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THE PYROCLASTIC ROCKS AND ASSOCIATED MAFIC DYKES AND PLUGS, NW LIBYA

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A B S T R A C T

Repeated highly explosive and effusive processes in north of the Town of Ghāryān and Qūmātāh area, NW Tripolitania blasted through Mesozoic country rocks, generated numerous small sizes individual isolated exposures of areally limited explosively fragmented aggregates. They are represented by near-surface vent-filling fragmentary rocks identifiable along roadcuts, but most commonly seen along wādi channels. They are comprised of a mixture of tuff, lapilli tuff, comminuted sediments and minor igneous and sedimentary rock fragments. A period of hydromagmatism, resulted from the interaction of ascending magma with externary-derived water at shallow depth, appears to characterize early stage of mafic volcanism. When no water interacted with the erupting magma, low viscosity alkalic basaltic magma was emplaced after short hiatuses, forming multiple discordant narrow dykes or plugs of mafic rocks. The dykes appear to be parallel sided and their trend in most cases, lie parallel to the major structure of their host rock. In Wādi Qābel and Kābdet al Jamel pyroclasts, there is evidence that the dykes were emplaced by injection associated with dilation of the dyke walls. It is possible that the localized nature of the pyroclastic deposits and their associated mafic dykes were controlled by regional tectonic stresses. Coarse-grained lherzolite nodules and clinopyroxene megacrysts of presumed upper mantle source origin are widely distributed and locally abundant in some vents and their associated mafic plugs. The presence of accidental blocks and foreign fragments within the volcaniclastic rocks of Wādi Qābel and Kābdet al Jamel, which can be recognized as coming from shallow levels of the walls of the conduit (Al Aziziyah and Abu Shaybah sediments) suggests shallow depth of fragmentation of the melt within/or below the stratigraphic position of the two formations. The dykes appear to have been emplaced along shear planes, the distribution and general similarity of the vents through the area have led to them being regarded as belonging to the same magmatic episode.

Keywords: Keywords: tuff, lapilli tuff, magma, dilation, lherzolite nodules, megacrysts, alkalic basaltic.

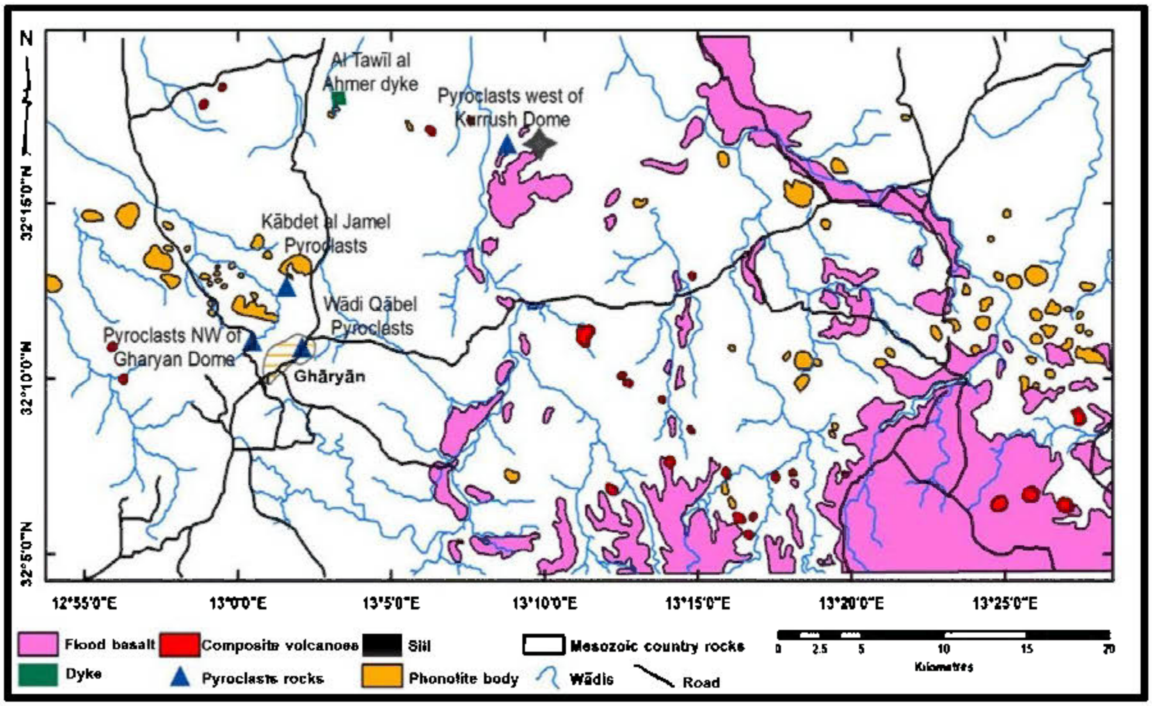

Figure 1. Geological map of western Libya showing the distribution of the igneous rocks and sample localities.

INTRODUCTION

Recent Tertiary-Quaternary volcanism on the central Jabal Nāfūsāh has been characterized by small-sized individual local occurrences of explosive pyroclastic rocks of limited areal extent and subordinate effusive eruptions that have distributed their products over relatively restricted areas [1], [2], [3].

Outcrops of vent filling mafic dykes and/or plugs representing the freezing of magma in route to the surface and pyroclastic rocks are limited to small isolated areas. Busrewil and Wadsworth [4] have briefly described these rocks in the context of the basanitic volcanoes of Ghāryān area (Fig. 1).

This study focuses on the physical description of the eruptive history of selected individual exposures of dykes, plugs and pyroclastic rocks; the origin of which are strictly of igneous source. The field data hereafter in the ensuing section forms the basis of the present work. Description and interpretation demonstrate the importance of phreatomagmatic activity in the evolution of the Ghāryān pyroclastic rocks. Rocks of this study are grouped into mafic sheets associated with pyroclasts, lava plugs with eroded pyroclasts, and dyke rocks.

MAFIC SHEETS ASSOCIATED WITH PYROCLASTIC FRAGMENTARY ROCKS

- **Wādi Qābel Pyroclasts (32°11'N and 13° 02'E)**

This discordant, non-bedded and poorly sorted tephra represents erosional remnants of fragmented materials that solidified in a feeding channel or conduit. A band of extensional dilation of the ground above the ascending pyroclastic vent eruption formed a narrow linear horst-shaped structure, striking N50˚W or less commonly north easterly, paralleling the two main fracture sets in the area, suggesting the emplacement mechanism was of simple dilatational process. The deposits are about 40 m wide in its widest exposed section. Near the base of the cliff on the south side of the wādi, subspherical armoured mud balls with a concentric internal structure, approximately one centimetre in diameter, are a common constituent of the lapilli tuff. Ball-milling formed in the vent through physical collision and abrasions, producing dense, egg-shaped, smooth-sided, unvesiculated boulders of basalt 10-15 cm in diameter are accumulated around the northern flank of the intrusion.

Transition in eruption behavior from phreatomagmatic to gentle effusion of basaltic lava took place during its final erupting phase when the feeding vent became sealed from adjacent water or water saturated sediments. In outcrop, the emplacement of a mafic dyke along the crest of the long axis of pyroclasts represents the freezing of lava within the conduit that once fed the pyroclastic materials. The dyke is subordinate to the pyroclastic rocks and because it is more resistant to erosion than the rest of the surrounding rocks, it stands up as thin, discontinuous segments of subvertical dark wall-like of basalt. Erosion has stripped away portions of the pyroclastic rocks and its sedimentary cover and segment of the dyke is well exposed at the bottom of the wādi (Fig. 2).

Figure 2. Eroded remains of a basaltic dyke, Wādi Qābel.

Eastwards and at higher altitude, a segment of the dyke, striking N30˚W, penetrated through the host-rocks of Ain Tobi Member of Upper Cretaceous age [5] and lies in line with the dyke in the wādi floor. It is seen to thin out towards the surface to the maximum of approximately 20 cm thick (Fig. 3). The host rocks on either side of the dyke dip 78˚ NE and moved apart normal to the margins of the sheet segment to accommodate the intrusion, suggesting that the magma was emplaced by wedging aside the bounding country rocks. It also indicates crustal stretching of the rigid host rock at a right angle to the elongation of the dykes. At the present level of erosion, the dyke is bounded by selvedge of altered country rock resulting from quenching of magma against the cooler wall rock. Upwards through a vertical distance of only 20 m from the base, greater section of the dyke lies below surface, though, the exposed portion of the sheet narrows rapidly to less than 6 cm wide before vanishing underneath the Ain Tobi sediments. Cracking or pulling apart the wall rocks by the injection pressure exerted by the intruding magma occurs and force a fracture (one metre wide and more than two metres long) to admit an upward injection of a concealed sheet; this can be seen only few metres away north of the exposed dyke. The magma infilled the dilational cracks and the congealed sheet serves as a tensional palaeostress indicator, normal to the margins of the injected dyke.

Figure 3. A dyke passing nearly vertically up the rock face with parallel walls of Ain Tobi carbonates at opposite contacts, Wādi Qābel.

The outlines shape of the pyroclastic rocks and their dilatation of the ground above the ascending dykes and its associated pyroclasts, demonstrate that their explosive pathways were controlled partly by pull apart of the walls of the country rocks regional extension and partly by the injection pressure of forcibly intruded magma.

Contact metamorphism occurred adjacent to the observed sheet principally because of thermal effects of magma intruding cooler shallow rocks. The invading magma recrystallized completely the contact aureole of the metamorphosed rocks formed in the host rocks to hornfelses 10-50 cm wide. Reticulate structure having lines crossing like the slender threads or fibres of a mesh is exposed adjacent to the mafic sheet.

II- Kābdet al Jamel Pyroclasts (32°12’N and 13° 01’E)

This is the most explicitly distinct kind of localized vent-filling volcaniclasts in northern Ghāryān area (al Ghāwāsem village, southwest of Kāf Tekūt). It is irregular in outlines approximately 200 m long with its widest exposed part ~ 30 m. The succession commenced with explosion lapilli tuff formed of materials ejected during the first outbursts. They are comprised of poorly sorted, highly fragmented lithic fragments of lapilli tuff (Fig. 4) but also include volcanic breccia of limited areal extent.

With time and renewal delivery of magma, short discontinuous segmented mafic dykes of alkali basalts intruded the pyroclasts. They are at the present level of denudation stand above the surface of the enclosing weaker pyroclastic rocks, marking an end to phreatomagmatic eruption in this locality. The dyke segments, exposed on the horizontal surface differ in attitude, but is generally steeply dipping and its strike nearly conforms to the same northwest (~ N 50°- 60° W) pattern exhibited by the dyke on Wādi Qābel. The erosional remnants of which vary in width from approximately 0.4 m in the south to several metres in the northwest (north of the paved road) with an average width at outcrop being approximately 2 m. At present, the margin of the segmented dyke is sometimes sharply defined and resisted more strongly than both of the associated pyroclastic deposits and the Abu Ghaylan limestones country rocks that enclosed it and therefore, the dyke project as vertical to near vertical wall with polygonal joint pattern in its interior (Fig. 5).

Figure 4. A close-up view of highly fragmented massive lapilli tuff deposits of Kābdet al Jamel volcaniclasts.

Figure 5. Kābdet al Jamel exposure, general view, viewed from the east.

The juvenile pyroclasts (more than 95% by volume of lapilli tuff) are the main constituent of the exposure down the east-facing roadside cross-section at 32°12’42″N and l3° 01’33″E. They are characterized by large amount of poorly sorted lapilli sized angular basaltic fragments mixed together with tuff. At this locality, they are characterized by the incorporation of a variety of accidental lithic clasts, derived from the underlying strata, having a size ranging from 0.5 cm to 15 cm, (Fig. 6) with rare 40 cm dispersed blocks in lithified ash matrix or volcanic breccia. The blocks generally consist of unvesiculted angular fragments of basalt (Fig. 7), rounded to rectangular sandstone as well as limestone of known crustal rock types derived from underlying strata (Abu Shaybah sandstone, Al Aziziyah carbonates and phonolites, (Fig. 8). This suggests that the hydroclastic explosion depth over which fragmentation occurred was within / or below the stratigraphic position of the two lithostratigraphic units at depths estimated between 40 and 70 m as suggested elsewhere [6].

Sparsely scattered hollow geodes and, cavities approximately 4 cm in size, with minor calcite filling are encountered. The pyroclasts are intersected by an almost E–W. directed group of multiple parallel mafic dykes or a dyke set that stepped a sideway to follow another plane of weakness; the width of each sheet is less than a metre. The dykes close upwards and are thought to have reached no higher than the exposed volcaniclastic surface. Eastwards, an altered phonolitic dykes eventually intrude the immediately adjacent Abu Ghaylan Formation and the altered phonolitic mass is inturn intersected by much younger mafic dyke (Figs. 9-10). Continuity of the latter sheet at higher topographic level in the southeast is not completely exposed and a section of it is at present roofed for its near-surface length, as revealed by the direction in which the Abu Ghaylan carbonates on either side moved apart to accommodate the intruded dyke.

Figure 6. Basaltic lapilli tuff dominated by lapilli-size basalt fragments and subordinate foreign accessory clasts picked up in transit scattered irregularly through the finer matrix of Kābdet al Jamel pyroclasts.

Figure 7. A block of a foreign near-surface country rock (light colour) ripped from the walls of the conduit supplying the surface materials and incorporated into the volcaniclastic rocks, Kābdet al Jamel.

Figure 8. Close-up view of included lithics of country rock derived from the immediately adjacent wall rocks engulfed in the pyroclastic of Kābdet al Jamel, field of view is ~ 45 cm long.

Figure 9. Altered phonolitic dyke cutting the Abu Ghaylan sediments.

Figure 10. A close-up view of a mafic dyke of basaltic composition tends to locally projects through an altered phonolitic sheet as a discordant tabular injected body, insignificant in relative dimension, uniform in width (~ 20 cm).

The sheet dilated the ground above it concomitant with the injection of more magma into its axial zone. The thinning of the overlying Abu Ghaylan Formation in this locality (less than 20 m thick; [7]) is possibly related to local uplift, erosion and weathering due to an outward-directed compression imposed by the expanding core of phonolitic magma body and subsequently by the rise of the basanitic dykes to the near-surface conditions [10].

III- Pyroclastic Exposure, NW of Ghāryān Dome (32°11'N and 13° 00'E)

Another locality of a vent source of lapilli tuff exposed along the Abu Rshādāh-Ghāryān paved road section, SW of Kāf Abu Ghānnoūsh, provides a useful example of concealed local exposure of pyroclastic rocks. The roadside section is partially exposed by road construction process, attaining a maximum exposed thickness of approximately 6 m thick. It had a surface trending north-northwest, and can be followed laterally for over several tens of metres.

The volcaniclasts may represent the root or feeder structure filled with explosively fragmented volcanic tuff and other debris. They lack vertical grading with no obvious change in texture along its lateral continuity. They are black, massive, chaotically sorted and show moderate signs of welding. The grain size of the deposits is dominantly in the lapilli-ash size range; basalt fragments predominate among lithic ejecta and disaggregated wall rock carbonate fragments from the vent wall, are scattered through the finer matrix (Fig. 11). Single exotic free clinopyroxene megacrysts (up to few centimetres in diameter) and facets of individual crystals up to few centimetres in diameter (glittering as they catch the light) as well as few ultramafic nodules, are most commonly found in the roadside lapilli tuff wall. A disaggregated block (~ 20 x 15 cm) of older country rock (Al Aziziyah carbonates, Fig. 12) plucked from shallow level phreatomagmatic eruption is detected constraining the shallow depth over which the fragmentation occurred.

Figure 11. Pyroclastic rocks, roadcut exposure NW of Ghāryān dome.

Figure 12. Close-up view of a disaggregated wall rock carbonate block of Al Aziziyah sediments.

IV- Lava Plug with Eroded Pyroclasts East of Rāʿs al Māseid (32°11’N and 13° 23’E)

The outcrops of pyroclasts are exposed along the roadside deserted quarry bit, east of Rāʿs al Māseid phonolitic body. The edifice is ovoid in plan, with long axis lying parallel to the dominant NW/SE direction. Currently the quarry face rises approximately 4 m above the surrounding low land and is, to some extent, obscured by a soil cover that tends to accentuate the concavity of the slope, as rainwater washed away detritus quickly.

The exposure is dominated by poorly sorted matrix-supported beige-coloured massive lapilli tuff (Fig. 13) and may represent a vent of an explosive hydromagmatic eruption. The lapilli tuffs of the southern quarry face lack interstratification; they appear very similar in hand specimens and display columnar jointing and welding texture. However, occasional blocks of older fine-grained basalt lithics (irregular in shape, up to 70 cm in diameter), representing clasts of comagmatic volcanic rocks from a conduit wall, are thrown out by volcanic explosion indicating occasional, more explosive activity and at present found in the ejected debris (Fig. 14). Scattered fragments of country rocks that were explosively ejected during eruption are also present (Fig. 14). Spinel lherzolites of presumed mantle derivation that were in the magma prior to eruption are overwhelmingly prominent in this exposed roadcut volcaniclast exposure. They occur as well-defined foreign materials in the form of subrounded to angular lumps of hard, dense crystalline rock measuring one centimetre to a maximum of 12 cm across (Fig. 15). Their essential minerals are forsteritic olivine, diopsidic pyroxene, enstatite with minor aluminum chrome spinel [4], [8].

Figure 13. Photograph of the products from phreatomagmatic eruption east of Rāʿs al Māseid, consist of a mixture lapilli tuff deposits, older basalt blocks, and accidental rock fragments (ultramafic nodules). Geological hammer is 38 cm long.

Figure 14. Massive lapilli tuff exposed in the southern section of the quarry exposure, east of Raʿs al Māseid. Geologic hammer is 28 cm long. Single woody Asphodelus sp stem from the root.

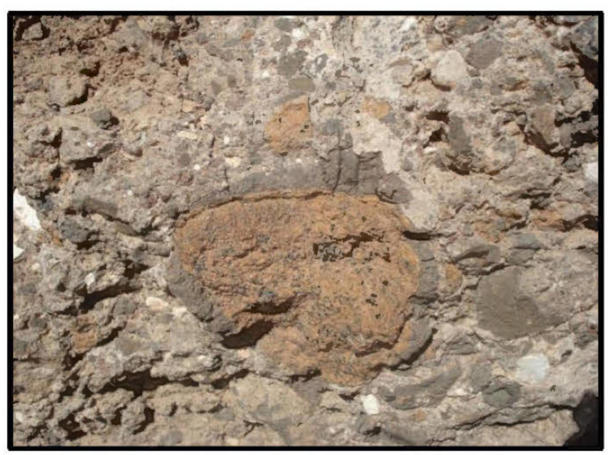

Figure 15. Close-up view of disaggregated basalt fragments (black) from pre-existing solidified rocks blocking the vent, rounded, yellow, weathered lherzolite nodule and minor accidental debris (light-coloured sediments). Field of view ca. 60 cm.

The style of the explosive igneous activity changed during its last phase of activity as rising magma was effectively cut off from the water supply, and the inferred ash cone produced in the north section of the edifice cinders and lava, suggesting that the eruption concluded with a relatively quiet eruption. The emplacement of a mafic dyke represents the final stage of igneous activity. Continued rise of magma above the feeding channel has infilled the volcanic neck or upheaved volcanic conduit plug-like substructure, completely overfilling and obscuring a preexisting vent depression (32°11'N/ 13°23'E) and solidified in the vent and plugged it.

The volcanic plug basalt or lava mound may represent a section of a bonded lava lake and at present, has a higher preservation potential than those of the adjacent pyroclastic rocks. The lava in the north and the dyke reinforced the skeleton, allowing it to stand higher than it could have, had it been built solely of pyroclastic debris. The upper massive parts of the plug exposure along the roadside, are characterized by nearly vertical columnar joints. They are oriented perpendicular to the upper cooling surface of the lava, and split it into four-sided polygonal columns. Like its host rock, the plug contains spectacular suite of lherzolites, showing sharp contacts with host basalt. The size of the nodules generally ranges from two to 5 cm in their greatest dimension. They show similar remarkable uniformity in mineral content and textural appearance with the lherzolites of the adjacent pyroclastic rocks.

The dyke, being more resistant to erosion than the weak volcaniclasts on both sides, emerged as the surrounding weaker pyroclasts were stripped away. Rounded and smooth-sided lapilli 4-7 centimetres in diameter (lapilli agglomerate) from the southern margin of basalts show the effects of crushing, physical collision and abrasion in the volcanic neck.

The southern contact between the lava and its adjacent tephra is draped with scoriaceous basalts (slaggy and vesicular) suggesting that the lava undoubtedly erupted subaerially, and amasses over the adjacent superficial volcaniclastic rocks. Welding and compaction of the pyroclastic rocks become increasingly sintered near the contact with the basalts.

V- Lava Plug with Eroded Pyroclasts, Qumātāh: (32°09'N and 13° 23'E)

The working face of the quarry along the southern bank of Wādi al Hāmmām segment, south of Qūmātāh settlement, is a sheet-like extrusion that is now characterized by a convex upper surface and surrounding talus apron. The hill marks the position of a small lava plug that overfilled and obscured a preexisting vent or a crater depression that was trapped by the walls of a vent filling pyroclastic rocks after explosive activity has ceased. It has been quarried and crushed for gabions that were used for erosion protection and silt filtering from runoff of the adjacent wādi. The conduit plug of the basalt has a relatively small cross-sectional area, less than 60 m in diameter. Nearly all the surrounding volcaniclastic rocks were quarried, or weathered, or eroded, and leveled with a moderate concavity of the eastern flank and ultimately only the lava plug remains.

When seen in cross-section in the quarry face, the lavas here show well developed, rather uniformly spaced columnar joints (Fig. 16) and is characterized by the presence of relatively abundant inclusions of peridotite nodules that contain distinctive fresh olive-green crystalline xenoliths (spinel lherzolites). The Joints developed two-tiered structure of massive subvertical columns or colonnades, separated by non-jointed scoriaceous basaltic materials (entablature, [9]). One set of columns advancing upward from a scoriaceous base and the other downwards from the top. Both sets of columns take on the form of uniformly spaced four-sided, sub-vertical, prismatic jointing but those in the upper tier are more regular in shape than those of the lower tier. Near the upper surface of the upper colonnade, rising gas bubbles formed a scoriaceous locally chilled tops (oxidized flow tops) during the cooling of the bonded lava suggesting that parts of lava projected above the surface. The central entablature is scoriaceous. It contains poorly developed curved and skewed columns. The overall eruptive sequence of this edifice is similar to those found at the roadcut exposure east of Rāʿs al Māseid.

Linear group of vesicles or vesicle cylinders approximately 50-70 cm in vertical or horizontal length (3-12 cm wide) and small subrounded pockets of similar appearance are exposed on the cliff face of the quarry. These are suggestive of a trapped pocket of hot gas and H2O-rich bubbles within the residual melt during congealment near the surface that were diffused through opening cracks in the impermeable solid rock near the middle of the lower colonnade (Fig. 17).

Figure 16. Working face of abandoned quarry showing polygonal columnar joints with slightly curved sides developed in lava bond, Wādi al Hāmmām, Qūmātāh settlement. Field of view is approximately 40 m wide.

Because the plug of lava is laterally confined in areal extent, and by analogy with the above-described plug east of Rāʿs al Māseid phonolitic mass, we interpret this locality as forming part of the inner walls of partially consumed vent-filling pyroclastic rocks. The quarry is one of several ultramafic inclusions-bearing alkali basalts localities on Qūmātāh area, and although there are many similarities between the sites, there are some important differences such as inclusion abundance and size.

Figure 17. Close-up view of linear development of a group of vesicular segregation veins in a congealed lava bond, quarry face, Qūmātāh settlement. The hand on the left gives the scale.

VI- Dyke Rocks

Remnants of a group of scattered plugs, necks and sheets of alkali basaltic composition, cutting older sedimentary sequences in front of the jabal foothills and on top of the plateau have low abundance. They range in size from few metres to over 80 m in basal diameter, and rise between five to 20 m above the surrounding low lands. Some plugs are nearly circular in ground plan, while others are oval in shape. Volcanic necks representing the roots of volcanoes that have eroded away are mostly irregular in plain view and are few score metres in diameter. However, in no case do dykes appear to be feeders to the flood lavas.

Al Tawīl al Ahmer dyke ridge (Fig. 18), located along the northeast foothills of Abu Ghaylan scarp at 32°18’0.9N/ 13°.03’17″E is a good example of a dyke that probably did not reach the surface in a liquid state, but has been exposed by erosion. The wall of the dyke at its present level of erosion is vertical. The exposed portion of the sheet is thin in comparison with its length, with a uniform width. It cuts across the Abu Shaybah sandstone, measuring ~ 20 m wide; 100 m long and extended as a linear geologic feature striking N28W. Only the eastern and western ends of the sheet are exposed (Fig. 18).

Figure 18. Al Ţawīl al Ahmer ridge recognizable by its black colour in contrast to the enclosing Abu Shaybah sandstone.

A small quarry pit fringing the northern section of Kurrush Dome exposes a low relief plug. The edifice has been extensively quarried and its original shape is not preserved. Remnants of the northern ridge exhibit a spectacular array of well exposed closely spaced horizontal columnar jointing (Fig. 19). In cross-section, the columns are regular in form and uniform in size measuring about 25 cm wide. Fanned and curved joints are exposed in the quarry face. A flat-lying tabular sheet concordant with the bedding of host rocks at 32°16'N/ 13°.09'E is exposed at the northwest corner of the eroded core of Kurrush Dome at country rock contact between Kurrush sandstones and Al Aziziyah limestones (Fig. 20). The main constituents of the igneous body, whose maximum thickness is about 7 m are augite phyric alkali basalts.

In the area NW of Kurrush Dome, at least six mafic igneous bodies representing possibly points of eruptions along Wādi Ghān fault system were counted in a NW striking Wādi al Hirāh channel. Individual edifices are small and their base level in the area is around 100 m; the volcanic bodies are not much more than 30 m high.

Figure 19. Cutaway section, showing well-developed horizontal columnar joints pattern at right angle to the columns. Estwing hammer for scale.

Figure 20. Road cut view showing cooling joints along Wādi Ghān road cut.

DISCUSSION AND CONCLUSIONS

Scattered occurrences of pyroclastic deposits, indicative of a history of phreatomagmatic activity, form an important pyroclastic succession in the area. In hand specimen, they are dark in appearance and commonly phyric or contain small proportion of titanaugites and olivine phenocrysts. They were derived through partial melting in the spinel lherzolite stability field and magma evolution is thought to had been dominated by fractional crystallization [4], [11]. The materials filling is represented by either scattered sheets, plugs of alkali basaltic lava or pyroclastic rocks indicating rather localized upwelling of magma.

Early NW fracture planes were intruded by pyroclastic fragmentary rocks (Wādi Qābel, Kābdet al Jamel, and Al Ţawīl al Ahmer mafic dyke). Individual plugs in Wādi al Hirah, NW of Kurrush Dome fall in an NNW-SSE lineament. The localized nature of these dykes and plugs is simply a manifestation of structural control on magmatic pathway.

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