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Pliocene–Quaternary basalts from the Harrat Tufail, western Saudi Arabia: Recycling of ancient oceanic slabs and generation of alkaline intra-plate magma

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ABSTRACT

Harrat Tufail represents a Caenozoic basalt suite at the western margin of the Arabian plate. This rift-related suite includes voluminous Quaternary non-vesicular basalt (with fragments of earlier Pliocene vesicular flow) that forms a cap sheet over Miocene rhyolite and minor vesicular basalt. The contact between rhyolite and the basaltic cap is erosional with remarkable denudations indicating long time gap between the felsic and mafic eruptions. The geochemical data prove alkaline, sodic and low-Ti nature of the olivine basalt cap sheet. The combined whole-rock and mineral spot analyses by the electron microprobe (EMPA) suggest magma generation from low degree of partial melting (~5%) from spinel- and garnet-lherzolite mantle source. Derivation from a mantle source is supported by low Na content in clinopyroxene (ferroan diopside) whereas high Mg content in ilmenite is an evidence of fractional crystallization trajectory. Accordingly, the Pliocene basaltic cap of Harrat Tufail is a product of mantle melt that originates by recycling in the asthenosphere during subduction of ancient oceanic slab(s). The whole-rock chemistry suggests an ancient ocean island basaltic slab (OIB) whereas the EMPA of Al-rich spinel inclusions in olivine phenocrysts are in favour of a mid-ocean ridge basaltic source (MORB). Calculations of oxygen fugacity based on the composition of co-existing Fe–Ti oxide suggest fluctuation from highly to moderately oxidizing conditions with propagation of crystallization (log10 f_{O2} from −22.09 to −12.50). Clinopyroxene composition and pressure calculation indicates low-pressure (0.4–2 kbar). Cores of olivine phenocrysts formed at highest temperature (1086–1151 °C) whereas the rims and olivine micro-phenocrysts formed at 712–9–796 °C which is contemporaneous to formation of clinopyroxene at 611–782 °C. Fe–Ti oxides crystallized over a long range (652–992 °C) where it started to form at outer peripheries of olivine phenocrysts and as interstitial phase with clinopyroxene.

1. Introduction

The term “intra-plate” is assigned to volcanism that is so remote from plate boundaries, and in which magma generation cannot be attributed to energy that releases at mid-ocean ridges, subduction zones and transform faults (Johnson, 1989). In several world examples, some workers explained the evolution of intra-plate magmatism inside continents in terms of the mantle plume theory in which magma probably forms in a pulsing mantle that practiced considerable metasomatism (Wilson et al., 1995; Witt-Eickschen and Kramm, 1997; Goes et al., 1999; Wedepohl and Baumann, 1999; Haase et al., 2004).

In Arabic, Harrats mean either stony areas or volcanic provinces (Wehr, 1976). Due to extension, the Harrat volcanic fields have been developed along old fractures that are dated back to the Precambrian (Coleman et al., 1983; Camp and Roobol, 1992; El-Akhal, 2004). One of the largest Caenozoic volcanic fields in the world is represented by the so-called “Harrats” that have been developed since the renaissance of the Red Sea in western Saudi Arabia and adjacent countries covering which are dated to the Oligo-Miocene, Pliocene, Pleistocene and Recent (Coleman et al., 1983; Pallister, 1987; Moufti et al., 2013; Németh et al., 2014). These Harrats are extensively encountered in Saudi Arabia and extend for about 3000 km from the south in Yemen to Jordan and Syria in the north. In northwestern Saudi Arabia, there are large Harrat fields such as Rahat, Kishb, Khaybar and Ithnayn that are aligned nearly N–S and confined to the so-called “Makkah-Madinah-Nufud (MMN)

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volcanic line" covering an area of about 15,200 km^2 (Fig. 1). The figure shows also some other small Harrats, for example the currently studied Harrat Tufail and the similar Harrat Lunayyir that are confined to the NW-trending Red Sea coast (Camp and Roobol, 1989). According to Coleman et al. (1983) and Camp and Roobol (1989), the Harrats are mostly alkaline basalts with contemporaneous minor intermediate and felsic rock varieties with: 1) two successive stages of the Red Sea rift in which the first started before 30–15 Ma whereas the second is 5 Ma to Recent, 2) when the Arabian plate collided with the Eurasian plate, and 3) uplift of the Afro-Arabian dome. Extension of the Harrats in the western Arabian Penisnula is represented southwards by the Afar volcanics and the famous mantle plume there. A hot spot model for the Harrats in the western Arabian Peninsula is excluded but can be

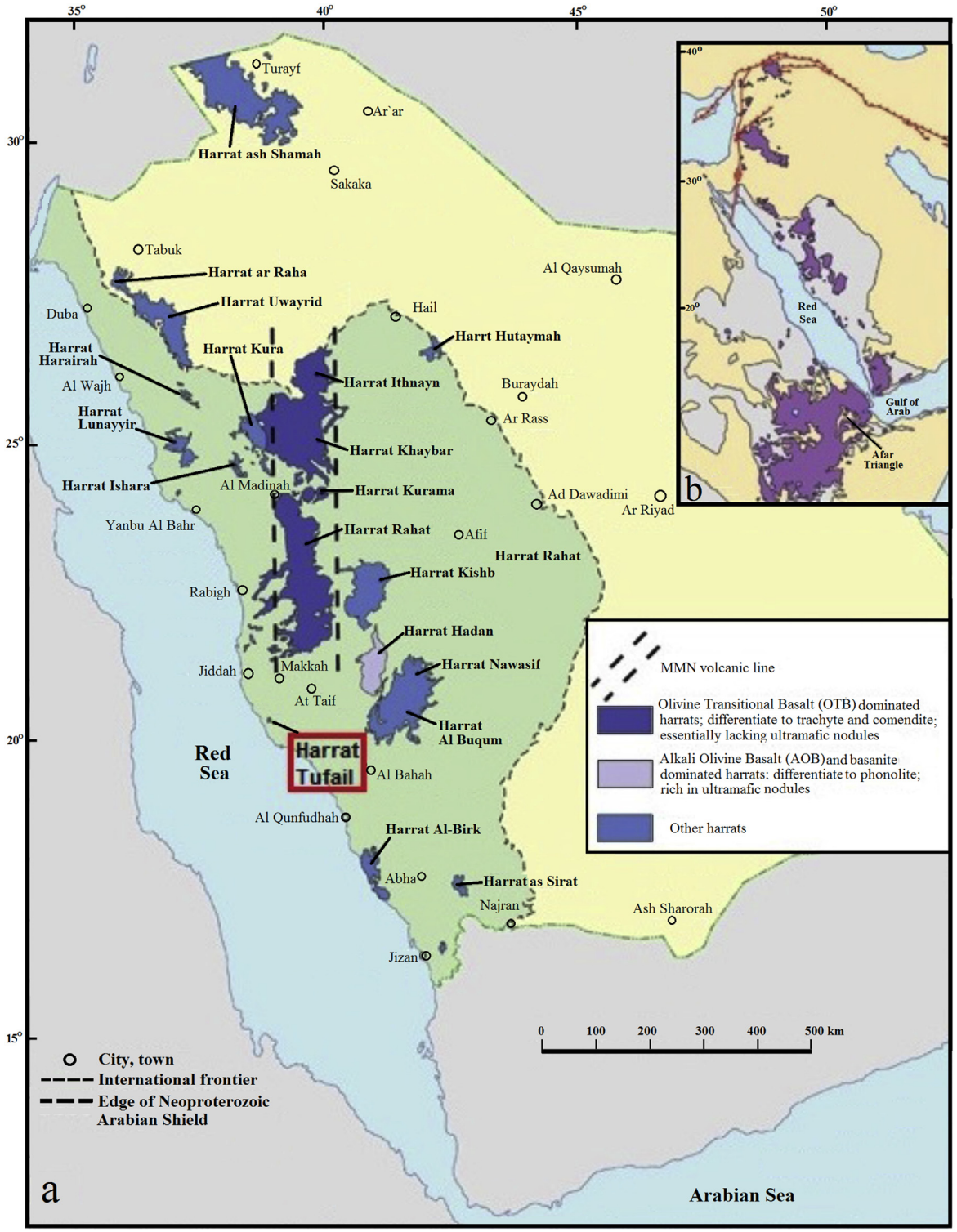

Fig. 1. Location map of Harrat Tufail and distribution of Harrat Volcanic Fields in western Saudi Arabia.