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Thermodynamic modelling of Sol Hamed serpentinite, South Eastern Desert of Egypt: Implication for fluid interaction in the Arabian–Nubian Shield ophiolites

Tamer S. Abu-Alam [a,b,c,*], Mohamed M. Hamdy [a]

[a] Geology Department, Faculty of Science, Tanta University, Tanta, Egypt
[b] Norwegian Polar Institute, Hjalmar Johansens gt. 14, NO-9296 Tromsø, Norway
[c] Egyptian Institute of Geodynamic, Cairo, Egypt

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ABSTRACT

The Arabian–Nubian Shield is the largest tract of juvenile continental crust of the Neoproterozoic. This juvenile crust is composed of intra-oceanic island arc/back arc basin complexes and micro-continents welded together along sutures as the Mozambique Ocean was closed. Some of these sutures are marked by ophiolite decorated linear belts. The Sol Hamed ophiolite (808 ± 14 Ma) in southeastern Egypt at the Allaqi-Heiani-Onib-Sol Hamed-Yanbu arc–arc suture represents an uncommon example of rocks that might be less deformed than other ophiolites in the Arabian–Nubian Shield. In order to understand fluid–rock interactions before and during arc–arc collision, petrological, mineral chemistry, whole-rock chemistry and thermodynamic studies were applied to the Sol Hamed serpentinized ophiolitic mantle fragment. These studies reveal that the protolith had a harzburgite composition that probably originated as forearc mantle in the subducted oceanic slab. We propose that these rocks interacted with Ti-rich melts (boninite) in suprasubduction zone, which latter formed the Sol Hamed cumulates. Spinel's Cr# associated with the whole rock V–MgO composition suggest that the harzburgites are highly refractory residues after partial melting up to 29%. The melt extraction mostly occurred under reducing conditions, similar to peridotites recovered from the subducted lithosphere. Protolith alteration resulted from two stages of fluid–rock interaction. The first stage occurred as a result of infiltration of concentrated CO_2-rich fluid released from carbonate-bearing sediments and altered basalt at the subduction zone. The alteration occurred during isobaric cooling at a pressure of 1 kbar. The fluid composition during the isobaric cooling was buffered by the metamorphic reactions. The second stage of fluid–rock interactions took place through prograde metamorphism. The increase in pressure during this stage occurred as a result of thrusting within the oceanic crust. In this process the forearc crust was loaded by roughly 20–30 km of overthrust rocks.

1. Introduction

Arabian–Nubian Shield (ANS) in Northeast Africa and West Arabia is the largest tract of juvenile continental crust of the Neoproterozoic age on Earth (Patchett and Chase, 2002; Stern et al., 2004). This crust was generated when arc terranes were created within and around the margins of the Mozambique Ocean, which formed in association with the breakup of Rodinia ~800–900 Ma (Stern, 1994; Hassan et al., 2014). These crustal fragments collided as the Mozambique Ocean closed around 600 Ma (Meert, 2003). Due to this collision processes a supercontinent variously referred to as Greater Gondwanaland (Stern, 1994), Pannotia (Dalziel, 1997) or just Gondwana (e.g. Abu-Alam et al., 2013) was formed. The collision of the island arcs during ANS evolution resulted in the formation of major linear suture zones of deformed ophiolitic rocks separating less deformed volcanic arc rocks (Fig. 1).

The major suture zones of the ANS can be classified into two types, arc–arc and arc-continent sutures (Abdelsalam and Stern, 1996). The arc–arc sutures trend mostly NE–SW representing the zones of closure of the oceanic basins between juvenile arc terranes at 800–700 Ma (Pallister et al., 1988; Kröner et al., 1992; Johnson et al., 2004). The Allaqi-Heiani-Onib-Sol Hamed-Yanbu and Nakasib-Bir Umq sutures are good examples of this type. Following arc–arc collision, the ANS collided with pre-Neoproterozoic

* Corresponding author at: Norwegian Polar Institute, Hjalmar Johansens gt. 14, NO-9296 Tromsø, Norway.
E-mail address: tamer.abu-alam@npolar.no (T.S. Abu-Alam).

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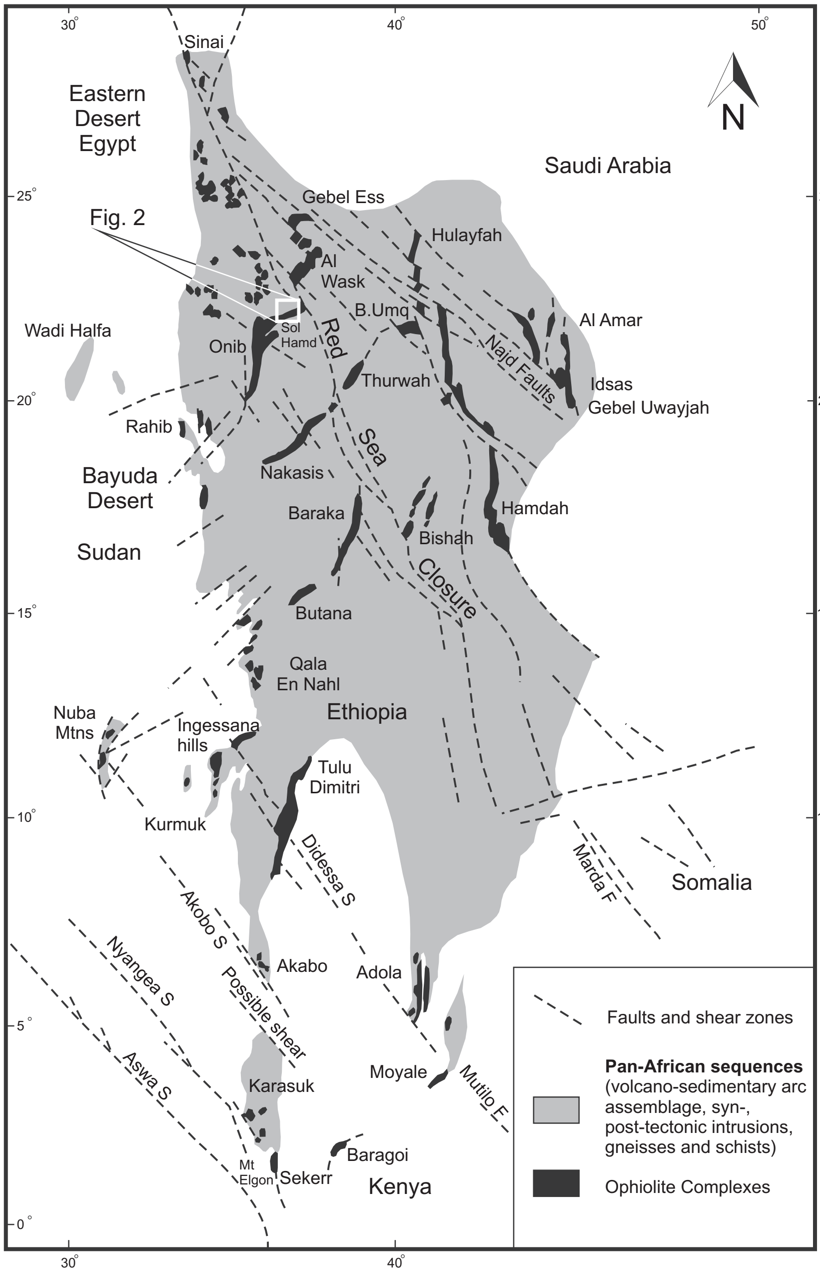

Fig. 1. Distribution of the ophiolites in the Arabian–Nubian Shield (modified after Vail, 1983; Hargrove et al., 2006; Ali et al., 2010; Azer et al., 2013; Abu-Alam et al., unpublished data).

continental blocks, East- and West-Gondwana, at 750–630 Ma (Stern, 1994; Johnson et al., 2004; Abu-Alam et al., in press). Abdelsalam and Stern (1996) referred to these boundaries as arc-continent sutures. These sutures trend north–south and their best examples are the Nabitah suture in the east and the Keraf suture in the west. The final collision of East- and West-Gondwana deformed the ANS along north trending shortening zones developed between 650 and 550 Ma (Abdelsalam and Stern, 1996; Stern et al., 2004; Abu-Alam and Stüwe, 2009). The well-known example of these zones is the Hamisana shear zone, which is characterized by east–west crustal shortening fabrics, steep folds, and thrust faults. The sutures, typically reactivated as transpressional/transcurrent zones, are located across the shield (e.g., Johnson et al., 2004, and references therein). Late deformation included the occurrence of lateral escape tectonics along transtensional or transpressional systems during the final stages of orogeny (e.g., Stern, 1994; Johnson et al., 2004; Meyer et al., 2014).

Ophiolitic rocks are remarkably abundant in the ANS. They are scattered across most of the shield, over a distance of ~3000 km from the farthest north (Gebel Ess) almost to the equator, and from Rahib in the west to Gebel Uwayjah (45°E) in the east (Fig. 1). The abundance of the ophiolites is a further indication that the Arabian–Nubian Shield was produced by processes similar to those of modern plate tectonics (Stern et al., 2004). The ophiolitic rocks of Eastern Desert (ED) of Egypt (Fig. 1) are interpreted to be formed in a suprasubduction zone (SSZ) (e.g. Ahmed et al., 2006; Azer and Stern, 2007), either in forearc (Stern et al., 2004; El-Gaby, 2005; Azer and Stern, 2007; Azer et al., 2013; Hamdy et al., 2013; Khedr and Arai, 2013) or back-arc (El-Sayed et al., 1999; El Bahariya and Arai, 2003; Farahat et al., 2004). However, some studies suggested that these rocks have been generated in mid-ocean ridges (Ries et al., 1983; Zimmer et al., 1995; El Bahariya and Arai, 2003; Farahat, 2010). The East- and West-Gondwana collision led to obduction of the SSZ ophiolitic rocks over a continental