

In this chapter the intraplate volcanic fields of the Arabian Peninsula will be presented in a global context through comparison with other intraplate volcanic fields, focusing on those with special relevance to known and/or planned geoheritage, geoconservation and geotouristic programs and geoparks.

2.1 Cenozoic Volcanic Fields of the Arabian Peninsula

The Red Sea Rift forms an active deformation zone between the African and Arabian continental plates, stretching about 2000 km from NNW to SSE (Fig. 2.1). The rifting along the Red Sea started about 30 million years ago, leading to the separation of the Arabian Plate from Africa (Avni et al. 2012; Bohannon et al. 1989; Bosworth et al. 2004, 2005; Camp and Roobol 1992; Corti 2009; Ghebreab 1998; Girdler 1991; Zeyen et al. 1997). The evolution of the marginal areas in reference to the axis of the Red Sea Rift was complex and consisted of a combination of (1) extension along the Red Sea basin (Bellahsen et al. 2003; McGuire and Bohannon 1989; Voggenreiter et al. 1988; Wernicke 1985); (2) a pronounced continental collision between Arabia and Eurasia since the middle Miocene about 13 Ma (Dewey et al. 1986; McKenzie 1978); and (3) the development of left-lateral strike slip zones in the northwest margin of the Arabian micro-continent (Garfunkel 1981; Garfunkel and Ben-Avraham 2001; Garfunkel and Ben-Avraham 1996). This geodynamically complex situation provided mantle melting and shear that fed magma rising to the surface, especially in the western and northern margin of the Arabian plate, to form volcanic fields close to the plate boundaries (Bord and Bertrand 1995; Camp et al. 1987; Camp and Roobol 1989, 1991, 1992; Camp et al. 1991, 1992; Harlavan et al. 2002; Ibrahim and Al-Malabeh 2006; Kaliwoda et al.

2007; Moufti and Anonymous 2004; Moufti et al. 2012a, b). As a result of this intracontinental volcanism, a thick pile of sheet-like lava flows and associated networks of shield and fissure-fed volcanoes formed in the past 30 million years across various harrats.

These lava flow dominated fields are generally known locally as harrats (Fig. 2.2). The word “harrat” is the possessive form of the singular Arabic noun “harra”, which means “stony area, volcanic country, lava field” (Wehr 1976); it is related to the adjective “harr”, meaning “hot” (cross-referenced from Camp and Robol 1989). The term harrat is commonly used and understood as a synonym for volcanic field. The generation of names for specific harrats is commonly locality driven, and refers to a nearby settlement or geographical marker. In this respect, especially for harrats that cover large surface areas, the boundary between specifically named harrats is fairly undefined or at least *ad hoc*. Here we follow the traditional naming of specific harrats, and will express a harrat’s potential volcanological significance through its association with a potential volcanic field, as defined in the volcanic literature (Barde-Cabusson et al. 2014; Brenna et al. 2012; Cimarelli et al. 2013; Connor and Conway 2000; Hernando et al. 2014; Le Corvec et al. 2013a, b; Németh 2010; Németh et al. 2011; Runge et al. 2014; Valentine and Gregg 2008).

Among these harrats, the largest (both in eruptive volume and surface area) is Harrat Ash Shaam (Fig. 1.1), which covers an area of 50,000 km² (Al Kwatli et al. 2012; Ibrahim et al. 2003; Ilani et al. 2001; Shaw et al. 2003; Trifonov et al. 2011; Weinstein et al. 2006). While Harrat Ash Shaam is the largest harrat in the Arabian post-30 Ma volcanic regions, the majority of its area is outside of the territory of the Kingdom of Saudi Arabia. In addition this harrat is difficult to access and no geoheritage studies have been performed on it; therefore, it is not included in this work. The largest harrats by occupied surface area, number of vents and

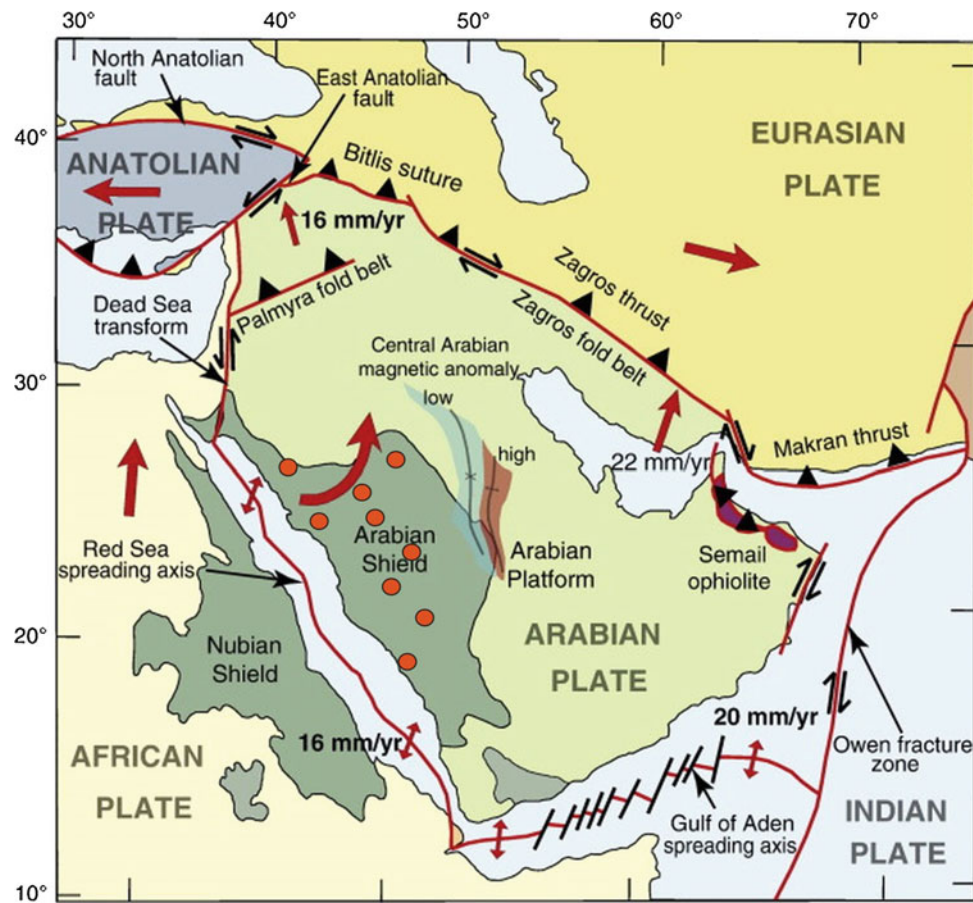


Fig. 2.1 General geotectonic framework of the Cenozoic harrats (red dots) of the Arabian Peninsula, concentrating volcanic fields mostly in the western region of the Kingdom of Saudi Arabia



Fig. 2.2 A typical view to a harrat in Saudi Arabia characteristic as a dark basalt-dominated rock desert such as shown in the picture from Harrat al Birk [17° 59' 46.32"N; 41° 42' 23.65"E]

estimated erupted volume in the territory of the Kingdom of Saudi Arabia are the Harrat Khaybar (20,564 km²) and Harrat Rahat (19,830 km²), which were both formed by a succession of volcanic eruptions at least 10 million years

long that produced several hundreds of individual volcanoes ranging from those with basaltic compositions to rhyolites (Camp and Roobol 1989; Camp et al. 1991). The majority of the harrats produced volcanoes erupted from alkaline



Fig. 2.3 Peridotite lherzolite nodules (about 10 cm across) from the Harrat Kishb alkaline basaltic lava flows and pyroclastic deposits near Aslaj volcano [23° 14' 18.16"N; 41° 16' 1.26"E]

magmas, such as alkaline basalt, mugearite, benmoreite and trachyte typical for intracontinental volcanism (Camp and Roobol 1989, 1992; Camp et al. 1991; Coleman and Gregory 1983; Moufti et al. 2012a, b). In regions such as Harrat Kishb the volcanism was bimodal and produced phonolitic lava domes and colees (Camp et al. 1992; Coleman and Gregory 1983). Harrat Kishb is also the region where abundant deep seated mantle and deep crustal-derived xenoliths (Fig. 2.3) are known in the eruptive products, including various peridotite lherzolite nodules (McGuire 1988). A similar trend is documented at the Harrat Hutaymah in the NW edge of the region of harrats of the Arabian peninsula (Thornber 1990). The volcanic fields are erupted over old lithospheric fragments that are composed of various Precambrian rocks. The vents in most cases show strong parallel alignment with older, potentially reactivated, structural elements of the basement, often forming dorsal zones of volcanoes in the harrats, such as in the case of Harrat Rahat (Fig. 2.4). While patterns in the vent distribution are apparent (El Difrawy et al. 2013; Runge et al. 2014), the

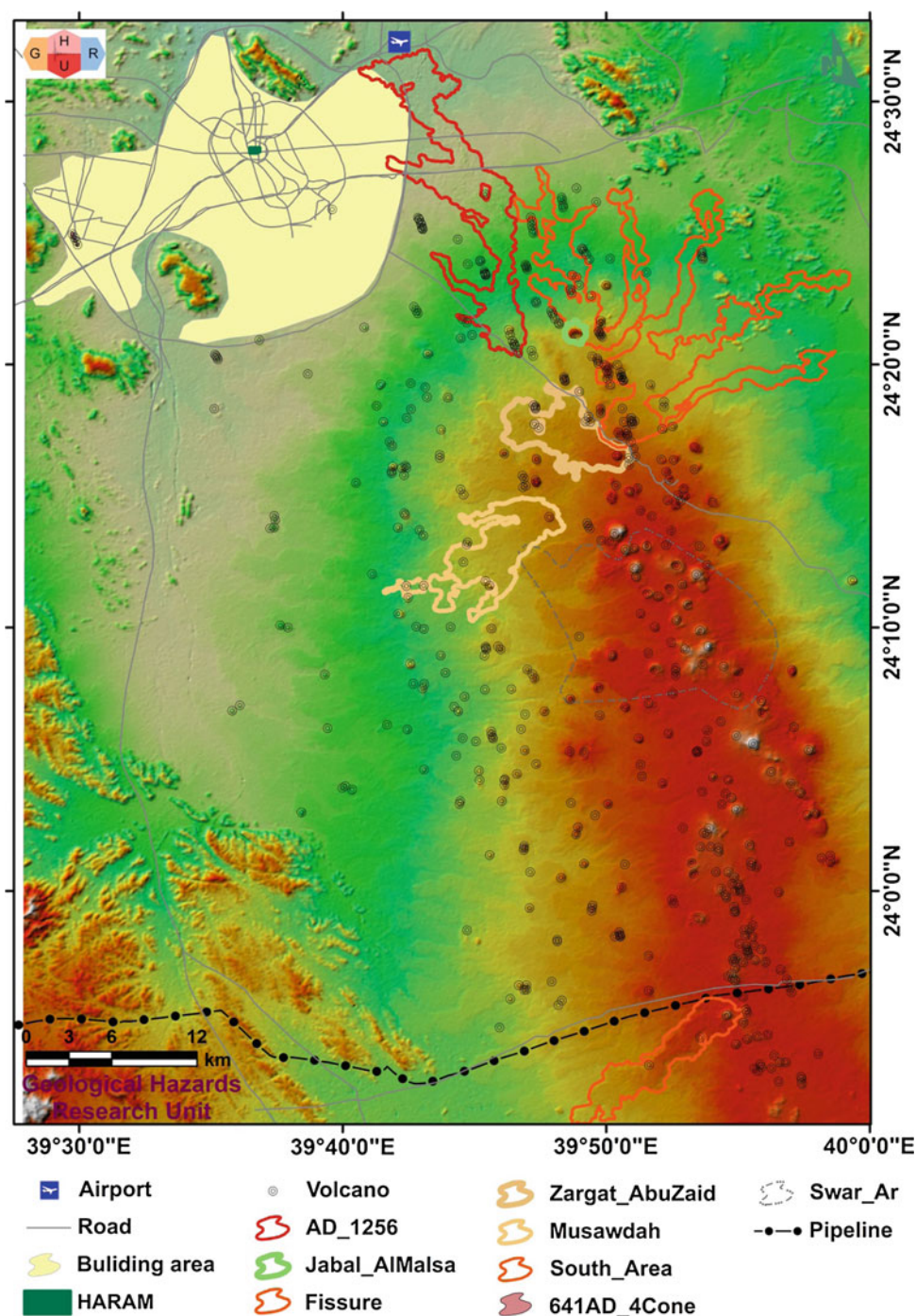
geological reasoning for them is not yet fully explained by detailed geological work and evidence.

2.2 Geological Setting of Harrat Rahat

The main subject of this book is to describe the geoheritage values of one of the largest harrats: Harrat Rahat. This volcanic region is located between the cities of Al Madinah, Jeddah and Makkah (Fig. 2.5) and, due to its good logistical position, its young volcanic landforms and numerous access points to its interior, it provides the perfect starting point to a develop volcanic geopark on the basis of defining its volcanic geoheritage sites.

The Rahat Volcanic Field defined by the Harrat Rahat consists of at least 500 individual volcanic edifices, many of them with typically complex edifice structures suggesting their prolonged volcanic activity (months to years) and common bimodal alkaline chemical nature (basaltic and trachytic) (Camp and Roobol 1989; Moufti et al. 2012a, b).

Fig. 2.4 Dorsal zone of the northern part of Harrat Rahat (Harrat al Madinah) shows high vent density and strong alignments of cones in small (edifice-scale) and large (field segment-scale) scales. Outlines of the youngest lava flows shown by thick coloured lines. The urban area with the haram in its centre is shown on the map in respect to their position to the volcanic field



The region located in the proximity of Al Madinah city is referred to as Harrat Al Madinah, and this region is extensively used as the main subject of this book. Due to logistical reasons, the dominant proportion of the detailed geological and stratigraphy information presented in this book comes from the Harrat Al Madinah region that then was extrapolated to the broader Harrat Rahat region.

The age of the volcanism of the Harrat Rahat was constrained dominantly by conventional K-Ar ages from whole

rock samples from various lava flows (Brown et al. 1989; Camp and Roobol 1989; Coleman and Gregory 1983), as well as ages derived recently from Ar-Ar incremental heating techniques on groundmass separates from different volcanic lava flows from Harrat Al Madinah in the northernmost part of the Harrat Rahat (Moufti et al. 2012a, b).

Early K-Ar age determinations allowed the volcanic rocks to be divided into three major stratigraphic units formally defined as: Shawahit basalt (~10–2.5 Ma), Hammah



Fig. 2.5 GoogleEarth satellite image of the region of northern Harrat Rahat commonly referred as Harrat al Madinah. Al Madinah city is in the top left corner of the view

basalt (~ 2.5 – 1.7 Ma), and Madinah basalt (~ 1.7 Ma—Recent) (Moufti et al. 2012a, b). Geological field mapping, aided by K–Ar and recent Ar–Ar dating, subdivided the Madinah basalt into the lower and upper Madinah basalts (Moufti et al. 2012a, b). From a lithostratigraphical perspective, the lower Madinah basalt comprises three stratigraphic (mapping) sequences labelled Qm1 to Qm3 (Qm1: ~ 1.7 – 1.2 Ma; Qm2: ~ 1.2 – 0.9 Ma; Qm3: ~ 0.9 – 0.6 Ma); while the upper Madinah basalt includes four sequences defined as Qm4 to Qm7 (Qm4: ~ 0.6 – 0.3 Ma; Qm5: ~ 0.3 Ma—4500 B.P.; Qm6: ~ 4500 – 1500 B.P.; Qm7: ~ 1500 B.P.—1256 A.D.) (Camp and Roobol 1989).

Intensive geoheritage studies were conducted in the region of the Harrat Al Madinah where a proposal to establish a geopark, called the Harrat Al Madinah Volcanic Geopark, was put forward recently (Moufti and Németh 2013). This proposed geopark is located in the area covered by eruptive products grouped into these various lithostratigraphic units and represents the youngest volcanic episode of the Rahat Volcanic Field (RVF). There is an apparent northward migration of volcanic events, at least in the last 10 Ma, which has been linked by some workers to the age progression of the lithospheric up-doming of the Western Arabian Swell and the northernmost extremities of the larger, regional up-doming of the Afro-Arabian Dome

(Almond 1986). This swell is inferred to be linked to the Ethiopian mantle plume, as its lobe reaches far north (Camp and Roobol 1992). Recent Ar–Ar dating has refined the previously proposed volcanic stratigraphy, providing evidence of far more evenly distributed volcanic events across the Harrat Rahat (Moufti et al. 2012a, b). Specifically, the longevity of volcanism in the northern section of the Harrat Rahat has been found to be greater than previously thought, suggesting less characteristic uni-directional migration of volcanic activity and challenging the idea of a fixed mantle plume over a steadily moving Arabian Plate as the source of the volcanism over the past 10 Ma (Moufti et al. 2012a, b). Instead, the NNW-trending distribution of the volcanic vents, i.e. nearly parallel to the Red Sea and its fault system, suggests that their origin is related to periodic extensional episodes along the reactivated Red Sea fault system (Moufti et al. 2012a, b).

The Harrat Rahat hosts numerous and diverse volcanic landforms that are well exposed and lack vegetation cover, offering a perfect site to see nearly unmodified volcanic landforms that are inferred to represent the syn-eruptive volcanic morphology of monogenetic volcanoes, as defined in (Kereszturi and Németh 2012). The most common volcanic landforms of the harrats in general are the basaltic scoria and lava spatter cones associated with pahoehoe and



Fig. 2.6 Lava domes are common in the Harrat Rahat and Khaybar. Many of them are silicic and they have a very high aesthetic value such as the “White Mountains” of Harrat Khaybar [25° 39' 28.36"N; 39° 58' 13.69"E]

a'a lava fields. Many of them show a complex eruptive history with multiple craters and nested crater rims. Lava domes of mugearite, benmoreite and trachyte compositions are particularly common in the centre of the Harrat Rahat (Camp and Roobol 1989) and Harrat Khaybar (Camp et al. 1991) and form a spectacular scene of circular (in map view) and steep sided lava domes, many of them crowned with a characteristic solidified spine a few tens of metres above the main lava dome body, as seen at the “*White Mountains*” of Harrat Khaybar (Moufti and Nemeth 2014) (Fig. 2.6). In addition to constructional volcanic landforms, there are few, but large in diameter and crater depth, volcanic craters commonly surrounded by tuff rings or steep sided pyroclastic constructs closely resembling tuff cones. Such volcanic landforms are most common in the Harrat Hutaymah (Fig. 2.7a) in the north, but there are also fine examples at the Harrat Rahat (Fig. 2.7b), Harat Kishb (Fig. 2.7c) and Harrat Khaybar (Fig. 2.7d). Large areas are covered by trachytic tephra blankets that are the result of pyroclastic surges, block-and-ash flows, and fallout and commonly form extensive coloured surface regions in many of the harrats (Fig. 2.8).

The proposed Harrat Al Madinah Volcanic Geopark (HAMVG) can provide a holistic geoeducation and geo-conservation program in a location where the diversity of intraplate dispersed volcanism in a long-lived volcanic field in an intra-continental region can be demonstrated. Volcanic fields can provide vital information on magma generation and ascent, on the style of volcanic eruptions and on the interaction between volcanism and the surrounding terrestrial basins in which the volcanoes erupted. This information can be related to the number and eruption styles of individual volcanoes (White 1991), the timing and frequency of eruptions (Conway et al. 1997, 1998; Kereszturi et al. 2011, 2013 Kiyosugi et al. 2010), the distribution pattern of volcanoes (Connor et al. 1992; Connor and Conway 2000; El Difrawy et al. 2013), and the relationship of the volcanoes to tectonic features, such as basins, faults, and rift zones (Connor 1987, 1990; Le Corvec et al. 2013a, b). Here we will present the major geoheritage values of the Harrat Al Madinah, followed by a comparative summary of geoheritage values of other harrats and demonstrate that the Saudi Arabian harrats can provide world-class sites to promote our understanding of one of the most common types of

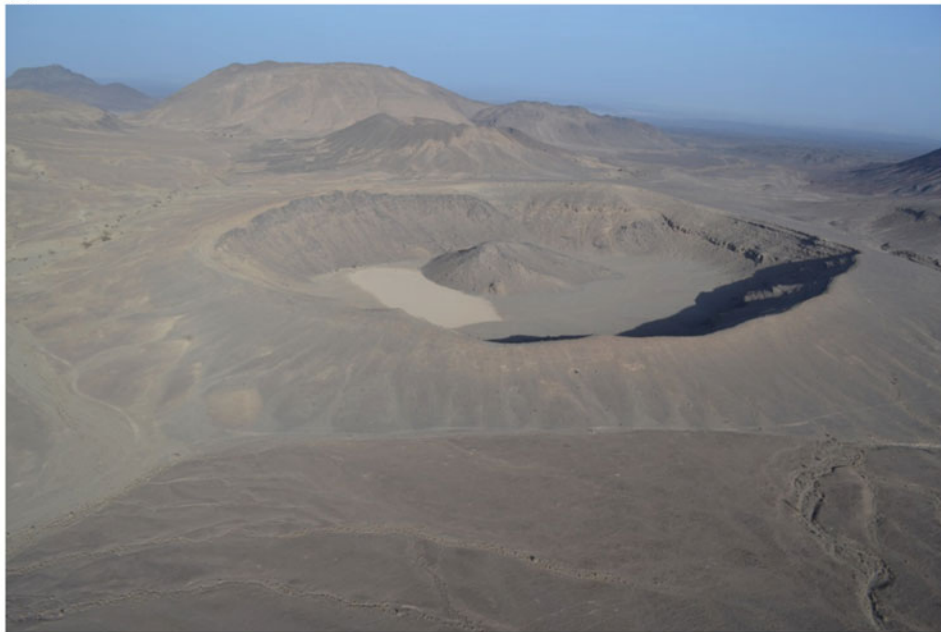
(a)



(b)



(c)



(d)



Fig. 2.7 Negative volcanic landforms such as explosion craters and maars are most common in Harrat Hutaymah (a 26° 59' 22.07"N; 42° 14' 24.17"E) but nice examples are known from the Harrat Kishb

(b 22° 53' 28.23"N; 41° 8' 31.08"E), Harrat Rahat (c 24° 11' 16.03"N; 39° 52' 24.37"E) and Harrat Khaybar (d 25° 39' 13.01"N; 39° 56' 16.35"E) as well



Fig. 2.8 Light coloured ash plains of silicic tephra clearly visible on a GoogleEarth satellite image of the Harat Khaybar. Top left corner of the map view is [25° 58' 9.94"N; 39° 24' 31.01"E]

volcanism on Earth and in the Solar System. In addition, the Saudi Arabian harrats together can form the geological basis to develop geoeeducational programs for both the general public and the research community.

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