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PRELIMINARY REPORT ON UK-SAUDI 2017 FIELDWORK AT WADI DABSA, ASIR PROVINCE, SAUDI ARABIA

R. H. Inglis[1,2], A. G. Sinclair[3], A. M. Alsharekh[4], D. N. Barfod[5], H. C. Chang[2], P. C. Fanning[2] D. T. Al Othaibi[6], H. K. Robson[1], A. Shuttleworth[7], A. Stone[8], and G. N. Bailey[1]

[1] Department of Archaeology, University of York, York, UK

[2] Department of Environmental Sciences, Macquarie University, Sydney, Australia

[3] Department of Archaeology, Classics and Egyptology, University of Liverpool, UK

[4] Department of Archaeology, King Saud University, Riyadh, Saudi Arabia

[5] Scottish Universities Environmental Research Centre, East Kilbride, Glasgow, UK.

[6] Saudi Commission for Tourism and National Heritage, Riyadh, KSA.

[7] Department of Anthropology, Durham University, UK.

[8] Department of Geography, University of Manchester, UK.

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1. Wadi Dabsa and the Palaeolithic of SW Saudi Arabia

1.1 Introduction

Understanding the ways in which hominin populations used the landscapes they inhabited is crucial to understanding their spread across the globe. At the crossroads between Africa and Eurasia, Arabia's Palaeolithic record is central to these debates (Petraglia, 2003; Petraglia & Alsharekh, 2003; Groucutt *et al.*, 2015). Spanning potentially over 1 million years, this record holds great potential for interpreting patterns of hominin landscape use and the role this played in the ways hominins dispersed. Yet the interpretation of artefact distributions within a landscape requires a thorough understanding of the geomorphological processes that control artefact preservation and visibility, and shape landscapes over time (Holdaway & Fanning, 2014). Combined geomorphological and archaeological methodologies for recording, analysing, and interpreting the archaeological record in its landscape context must therefore be applied to the Arabian Palaeolithic record to fully realise its potential to inform on early hominin landscape use.

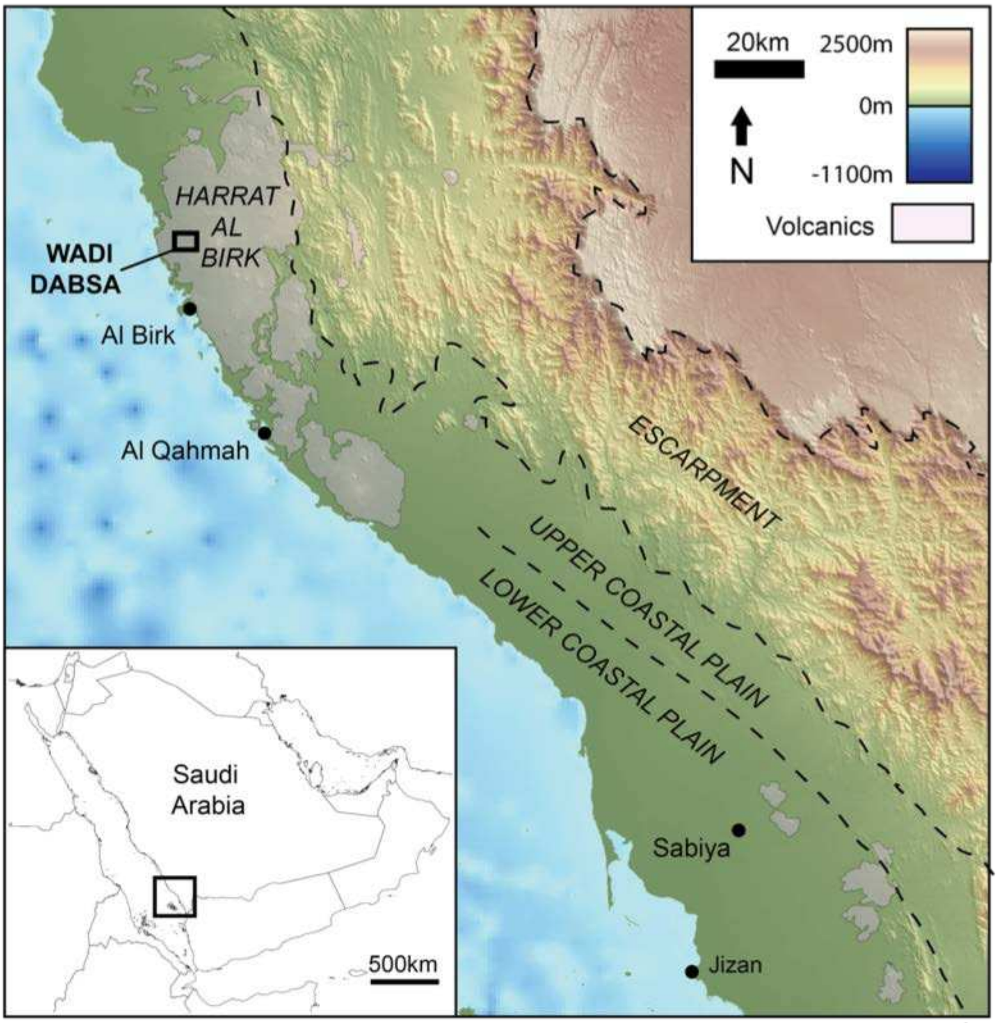

Figure 1: Location of the 2017 study area and Harrat Al Birk, southwestern Saudi Arabia.

The Red Sea coast of southwestern Arabia has a rich, but not comprehensively understood, record of Early and Middle Stone Age (ESA and MSA) archaeology. Remaining relatively humid during the Pleistocene, it may have been one of the Peninsula's most persistently attractive regions (Bailey, 2009; Bailey *et al*., 2015). It was easily accessible to populations migrating across both the Southern Route (Bab el Mandab/Hanish Sill) from East Africa, and the Northern Route via the Nile/Sinai (Lambeck *et al.*, 2011), making the region crucial to understanding hominin dispersals. A newly-discovered major concentration of ESA/MSA artefacts at Wadi Dabsa, in the Harrat Al Birk, Asir, southwestern Saudi Arabia (Foulds *et al*., In Press; Inglis *et al.*, 2015) therefore presents a rare and exciting opportunity to apply interdisciplinary approaches to a significant lithic assemblage to understand the environmental and behavioural context of the artefacts and implications for early hominin dispersals out of Africa.

1.2 Geology and Archaeology of the Harrat Al Birk

The Harrat Al Birk, Asir province, consists of over 1800 km^2 of lava flows and cinder cones stretching between the modern-day coastline and the foothills of the Arabian escarpment between approximately N18.76°–17.79° latitude. Remote sensing of the region shows flows of varying apparent age and degree of erosional degradation. Numerous younger flows emanating from dozens of extant cinder cones, overlie extensive dissected fields of older flow deposits. Erupted products consist of flows and scoriaceous deposits, dominated by alkali olivine basalts and hawaiites.

The age and duration of volcanism in the Al Birk field is poorly constrained. The timing of activity derives exclusively from 17 K-Ar whole-rock dates ranging from 0.2 to 2.6 Ma (Coleman *et al.,* 1983; Dabbagh *et al*., 1984; Zarins *et al.,* 1981). The most recently obtained dates were measured on a single basalt flow 8 km south of the town of Al Birk, yielding K-Ar whole rock ages of 1.37 ± 0.02 and 1.25 ± 0.02 Ma (Bailey *et al.*, 2007). Although representing a considerable analytical effort, the inherent limitations of whole-rock K-Ar ages and the lack of concordant results for some replicated analyses, call into question the accuracy and precision of the existing temporal framework and highlight the need for an extensive geochronological study using modern $^{40}Ar/^{39}Ar$ methods. Nevertheless, post-rifting volcanism in the region appears to be dominated by Pleistocene or younger ages, generally <1.5 Ma, postdating the first known dispersals of *Homo* out of Africa and indicating that volcanic eruptions may have altered a landscape already inhabited by hominins.

The driving factors that generated the Al Birk volcanism are enigmatic and may not directly relate to rifting of the Red Sea. Lying to the northeast of the Al Birk field, regionally extensive Oligocene to Miocene (ca. 20–25 Ma, Bosworth & Stockli, 2016) mafic dikes trend parallel to the Red Sea coast, marking the opening of the Red Sea rift, significantly predating Al Birk volcanism. Coleman *et al.* (1983) note that the overall trend of eruptive centres shows a NNE alignment, distinct from the NNW trend of the Red Sea margin and spreading centre. Since the beginning of the Pleistocene, the Harrat al Birk was more than 100 km distant from the Red Sea axial valley, suggesting that the origin of the Al Birk volcanism is unrelated to seafloor spreading and more likely akin to the intraplate volcanism seen in the other *harrats* of western Arabia (Bosworth & Stockli, 2016).

The Harrat al Birk is drained by a series of wadis that flow west to the Red Sea. Some, such as Wadi Najla, have become deeply incised, exposing the bedrock of shales and schists underlying the basalt flows, while others, such as Wadi Dabsa, have undergone less incision. This variation is probably related to the age of the basalt flows that shape each area, as well as variations in catchment size. In many of these wadis it is clear that past lava flow emplacement has altered wadi courses, as well as filled pre-existing valleys (Inglis *et al*., 2014a).

Our understanding of the archaeological record of the Harrat al Birk is emerging. The Comprehensive Archaeological Survey Project (CASP) in the 1970s and 1980s identified numerous locations where Palaeolithic stone tools were preserved (Zarins *et al*., 1980, 1981). Following preliminary work in 2004 and 2006 (Bailey *et al.,* 2007), a series of surveys from 2012–2015 by the UK-Saudi team, under the umbrella of the DISPERSE project, expanded this understanding of the distribution of Palaeolithic artefacts across the *harrat* (Bailey *et al*., 2012, 2015; Foulds *et al*., In Press; Inglis *et al*., 2013, 2014a, 2014b, 2015). During these surveys, discovery of a large number of Palaeolithic artefacts at Wadi Dabsa provided the largest assemblage of ESA and MSA artefacts yet recorded from the Harrat al Birk, and indeed the wider southwestern Saudi Arabia region. Most critically, it was observed during these surveys that the rapid pace of development in the Harrat Al Birk region threatens its abundant archaeological record, rendering the survey and recording of the artefacts particularly timely.

1.3 Wadi Dabsa

In 2015, numerous ESA/MSA artefacts were recorded in the headwaters of Wadi Dabsa, located on the surface of, and apparently embedded within, a 1 km^2 area of tufa carbonate deposits (Inglis *et al*., 2015). More than 900 Palaeolithic basalt artefacts were recovered from a 40 x 50 m grid, with the deposit/artefacts extending for at least this same area again. Initial analysis indicated that the assemblage had potential for refitting flakes to their parent cores and identifying patterns of learning in stone tool manufacture. Formed under past wetter conditions, the tufa potentially contained a dateable isotopic record of past environments. The association of a major artefact assemblage with a palaeoenvironmental archive thus provided, potentially, a unique opportunity to examine Palaeolithic activity in its environmental context.

1.4 Aims and Objectives

The 2017 UK-Saudi fieldwork aimed to examine the behavioural and environmental context of the Palaeolithic artefacts at Wadi Dabsa, Asir Province, to further understand early hominin landscape use in a region key to global dispersals.

Objectives

1. Use remote sensing and satellite data to map geomorphological units surrounding the Wadi Dabsa site to target archaeological and geomorphological survey and excavation.

2. Conduct geomorphological survey of the locality and its environs to provide a robust model of landscape evolution within which to situate the archaeological interpretations.

3. Record the distribution of, and collect, surface artefacts.

4. Analyse collected artefacts to illuminate hominin behaviour at the locality, and its implications for the Arabian record.

5. Excavate the tufa deposits at targeted locations to confirm relationships between the artefacts and tufa deposition.

6. Sample the tufa deposits for ^{234}U–^{230}Th dating and palaeoenvironmental analysis using stable isotopes to provide both a chronological framework for Palaeolithic activity and a palaeoenvironmental archive in this semi-arid region where preservation of archives is rare.

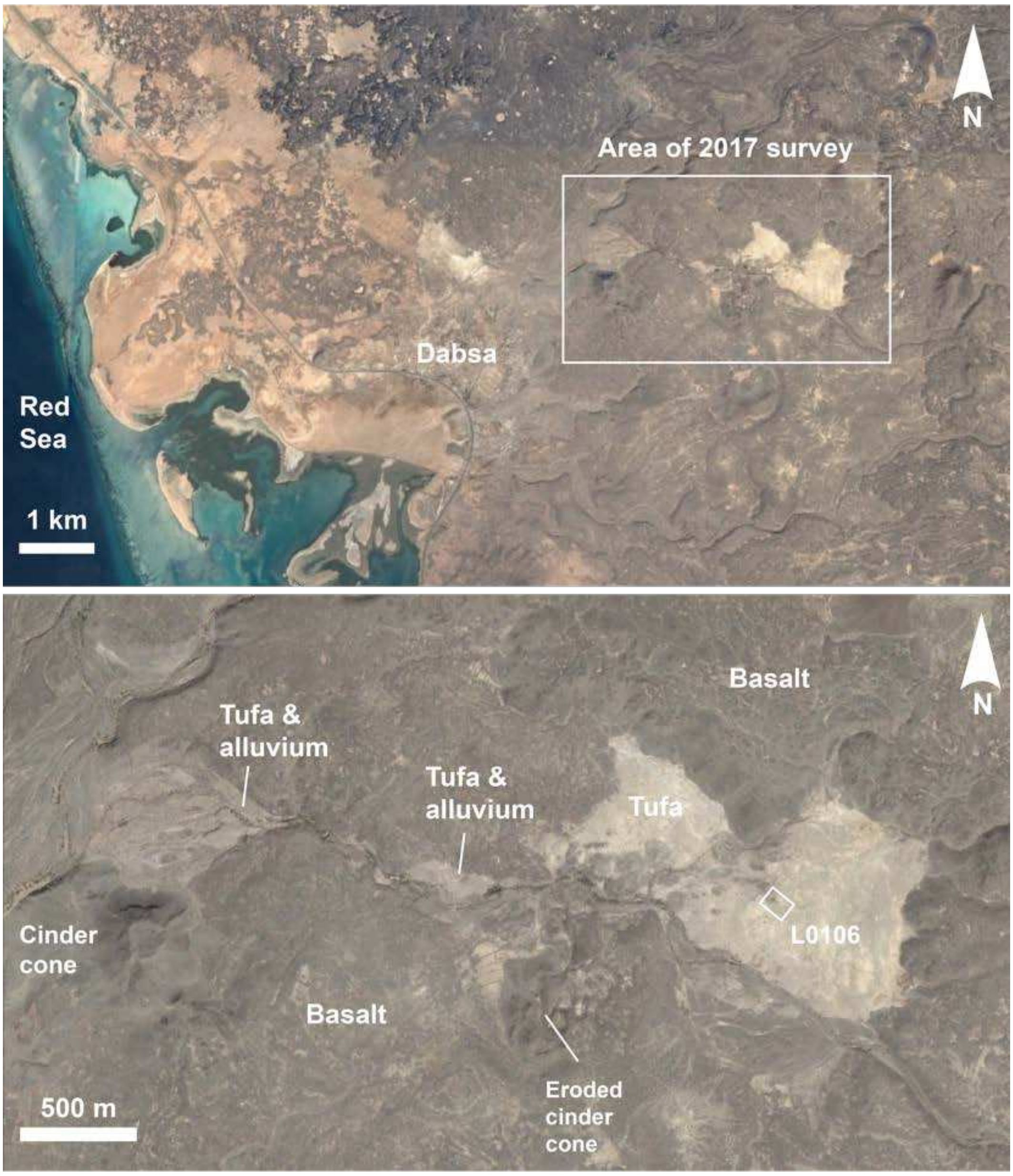

Figure 2: Overview of the Wadi Dabsa basin showing the 2017 area of investigation, and the location of the 2015 artefact collection grid, L0106. Imagery © CNES/Airbus, Imagery date 15/11/2016, accessed through Google Earth.

The fieldwork took place over four weeks in January/February 2017 (three weeks of survey/excavation and one of post-excavation analysis of the lithic artefacts). During this time, the team achieved all of the above objectives, and produced a detailed record of a large assemblage of ESA/MSA artefacts, further analysis of which will provide a rare coherent insight into the technology and behaviour of early hominin populations in their landscape context. Following analysis, the artefacts were packed for long-term storage in the Asir Regional Museum, Abha. The geological samples were exported to the UK for specialist analysis.

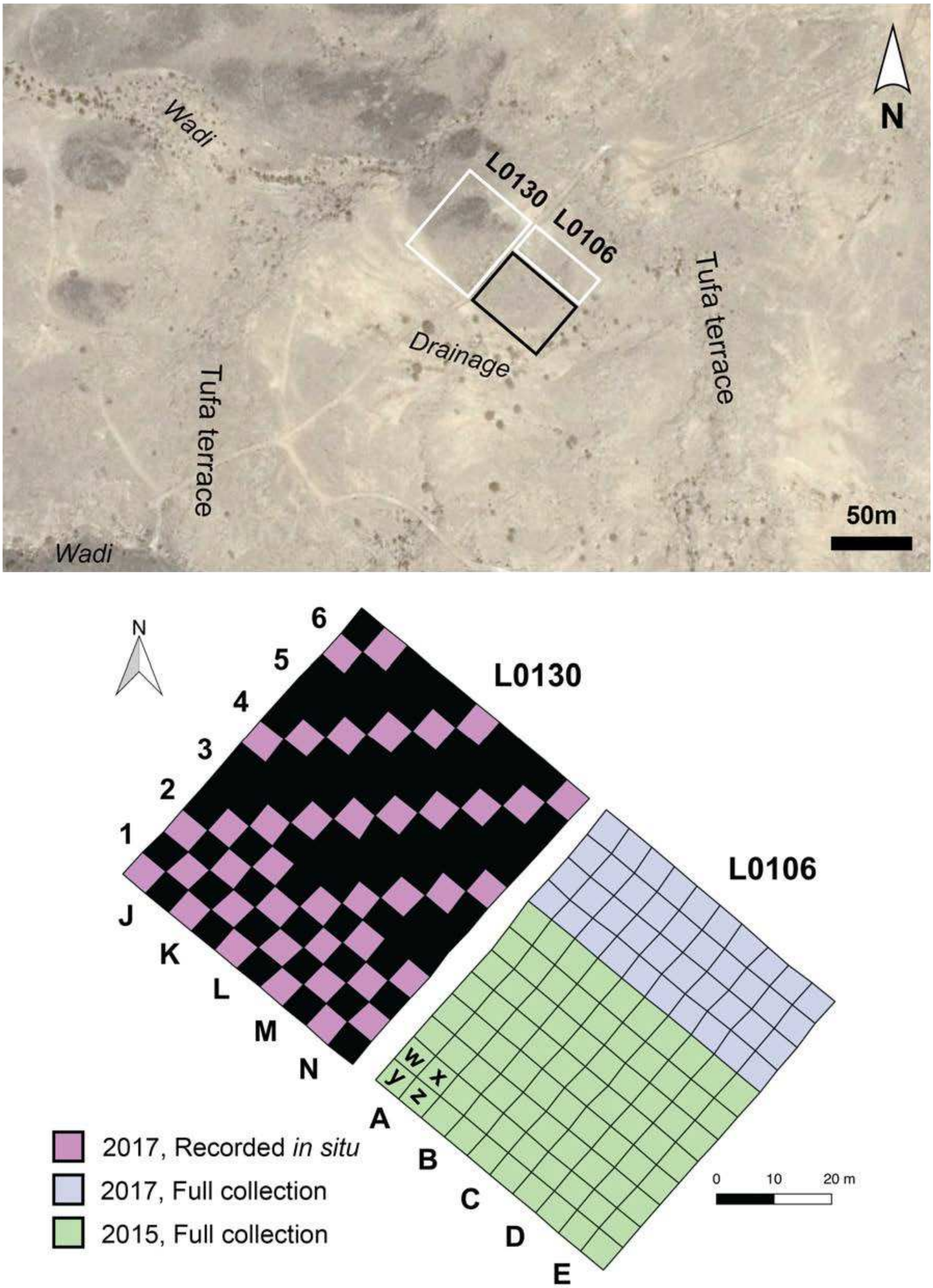

Figure 3: (a) Overview of grid location in landscape, base map © CNES/Airbus, Imagery date 15/11/2016, accessed through Google Earth; (b) schematic summary of date of survey, collection methods, and quadrants recorded across grids.

2. Methods

A multi-scalar geoarchaeological approach to understanding the locality, its landscape and the archaeology was undertaken, working in from the wider landscape to the area where the highest number of basalt artefacts had been recorded in 2015. The artefacts in this area had been sampled by collecting all lithic artefacts within a 40 x 50 m grid, (designated L0106, Inglis *et al*., 2015). In 2017, this grid was extended to the northeast by 20 m, increasing the area collected over the two seasons to 50 x 60 m (i.e., 3,000 m^2). In addition, a second 50 x 60 m grid (designated L0130) was set up to the west of L0106, offset 5m to the west to avoid a vehicle track that runs northeast/southwest through the concentration of artefacts (Figure 3). As with to L0106, L0130 was divided into 10 x 10 m squares, each of which was further divided into four 5 x 5 m quadrants (labelled w, x, y and z). The location of each quadrant corner across the entirety of both the 2015 and 2017 grids was recorded in ArcPad 10 using a Trimble Geo7X with Zephyr Model 2 external antenna, and its relative height recorded using a dumpy level and staff to ensure maximum precision over the gently sloping area.

2.1 Regional Geomorphological and Surface Condition Mapping

Desktop analysis of satellite imagery was undertaken to map the landform units within the Wadi Dabsa basin, to: (a) build a working landscape stratigraphy that, after groundtruthing, would elucidate landscape development as well as guiding sampling for $^{40}Ar/^{39}Ar$ dating of basalts and $^{234}U–^{230}Th$ dating of the tufa; and (b) assess these landforms in terms of their potential for the exposure, preservation and visibility of Palaeolithic surface artefacts.

The units were defined by visual examination of Pléiades 1 Satellite panchromatic (50 cm resolution) and 4-band (2 m resolution; blue, green, red, near infra-red) multi-spectral images, dated 29/2/2016, in QGIS 2.0.1 Dufor, with reference to the ASTER Global Digital Elevation Model (30 m resolution) as well as true-colour imagery (red, green, blue) accessed through Google Earth (dated 19/01/2014). Units were defined by their assumed geological and geomorphological origins and the processes that had shaped them, e.g. basalt flows, basalt terraces, tufa, etc.

More detailed mapping of surface condition, influencing artefact visibility across the tufa deposits (the focus of the 2017 fieldwork), was carried out using automatic classification of Google Earth imagery. Unsupervised classification of the imagery into ten classes was carried out using the ISOData method in ENVI 5.2 (output image cleaned by smoothing to 3 pixels, aggregation to 5 pixels) The resulting classification of the tufa surface condition was groundtruthed through visits to the various mapped areas on the tufa surface to verify the surface condition classes and their boundaries. This data will be used in future work to further refine the surface classifications derived from satellite data.

2.2 Local Landform and Surface Condition Mapping

Landform units, defined as areas of relatively uniform surface morphology, were mapped across the two grids by recording their boundaries as polylines in ArcPad10 using the Trimble and external antennae. The polylines were later used to generate polygons of each landform unit in QGIS 2.1 Las Palmas. Six landform units were identified and mapped: Ridge, Crest, Upper Slope, Lower Slope, Drainage Depression, Disturbed.

Surface condition within each of the defined landform units is variable, and affects the visibility of artefacts. Three surface condition types were recorded within each quadrant across the grid where artefacts were collected or recorded: % of bare tufa, % sediment cover and nature of sedimentation, and % vegetation cover.

2.3 Artefact Collection

After extending the L0106 grid from its 2015 boundaries, all surface lithic artefacts were collected from the new area (total 20 x 50 m) in 5 x 5 m quadrants, following the methodology employed in 2015. In L0130, given the already large sample of artefacts collected from L0106 and due to time constraints, artefacts were recorded and photographed but were (bar a single handaxe) left *in situ*. In L0130, only artefacts in the x and y quadrants were recorded in alternating squares in a chequerboard pattern, apart from Rows 1 and 2 where, due to the low density of the artefacts, it was possible to record the artefacts within x and y quadrants of all the squares (Figure 4).

2.4 Archaeological Excavation

In addition to the surface collections, two small excavations were carried out in L0106 to investigate the depth and nature of the sediment overlying the tufa and relationships between the surface artefacts, sediments and tufa. Two 100 x 50 cm pits were excavated in quadrants 5Ax and 6Az/By to examine the stratigraphy of the sediments in the 'Crest' landform unit, reaching depths of up to ~30cm. The 'Crest' landform unit (Figure 11) is where sediment is most abundant, and the relationship between the artefacts, the sediments and the tufa can be most readily investigated.

2.5 Lithic Artefact Analysis

Collected lithic artefacts (from L0106) have been described according to a system of lithic analysis developed for the examination of lithic artefacts as part of a previous landscape survey in southern Africa (McNabb *et al.,* 2003; Sinclair & McNabb, 2005). The use of a combined typological and techno-typological recording system allows us to expand upon the purely typological information collected previously by the CASP (Zarins *et al.,* 1980, 1981). By including technological information, we can begin to identify different aspects of manufacturing activity happening at varied locations by following a chain of reduction from nodule to final discarded fragment. In so doing, this information will also help us recognise the processes of hominin artefact transport across the study area.

In typological terms, the system records the type of lithic blank (flake, blade, core, etc.) as well as the specific type of tool if the piece has been modified by retouch. For the artefacts collected and recorded from Wadi Dabsa these retouched types include types appropriate to the ESA/Acheulean as well as the MSA/prepared-core periods and following standard typologies (Bordes, 1979; Debenath & Dibble, 1994).

In technological terms, the recording system identifies the type of lithic material from which the artefact has been made, the percentage of cortex present, the state of weathering and roundedness, as well as the metric dimensions. For cores, the technological recording system also identifies any separately identifiable episodes of debitage, and the form of working that occurred. For flakes and other products of debitage, the recording system also records the pattern of prior removals identifiable through the patterning of negative flake scars on the dorsal surface, the form and location of any retouch, and any form of macroscopic edge damage. For the analysis of prepared-core working, which comprises much of the assemblage recovered from Wadi Dabsa, the system of technological recording also identifies whether flakes derive from the preparation of the upper surface or the lower surface of prepared cores following the scheme originally proposed by Boëda (1995) in which prepared core technology proceeds through the preparation and maintenance of upper and lower 'volumes' above and below a central level within the core.

Finally, all collected artefacts greater than 20 mm in length have been digitally photographed for both the dorsal and ventral surface against a 10 mm squared grid. This allows for the same square grid to be superimposed as a new layer on top of the artefact to facilitate the creation of line-drawn illustrations of selected lithic artefacts for publication at a later stage.

In the case of the artefacts observed but not collected in L0130, a brief typological and technological description was assigned to artefacts in the field, and the ventral and dorsal surfaces of each were photographed against a plain background with a standard photographic scale prepared for the survey.

2.6 Chronometric Sampling

2.6.1 Basalt Sampling

The basalt sampling strategy aimed to acquire the freshest possible samples from all of the morphologically distinct basalt units within and surrounding the basin and in the artefact recording grids, in order to chronologically constrain the emplacement of the lava flows through $^{40}Ar/^{39}Ar$ dating. Sample collection sites were chosen to ensure, to the greatest extent possible, that the sampled rocks were *in situ* with respect to initial deposition as a lava flow. Each sampled basalt consisted of ~ 1 kg of material extracted from the interiors of larger boulders, typically 40–60 cm in diameter. At the end of fieldwork, the samples were transported to the UK for analysis in the NERC Argon Isotope Facility at the Scottish Universities Environmental Research Centre, East Kilbride.

2.6.2 Tufa Sampling

Samples of tufa were collected from locations across the basin, within wadi channels and within the artefact recording grids, to provide an understanding of the timing (through forthcoming ^{234}U–^{230}Th dating) of their deposition, related to past humidity. Stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) from the same samples will be analysed to provide a palaeoenvironmental reconstruction relating to source moisture and palaeotemperature. Samples were selected on the basis of their appearance in hand section, targeting carbonate that was densely cemented and looked clear of non-carbonate detritus, following the experience of Stone *et al.* (2010), in order to minimise potential problems of detrital contamination and open-systems behaviour for ^{234}U–^{230}Th dating. At the end of fieldwork, the samples were transported to the UK for analysis in the NERC Stable Isotope Facility at the British Geological Survey, Keyworth, and the Department of Geography, Royal Holloway University of London.

3. Results

3.1 Landscape Evolution

3.1.1 Remote Sensing Observations

From observation of the satellite imagery, it is clear that the landscape of the Wadi Dabsa basin is dominated by basalt flows (Figure 4), laid down by successive eruptions from the various cinder cones that dot the landscape. These flows and cinder cones exhibit the effects of varying degrees of erosion, suggesting an extended history of magmatism, likely spanning millions of years (Bosworth & Stockli, 2016; Coleman *et al.*, 1983).

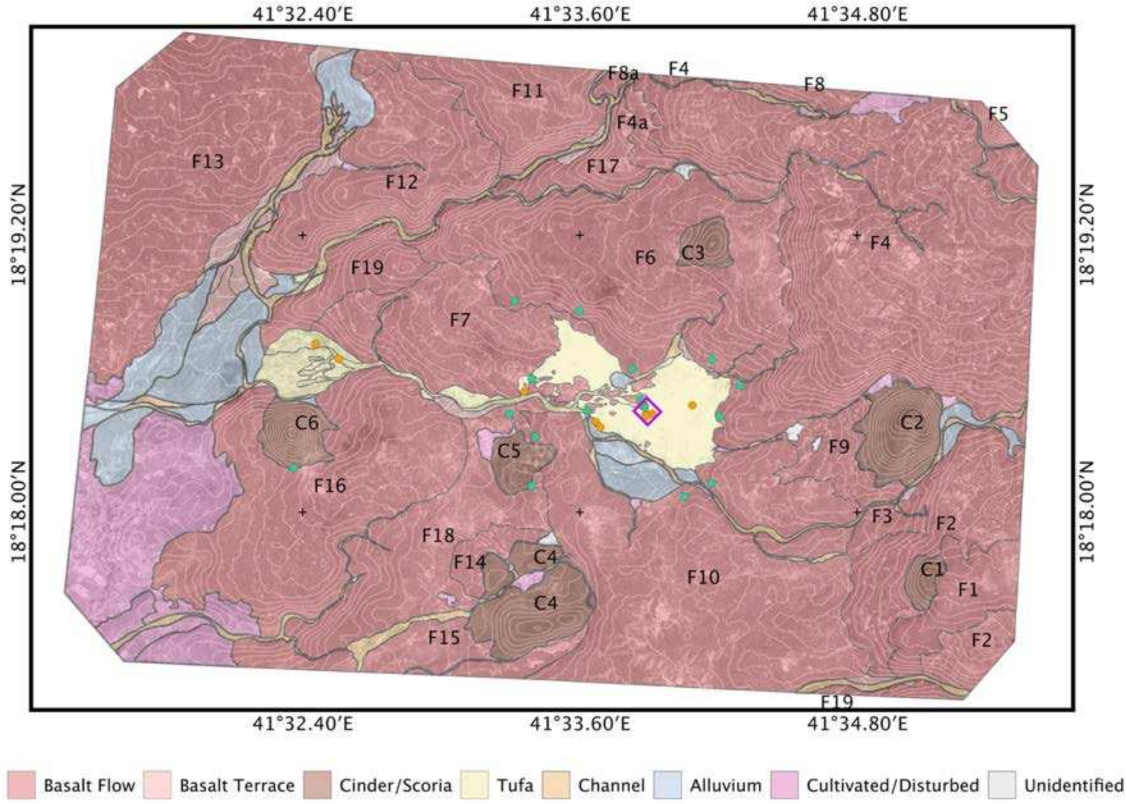

Figure 4: Landform mapping of Wadi Dabsa basin showing location of samples of basalt (green) and tufa (orange) collected in 2017. Purple rectangle in centre of tufa unit locates position of artefact recording grids.

Mapping of the flows from satellite imagery was straightforward, given the lack of vegetation on the surface. Flows to the east of the study area were markedly more defined on the satellite imagery than those to the west and southwest, possibly indicating a younger age for these flows in comparison with those in the southwest. Superimposition of the flows based on remote sensing observations allowed the development of a phasing matrix of flow emplacement to be used to both understand the development of the basin as well as guide the sampling (Figure 4).

One particular area of interest highlighted by the landform mapping was the relationship of flow F4, one of the youngest inferred flows, and the tufa at the eastern edge of the basin. The shape of this flow, especially the lobate form of its boundary with the tufa, suggests that it may have flowed along a pre-existing drainage depression in the older basalt, and onto the tufa. Such a disruption of drainage at the upstream end of the basin may have altered the hydrological conditions in the basin, perhaps reducing water flow across the floor of the basin and hence reducing the attractiveness of this landscape to hominins and their prey. Groundtruthing of the relationship between the basalt and tufa at this location was therefore a high priority (see below).

Unsupervised landscape classification of the Wadi Dabsa basin and its immediate surroundings using Google Earth imagery (RBG) produced three land surface classes related to the sedimentation conditions on the surface of the tufa, and seven classes corresponding to differences in the basalt flow surfaces (Figure 5). From satellite observations, these three tufa surface classifications were interpreted as corresponding to:

Red – bare surfaces composed of tufa;

Teal – bare tufa surfaces, but potentially more heavily weathered;

Bright Green – unconsolidated sediment, e.g. fluvial sediment along drainage channels; aeolian sediment on crests and slopes.

Field observations of these three classes resulted in the following additional information being recorded:

Red – tufa surfaces with very little or no sediment cover;

Teal – areas of tufa or sediment (but most commonly tufa) with a significant amount of basalt clasts scattered across the surface;

Bright Green – unconsolidated sediment, ranging from fined grained aeolian deposits, sandy to gravelly lag deposits overlying tufa, outcrops of grey silty material that has a buff-coloured wind-blown dust veneer, and alluvial sediment in shallow drainage channels and depressions.

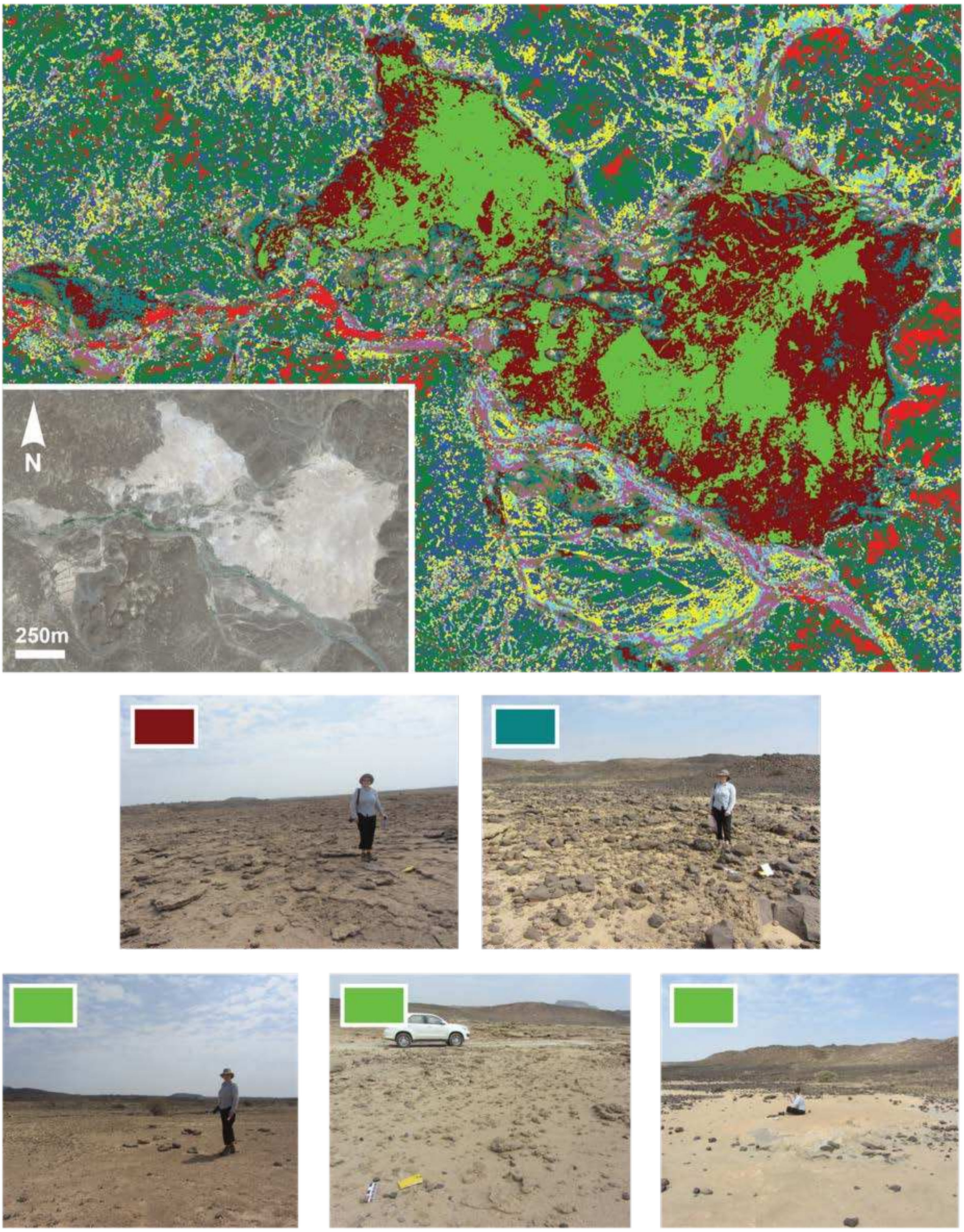

Figure 5: Map of surface sediment classes identified through the unsupervised classification of Google Earth imagery (Imagery © CNES/Airbus, Imagery date 19/01/2014, accessed through Google Earth) and photographs showing variability in surface sediment at locations used for groundtruthing.

The unsupervised classification of remotely sensed imagery therefore produced a largely robust distinction between areas of sediment cover on the tufa and areas of bare tufa, as well as identifying areas of tufa exposure partially covered by basalt clasts that had been interpreted from the satellite imagery as solely heavily-weathered tufa. These broad-scale distinctions were observed in particular on the landforms in the direct vicinity of grids L0106 and L0130, providing a robust method of medium-scale surface-cover mapping across the tufa, which will, after refinement through the field observations, guide future surveys of the tufa surface.

3.1.2 Field Observations

In the field, the lava flow surfaces were predominantly low-relief boulder fields. Basalt clasts ranged from cm- to metre-scale, showed signs of aeolian abrasion and thermal expansion weathering and were typically embedded silt and sand, deposited by aeolian or fluvial processes. On the basin floor, where many of these flows have been engulfed by later water-lain tufa deposits, only the uppermost surfaces were exposed as patches. The patches contained basaltic clasts within a loose matrix of yellowish brown silts and fine sands, and sparse coarser fragments (cm-scale) of siliciclastics (e.g. quartz granules) and tufa. The majority of basaltic clasts were vesicle-poor, with rare vesiculated clasts interspersed. Basaltic clasts of varying texture interspersed with other coarse grain clastic materials or isolated basaltic clasts distributed across the tufa deposits are suggestive of relatively high-energy sedimentation events affecting significant portions of the generally flat basin floor, e.g. sheet floods or debris flows.

Figure 6: General views across (a) tufa surface with variable sediment cover, looking east from the western edge of tufa exposure; and b) basalt fields with small sediment patches, looking north-east from basalt fields at the western edge of the study area.

Channels within the central/eastern portions of the basin exposed a number of basaltic units, clastic deposits and tufa structures. The basaltic units hinted at original, coherent lava flow structures such as colonnades, but in general showed a similar amount of erosion as basaltic material exposed on the basin floor. Further downstream, to the west of the main basin (Figure 4), weathered basalt with well-developed columns (~ 1 m diameter) and overlain by coarse clastics including metre-scale clasts of tufa and basalt, was exposed on the floor of the wadi.

A full assessment of the stratigraphic relationship between the F4 basalt flow and the tufa was hampered by aeolian sedimentation that covered much of the boundary between the tufa and basalt. However, at one location (WP5000) on the southwestern lobe of the F4 basalt flow (Figure 4), a small (c. 10 x 15 m) patch of tufa was observed directly overlying this flow (Figure 7), demonstrating that, at least at this location, tufa deposition occurred after basalt flow emplacement. Nowhere around the basin was tufa found underlying an *in situ* basalt flow, although the assessment of stratigraphic relationships around the margins of the basin was hampered by erosion of the edges of the tufa at the contact with the basalt, and the filling of these depressions with younger sediments of unknown provenance.

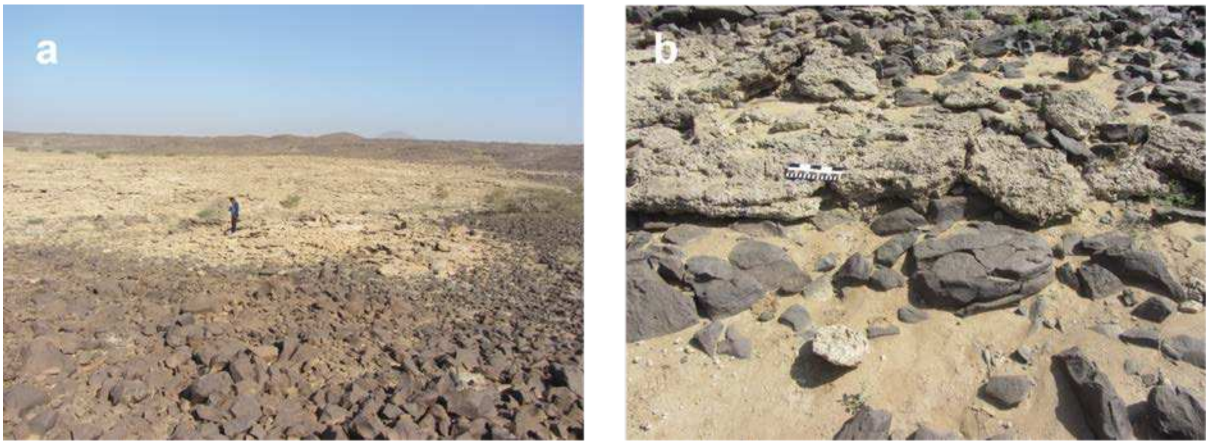

Figure 7: Tufa deposits overlying F4 basalt flow at WP5000.

3.2 Basalt Morphology in the Wadi Dabsa Basin

Seventeen samples of basalt were removed from around and within the Wadi Dabsa basin (Figure 4). In addition, eight further samples were collected from locations further afield in the Harrat al Birk, with a view to their dating providing a wider and broader understanding of the timing of development of Harrat al Birk (Appendix 2).

The basalts observed and sampled (Figure 8) were mostly fresh, with thin weathering rinds typically less than a few millimeters thickness and, in many samples, almost non-existent.

The groundmass phases of most samples were relatively fresh, with a micro-phaneritic texture and plagioclase rich. Vesicularity varied from 0% to >20% by volume, with most samples <5% vesicles and vesicle sizes of no more than a few millimetres. Phenocrysts were sparse, accounting for <2–3% by volume of most samples. Only two samples appeared to be aphyric. Olivine was the most prevalent phenocryst, generally 1–2 mm in diameter and displaying varying states of alteration, from minor (slight discolouration) to more extensive alteration to hydroxides/iddingsite, etc. Black, equant clinopyroxene was also present as a phenocryst phase, ranging up to 1 mm diameter but less common than olivine. One sample contained xenolithic and antecrystic fragments. The xenolith in this case (~ 1 cm long) appeared to be both silica- and volatile-rich, having partially melted to form a grey glass, strongly vesiculated within the basalt host. This same sample also hosted pyroxene+olivine glomerocrysts of a few millimetres diameter. A number of samples displayed formation of some alteration or secondary phases, typically lining vesicle walls with whitish or grey/blue minerals. In many of these types of samples, not all vesicles showed secondary mineral linings, suggesting that groundwater percolation through the samples was limited in extent.

Figure 8: Examples of basalt samples collected for $^{40}Ar/^{39}Ar$ dating at locations in Wadi Dabsa and the Harrat al Birk.

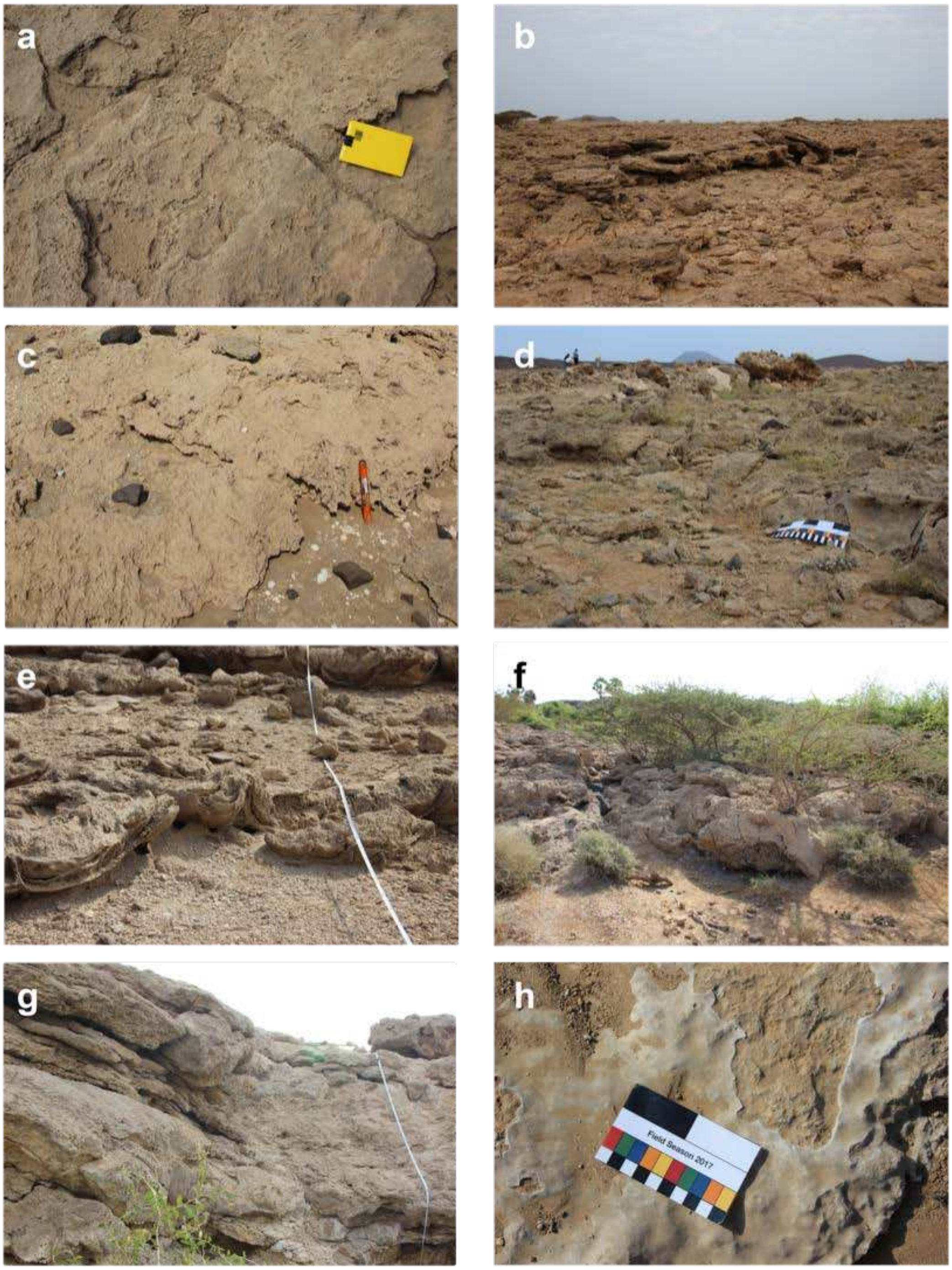

Figure 9: Tufa facies, where (a) is massive intact sheet, (b) is broken and dissected sheet, (c) pool-type with clear phytoherm framework, (d) heavily weathered former small barrage, (e) barrage cuspate forms, partly eroded, (f) tufa barrage in narrowing of channel, (g) cascade-type form, (h) crust or 'flowstone'-type.

3.3 Tufa Development in the Wadi Dabsa Basin

Tufa in the Wadi Dabsa basin comprises two sub-basins in the upper part of the valley and a fan-shaped deposit downstream of the basin in the west (Figure 4). At all identified locations, the tufa appears to overly, and therefore post-date, the emplacement of the basalt flows that have shaped the basin. The variety of morphologies present can be broadly categorised as massive sheets greater than 1 m thick that are sometimes intact and sometimes highly broken-up, pool-type deposits, fan-type deposits, fluvial barrages (both heavily weathered, low relief forms and larger preserved features in more constrained channels), fluvial cascades at larger breaks in the underlying topography, and crusts (or tufa flowstone) coating a variety of larger features (Figure 9).

The Wadi Dabsa basin floor, underlain by tufa, declines in elevation from ~124 m in the east to ~89 m at its westernmost extent. Drainage is consequently from east to west. A 220 m long incised section of the wadi marks the western boundary of the two main sub-basins, where the wadi flows through to the fan-shaped tufa deposits downstream of the main basin (Figure 5). However, the spatial pattern of tufa morphologies suggests that, in the past, water also flowed from north to south and/or NNE-SSW across the basin. This is demonstrated by:

- patches of sheet tufa overlying basalt at the highest elevations within the north-east alcoves in the two main sub-basins of the wadi;
- the northeast to southwest direction of slope of the broken massive sheet tufa at the southern end of the eastern sub-basin towards the incised wadi channel that skirts the southern edge of the basin; and
- thick (2 to 4 m) tufa-cascade morphologies on the northern banks of the west to east flowing wadi and its tributaries, most likely resulting from water flowing from north to south over a break of slope, possibly initiated by fluvial incision of the wadi.

Thirteen samples were collected from ten locations around the Wadi Dabsa basin, including three from within the artefact sampling grids (Appendix 3). The tufa upon which the L0106/130 artefact collection grids were situated are heavily eroded barrage morphologies, some of which provided material potentially suitable for dating. From the northwestern edge of L0130 grid, a tufa barrage complex extends in a NW direction down into an incised channel (Figure 10a–c). This complex is composed of six discrete former barrages separated by flat regions of gravel pavement, which are eroded to different degrees and range in size. The smallest at the top (Barrage 1) represents vertical break of slope of 5 cm, whilst the largest is Barrage 6, which itself is a complex of multiple prograding cuspate-shaped forms (Figure 10a). Sample WD Tufa 9 was taken from Barrage 4 (Figure 10e) and WD Tufa 11 from Barrage 6 (Figure 10d). Samples WD 12–14 were taken from locations on the L0106 grid.

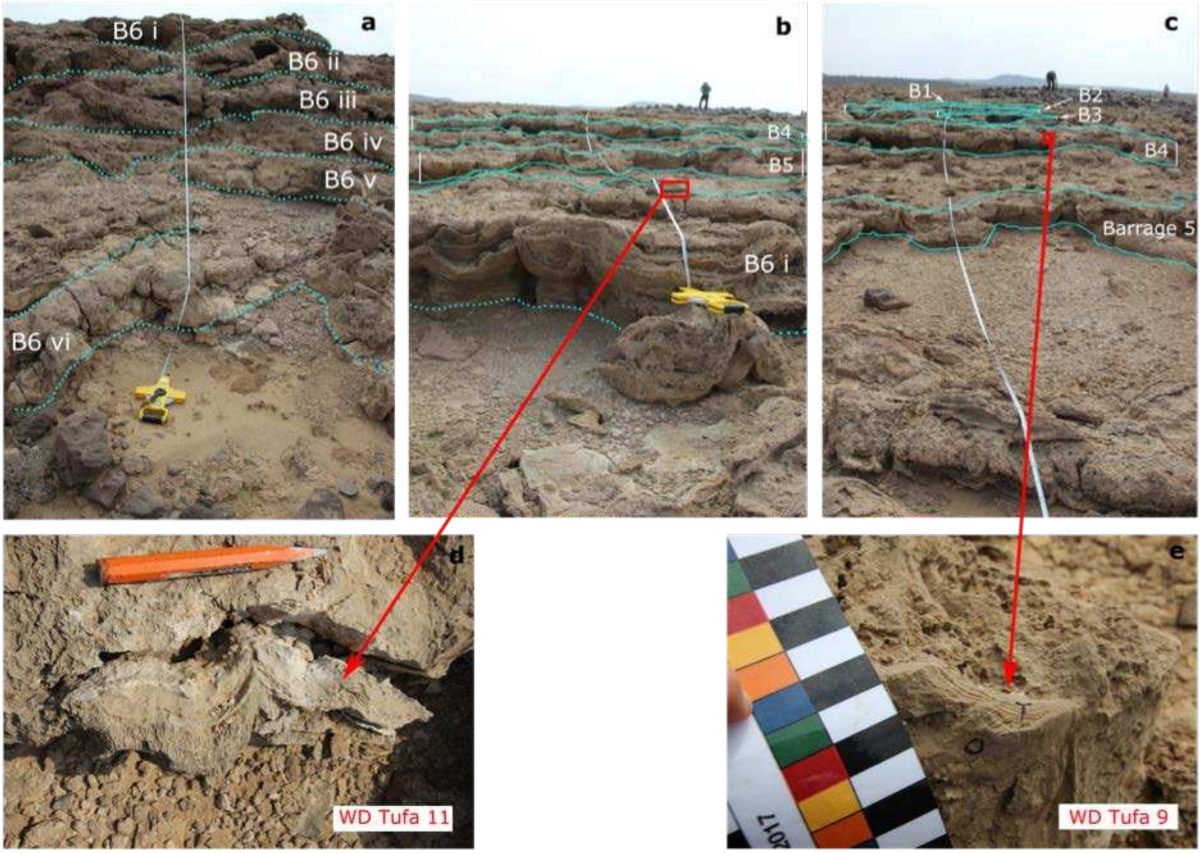

Figure 10: Tufa barrage complex, locates at NW edge of L0130 grid, illustrating location of samples WD9 and WD11.

3.4 Local Landform Mapping and Surface Condition Recording

The artefact survey grids are located on a small rise in the centre of the eastern part of the Wadi Dabsa basin, one of a number of tufa 'terraces' that rise in elevation to the north and east (Figure 3). The survey area is bordered to the south and southwest by a sandy drainage depression.

Six landform units were identified and mapped (Figure 11):

Ridge: This unit forms the highest part of the survey area, in the northwestern section of L0130, where it is characterised by the presence of a basalt outcrop consisting of rounded to sub-angular basalt boulders, cobbles and gravel. It also occurs as minor outcrops of basalt at the southeastern end of the spur in L0106 within the 'Crest' unit. In L0106, the surface between the basalt rocks is covered with fine to coarse, angular to sub-rounded, basalt gravel mixed with what looks like fine-grained pedogenic carbonate nodules (i.e., not tufa). In L0130, the surface between the rocks varies from this same carbonate gravel to silty sand.

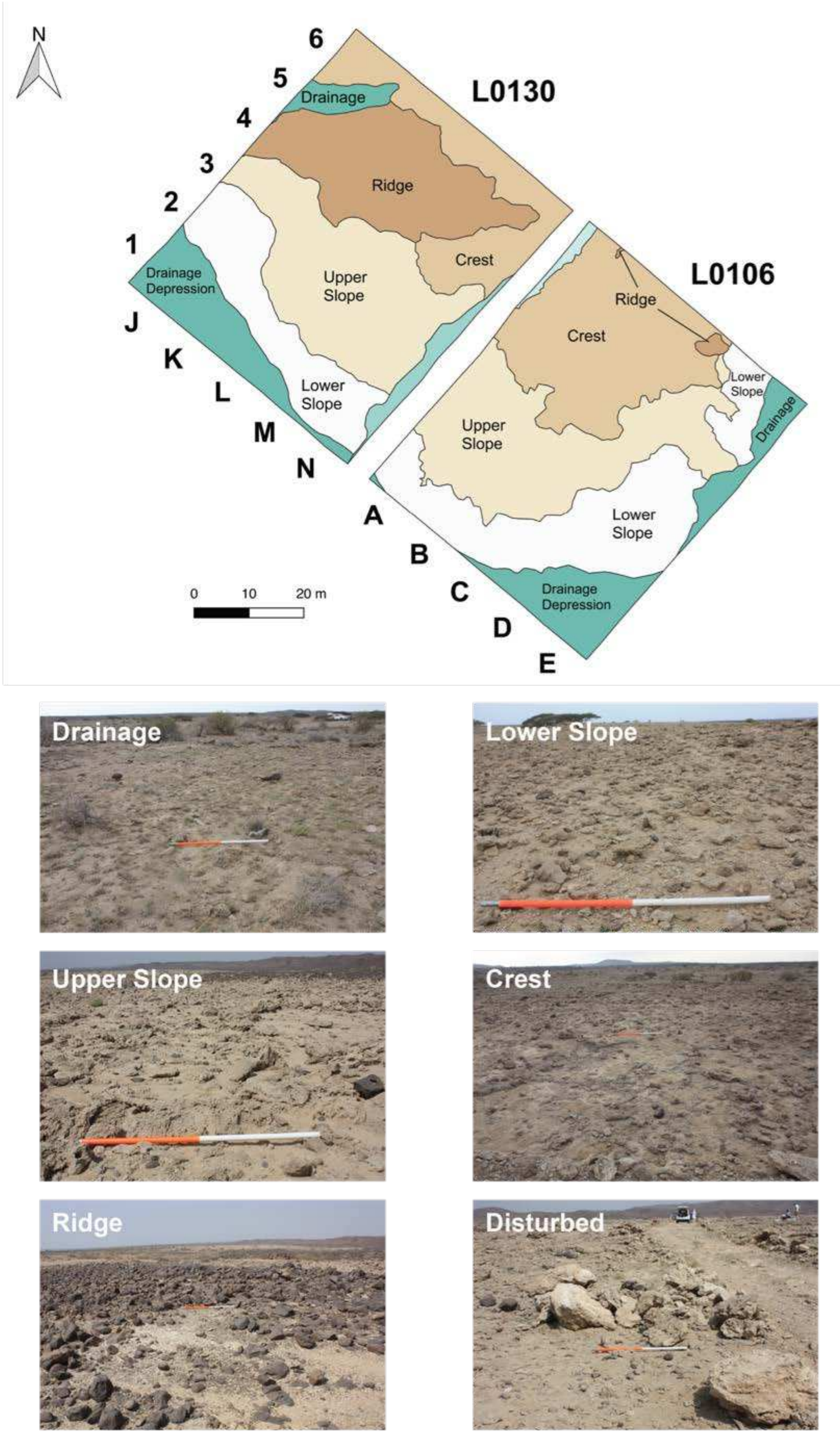

Figure 11: Map and photos of landform units across L0106/130.

Crest: This unit comprises the broad, flat surface of the northwest to southeast trending spur on which the L0106 and L0130 grids are located. The surface is mostly bedrock (predominantly tufa in L0106 and basalt in L0130), with patches of buff-coloured silty sand becoming more extensive to the northeast.

Upper Slope: This unit consists of a stepped or terraced surface across tufa bedrock outcropping on the southwest-facing slope of the survey area. The surface is mostly bedrock (tufa in L0106; tufa and basalt cobbles in L0130), with patches of sandy to gravelly sediment on the flat treads of the terraces.

Lower Slope: This unit comprises a low-angled footslope towards base of the southwest-facing slope of the survey area. The surface consists of tufa and basalt gravel and cobbles lying on sandy to gravelly sediment. Basalt gravel and cobbles are more abundant towards the northwestern boundary of L0130. Plant growth was present at the time of survey, but it was very sparse.

Drainage Depression: This unit is characterised by a relatively low-angled drainage depression bordering the survey area to the east, south and southwest. In the northeastern section of L0130, it takes the form of an eroding drainage line leading downslope from the crest to northwest. In the eastern corner of the grid in L0106, this unit consists of numerous shallow rills through sandy, gravelly sediment. Plant growth is more abundant in this unit than any of the others, indicating occasional water flow. At the south/southwest boundary of the grids, this landform unit has flatter topography and marks the distal margin of the drainage depression at the base of the southwest-facing slope. The surface here is covered with sediment, mostly buff-coloured silty fine sand. There are rare gravels and cobbles on the surface, and sparse plant growth. Shallow distributary rill channels indicate that water flows across this surface from time to time.

Disturbed: This unit comprises narrow strips of land on either side of the unsealed track that separates L0106 from L0130, where track construction has disturbed the original surface, and inverted and redeposited large boulders of tufa.

Surface condition observed in the surveyed quadrants (Figure 12), were, in general, consistent with the characteristics of the wider landform units: sandy sediments are ubiquitous in all quadrants within the Drainage Depression landform unit; the Lower Slope unit quadrants consisted of varying amounts of tufa and basalt clasts overlying unconsolidated sediment, with the occasional *in situ* tufa exposure; and quadrants within

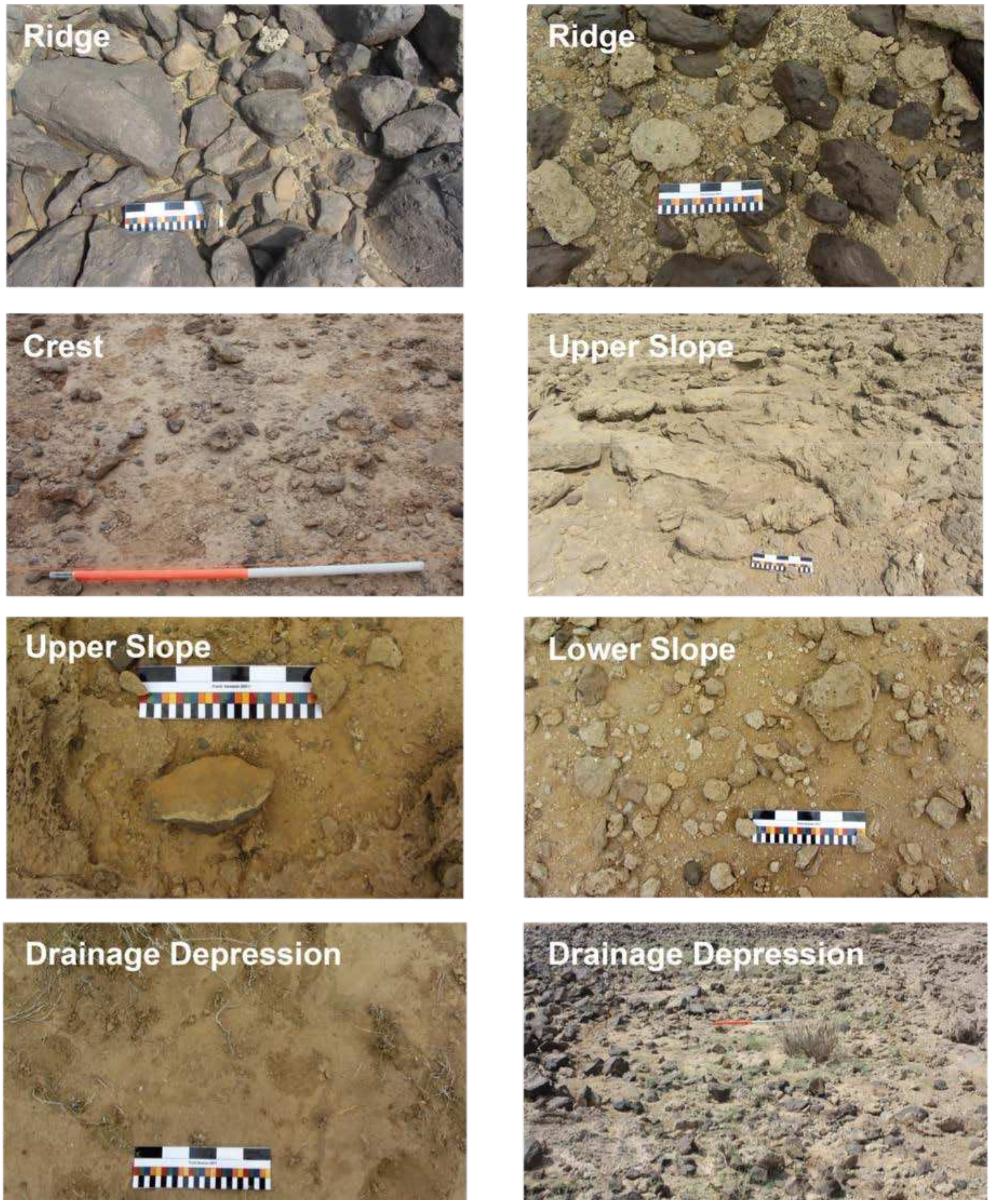

Figure 12: Examples of varying surface conditions across the L0106 and L0130 grids, showing in some cases the variability of surface conditions within landform units (Ridge, Upper Slope, Drainage Depression).

the Crest landform unit were predominantly sediments covered with a deflated lag of clasts comprising artefacts, tufa and basalt, with quadrants close to the Disturbed landform unit displaying an increase in sandy sediments. The greatest variation in surface condition was observed in the Upper Slope landform unit, where quadrants contained widely varying percentages of bare, *in situ* tufa and sediment pockets with similar characteristics to those observed in the Crest unit. These observations therefore illustrate that, within landform units, there is still significant variation in lithology and active geomorphological processes that affect the preservation, exposure and visibility of surface artefacts.

3.5 Spatial Distribution of Surface Artefacts

Over two seasons of fieldwork, 2847 lithic artefacts have been collected from grid L0106. In 2015, 909 artefacts were collected from Rows 1 to 4; a further 1938 artefacts collected from Rows 5 and 6 in 2017. A further 399 lithic artefacts have been recorded but not collected from the accompanying grid L0130. Given the time constraints for the survey and recording of material in grid L0130, this assemblage is likely to represent a small proportion of the artefacts that might be present in this grid.

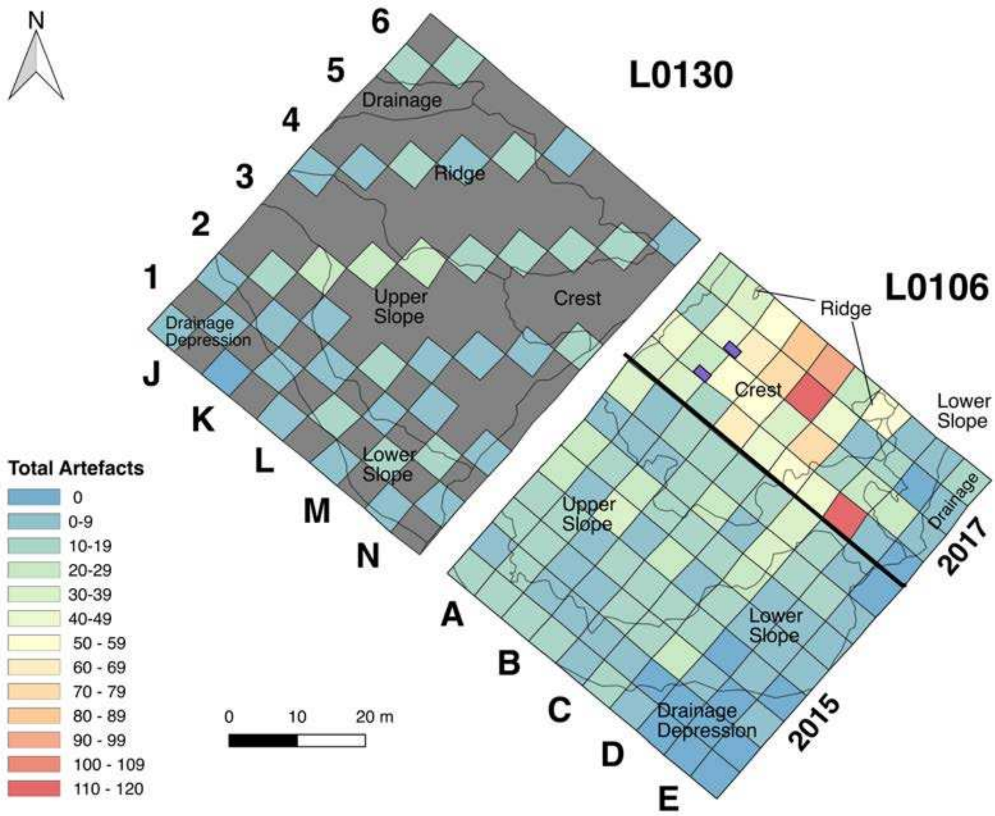

Figure 13: Spatial distribution of artefacts counts and landforms across L0106/130 grids.

In L0106, the mean number of artefacts per quadrant recorded across the surveyed quadrants is 23.7 (0.94 artefacts / m^2), and there is a clear increase in numbers of artefacts per quadrant towards the northeast edge of the grid (Figure 13), with some quadrants in Rows 6 and 5 containing over 80 artefacts each (>3.2 artefacts / m^2). These quadrants are located on the flattest part of the Crest landform unit, although 5Dz, the quadrant with the second highest observed lithic count, is within the Upper Slope landform unit. As shown in Figure 13 the highest artefact densities are found on the landform units with the highest visibility surfaces (i.e., Crest and Upper Slope) while the lowest densities are found on the landform unit with the lowest visibility surface (Drainage Depression).

3.6 Excavation and Artefact Condition

Two small test pits were excavated on the Crest unit to determine the relationships between the surface artefacts and the underlying sediments and bedrock. Two sediment layers were observed, a buff-coloured silty fine sand layer of variable thickness (~10 cm) overlying, with a clear boundary, a layer of grey silty fine sand, with an abrupt lower boundary with the tufa bedrock beneath (Figure 14a). Both units contain clasts of both tufa and basalt, and lithic artefacts made on basalt. The similarity of the field texture of the two layers, but difference in colour, suggests that the buff layer may be a layer of active accumulation by aeolian deposition, while the grey layer may have had the same origin (i.e., aeolian deposition) but with accumulation of organic matter perhaps producing the grey colour. Samples of both the buff and grey layers were collected for further analysis in the lab.

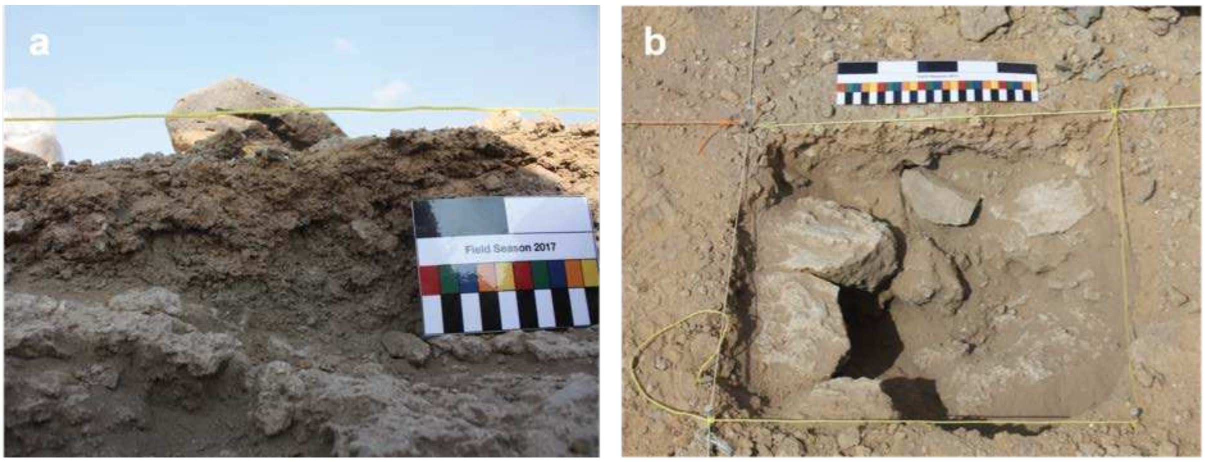

Figure 14: a) Test Pit 1, Quadrant 6By, showing sharp lithic artefact within grey unit; b) stratigraphy in Test Pit 2, 5Az, showing grey silty sand layer overlain by buff layer

In one pit, an artefact was found lying on top of the tufa, within the lower of the two sediment units (Figure 14b). Artefacts within this unit overly, and therefore postdate, the tufa. Artefacts from the grey layer exhibited a greyish patina and very sharp edges, suggesting rapid burial following manufacture and discard, while those in the buff layer exhibited weathering states ranging from fresh (i.e., grey and sharp) to a dark brown colour close to the colour of the basalt outcrops in the grids, with a slightly polished patina and subangular to subrounded edges (Figure 15). The latter characteristics suggest a period of exposure at the surface after manufacture and discard.

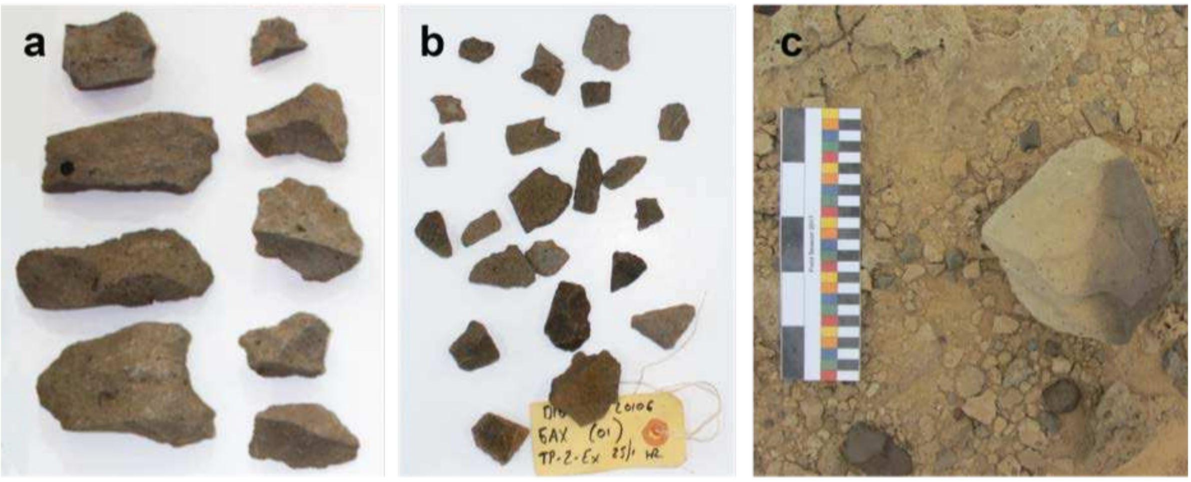

Figure 15: Different patination states for basalt artefacts at L0106: (a) grey, sharp artefacts from lower 'grey layer' of test pit; (b) mixed grey/sharp and brown/polished artefacts from 'buff layer' of test pit; (c) surface artefact (core) exposed on previously-surveyed 2015 grid showing differential patination/weathering.

This variation in patina shown in the buried artefacts is the same as that observed in the surface assemblage: the vast majority of the artefacts collected and observed in the 2015 and 2017 surveys were dark brown, some with a slightly polished appearance, although with still distinct flake scars. Others were either completely grey with sharp edges, or exhibited both patinas and grades between them (Figure 15).

The observations from the test pits suggest that artefacts contained within the Crest unit may, after manufacture from the local basalt, have developed a grey patina during burial in the grey unit. Exposure of these artefacts on the surface by deflation of the fine-grained sediments in which they were buried then allowed the grey patina to be weathered and removed, either physically through the polishing effect of aeolian erosion or chemically through oxidation, or a combination of both processes. It is therefore possible that the surface artefacts were originally all buried within the grey sediment unit. During the 2017 fieldwork, numerous artefacts were observed on the surface of the quadrants that had been surveyed and fully collected in 2015. While it is possible that these artefacts were missed in the original survey, given that most of these artefacts exhibit variable patina conditions it is also possible that they have become exposed by deflation since the 2015 survey. In addition, some may have moved downslope from the as yet uncollected Rows 5 and 6 between 2015 and 2017.

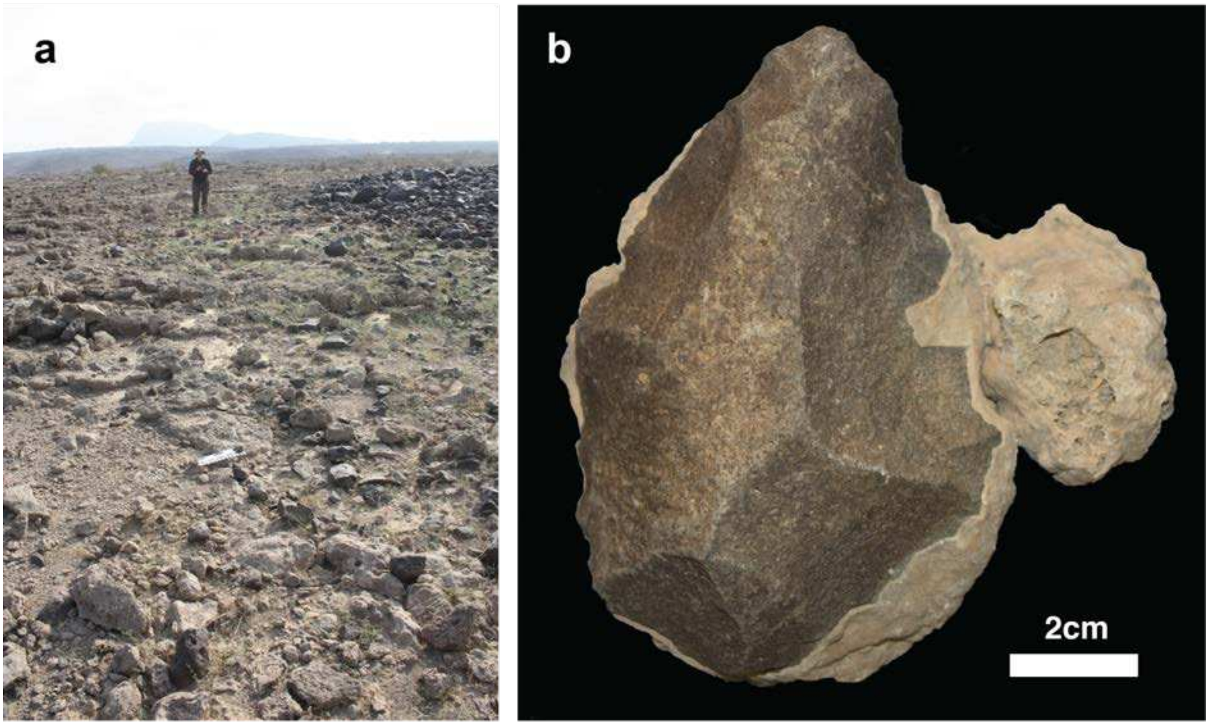

Figure 16: Tufa-encased handaxe found on L0130 grid showing a) location of the findspot in L0130, Quadrant 5Jw, where the handaxe was found as a loose clast on the Drainage Depression landform. Handaxe is just in front of scale, which is 30cm; b) tufa-encased handaxe, dorsal view.

The probable burial of artefacts within the grey unit identifies their deposition as post-dating tufa formation, as the grey unit overlies them, yet it cannot be dismissed that some artefacts may never have been buried in this grey layer, but had a different relationship to the timing of tufa deposition in the basin. A single find from the L0130 grid suggests a different relationship between the artefacts and tufa deposition: in Quadrant 5Jw, a basalt handaxe partially encased in tufa was found on the edge of a small rill that drains the NW corner of L0130 (Figure 16). While the find was a loose clast, and removed from the geomorphological context in which it developed the tufa coating, it illustrates that a period of tufa deposition occurred after manufacture of at least some of the artefacts. The tufa therefore has the potential to provide a minimum age for the handaxe. Detailed analysis of samples of the tufa will be undertaken at the NERC Stable Isotope Facility at the British Geological Survey, Keyworth, and the Department of Geography, Royal Holloway University of London.

3.7 Lithic Analysis

The artefact assemblage from Wadi Dabsa is the largest assemblage collected and recorded from southwestern Saudi Arabia by the UK-Saudi fieldwork team; it is more than twice as large as the other major collection from the Wadi Dhahaban (Inglis *et al.*, 2014a, b).

In broad terms, the assemblage comprises artefacts and manufacturing debris that can be typologically assigned both to the ESA and MSA on typological and technological criteria, with some limited potential evidence of artefacts from a later time period as noted below. As might be expected from the abundantly available basalt deposits surrounding the site, the artefacts at Wadi Dabsa are overwhelmingly made on the locally available raw material either sources as naturally exfoliated basalt flakes or collected in the form of rolled cobbles. The quality of the material used varies from a fine-grained, dense and homogeneous basalt through to a less dense material with a greater proportion of vesicules. Just five artefacts collected from Grid L0106 are not made from locally-available volcanic materials; these include two pieces each of chert and of quartz and one piece of indurated shale. The size, presence of retouch and typological form of these exotic pieces suggests that they may date to the LSA in this region and represent tools brought from outside the basin to the site.

The assemblage from Grid L0106 contains artefacts from all stages of lithic reduction (Table 1) including tested clasts, cortical and semi-cortical flakes, cores and core-preparation materials, retouched pieces and a large number of shatter fragments attesting to the flaking of basalt at this location. A large number of cores show working that is both carefully prepared as well as relatively expedient and simple (Table 2). The assemblage even includes a small number of probable hammer stones. In addition to the evidence of lithic manufacture, there are more than 280 retouched pieces which include a range of classic retouched forms from the ESA/Acheulean as well as the MSA whose forms indicates a range of activities that might have been undertaken at the site, and in certain cases the preparation of armatures for use elsewhere (Table 3). A selection of exemplar artefacts is presented below (Figure 17).

The assemblage recorded but not collected from L0130 is, as noted above, smaller in number and almost certainly missing the not easily spotted pieces. Despite this, the range of technological pieces as well as retouched pieces suggests that the assemblage in this grid closest mirrors that from L0106 both in chronological periods and the range of technological activity; there is evidence for a range of ESA and MSA tool forms as well as a similar range of manufacturing activities.

Technological Type	**L0106 Frequency**	**L0130 Frequency**
Flakes		
Cortical Flakes (Cortex = 100%)	82	49
Semi-cortical Flakes (Cortex > 50%)	56	6
Semi-cortical Flakes (Cortex < 50%)	40	13
Semi-cortical Flakes (Cortex < 20%)	22	
Flakes	652	68
Prepared Core Flakes		
centripetal	85	34
convergent	86	11
lateral & directional	20	
lateral & mixed-directional	20	
flake blades	90	29
shattered	18	
True Blades	7	
Bladelets	4	
Biface Trimming flakes	21	1
Burin Spalls	2	
Tranchet Flakes	6	
Retouched pieces	282	54
Cores		
Cores (whole)	228	76
Core (fragments)	19	
Core rejuvenation flakes	12	
Prepared-core preparation flakes	312	34
Shatter	698	
Indeterminate (including tested clasts)	81	11
Hammer Stones	4	5
Ceramic		8
TOTAL	**2847**	**399**

Table 1. The frequency of different technological types from Wadi Dabsa (L0106 & L0130).

Chronological Period	**Core Form**	**L0106 Frequency**	**L0130 Frequency**
Early Stone Age	*Discoidal cores*	26	22
Middle Stone Age	*Centripetal-prepared core*	57	12
	Convergent-prepared core	42	1
	Prepared-core preform	5	
Not-chronologically determinable	*Single-platform cores*	49	10
	2-platform cores	29	5
	Globular cores	6	23
	Cores on flake	33	3
TOTAL CORES		**247**	**76**

Table 2. The frequency of core types within the assemblages recorded at Wadi Dabsa (L0106 & L0130).

Figure 17. The lithic assemblage collected from Quadrant 6Bz (L0106). The top rows of artefacts include large ESA flakes, as well as early-stage decortification flakes for the preparation of prepared cores. The second and third row include prepared core flakes, including a convergent flake and a flake blade, as well as prepared core preparation flakes for both the upper and lower surfaces. The final two rows include small platform preparation flakes as well as examples of shatter pieces that detach from the core during working.

3.7.1 ESA/Acheulean Elements at L0106

Approximately 25% of the retouched tool collection comprises pieces that can be ascribed to the ESA/Acheulean on typological grounds. This includes a number of bifaces (42 examples), cleavers (ten examples), choppers (six examples) and a collection of large cutting tools (38 examples). Most of these tools have been relatively simply retouched using the minimum number of retouch flakes to create a functional tool shape. There is evidence to suggest that at least the final stages of biface making took place at this site through the presence of a collection of clearly identifiable biface trimming flakes (22 examples) within the assemblage, and a small number of tranchet flakes (six examples) used to sharpen the edge of these tools.

3.7.2 MSA/Prepared Core Technology at L0106

The clearest evidence for the use of this locality in the MSA takes the form of the extensive collection of prepared core forms (both centripetal- and convergent-prepared: 69 examples and 43 examples respectively), a number of core preparation flakes (346 examples), and the intended prepared core flakes themselves, again in both centripetal and convergent forms (119/97 examples respectively). In addition to these forms, there is also a large number of flake-blades produced either as lateral blades on centripetal cores or as flake clades with clear central ridges (119 examples). Finally, there are a small number of true blades and bladelets deriving from prismatic blade cores, possibly of MSA age, or younger (7/4 examples).

Within the extensive collection of convergent prepared core flakes, some flakes have been retouched into point forms (11 examples), and a small number of fragmented convergent flakes and points suggested that some had been hafted and then broken in use, with the fragments removed from the hafts at the site and then refitted with new point forms. A small number of the convergent flakes and point forms also show evidence of probable impact fractures at the tip, further supporting their use as weapons. Finally, a number of borers or piercers (33 examples), both large and small, as well as burins (13 examples) indicate the likely working of softer materials such as wood or skin.

Retouched Type	**L0106 Frequency**	**L0130 Frequency**
Chopper	6	
Core Tool	11	
Biface	34	8
Pic	7	
Cleaver	4	6
Large Cutting Tool	30	8
Backed Knife	6	4
Point	10	1
Bitruncated Piece	3	
Notch	19	6
Denticulate	10	
Burin	13	
Borer / Piercer	30	3
Scrapers		12
Side	36	
End	21	
Convex	9	
Transverse	4	
Convergent	1	
Concave	1	
Splintered Piece / wedge	3	
Indeterminate	24	6
TOTAL	**314**	**54**

Table 3. The frequency of different retouched pieces recorded at Wadi Dabsa (L0106 & L0130).

3.7.3 Potential for Further Analysis

Despite the predominantly surface-collected nature of the assemblage, and the attendant problems of palimpsest formation, in contrast to all the sites previously encountered through field survey, the Wadi Dabsa assemblage presents a great opportunity to understand in detail the processes of lithic manufacture for both ESA and MSA time periods. Specifically, the abundance of locally available raw materials, along with the presence of manufacturing debris from the earliest stages of material acquisition, through core preparation, use and maintenance of both cores and finished products offers a, so-far, unique opportunity in the region to reconstruct in detail the process of manufacture and the range of expertise present at the site.

Taking the cores as an example, there are 247 cores so far collected from the site, approximately 10% of the collected assemblage (Table 3). Many of these cores display similar patterns of working to cores and tools encountered at other sites: short episodes of working of through either one or two episodes of parallel flaking (single platform and 2-platform cores – 78 examples). There are also a significant number, however, of cores designed for longer episodes of exploitation either as ESA discoidal cores (26 examples), or as MSA prepared cores (104 examples) in wither centripetal or convergent forms with the former producing flakes suitable for later working into scrapers, and knives and the latter producing flakes suitable for hafting as weapon points. The abundance of prepared core forms makes it possible to explore whether the prepared-core technology of Wadi Dabsa conforms to the Nubian technique of prepared core manufacture as seen at other sites in Arabia and identified as a form of technology that may help in the identification of the processes of hominin dispersal (see Rose *et al.,* 2011; Hilbert *et al.,* 2017 and references therein).

Moreover, there are signs of a clear disparity in the quality of preparation amongst the prepared cores, possibly reflecting different levels of lithic manufacturing expertise amongst hominins at the site. As noted above, prepared cores require an understanding of the balance between the volume and shape of raw material above and below a central level within the core (Boëda, 1995). These volumes must be carefully prepared in the working of the raw material from initial 'block' through to core, hence the term prepared-core. This requires a sequence of flakes to be removed as both upper- and lower-surface preparation flakes. With the removal of each preparation flake, there a chance that the intended flake will not detach smoothly leaving a future 'problem' in the core (for example a step-fracture on a flaking

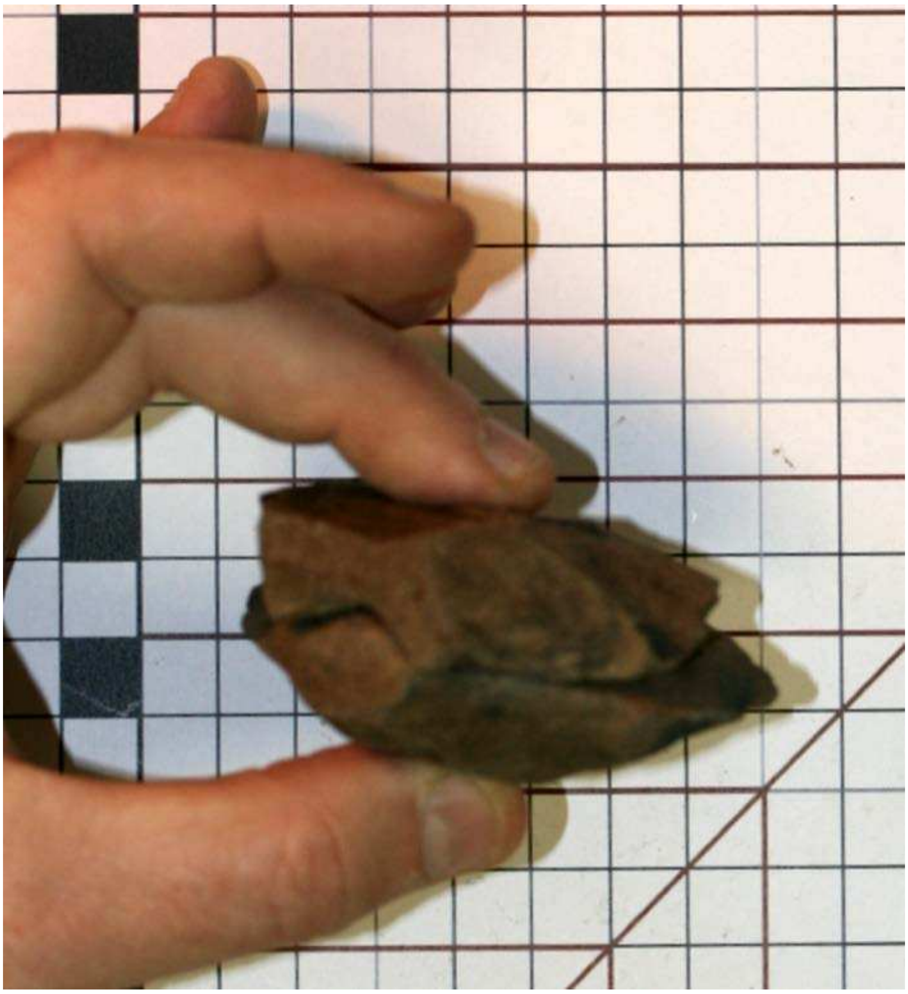

Figure 18. An example of two prepared core flakes that refit at the butt end. The upper flake in this picture has been further retouched around the distal end and no longer fills its negative flake scar

surface that prevents further preparation of the flaking surface unless removed) that must be worked around if the core is to be prepared for the successful removal of the intended flake form. Amongst the prepared cores at Wadi Dabsa, there are examples of cores that have been successfully prepared (both centripetal and convergent), and re-prepared (maintained) for the detachment of flakes of a designed shape. There are also cores that demonstrate a clear understanding of the appropriate strategy for creating centripetally-prepared cores whilst at the same time demonstrating a lack of the practical skills necessary to work around the errors produced in core preparation. The opportunity of reconstructing some of this process of working is suggested by the presence of two refitting flakes identified by chance in the analysis of the lithic assemblage collected in 2015 (Figure 18).

4. Discussion

4.1. Evolution of the Wadi Dabsa basin

Fieldwork at Wadi Dabsa clarified the preliminary desktop mapping of landscape units using remote sensing data, and provided a solid framework to begin to interpret the artefacts we recorded from the basin within a dynamic landscape context.

The regional landscape mapping had suggested that the basalt flow F4 at the eastern end of the basin may have post-dated formation of the highest elevation tufa, thus potentially providing a minimum age for tufa deposition, and also a potential mechanism by which tufa formation may have been interrupted by blockage by basalt of the pre-existing drainage system. The observation we made of tufa overlying part of the northwestern boundary of this basalt flow, however, shows that tufa deposition post-dated the emplacement of the flow and, in the absence of any further field evidence showing basalt emplacement over tufa, indicates that tufa formation, at least in this part of the basin, occurred more recently than the youngest basalt flow. This sequence, of tufa overlying basalt, is repeated over the entire basin, especially in the incised wadis, and indicates that the tufa was forming in, and filling, a basin whose underlying morphology was controlled by the basalt flows. It is likely, however, that there was more than one phase of tufa deposition in the basin, and that deposition of tufa and basalt may well have overlapped. The absolute dating of the tufa and basalt flows should test this hypothesis.

It seems likely that the input of water and dissolved $CaCO_3$ into the Wadi Dabsa basin has both a surface water and a groundwater component, although the balance between the two requires additional investigation within the region. It is also likely that the $CaCO_3$ is ultimately derived from the limestones and shales of the Asir Mountains, approximately 60 to 80 km to the east of the survey location, and that Ca might also be derived from the weathering of the mafic basalt at, and surrounding, the site. Clarification of carbonate source should be resolvable in future using $^{87}Sr/^{86}Sr$ isotopic ratios of the carbonate. The possibility of a groundwater component in tufa formation in the Wadi Dabsa basin is supported by the following observations:

(i) It was observed that the east-west flowing wadi to the south of the artefact survey area has no visible tufa deposits, whereas the deeply incised wadi channel between the basin and the downstream fan contains extensive, thick tufa deposits;

(ii) Many of the tributary wadis on the eastern margin of the basin do not contain tufa deposits;

(iii) The higher elevation tufa deposits in the northeast sections of the two sub-basins occur where there is no obvious fluvial channel input. It is possible, however, that the basalt lava flows in these areas have infilled and cut off former fluvial channels, so that drainage is now via shallow groundwater and perhaps even in the unsaturated zone through the basalt flows. Channels may also have incised below the level of the uppermost tufa. Vertical boreholes drilled through the floor of the basin would help to clarify these issues.

4.2 Geomorphological Context of the L0106 & L0130 Artefacts

Observations from the 2017 field season have revealed a complex relationship between the artefacts and tufa formation. The tufa-coated handaxe discovered on the northeastern side of Grid L0130 shows that a period of tufa deposition occurred after manufacture and deposition of the artefact. Yet in the test pits excavated in Grid L0106, artefacts appear to lie within a sediment layer directly overlying the tufa, suggesting that deposition of the artefacts post-dates the formation of the tufa. Such variability in tufa-artefact relationships is, however, unsurprising given the potentially long time span of activity represented by the presence of ESA, MSA and LSA artefacts at the site, and the evidence we have so far for complexity of tufa formation within the basin. The lithic artefact assemblages and the tufa are probably both the product of multiple phases of human activity and tufa deposition across the basin, phases that potentially occurred over extended periods of time.

The stratigraphy of the test pits, and the observation of new artefacts found exposed on the previously collected areas of the L0106 grid, suggest that at least some of the artefacts at L0106 were buried within a silty sand layer that overlies the tufa that was subsequently deflated by wind and water erosion, exposing these artefacts to weathering and erosion at the surface. The origin of this layer is currently unknown – it may be a remnant of a soil that formed on the surface of the tufa. Elsewhere in the basin, a greyish silty sand material was observed underlying tufa structures, again highlighting the complexity of tufa formation and its subsequent weathering and erosion.

The presence in 2017 of numerous artefacts on the area of L0106 that underwent full collection in 2015 may be the result of one of two possibilities. Either, they were missed in the original survey, or they have become exposed since that survey. A number, but not all, of these artefacts are patinated, indicating their recent exposure. Late 2016 saw heavy rainfall in the region which may have intensified deflation of the artefact-containing sediments, primed perhaps by the 2015 team members disturbing a previously stable surface by trampling it during survey. A similar situation was observed by one of us (PCF) at semi-arid field sites in western New South Wales, Australia (Fanning *et al.*, 2009). The increase, however, is of an order of magnitude, and the distribution of artefacts across the landforms units surveyed in 2017 still shows patterning consistent with the rest of the grid, indicating that this variation is not simply an artefact of observing the distributions before and after a two-year hiatus.

Geomorphological mapping and observations of the artefact distributions across the grids has allowed the examination of whether the artefact distribution at the grid scale is influenced by geomorphic processes that control the preservation, exposure and visibility of artefacts. There are low counts of artefacts on the landform units most likely to exhibit surface conditions that inhibit the visibility of artefacts, such as the Drainage Depression unit and, to some extent, the Lower Slope unit, with its mix of fine sediment and large clasts.

The relatively high density of artefacts recorded within the Crest landform unit which has abundant sediment cover and therefore, theoretically, low artefact visibility, is an example of how the interplay between preservation and exposure of artefacts is key to where artefacts are observed. The Crest is the landform unit that preserves the greatest extent of the artefact-bearing sediment layer. The low relief of the landform means that, while there is active deflation occurring across the surface, it is the fine-grained sediments that are being eroded. The larger clasts, including the artefacts, are not moving very far laterally, if at all, but instead form a 'pavement' or 'lag' of clasts on the land surface in which the visibility of artefacts is high. The stepped nature of the 'Upper Slope' unit mirrors this situation, with the flatter areas behind the bare tufa ridges and barrages exhibiting a similar 'pavement' where sediment is preserved, and containing slightly higher counts of artefacts than the quadrants with a predominance of bare tufa. The tufa ridges, in contrast, are environments in which artefacts on the surface, are susceptible to downslope movement because of their exposure on irregular or sloping surfaces. This mixture in artefact preservation and exposure across the two different types of surface condition within the 'Upper Slope' landform unit explains why the artefact counts within this landform lie between those of the Lower Slope unit and the Crest unit. Testing of these models in the L0130 grid is not really possible given the rapid survey that was undertaken there in comparison to the full collection carried out in L0106. In addition, the surveyed squares did not intersect the Crest landform unit in this grid.

4.3 The Wadi Dabsa Lithic Assemblage in Techno-Typological Context.

The assemblage from the Wadi Dabsa comprises a mixture of ESA/Acheulean pieces including a collection of bifaces, large cutting tools and cleavers, as well as an extensive range of MSA/Middle Palaeolithic pieces including both an extensive collection of manufacturing debitage as well as retouched pieces. All of these materials appear to be made on locally available volcanic rocks, that can be accessed, at present, both at the site itself and throughout the Wadi Dabsa basin. In a similar fashion to sites examined elsewhere in southwestern Saudi Arabia, the abundance of locally available raw materials would appear to have created a situation in which hominins did not need to maximise the efficiency with which they used materials. As a result, many of the pieces are simply retouched with just the working tips of bifaces, for example, finely retouched to produce rectilinear edges and the buts remaining often either cortical or very simply retouched. There are a few examples of lithic materials that are not obviously occurring in the local basin (including quartz, chert and indurated shale) and these pieces also show greater preparation and retouch. It seems likely at the moment that these pieces represent the discard of later, post MSA hominins. Likewise, there are a few examples of tool types (endscrapers and burins) that are normally associated with Upper Palaeolithic assemblages in Europe, although such tools have been found in MSA assemblages in Africa.

Looking beyond the Wadi Dabsa basin, the lithic assemblage itself contains pieces that are similar to examples found during the course of the fieldwork by the UK-Saudi team since 2013, but the quantity and, specifically, the quality of the technological information present at Wadi Dabsa is more extensive and complete in sequence than at any other site located so far. The variability in evident skill among the examples of prepared cores also suggests that the assemblage represents a cross-section of ages and experience in lithic manufacture; this is unique to this site.

5. Summary and Conclusions

The January/February 2017 field season in Wadi Dabsa, Asir Province, Saudi Arabia, achieved the stated objectives and provided a wealth of information on the Palaeolithic artefacts and their geomorphological and geological setting.

Objectives achieved

1. Remote sensing and satellite data, groundtruthed by field observations, proved invaluable in the definition of landscape units within the wider basin, the development

of sampling strategies, and the understanding of sediment cover across the basin and its potential to impact on artefact visibility.

2. Geomorphological survey of the locality and its direct environs, with specific focus on the tufa deposition and basalt, allowed the development of hypotheses regarding the landscape setting of L0106/130, and geomorphological controls on the preservation, exposure and visibility of the artefacts in the wider landscape. Detailed landform and surface mapping of the collection grids themselves furthered the understanding of artefact distribution at the locality and the geomorphological controls acting upon it.
3. A total of 1938 Palaeolithic artefacts were collected from the 20 x 50 m extension of L0106, with a further 399 lithic artefacts recorded in situ across L0130, comprising a recorded assemblage over the two seasons of 3226 artefacts, many of them with ESA or MSA affinities, one of the richest Palaeolithic assemblages so far recorded in SW Saudi Arabia.
4. Comprehensive post-excavation analysis of the artefacts collected from L0106, coupled with the *in situ* recording of the L0130 artefacts, has allowed the assemblage to be considered in relation to those from neighbouring regions.
5. Excavations of two small test pits and the discovery of a handaxe encased in tufa have indicated a complex relationship between the artefacts and tufa deposition, perhaps resulting from the extended period of time spanned by the activity at the site (suggested by the techno-typological characteristics of the artefacts) and/or multiple phases of tufa deposition.
6. Samples for both ^{234}U–^{230}Th dating of tufa and $^{40}Ar/^{39}Ar$ dating of basalt lava flows were collected from locations in the Wadi Dabsa basin and further afield to provide a future chronological framework for the development of the basin and the archaeology within it. The tufa samples will also potentially provide, through isotopic analyses, high-resolution snapshots of palaeoenvironments in the basin.

The 2017 field season, whilst very successful in achieving its stated objectives, has only just begun to realise the potential of the Wadi Dabsa basin for informing on ESA and MSA hominin behaviour. The geomorphological work at the site, particularly the mapping and sampling of the tufa, has proven its complexity, and indicated that there is much more to be done in terms of survey to understand the geomorphological controls and landscape context of the archaeology of this region.

Future work in the Dabsa basin must focus on two main issues. The first is the further understanding of the timing and conditions of tufa deposition within the basin. Detailed mapping using high-resolution remote sensing and field observations, coupled with detailed stratigraphic and microscopic analysis of the tufa facies should be used to unravel the nature and sequence of the depositional environments. This stratigraphic framework, along with the data from the pilot isotopic analyses and ^{234}U–^{230}Th dating programme from the 2017 samples, would then be used to target further palaeoenvironmental investigation, and chronological constraint of, the tufa deposition in the basin.

The second area is the expansion of the surveyed areas to further understand the L0106/130 assemblage in the context of the artefact distributions across the basin – is the density of artefacts at this location unusual, and if so, why might there be a concentration of artefacts deposited or preserved here? The 2015 transects, considered along with the low density of artefacts observed during geomorphological investigations across the basin, indicate that the number of artefacts at L0106/130 is unusually high. Further archaeological investigation of similar geomorphological settings to this assemblage around the basin, targeted through detailed geomorphological and tufa mapping, however, should be carried out to confirm that it represents an unusually dense concentration of artefacts, in order to understand the potential for the assemblage to inform on human activity at this location.

6. Official Meetings

During our visit to Saudi Arabia, members of the team carried out a number of official meetings. Professor Geoff Bailey presented the work of the team and future plans to HRH Prince Sultan Bin Salman bin Abdal Aziz at a meeting at the SCTH in Riyadh on 16th January. Members of the team attended an audience with HRH Prince Faisal bin Khalid bin Abdul Aziz Al Saud in his offices in Abha, Asir province on 1st February, where they presented information about the project which was received with great interest. In addition, members of the team met the Mayor of Al Birk, in his offices in Al Birk to provide information on our work and highlight the cultural potential of the area to thank him and the various government departments for their extensive logistical support towards our research activities in the region.

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Appendix 1: Field Team

Dr Robyn Inglis, University of York, UK

Prof. Anthony Sinclair, University of Liverpool, UK

Prof. Geoff Bailey, University of York, UK

Dr Harry Robson, University of York, UK

Dr Patricia Fanning, Macquarie University, Australia

Dr Abi Stone, University of Manchester, UK

Dr Dan Barfod, Scottish Universities Environmental Research Centre, Glasgow, UK

Dr Abdullah Alsharekh, King Saud University, KSA

Mr DhaifAllah Tha'ar Al Othaibi, SCTH, Riyadh

Mr Bandar Al Wabr, SCTH, Riyadh

Mr Abdulrahman Al Hammad, SCTH, Asir

Mr Saeed Abu Mater, SCTH Asir

Mr Saleh bin Hashwal Al Qatani, SCTH, Asir

Mr Faia' Essa Assiri, SCTH, Asir

Mr Ahmed Al Sharef, SCTH, Riyadh

Appendix 2: List of Basalt Samples Collected in 2017

Sample No.	Coordinates	Description
Samples from Wadi Dabsa Basin		
AB1	N 18.306903 E 41.570055	F4 basalt flow snout, central lobe, 123 m elevation. 1–2 kg mined from larger block. Sparse olivine and clinopyroxene phenocrysts, up to 1 mm diameter, no vesicles. Groundmass is fresh. Flow surface is boulder and seems to have undergone aeolian erosion.
AB2	N 18.309157 E 41.571555	F4 basalt flow snout, 136 m elevation. Sparsely phyric, similar to sample AB1 (possibly same flow).
AB3	N 18.311031 E 41.569493	F6 basalt flow, 128 m elevation. Olivine phyric, vesicular basalt.
AB4	N 18.310359 E 41.563783	F6 basalt flow, 116 m elevation. Olivine and clinopyroxene phyric, vesicular basalt. Very sparse xenoliths present as olivine-clinopyroxene glomerocrysts and partially melted vesicle-rich silicic inclusions.
AB5	N 18.309636 E 41.556531	Basalt of flow protruding through tufa. 93 m elevation. Olivine phyric, vesicular basalt.
AB6	N 18.302100 E 41.569500	F10 basalt flow. Olivine & clinopyroxene phyric vesicular basalt. Olivine shows slight brownish discoloration. Phenocrysts range up to 1 mm diameter. Groundmass is fresh and dense but has pervasive irregular microvesicles. Flow top is relatively flat. Sample taken from site above stream.
AB7	N 18.301836 E 41.568121	Scoriaceous composite spatter clast (~15 cm) from river channel cut. Sample from chaotic, matrix supported deposit adjacent to a megablock (~ 3 m diameter) oxidised pyroclastic material, The pyroclastics of the megablock appear to be spatter, i.e., irregular cm-scale clasts. Weathering obscures contacts, but the scoria bearing diamicton appears to encase the megablock. Megablock is also overlain by a thin lava flow, a few tens of cm thick, and relatively flat lying that is overlain in turn by basaltic cobbles. May be debris avalanche deposit overlain by subsequent flows.
AB8	N 18.301883 E 41.556533	Olivine phyric basalt. The elongate features of the ‘C5’ cluster are mostly likely a set of eroded dikes. There was no scoria deposit there, only dense lavas. The sample was taken from the foot of one of these ridges, above the surrounding plain. Basalts have a hackly, but weathered appearance here. Abundant olivine phenocrysts, up to 1 mm, light brownish alteration. Dense, moderately fresh groundmass.
AB9	N 18.315283 E 41.555300	Sample from F6 basalt flow, top of flow snout. Olivine phyric, vesicular basalt. Some vesicles show secondary minerals and caliche. Sparse olivine phenocrysts, up to 1 mm, are lightly altered to a brown color.
AB10	N 18.314583 E 41.559967	Sample from F6 basalt flow snout. Olivine phyric, basalt. Groundmass is fresh, dense and vesicle free. Conspicuous spheroidally weathered zones, ~ 0.5 m diameter.
AB12	N 18.307367 E 41.560533	Sample from basalt of unknown flow protruding through tufa. Sparsely olivine phyric, vesicular basalt. Sparse, large vesicles. Bouldery snout, clasts (?) up to 1 meter diameter. Maybe debris flow snout? low surface relief (10–20 cm) and small clasts of tufa distributed across the surface suggest at least some sedimentation.
AB13	N 18.308167 E 41.564383	Sample from basalt of unknown flow protruding through tufa. Olivine phyric, vesicular basalt. Olivine is lightly altered and some vesicles have secondary minerals. ~30 meters distant from L0130 grid. Sparse phenocrysts and vesicles.
AB14	N 18.307650 E 41.564583	Sample from basalt of unknown flow protruding through tufa under L0130 grid. Olivine phyric, vesicular basalt. Sample from 0.5 m boulder. Vesicles have secondary minerals, caliche and light alteration. Sparse olivine phenocrysts range up to 3 mm diameter and show variable light alteration.
AB15	N 18.305467 E 41.556783	Basalt from flow F10. Olivine phyric, vesicular basalt. Pervasive alteration. Olivine and vesicle rich. Olivine phenocrysts are moderately altered to brownish minerals and vesicles are mostly lined with secondary minerals.
AB16	N 18.307100 E 41.554917	Basalt from flow F18. Olivine phyric, vesicular basalt. Abundant olivine shows variable alteration, from light discoloration to complete replacement. Minor vesicles are lined or filled with secondary minerals. 87 m elevation, above tufa barrage.
AB17	N 18.303183 E 41.539350	Basalt from cinder cone C6. Aphyric basalt. Dense, black aphyric basalt. Single exception is a large, anhedral plagioclase megacryst (~10 mm) with smooth, sharp contacts against the host basalt. Megacryst contains oxide inclusions, up to 1 mm diameter. This sample is from the foot of the cone, above the surrounding plain.

Samples from Harrat Al Birk Region		
AB11	N 18.071567 E 41.624333	Sample from Dhahaban Quarry. Olivine phyric basalt. 14 m elevation. Cone near highway. Abundant phenocrysts of olivine, up to 1 mm diameter, are altered to a brownish color. Groundmass is dense and fresh.
AB18	N 18.223900 E 41.542850	Sample from columnar basalt flow to NE of centre of Al Birk. Olivine phyric basalt. Sparse olivine is lightly altered. Groundmass is reasonably fresh. Colonnade is overlain by cinder cone deposits.
AB18b	N 18.223900 E 41.542850	Sample from scoria bomb to NE of centre of Al Birk. Aphyric, variably oxidized, vesicular basalt. 47 m elevation.
AB19	N 18.262817 E 41.594633	Columnar basalt along Al Birk/Muhayil Road. Olivine phyric, vesicular basalt. Sparse olivine is discoloured to light brown. Vesicles are abundant but very small, <0.5mm. Groundmass is fresh. 192 m elevation
AB20	N 18.281867 E 41.617733	Basaltic scoria bomb along Al Birk/Muhayil Road. Olivine phyric, vesicular basalt, very fresh. Minor, large plagioclase phenocrysts. Groundmass is variably oxidized 259 m elevation.
AB21	N 18.297700 E 41.645117	Sample from basalt along Al Birk/Muhayil Road. Olivine phyric basalt. Sparse olivine is slightly discoloured. Weathered, hackly appearance of basalt outcrop surface. 279 m elevation.
AB22	N 18.421050 E 41.639717	Sample from basalt along Al Birk/Muhayil Road. Olivine phyric basalt. Olivine is altered and discoloured. Groundmass is reasonable fresh. Sample has sparse vesicles. Flow surface is eroded and deflated, low relief cobble field. 267 m elevation.
AB26	N 18.089167 E 41.697683	Columnar basalt flow in Wadi Najla. Prominent colonnade in river channel. 55 m elevation. Basalt is altered, minor vesicles are lined, but dense groundmass is of moderate quality. Olivine is discoloured and lightly altered. Basement outcrops of sandstone make up the north side of channel, which are in turn capped by basalts many 10's of meters above the channel floor.
AB27	N 18.198300 E 41.572233	Sample from vesicular basaltic scoria bomb in cinder cone, approx.. 0.5 m diameter. Vesicular olivine basalt. Olivine is lightly discoloured. 81 m elevation. Deposit is combination of scoria and spatter.

Appendix 3: List of Tufa Samples Collected in 2017

Sample No.	Coordinates	Description
Samples from Wadi Dabsa basin environs		
WD1	N 18.308746 E 41.556010	Within (but not *in situ*) a dry channel running E-W in the western sub-basin of Wadi Dabsa. WD1 is dense carbonate. WD2 contains wavy thin bands.
WD2		
WD3	N 18.312167 E 41.540917	Extracted from a large intact boulder within E-W tufa ridge preserved in fan area. Massive tufa without banding and with some porosity.
WD4	N 18.311083 E 41.542611	Sampled at 1.6 m height in a south-facing section (6 m thick) into a large, near-horizontal-topped tufa cascade feature (140 m wide, 200 m long, 7 to 10 m thick) located at the mouth of the fan area. Thin, densely cemented tufa, with thin bands sampled within a vugh (airspace).
WD5	N 18.306528 E 41.561139	Sampled from ~ 2m height within a south-facing section of tufa (~3 m thick), within a channel that skirts the southern edge of the Wadi Dabsa basin. Both samples are densely-cemented and banded, sampled from the top of a unit of massive phytoherm framework tufa. The overall 3 m section contains repeated massive phytoherm tufa and tufa-cemented gravel-to-boulder units.
WD6		
WD7	N 18.307722 E 41.568111	A small former barrage a few hundred meters northwest of the 2015 L0106 grid. Sample removed from the cuspate vertical face. It is 5 cm thick and contains repeated sets of narrow-bands, separated by phytoherm framework material.
WD8	N 18.306139 E 41.561472	Located in the south at the centre of the basin. Sampled from a 14 cm thick front of a former prograding barrage that has been eroded down to ground level. The narrow-bands are orientated vertically and are slightly diffuse in places.
Samples associated with L0106/130 collection grids		
WD9	~7 m W of L0130 Quadrant 5Jx	The outermost coating on the vertical front of Barrage 4, it is 1.5 cm thick and contains well-defined near-parallel narrow bands.
WD10	L0130 Quadrant 6Jz	Taken from the front-portion of an eroded barrage (the banding is orientated vertically, so that this sample represented the downward face of the barrage step). It is a 2.5 cm thick densely-cemented unit containing well-defined wavy narrow bands.
WD11	~10 m W of L0130 Quadrant 5Jx	~ 5 cm thick unit taken from the vertical front of the first of the complex at Barrage 6. It contains wavy narrow bands that become diffuse and grade into a phytoherm framework.
WD12	L0106 Quadrant 5Dx	2 cm thick densely cemented unit with near-horizontal diffuse narrow bands, taken from the front edge of barrage
WD13	L0106 Quadrant 2Ay	~ 1 cm thick densely cemented unit, nearly crust/flowstone, coating the front edge of a heavily eroded barrage.
WD14	L0106 Quadrant 1Bz	~ 0.5 cm thick crust/flowstone, coating the front edge of a heavily eroded barrage.