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Research paper

The geology and geochronology of Al Wahbah maar crater, Harrat Kishb, Saudi Arabia

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ABSTRACT

Al Wahbah is a large (~2.2 km diameter, ~250 m deep) maar crater in the Harrat Kishb volcanic field in western Saudi Arabia. It cuts Proterozoic basement rocks and two Quaternary basanite lava flows, and is rimmed with an eroded tuff ring of debris from the phreatomagmatic explosion that generated the crater. A scoria cone on the northern wall of the crater was dissected by the explosion and exposes a dolerite plug that was intruded immediately prior to crater formation. The dolerite plug yields a $^{40}Ar/^{39}Ar$ age of 1.147 ± 0.004 Ma. This is the best possible estimate of the time Al Wahbah crater formed. It is a few tens of thousand years younger than the age of the lower and upper basalt flows, 1.261 ± 0.021 Ma and 1.178 ± 0.007 Ma respectively. A dolerite dyke exposed within the basement in the wall of the crater is dated at 1.886 ± 0.008 Ma. This is the most precise age so far determined for the initiation of basaltic volcanism of Harrat Kishb, and confirms that it is significantly younger than the other post-rift volcanic provinces in the region. This study provides constrains the timing of humid climatic conditions in the region and suggests that the Quaternary basaltic volcanism that stretches the length of the western side of the Arabian peninsula may prove to be useful for establishing palaeoclimatic conditions.

1. Introduction

The western margin of the Arabian peninsula is covered by approximately 180,000 km^2 of Cenozoic to Recent basalt flows and related volcanic rocks. The volcanic fields stretch from Yemen to northern Syria and are comprised dominantly of alkali olivine basalts and hawaiites that were erupted onto Neoproterozoic crust of the Arabian-Nubian shield. Volcanism started in the late Oligocene to early Miocene, slightly earlier than the main stage of continental extension that has subsequently produced the Red Sea Rift (Coleman et al., 1983; Camp and Roobol, 1989).

Several major volcanic fields (termed harrats) occur throughout the western part of the Kingdom of Saudi Arabia (KSA) (Fig. 1). A series of seminal studies of these lava fields was undertaken in the late 1980s and early 1990s by the Saudi Arabian Directorate General of Mineral Resources (Camp and Roobol, 1989, 1991, 1992; Camp et al., 1991, 1992; Roobol and Camp, 1991). The largest volcanic fields form a 600 km-long north–south oriented trend that may be related to an underlying rift zone within the Proterozoic basement (Fig. 1). This trend, called the Makkah–Madinah–Nafud (MMN) volcanic line (Camp et al., 1991), links Harrat Rahat in the south with Harrat Khaybar and Harrat Ithnayn in the north. The MNN line is a rift zone that has been extending at approximately 0.05 mm/year for the last 10 million years.

The volcanic fields are dominantly composed of mildly alkalic basalts (olivine basalt and alkali olivine basalt) and lesser amounts of fractionated products. Volcanism may have migrated northwards with time (Camp and Roobol, 1989; Camp et al., 1991). Harrat Kishb lies approximately 100 km east of the MMN line, and Harrats Kura, Raha, and 'Uwayrid are a similar distance to the west. These fields are dominated by basalts that are more strongly alkalic than those of the MMN line. The compositional contrast with the adjacent fields implies that they originate from melting at different P-T conditions than those from the MMN line. The MMN basalts were probably derived from greater degrees of partial melting, at shallower depths (Camp and Roobol, 1992).

The timing of volcanism is constrained from several K–Ar age determinations of basalts from all the main volcanic fields (Camp

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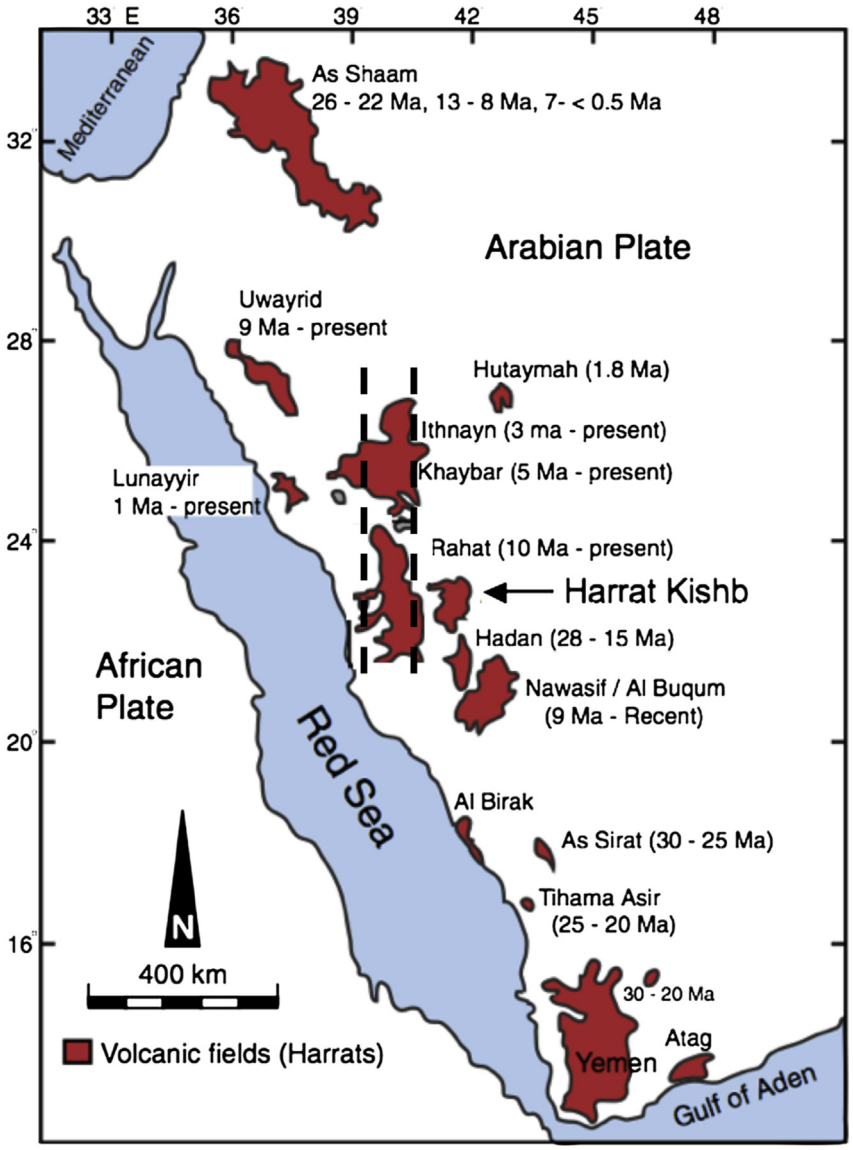

Fig. 1. Map showing the main Cenozoic volcanic fields, with ages, of the Arabian peninsula, including Harrat Kishb (modified from Moufti et al., 2011). Dashed lines define the Makkah-Madinah-Nafud line (see text for details).

and Roobol, 1989; Camp et al., 1991, 1992). In a compilation of published and unpublished basalt ages, Moufti et al. (2012) show a general increase in the number of basalts erupted over the past 10 million years. This implies that the eruption rate is increasing with time. This may be, in part, an artifact of sampling, and does not necessarily reflect the volume of basalt erupted, but it serves to underline that the region remains volcanically active. The most recent basalt eruption in KSA occurred in 1256 AD at the northern end of Harrat Rahat where a 23 km-long basaltic lava flow came within a few kilometers of the holy city of Al Madinah (Camp et al., 1987).

Climatic conditions across the Arabian peninsula have fluctuated between wet and dry extremes several times throughout the Quaternary and have had a profound effect on environment and the development of human populations in the region (e.g. Thompson, 2000). However, the existing chronological constraints on the climatic changes are poor. Precise determination of when key volcanic features formed has the potential to refine the climatic and environmental evolution of the region.

The harrats of KSA contain numerous tuff rings and maar craters that were produced by phreato–volcanic activity. They maars clearly formed at a time when surface water was more abundant than now, and the climate was considerably more humid. Al Wahbah crater in Harrat Kishb is the only maar that is not filled with erupted material, sediments derived from wall rocks and wind-borne dust. It is likely to be the youngest maar in the region, and certainly the most spectacular maar in the region (Fig. 2). It has a significant place in regional folklore, often called Makla Tameya. Here we present a new study of the geology of Al Wahbah maar crater, combined with the first high precision geochronology of the local volcanic rocks in order to place much-needed constraints on the palaeoclimate history of the region.

2. The geology of Al Wahbah crater

Al Wahbah crater (41°08′299″E, 22°54; 040″N) is located in western part of the Harrat Kishb volcanic field. Harrat Kishb is approximately 6000 km^2 and is the youngest of the volcanic fields