Plio/Pleistocene Flood Basalt Related Scoria and Spatter Cones, Rootless Lava Flows, and Pit Craters, Al Haruj Al Abiyad, Libya

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ABSTRACT: *The Al Haruj al Abiyad (HA) is part of an alkaline basaltic intracontinental flood basalt field in central Libya (~6 to 0.4 Ma). The study area of 1400 km[2] contains ~120 vents, comprising shield volcanoes, spatter and scoria cones, formed on a lava plateau. Eighty-four vents fall into an ESE–WNW-trending, ~60-km long, <10-km wide alignment similar to the orientation of the Tibesti Line. Short alignments of 3 to 5 vents (<3 km) suggest eruptions through fissures. Most of the shield volcanoes had an eruptive phase characterized by gas exsolution, magma disruption and Hawaiian-style lava fountaining indicated by the presence of thin welded agglutinate. On the flank of the shield volcanoes lava channels are inferred to empty the shallow magma chambers and/or lava lakes, causing subsidence and pit crater formation often with non-uniform collapses. Pyroclastic deposits are massive to poorly bedded, have abundant flattened, deformed spatter, and low proportion of dense coherent lava fragments supported by fine matrix or they are matrix-poor. Spatial relationships between lithofacies, steep dips, and rapid changes in thickness and grain size of the beds allow the interpretation that the deposits are a part of eroded remnants of Hawaiian and Strombolian cones. The lack of accidental lithic rocks and chilling of juvenile fragments indicate that the volcanism of HA occurred in an area of minimum water availability.*

KEY WORDS: *flood basalt, scoria, spatter, clastogenic lava, aa lava, pahoehoe, lava fountain.*

Introduction

The Al Haruj intracontinental alkaline flood basalt field is the largest of four Tertiary to Recent volcanic provinces in Libya (Busrewil and Suwesi 1993) (Fig. 1). Al Haruj al Abiyad (HA) falls within the Al Haruj basalt field; it is located southwest of the main and youngest region of the field which is called Al Haruj al Aswad. The extensive lava plateaus cover an area of at least 16,000 km[2] in Al Haruj al Aswad, preserved in variable eroded aa lava fields and subordinate pahoehoe lava flows (Busrewil and Suwesi 1993). The entire Al Haruj totals 45,000 km[2] in volcanic area, thus it is significantly greater than the Tibesti volcanic region (Klitzsch 1968, Vincent 1970). At HA, also the lava fields are the volumetrically most important features. The age of the volcanic area has been determined by combined paleomagnetic and K/Ar whole-rock radiometric age dating methods, giving ages between 6.0 and 0.4 Ma (Ade-Hall et al. 1974, Busrewil and Suwesi 1993). Most of the well-exposed lava flows at Al Haruj al Aswad are younger than 2.2 Ma (Busrewil and Suwesi 1993). The preliminary geochemical studies indicate that most volcanic rocks belong to the alkaline olivine basaltic suite and range in composition from basalts to hawaiite; however, a systematic compositional variation cannot be drawn (Busrewil and Wadsworth 1980b, Woller 1984). In this respect, Al Haruj volcanic province does not differ significantly from other large-volume Tertiary volcanic suites in Libya (Busrewil 1974, Busrewil and Wadsworth 1980a, 1983, Woller 1978, 1984, Woller and Fediuk 1980, Vesely 1985). The origin of the volcanism is still not clear. The region is a typical intraplate setting (term after Walker 1993), located far from plate boundaries, but counts among the volcano-capped swells randomly distributed on the African plate and inferred to be a result of hot spot activity (Burke 1996, 2001). Many simila-

rities can be found with other intraplate alkaline basaltic fields in northern Africa, such as the Meidob volcanic field in NW Sudan (Franz et al. 1997). However, one striking difference is the complete lack of evolved eruptive products (e.g., phonolite) at the HA. In this short note, preliminary results are presented of the volcanological features identified at HA during the 1:250,000-scale mapping project performed by the MÁFI-Er-Petro-IRC research group.

Vent distribution

The study area consists of at least 120 vents over 1400 km[2]. These are predominantly scuttulum-type shield volcanoes, spatter cones and scoria cones, formed on an extensive lava plateau with aa and subordinate pahoehoe lava fields, strongly modified by erosion. The vent distribution has been characterized by manual cluster analysis on a rectangular grid with 1-km spacing and 2.5-km search radius (Fig. 1). Eighty-four out of 120 vents fall within an ESE–WNW-trending, ~60 km long and <10 km wide alignment. This orientation is similar to the orientation of the Tibesti Line that is considered to be a major tectonic lineament, traceable for a length exceeding 6000 km in northern Africa (Guiraud et al. 2000). The rest of the vent cluster in a shorter, more-or-less east–west-trending alignment 20 km in length and <10 km in width. Four vents lie beyond both alignments. In both vent chains, shorter alignments formed by 3 to 5 vents <3 km long were identified, suggesting eruptions through fissures. The elongation of individual vent zones as well as the elongation of the individual vents (e.g., axis of ellipsoid of a volcano) are in good agreement with the general vent alignment orientation,

suggesting a strong structural control on the location of volcanic vents similarly to other intracontinental volcanic fields such as Yucca Mountain, Nevada (Connor et al. 2000).

Shield volcanoes and pit craters

Shield volcanoes at HA are medium-sized (Fig. 2) (<10 km in diameter, and <100 m in relative elevation) and composed of spongy, often twisted, fluidal, micro-pahoehoe lava in the top section, and dense, aa and/or blocky coherent lava in the flow base. Thicknesses of individual flows vary between few dm to

a metre size, with a steady thickness on a km-scale. Vesicular flow tops and bases are prominent in a cm-scale thickness with elongated vesicles (cm-scale). Most of the shield volcanoes showed eruptive phase culminating by gas exsolution, magma disruption and consequently Hawaiian-style lava fountaining indicated by the presence of thin, densely welded agglutinate and/or spatter deposits preserved around the strongly eroded crater zone of the volcanoes. On the flank of the shield volcanoes, wide (tens of metres) coherent lava channels are interpreted to have emptied shallow magma chambers and/or lava lakes, causing subsidence and pit crater formation. Wide, crater-like
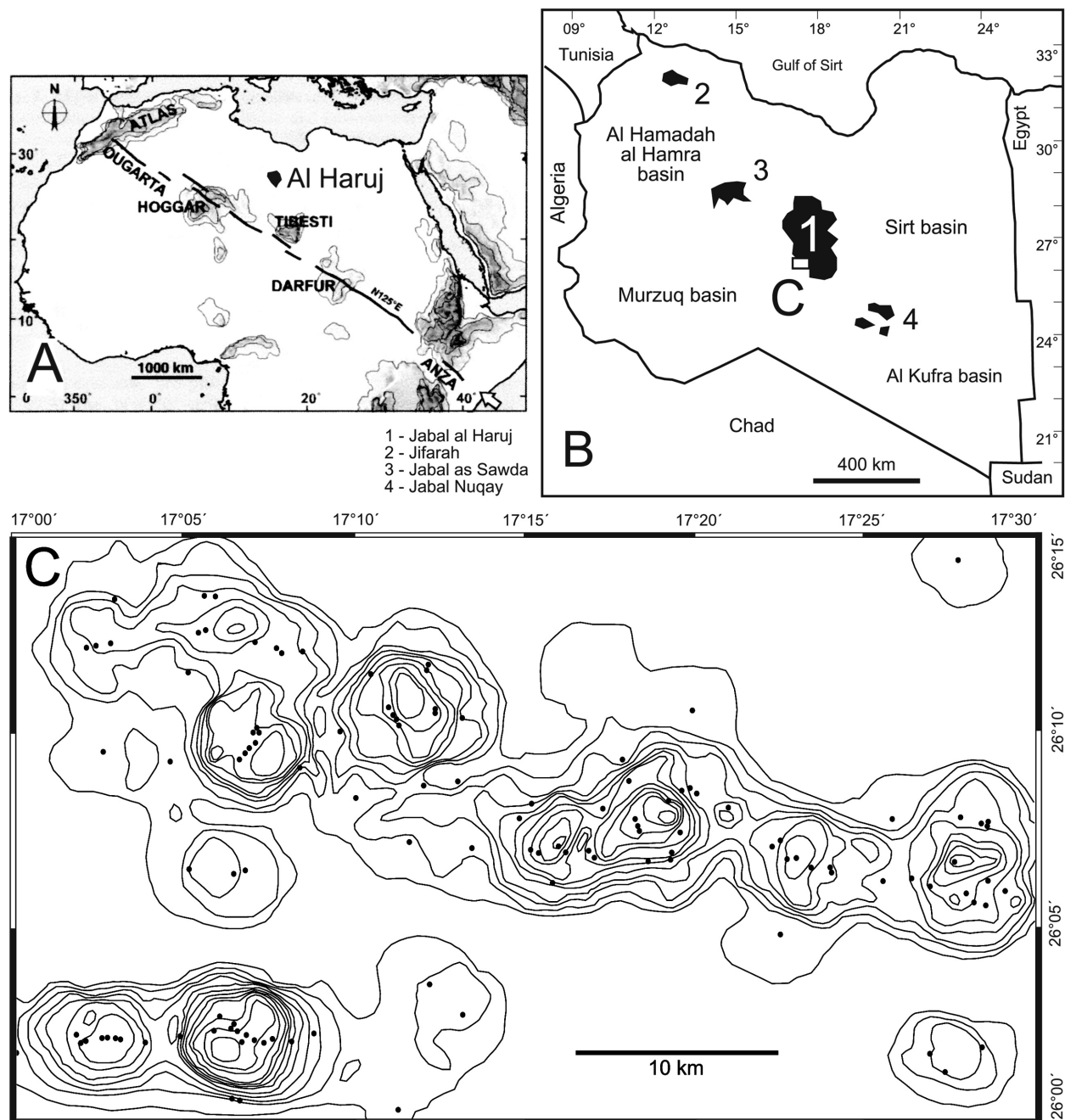

1 - Jabal al Haruj
2 - Jifarah
3 - Jabal as Sawda
4 - Jabal Nuqay

Fig. 1. Overview maps of the study area. A) Tibesti Line in northern Africa after Guiraud et al., 2000. Shaded areas are elevated parts of the region., B) overview map of Libya showing Tertiary alkaline basaltic volcanic fields, C) vent density contour map featuring two pronounced vent alignments characteristic of the southern part of the Al Haruj al Abiyad volcanic field.
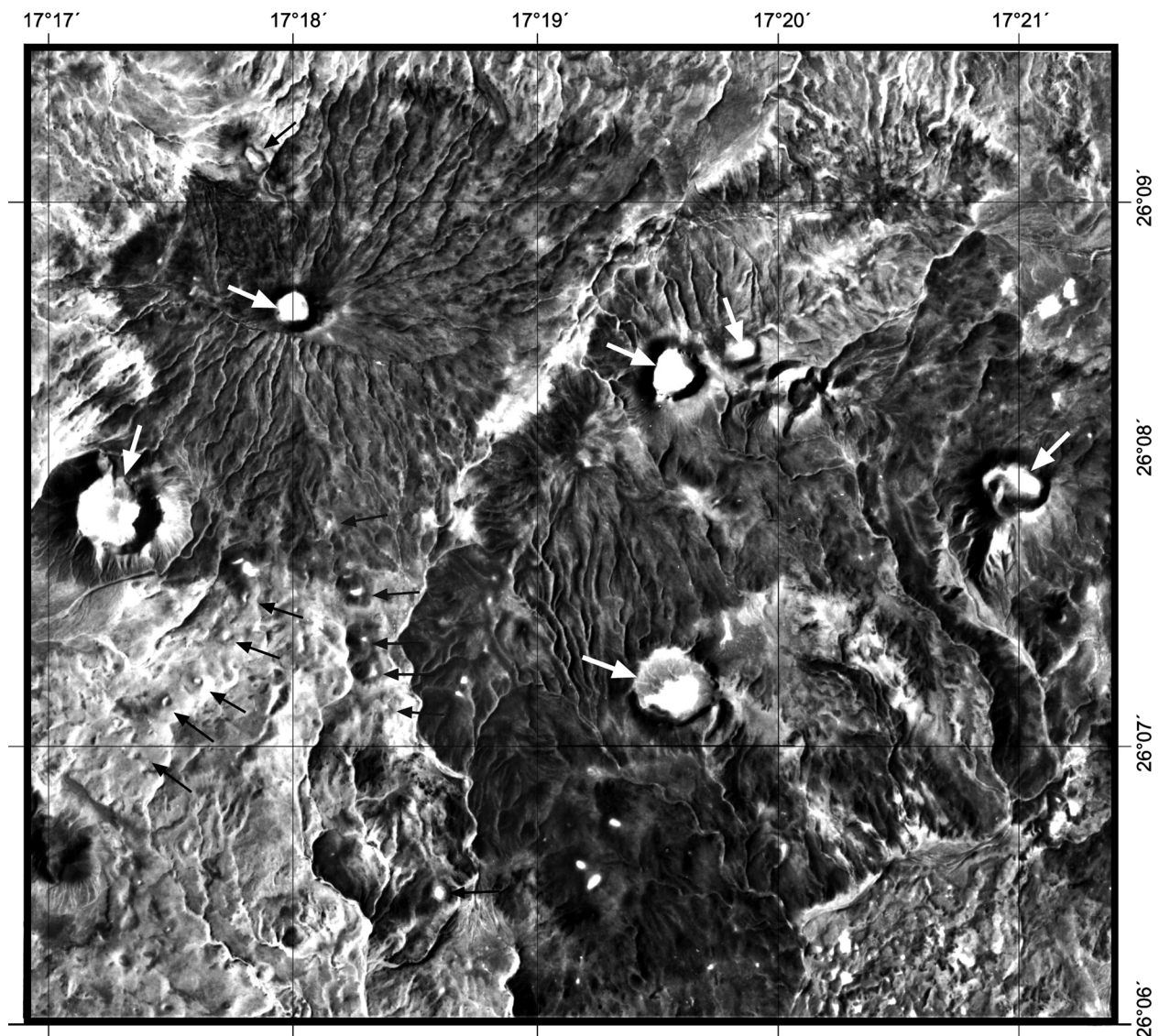
Fig. 2. A photomosaic (by KLM at Industrial Research Centre, Tripoli) of the central part of the volcanic chain exhibiting large shield volcanoes with wide pit craters on their tops (white arrows) and smaller pit craters on their flanks (black arrows). High volcanic cones with wide and deep craters surrounded by scoriaceous, lava spatter-rich tephra and agglutinate are inferred to be the result of violent Strombolian and Hawaiian-style explosive eruptions accompanied by crater floor subsidence and pit crater formation.

depressions on top of flat, wide volcanoes, which predominantly consist of dm-scale thick lava flows, are interpreted as pit craters (Fig. 2). The lack of, or the presence of only a thin veneer of, fine-grained pyroclastic deposits and/or cone-shaped pyroclastic piles around these craters as well as the lack of evidence to support disruption of country rocks indicate that the major cause of the formation of these craters was rather passive gravitational subsidence than energetic explosive disruption-triggered subsidence (e.g., hydroexplosion). Slickenslides on lava surfaces in the inner crater wall are characteristic, however, they could be not always identified. Pit craters are circular in plan view (Fig. 2) with steep walls exposing alternating lava flows (dm-scale thick flow units). These lava flows show clastic, rheomorphic texture

in a mm-to-cm-scale and are thus inferred to be clastogenic. Diameter of pit craters ranges from few metres to ~1 km whereas the depths range from few metres to ~100 m. Multiple platforms in pit craters suggest non-uniform collapses. They typically develop with initially steep, locally overhanging walls. During wall collapse, the craters got filled with talus and their shape changed to inverted elliptical cones. Two types of pit craters were distinguished; a) pit craters associated with the summit region of a broad shield volcano, and b) pit craters developed on the flank of a shield volcano and/or on lava fields between larger volcanic edifices. Pit craters on the summit zone of shield volcanoes are characteristically larger than pit craters on the flank zones having only few metres in diameter (Fig. 2). Based on our observations,

mechanical considerations, and other data from existing literature we infer that pit craters form by piston-like collapse over broad magma bodies and voids in summit regions (Cruikshank and Wood 1971, Roche et al. 2001) or by stoping over an underlying large-aperture rift zone fracture in flank regions (Okubo and Martel 1998). This interpretation is supported by the common association of Hawaiian spatter deposits, by the presence of lava lakes, and coherent lava tube remnants in the summit pit craters in contrast to the flank zone craters having none of these features indicating passive formation of the depression, probably over a fissure fracture (Okubo and Martel 1998).

Scoria and spatter cones

Pyroclastic deposits of HA are massive to poorly stratified, with abundant flattened and deformed spatter and a low proportion of dense coherent lava fragments. They are supported by matrix of fine lapilli or are matrix-poor. At least three lithofacies are proposed, based on the size and shape of clasts and inferred degree of welding: (1) non-flattened scoria deposits with angular, moderately vesicular, red to brown lapilli are present in beds at the base of the cones; (2) mixed scoria deposits, rich in lapilli-sized fragments of twisted, fluidally shaped lava spatters, located in the middle flank zones of the cones; and (3) densely welded scoria deposits, often associated with clastogenic lava tongues in the crater rim zones. Spatial relationships between lithofacies, steep primary dips, and rapid changes in thickness and grain size of the beds support the interpretation that the deposits are the eroded remnants of Hawaiian and Strombolian cones (Vespermann and Schmincke 2000). Different degrees of welding at each vent reflect local variation in accumulation rates and clast temperature on deposition dependent on magma residence time in the vent, distance from vent to point of deposition, and clast size (Calderone et al. 1990, Johnston et al. 1997). Pyroclastic deposits of the studied cones of HA are interpreted to have been deposited by fall-out, and by rolling and local grain-avalanches down on a steep cone slope. Inversely graded lapilli beds in the middle and lower flank of the volcanoes are common features in growing steep scoria cones (Houghton and Schmincke 1995, Wilson and Houghton 2000). Fluidally shaped lapilli are dominant in most of the pyroclastic beds, suggesting that the eruptions were rather derived from a near-continuous tephra uprush and jetting during violent degassing of near-surface magma, instead of discrete bubble outburst in the upper zone of the magma-filled conduit (Head and Wilson 1989). Pyroclastic breccias and welded agglomerates are often rich in dense coherent lava bombs and blocks in the inner crater wall or near the outer crater rim. They are rotational, cylindrical, or spindle-shaped, indicating ballistic transportation of magma fragments propelled out from the degassed melts residing in the vent zone (Vergniolle 1996). The spatters are (i) flat, highly vesicular and (ii) irregular in shape, twisted, rolled and semi-rounded, both parallel with steep bedding surface. The twisted lava spatters are inferred to have rolled down-slope on the steep cone flank. In lapilli tuffs of large (~200 m) scoria cones, gravel-like (cm-scale), strongly abraded peridotite lherzolite nodules were found, suggesting continuous and

energetic upflow of magma from mantle source in the volcanic conduit (Spera 1984). The agglutinates and spatter-rich tephras suggest that lava fountains erupted continuously reaching ~1 km elevation (Wolff and Sumner 2000). The scarcity of accidental lithic rocks derived from pre-volcanic substrates and the lack of evidence of chilling of juvenile fragments due to magma-water interaction (Heiken 1972, Lorenz and Zimanowski 1984) indicate that the volcanism of HA occurred in terrestrial environment in an area of minimum water availability. However, there is a controversial problem delineated at HA: large (~200 m) scoria cones with wide (~400 m) and deep (~100 m) craters (Fig. 2) are surrounded by scoriaceous tephra often containing peridotite lherzolite nodules. These are more characteristic for deposits developed due to magma/water interaction generating phreatomagmatic explosions. In contrast to this morphological evidence, there are no fine-grained tephra beds rich in angular and chilled juvenile ash, which supports phreatomagmatic origin. In fact, they may have been eroded or masked and/or mixed with desert sand. However, fine-grained, extensively dispersed tephra beds with angular basaltic lapilli and ash units surround a 4 km wide, up to 100 m deep depression south of the HA main volcanic fields – which is called Waw-an-Namus – inferred to be developed during an initial phreatomagmatic explosive eruption followed by crater floor subsidence (Busrewil and Wadsworth 1983). The studied HA craters surrounded by thick and welded spatter deposits suggest that explosive Strombolian-type activity evolved to the paroxysmal phase with the formation of high lava fountains similarly to Vesuvius 1906 violent fire fountaining (Mastrolorenzo et al. 1993).

Conclusion

The study area of Al Haruj al Abiyad is considered to be part of an intraplate alkaline basaltic flood lava field. On the basis of vent distribution study as well as field evidence of small-scale geometry of vents, it has been suggested that the eruption of HA occurred through fissures in a similar way as in other well-documented fissure eruptions such as the Krafla (Rossi 1997, Harris et al. 2000) or Laki (Thordarson and Self 1993), both in Iceland. The studied fissure system at HA is more than twice as long than the fissure of the most powerful fissure eruptions in historic time (Laki ~ 27 km). The ~ 60 km vent chain at HA is composed of an almost continuous row of vents consisting of scoria cones, spatter cones, modified to a variable degree by erosion. Tuff ring characteristics typical for phreatomagmatic eruptions were not identified, however, the origin of wide craters needs to be studied in more detail in the future. It is inferred, at this stage of research, that the HA developed in an area with limited water availability. Lava fountaining was dominated by fissure-style eruption of more than 100 vents of the HA.

Acknowledgements

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