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The Al Wahbah Crater of Saudi Arabia and its geotourism potential

Krater Al Wahbah i jego potencjał geoturystyczny, Arabia Saudyjska

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Abstract: *The Al Wahbah Crater of Harrat Kishb in western Saudi Arabia is an impressive (2 km wide, 250 m deep) maar crater that formed explosively when rising magma encountered an aquifer during Pleistocene times. The crater and surrounding areas display several Quaternary and Recent volcanic features that are of interest to geoscientists, including a volcanoclastic ejecta layer, an elevated crater rim, scoria fields, an oasis with a natural mineral spring, an ephemeral playa lake on the crater floor, and a pre-existing volcano that was bisected by the explosion. The ejecta layer is overlain by a more recent basaltic lava flow that displays a typical pahoehoe surface. The site is an area of outstanding natural beauty, and new infrastructure is currently being developed to accommodate geotourism. The Al Wahbah Crater is a two-hour drive from the international airport in Taif and can be easily accessed via a major east-west highway and paved local roads.*

Keywords: *Quaternary; volcanism; Maar Crater; Red Sea; Saudi Arabia*

Treść: *Krater maaru Al Wahbah w Harrat Kishb w zachodniej Arabii Saudyjskiej (2 km szerokości, 250 m głębokości), uformował się podczas freatycznej erupcji w plejstocenie. W otoczeniu krateru znajdują się czwartorzędowe i współczesne formy wulkaniczne, interesujące dla studentów nauk o Ziemi. Są to między innymi: warstwa wulkanoklastyczna, podniesiona krawędź krateru, pola scoria, oaza z naturalnym źródłem mineralnym, efemeryczne jezioro playa na dnie krateru i wcześniej istniejący wulkan, który został przecięty przez eksplozję. Warstwa scorii i popiołu jest pokryta młodszym bazaltowym potokiem lawy, który pokryty jest klasyczną skorupą law pahoehoe. Teren charakteryzuje się wyjątkowo pięknym krajobrazem, a obecnie rozwijana jest nowa infrastruktura dla geoturystów. Krater Al Wahbah znajduje się dwie godziny jazdy od międzynarodowego lotniska w Taif i można do niego łatwo dojechać główną autostradą wschód-zachód i utwardzonymi drogami lokalnymi.*

Słowa kluczowe: *czwartorzęd; wulkanizm; maar; Morze Czerwone; Arabia Saudyjska*

Introduction

While most volcanic eruptions are associated with lava and volcanic ash emission, steam explosions are also common, which form features known as maar volcanos (Kereszturi & Németh, 2012; Moufti *et al*., 2013; Moufti & Németh, 2016; Németh & Kósik, 2020). The Al Wahbah Crater (alternate English transliterations: Al Wahba or Al Wa'bah; Arabic: فوهة بركان الوعبة) located in the Makkah Province of Saudi Arabia 200 km from the Red Sea, was formed by a massive steam explosion (Grainger, 1996). The crater is about 220 m in depth and 2 km in diameter (Daoudi *et al*., 2018).

The Al Wahbah Crater is stunning example of the Pleistocene volcanism that post-dates the rifting of the Red Sea (Bosworth *et al*., 2005; Ahmed *et al*., 2016; Murcia *et al*., 2017).

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Lava flows, columnar basalts, recent stratovolcanoes, cinder cones, as well as scoria and lapilli fields are readily observed nearby. The white volcanos Jebel Baydah and Jebel Abyad are located some 500 km to the north as part of the Harrat Khaybar (Fig. 1) (Kaminski *et al*., 2014; Moufti & Németh, 2014; Németh & Moufti, 2017).

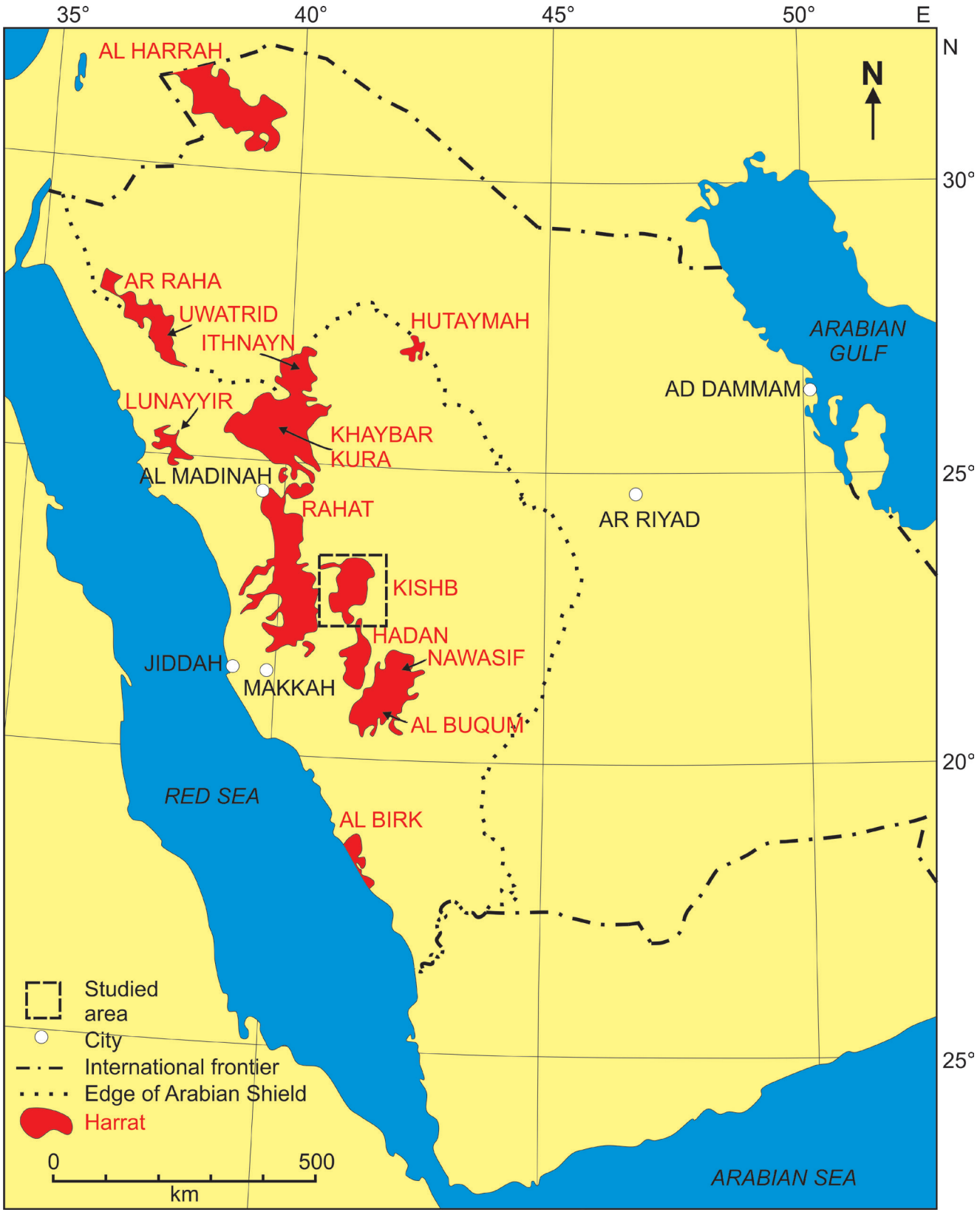

Fig. 1. Major Cenozoic lava fields of Saudi Arabia (after Pint, 2006)

Tourism in Saudi Arabia, including geotourism, is becoming more accessible, as the Kingdom has introduced tourist visas, and the country is now served by the Polish national airline, LOT Polish Airlines. A visitors' center with restroom facilities has been built at the rim of the Al Wahbah Crater. Nowadays, three- to seven-day cruises of the Red Sea are available from the port of Jeddah. In addition to the Jebel Abyad white volcano, the Paleozoic geological features in Qassim Province have been previously reported as potential geotourism destinations (Kaminski *et al*., 2019). The purpose of this paper is to provide the geological background information on another potential geotourist destination – the Al Wahbah Crater of Makkah Province in western Saudi Arabia.

The Harrat Kishb volcanic cluster

Saudi Arabia has over 80,000 km^2 of lava fields (Camp *et al*., 1992; Pint, 2006), which are locally known as "harrats". Between forty and thirty million years ago, continental drift processes began to separate Africa from the Arabian Peninsula, because of the thermal doming effect of the Afar hotspot (Ebinger & Sleep, 1998). Before the Red Sea finally formed, many actual and would-be rifts attempted to open, spawning hundreds of volcanoes. Some of those splits in the Earth's crust were small and some much larger, such as Africa's Great Rift Valley. In the area of the northern Red Sea, hot mantle material from the Afar Hotspot is offset in an eastward direction and extends beneath western Saudi Arabia (Chang *et al*., 2011). This explains the recent volcanism in many areas of the western Arabian Shield, but the specific cause of volcanism in the area is still under discussion (Murcia *et al*., 2017).

Dozens of spectacular volcanic peaks are the legacy being left to western Saudi Arabia by this ongoing continent sculpting process. The volcanoes are distributed in irregular clusters known as "harrats" (Fig. 1). These are surrounded for kilometers around by their lava flows and scoria fields. One of them, Harrat Kishb is located further east than most harrats, and contains younger geological features, with 180 volcanoes that are less than two million years old (Camp *et al*., 1992). They are scattered across a rectangular-shaped area spanning 60 by 90 km, a two-hour drive from the city of Taif (Fig. 2).

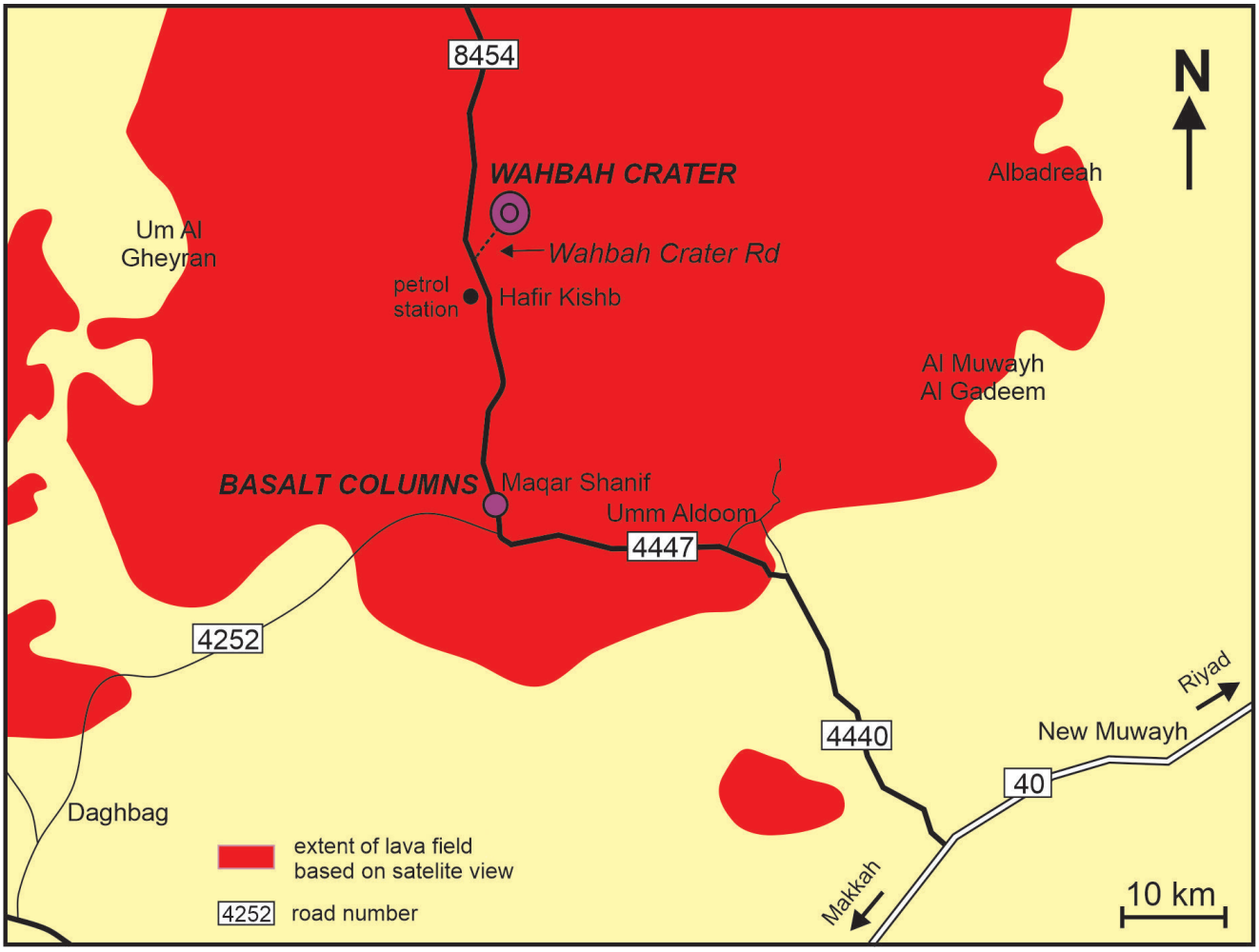

Fig. 2. Location of the Al Wahbah Crater in Harrat Kishb

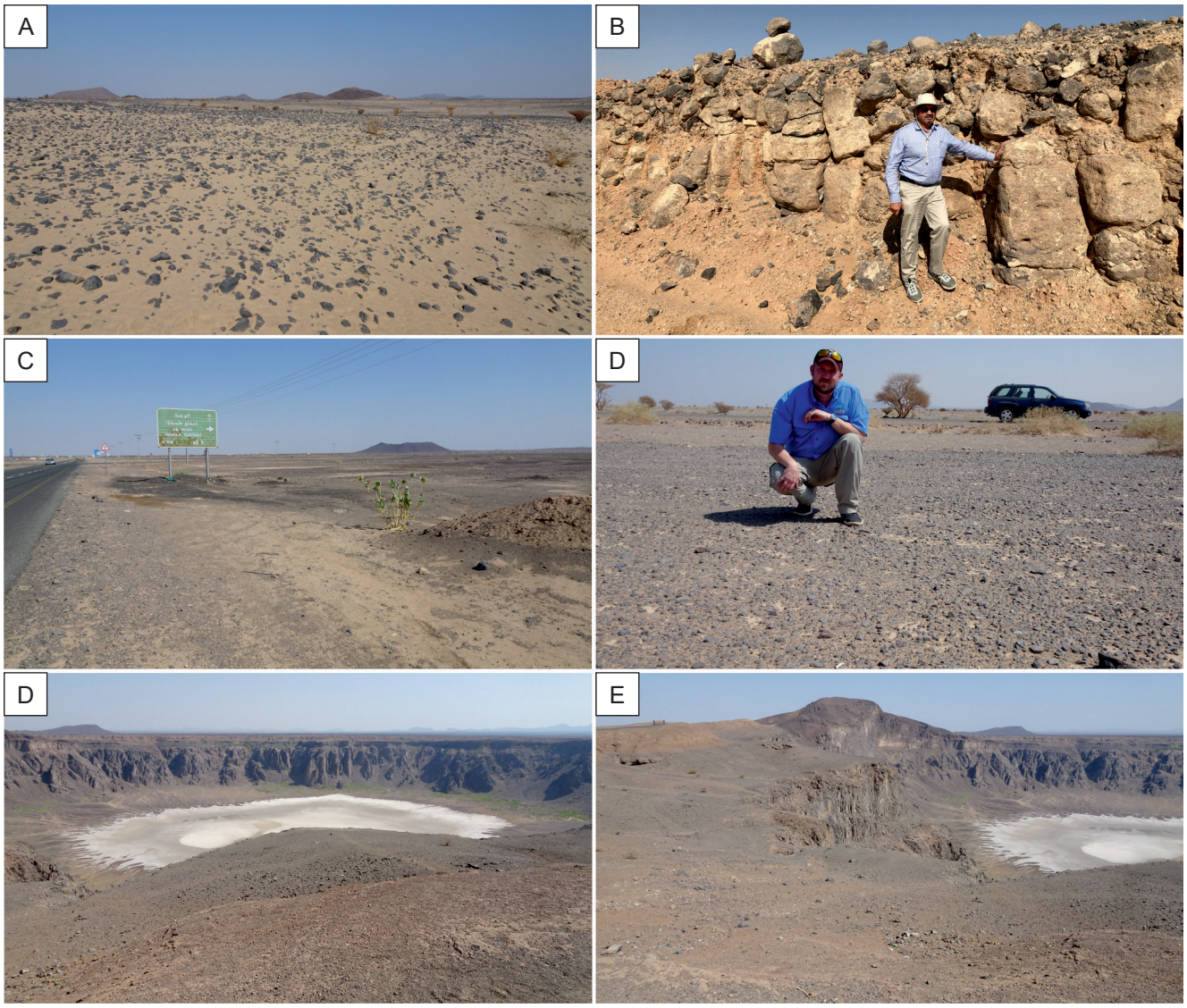

Fig. 3. Scoria field in the southern part of Harrat Kishb. Several stratovolcanoes are in the distance (A). Basalt columns exposed in a road-cut along Road 8454 (B). The turnoff onto the Wahbah Crater Road from national road 8454 (C). Lapilli field near the entrance to Wahbah Crater Road (D). View of Wahbah Crater from the viewing platform on the south rim (E). The bisected pre-existing volcano on the west rim of the crater (F) (photos A, C–F by M.A. Kaminski, photo B by T.F. Garrison)

Entering the harrat from the south, we first observe fields of basaltic scoria and some cinder cones and small stratovolcanoes in the distance (Fig. 3A). The road mounts a small hill, and in the roadcuts on either side weathered columns of basalt are exposed (Fig. 3B). Basalt forms regular six-sided columns when it cools – some spectacular textbook examples include the Devil's Causeway in Scotland. The road continues to a small town that is host to a petrol station where it is possible to purchase cold drinks and snacks for the onward journey to the crater. The turn-off to the Wahba Crater Road is marked by a green sign (Fig. 3C). The road leads past fields covered with lapilli (Fig. 3D), small pebbles of vesicular basalt which are like the "volcanic popcorn" thrown out of cinder cones.

The Al Wahbah Crater

This crater is the best-known volcanic feature in Harrat Kishb. It is considered one of the most spectacular natural wonders of Saudi Arabia, and a large photo of the crater hangs in the Geology Hall of the Saudi National Museum in Riyadh. The Al Wahbah Crater (Maqla Tamia in Arabic) is 254 km from Taif on the western edge of the Harrat Kishb basalt plateau. The area is covered with volcanic features including many volcanic cones and lava flows (Figs. 3–6). The crater is about 2 km in diameter and ~235 m deep and based on $^{40}Ar/^{39}Ar$ dating of a volcanic plug exposed in the crater wall is believed to have formed some 1.47 million years ago (Abdel Wahab *et al*., 2014). The bottom of the crater holds

an ephemeral playa lake covered with white salt consisting of sodium phosphate crystals (Fig. 3E).

The stage for Al Wahbah Crater formation was set some 300,000 years earlier when a volcano erupted. This volcano spread at least two sheets of lava with a total thickness of 50 m across the landscape. Below that was a dense, hard rock layer (diorite) over 160 m thick.

When molten rock began rising from deep within the Earth to form yet another volcano an interesting hydrovolcanic event took place. The magma encountered an underground aquifer, heating it far beyond water's normal boiling temperature. Steam seeping out of the ground normally relieves such pressure. However, the impermeable rock and old lava layers above locked the steam in. As the pressure caused by the steam built up, it eventually exceeded the confining pressure, and one day the magma chamber exploded.

It is difficult to comprehend the scale of the Al Wahbah blast. The crater size suggests that roughly two billion tons of rock were blown skyward in a powerful volcanic eruption. Accompanying the explosion, vast amounts of volcanic blocks and volcanic ash were generated, much of deposited from a horizontally moving pyroclastic density current.

A sobering reminder of that violent day can be seen perched precariously on Al Wahbah's northwest rim. One side of an older volcano has been obliterated, neatly bisecting it (Fig. 3F). This is likely the same volcano whose hardened lava flows caused steam pressure to build up during the hydrovolcanic event.

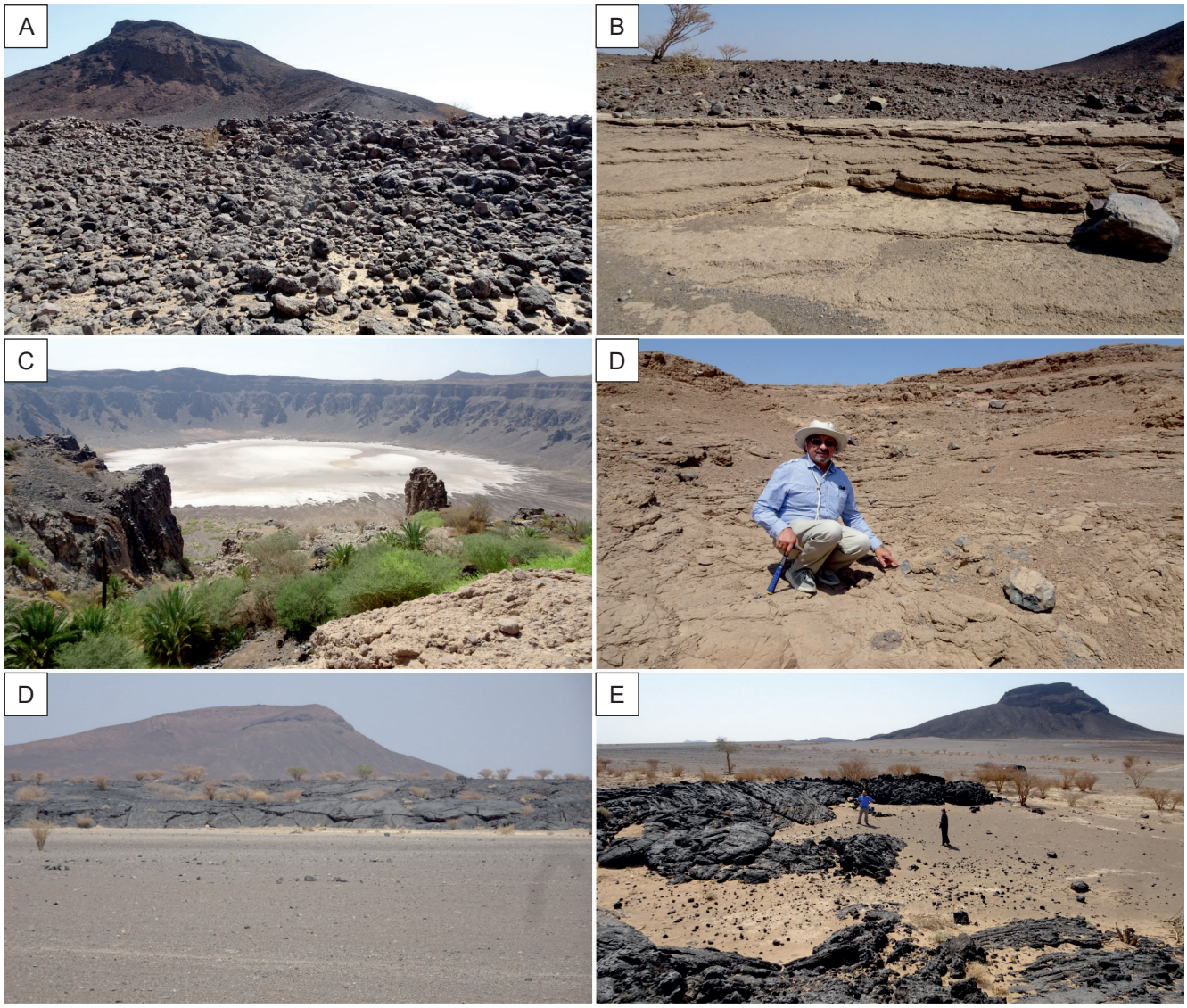

Fig. 4. Scoria field south of the dissected volcano (A). Ejecta layer from the explosive event, exposed in a small wadi south of the bisected volcano (B). View of the crater from the west rim, with the date palm oasis in the foreground (C). Volcanic blocks contained within the ejecta layer, west rim (D). Recent lava tube west of the crater (E). Surface of the lava tube showing pahoehoe texture, with the bisected volcano in the background (F) (photos A–C, E, F by M.A. Kaminski, photo D by T.F. Garrison)

Fig. 5. Calcareous tufa rock containing volcanic clasts (photo by M.A. Kaminski)

The cross-sectioned remnant provides a unique chance to see the internal structure of a volcano. Even the subterranean channel through which magma flowed upwards lies exposed to view. Trails wind up to the 134-meter summit of the surviving half cone. From there, visitors have a spectacular afternoon view of Al Wahbah Crater and the surrounding countryside.

An interesting hike is to the crater floor from the north rim of the crater. A single-lane desert track leads from the visitor's centre car park clockwise around the crater rim. The track bifurcates along the way after crossing a scoria field (Fig. 4A) and a wadi where the eject layer is nicely exposed (Fig. 4B). Keep to the right and proceed to a parking place near the remains of a building. Tracks on the north side of the crater lead down to a wide ledge housing an oasis planted with date palms (Fig. 4C). The trail initially cuts through the ejecta layer, which at this locality contains large angular volcanic blocks (Fig. 4D). A steeper trail down a gully cut in the crater wall gives access from the oasis to the floor of the crater. Along the way a curious rock type can be observed – this is a white carbonate rock containing angular volcanic clasts (Fig. 5). The clasts are rimmed with white calcite. This is a tufa rock formed from the deposition of dissolved minerals carried by the spring water that flows downhill from the oasis.

It takes about 30–90 min to descend to the bottom of the crater. The track is steep in places and can be difficult, as it is strewn with loose rocks. The risk of accident is ever present. Hikers are advised to pack sufficient drinking water and to carefully mark the trail's end before reaching the crater floor. Currently there is restriction to go down now as two deaths happened recently due to the high temperature (+50°C) on the crater floor. Al Wahbah's salt-covered floor is immense. The many gullies extending down the north rim all look the same from the bottom of the crater, but most end blindly at the base of sheer cliffs. The return climb takes approx. 50–120 min and is physically demanding. There is only one safe route to ascend back to the oasis.

The Jebel Hil lava flow

One nearby feature is a younger, jet-black lava sheet, the surface of which shows a pahoehoe texture (Figs. 4E, F, 6A). The lava flowed from Jabal Hil, which is located 22 km to the east. Along part of its route the lava flow consists of a lava tube up to 20 m wide and up to 5 m in height (Pint, 2006). The lava tube contains numerous collapse features. The lava came dangerously close to the crater, but fortunately Al Wahbah's raised rim perimeter is slightly uplifted compared with the surrounding topography. Otherwise, the Jebel Hil lava might have entered and completely filled the giant crater.

Olivine

A substantial amount of olivine crystals is observed in the ejecta field surrounding the Al Wahbah Crater. A few green crystals approach gem quality, which is more commonly known as peridot. The size of the crystals ranged up to the size of a pea. A good place to search for the crystals is on the surface of the brown eject layer in front of the car park (Fig. 6B).

Olivine forms under high temperature conditions located deep underground. On the surface, olivine weathers easily. It is unique among semiprecious and precious gemstones in that it is one of two gemstones that forms in the Earth's mantle, the other being diamond. The olivine at Al Wahbah Crater is a Mg-rich end member of the forsterite-fayalite solid solution series and is mined locally from scree and wadi deposits (Surour, 2018).

Fig. 6. Collapsed section of the lava tube (A). Searching for peridot crystals on the ejecta layer near the entrance to the car park (B). The new viewing platform and visitors centre on the south rim of the crater (C). View of the new visitor's center (D) (photos by M.A. Kaminski)

Geotourism potential

The Al Wahbah Crater and surrounding volcanic field in Harrat Kishb provide textbook examples of volcanic features that are described in popular introductory geology textbooks. A field excursion to Al Wahbah would serve as an excellent introduction to the subject of volcanology for geology students. The crater is a three-hour drive from the airport in Taif (and about four hours from Jeddah), and therefore the site can be visited in a single day.

The recent years has seen increased tourism to the site, and paved roads and signs have been put in place to expedite travel. Most recently, a paved car park and a small visitor's centre with a museum and viewing platforms have been constructed on the south rim of the crater (Fig. 6C, D). The visitor is advised to bring sufficient drinking water and a packed lunch, as such items might not be available on site. There is a petrol station with a small shop in the village (Hafir Kishb) several kilometres before the turn-off to the crater where cold drinks and snacks can be purchased, but there are no restaurants in the village. The closest accommodation of international standard can be found in the city of Taif, which hosts a number of 4- and 5-star hotels.

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