MBSB. The result suggests that three ductile Late Neoproterozoic deformational events have been involved in the structural history of the MBSB, a coaxial/flattening D_1 and a transpressional sinistral (D_2) and dextral (D_3) over NNW-directed thrusting D_1. These three ductile deformational events are later followed by a younger D_4 brittle deformation.

2. Geology of the Mubarak–Barramiya shear belt

The Mubarak–Barramiya shear belt (MBSB) runs NE–SW to ENE–WSW in the CED (Fig. 1) and deforms supra-crustal successions and structures associated with the NW-trending shear fabric. It constitutes well-defined ophiolite-decorated linear belt where serpentinites represent the most characteristic lithological unit. The geology of the MBSB is commonly described in terms of three major lithotectonic units, namely (i) ophiolite slices and ophiolitic mélange, (ii) island arc metavolcanic and metasedimentary successions and (iii) syn- to post-orogenic gabbroic to granitic intrusions. The ophiolites display imbricate thrust sheets and slices of dismembered ophiolite suites distributed along several localities within the MBSB (Fig. 1).

The ophiolitic rocks cropping in MBSB include serpentinized peridotites and dunites, metagabbro, diabase and pillow lavas. They occur as fragments in a metasedimentary matrix that encompasses conglomerates, greywackes, mudstones, volcanoclastics and schists (Takla et al., 1982; Abu El-Ela, 1985; Khalil and Azer, 2007; Ali-Bik et al., 2012). The ophiolitic rocks were dated at approximately 870–740 Ma (Stern et al., 2004; Johnson et al., 2004) and have been formed in the Mozambique Ocean that was formed upon rifting of Rodinia (Abdelsalam and Stern, 1996; Stern, 1994). Farahat et al. (2004) suggested continental (ensialic) back-arc basin origin for Mubarak and Ghadir ophiolites.

Serpentinite exposures are thrust-bounded and usually aligned along major suture zones or thrust faults separating the structural basement from the Pan-African nappes. The structural trend and the elongation of serpentinite masses are controlled by major folds which trend mainly NE–SW and NW–SE respectively (Ries et al.,