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Petrology and geochemistry of the Tertiary Suez rift volcanism, Sinai, Egypt

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ABSTRACT

The Tertiary basaltic rocks of Southwestern Sinai, situated along the Wadi Nukhul–Wadi Matullah–Wadi El Tayiba join, were selected to study the Gulf of Suez rift related-lavas and their geochemical and petrological relation with the rifting process. Whole rock samples were studied petrographically and analysed for major and trace elements. The samples from dykes, sills and flows from multiple magmatic events display a large variety in texture and in modal mineral compositions. They range from olivine dolerites and olivine-bearing basalts to vitrophyric, texturally heterogeneous basalts and crystal lithic tuffs. The transitional tholeiitic basalts display low compatible element concentrations and an enrichment of the whole spectrum of the incompatible elements. Major, trace and Rare Earth Element data suggest that the melts formed by 5% melting of mantle peridotite at the spinel–garnet transition zone (80–90 km depth), in the presence of 2–4% residual garnet. During the melt ascent, the fractionating phases were olivine, clinopyroxene and, to a lesser extent, plagioclase. Thermobarometric calculations indicate the presence of two crystallization levels beneath the Gulf of Suez rift: a shallower stage at 15–20 km and a deeper stage at depths of 25–30 km. The mantle source consists of streaks and blobs of enriched mantle, preserved in the geochemical signatures of these rocks. The enriched mantle sources melted preferentially compared to the surrounding ambient mantle and thus led to a preferential enrichment of the sources of the Gulf of Suez rift.

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1. Introduction

The extension and initiation of rifting of continental lithosphere and the succession into oceanic spreading has been a matter of active debate. The causes of initial rifting and the associated processes involved a range from passively to actively upwelling material (McKenzie, 1978; Illies, 1981; Mohr, 1982; Courtillot et al., 1999; Kazmin and Byakov, 2000; Courtillot and Renne, 2003).

The continental rift in the Gulf of Suez is the north-western extension of the larger Gulf of Aden-Red Sea rift system that separates the African and Arabian plates. The rift constitutes a transition from continental to oceanic rifting with the development of sea floor spreading centres in the north (Bosworth et al., 2005). This rift system produced voluminous flood basalts accompanied by crustal doming specifically in the southern part of the Red Sea along the Arabian and African plates (Baker et al., 1996; Hofmann et al., 1997). In contrast, the northern Red Sea-Gulf of Suez rift exhibits asymmetric volcanism and doming, where the Arabian flank displays crustal doming and large volumes of plateau basalts e.g. the Harrats in Saudi Arabia (Camp and Roobol, 1992), Jordan (Shaw et al., 2003) and Syria (Krienitz et al., 2006). The African plate, in contrast, displays less pronounced doming and has few basaltic outcrops. It is noteworthy mentioning that at ca 14 Ma the Levant–Aqaba transform started, where the Red Sea extension changed from rift normal (N60E) to highly oblique (N15E) and the Gulf of Suez extension slowed dramatically but did not stop completely (Bosworth et al., 2005). This variability in degree of crustal doming, extent of volcanism along the Red Sea, and extension has raised a controversy as to its origin.

More recent models of continental rifting suggest that magma ascent in extensive dike systems is required to weaken the lithosphere for the initial rifting to occur (Buck, 2006). Geochemical and chronological studies along the northern Red Sea suggest the presence of a fossil plume head underneath the Arabian plate (Ilani et al., 2001), on the basis of Nd versus Sr isotopic compositions of basalts. Geophysical measurements described a channel-shaped, low velocity anomaly extends from Afar (Afar plume) but does not align well with the Red Sea; it underlies the southern Red Sea and extends northwards beneath Arabia (NorthArabia/Jordan plume) leaving the central and northern Red Sea without underlying hot material (Chang and Van der Lee, 2011). This is supported by lack of seismicity and oceanic crust in Central Red Sea as well as MORB-nature of its oceanic basalts, e.g. basalts of the northern Shaban Deep (Haase et al., 2000) in contrast to high seismicity, oceanic

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crust and plume-nature oceanic basalts of the southern Red Sea (Volker et al., 1997; Chang and Van der Lee, 2011). Additionally, the Harrat basalts were contemporaneous with the crustal uplift, resulting in the Western Arabian swell (Camp and Roobol, 1992). Few major and trace elements geochemical data are available from the rift-related volcanic rocks, implying that the olivine-bearing dolerites are alkaline-transitional to tholeiitic and derived from an enriched mantle source (e.g., Abdel Kader and El Bayoumi, 1984; Moussa, 1987; Samuel et al., 1997).

This research presents new petrological and major and trace element data for lavas from the Tertiary rift in southwestern Sinai, in order to investigate the nature of the magmatic activity and to infer the melting processes. We show that the mantle underneath the African–Arabian plate is not homogenous but rather consists of portions of enriched and depleted mantle material. We observe a change of the degree and depth of melting along the Red Sea-Gulf of Suez rift system that results in marked changes of the geochemical composition.

2. Geologic setting

The Gulf of Suez rift is a non-magmatic rift system with a complex graben/half graben structure, located between two uplifted basement blocks: the Sinai and the Eastern Desert mountains. Structurally the Gulf of Suez comprises three main dip provinces that are separated by two major accommodation zones; each of these provinces is in the form of asymmetric half-graben bounded on one side by a major NW-trending border fault system with large throws: the northern (Darag) and southern (Amal-Zeit) provinces are southwesterly-dipping; whereas the central (Belayim) province, where the study area is located, is northeasterly-dipping (e.g. Bosworth and McClay, 2001). The areal extent and degree of doming of basement crystalline rocks (upper igneous crust) are far greater on both sides of the Red Sea rift than those bounding the Suez rift (Saleh et al., 2006). The pre-Miocene structural fabrics imparted to the Northeast African continental crust played a significant role in controlling the subsequent structural development of the Gulf of Suez area (Patton et al., 1994). The study area consists of two sedimentary packages (El Barkooky and El Araby, 1998): a) the Coniacian to upper Eocene pre-rift package, that comprises the Matulla clastics, Sudr chalks, Esna shales and Thebes limestones (older to younger); and b) the Oligocene to Miocene Syn-rift package that encompasses the lower Tayiba red beds and the upper Nukhul clastics (Fig. 1).

The Gulf of Suez rift contains few, asymmetrically distributed and volumetrically insignificant late pre-rift to early syn-rift basic dykes and isolated basaltic lava flow units (Kazmin and Byakov, 2000; Bosworth and McClay, 2001). The Oligo-Miocene magmatism then marks the beginning of the Gulf of Suez rifting (Patton et al., 1994). Whole-rock K.– Ar dating revealed a bimodal distribution of ages with one group at 27 Ma and a younger group at 24–22 Ma (Steen, 1984; Meneisy, 1990; Plaziat et al., 1998) indicating two main phases of volcanism. A much older event of 31 Ma was detected through apatite fission-track dating of the Matulla variegated shale and sandstone clastics in contact with the volcanics of Wadi Matulla, which likely represents the early eruption of rift-related volcanics and the initiation of the Suez rift (Hammed, 2004).

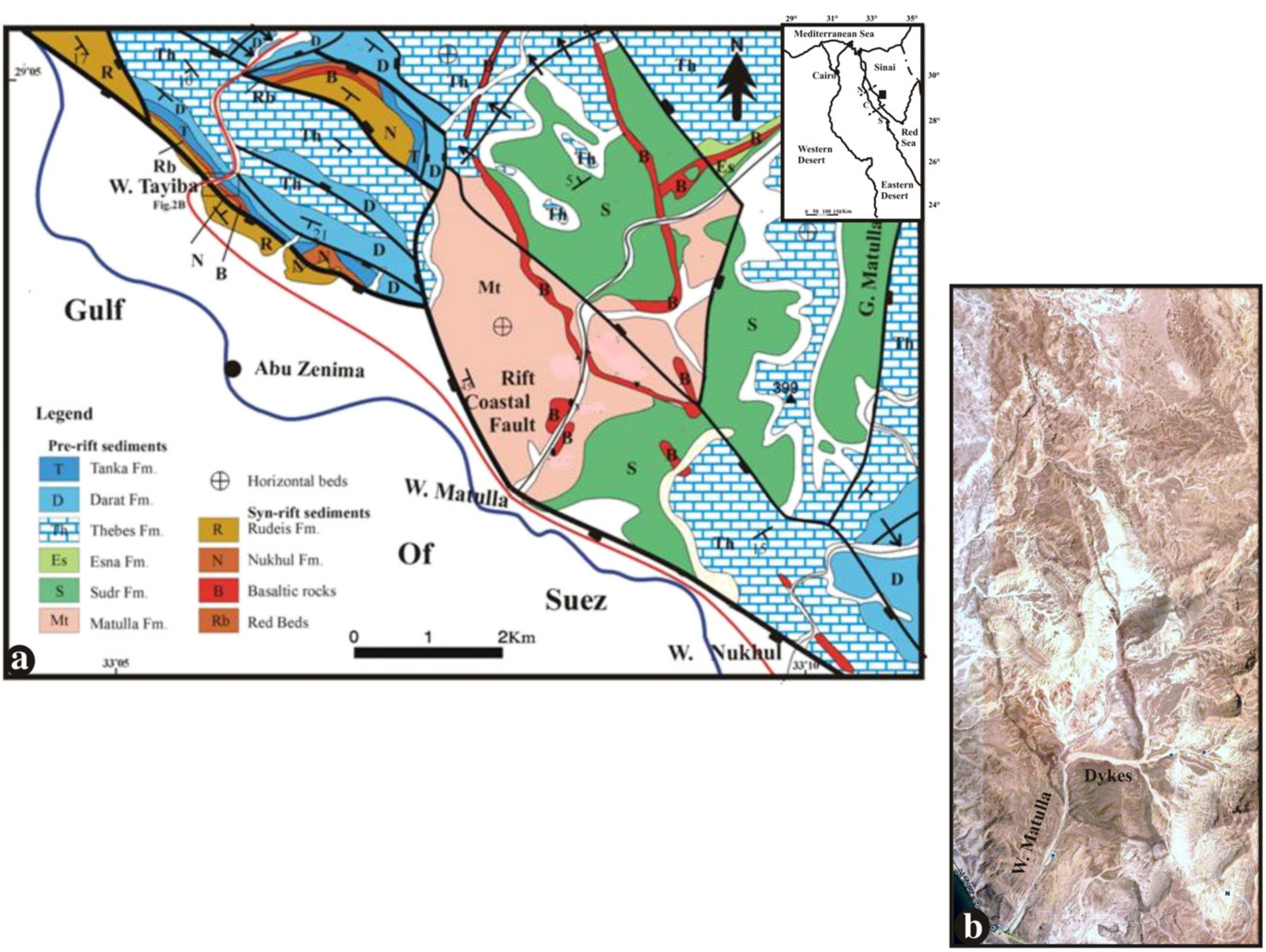

Fig. 1. a. Sample localities and geological map of the Eastern side of the Gulf of Suez, Egypt modified from Hammed (2004). D: Darag B: Belayim A: Amal-Zeit. b. An overview of the Wadi Nukhul–Wadi Matulla land stretch showing the two longest dykes in the area, referenced from Google earth Version 7.1.1.1888.

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