Kites and other Archaeological Structures along the Eastern Rim of the Harrat (Lava Plain) of Jordan, Signs of Intensive Usage in Prehistoric Time, a Google Earth Images Study*

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Abstract

Google Earth offers a unique opportunity and methodologically new approach to study geological and archaeological phenomena over large areas. We have evaluated a high resolution strip of images along the eastern rim of the Jordanian Harrat along 38°E where basaltic Quaternary lava flows override Upper Cretaceous and Lower Tertiary limestones and cherts of the Hamad.

Within this strip we recorded and evaluated statistically 44 'kites' (km-large structures of walls resembling children's kites from the air) many more than was previously known there. 'Kites' consist of km-long guiding walls ending in hectare-sized enclosures erected most probably in Neolithic times to hunt migrating gazelle. They form N-S oriented continuous chains, effectively intercepting animal migration routes. Distances between 32 kites of the easternmost chain were 1.62±0.94 km, covering 48 km N-S. The longest guiding wall found is >10 km long, the total length of all walls being >150 km. Northern, central and southern guiding walls average 2.00±1.35 km (N = 39), 0.78±0.66 (N = 25) and 2.06±1.31 km (N = 38), respectively. The enclosures, situated behind a low sill to hide them from view of approaching gazelle, are star-shaped and 1.80 ± 0.91 ha (from 4.46 to 0.23 ha) in size with circumferences of 624±195 m (1,056 m to 228 m). Enclosures have up to 14 stone circles at their tip, so called 'blinds', historically interpreted as 'hides' for hunters to shoot gazelle. However, we argue that they must have had a different use, i.e. they were the actual traps. Once the gazelle had jumped into them, they could not jump out again lacking the forward speed. The data suggest a structural stratigraphy of trap construction in the area, that began with meander walls, proceeded with bag-like traps and culminated with the construction of kite chains. Later some kites were decommissioned by extending the guiding walls of adjacent kites. This process was repeated and only 19 kites remained functioning from the original 36. Calculation of energy to construct these traps shows that they must have been highly profitable in terms of caloric return. After the hunting period, kites were partly destroyed by houses and corrals that were built by later herders. Among them are 'jelly fish/wheel' houses and other clearings. The most enigmatic structures found are 103 'circular paths', on average 43.3±17.7 m long and 31.7±13.7 m wide, that appear to be very old. All these structures form a rich heritage, unique world-wide, that is not only a challenge for further ground-based archaeological studies but also urgently needing protection against further bulldozing and the spreading of 'civilization' into this area.

Keywords: Jordanian Harrat, kites, Neolithic, hunting, gazelle

1. Introduction

1.1 Geology and geomorphology

Two very different landscapes determine the geomorphology of northeastern Jordan: The flat peneplain of the Hamad, consisting of Oligocene to Paleocene limestones, in the east and the hummocky Harrat, consisting of Oligocene to Quaternary volcanites (Tarawneh *et al.* 2000), in the west. The border between the Harrat and Hamad roughly runs N-S along 38°E (Fig. 1). The Harrat features shield volcanoes (Kempe *et al.* 2008), tephra cones (e.g., Al Malabeh 2003, 1994), >100m high strato-volcanoes (Ashgaf or the Al-Shahba volcanoes) and three or four up to 100 m long NW–SE striking fissure eruptions (e.g. Al-Malabeh *et al.* 2002) (Fig. 1). The erupted lavas occur both as thick a'a or as thinly-sheeted pāhoehoe flows. The latter were transported through pyroducts (lava tunnels, lava tubes) for many kilometres, accounting for the wide spread of the lavas and the low slope of the south-dipping plateau (Al-Malabeh *et al.* 2006; Kempe *et al.* 2006). Post-eruptive faulting produced local ridges in the SE-Harrat (Fig. 1). Depending on age, wadis have cut canyons (Wadi Rajil). The plateau was covered with a 1 to 2 m of silty, carbonate and quartz-containing loess. Through the poorly understood process of 'stone heaving', loose rocks of the underlying lava moved up to the surface, covering the loess in a protective manner against deflation and erosion. Erosion washed loess into the depressions in the hummocky terrain producing playa flats giving the terrain a "mottled" pattern. Today, annual precipitation in the area is less than 100 mm

* *This paper is a much shortened version of Kempe & Al-Malabeh (2010).*

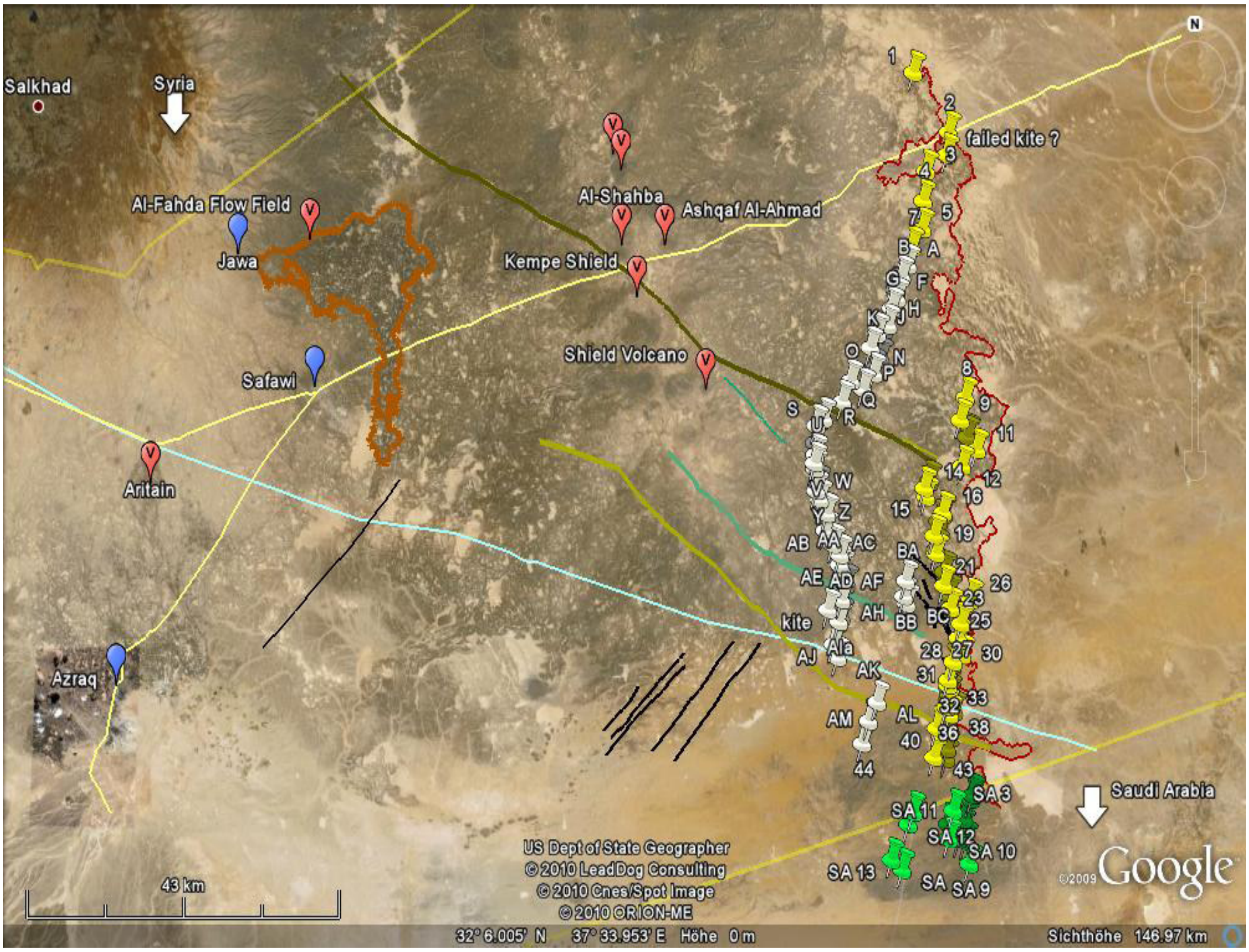

Fig. 1. Google Earth overview of the Harrat in eastern Jordan with some of the pertinent geological, volcanological and geographical features (Volcanoes marked in red; towns of Safawi and Azraq and the Bronze Age city of Jawa marked in blue. Bold, yellow lines: international borders; thin yellow lines: roads; light blue line: Trans-Arabian Pipeline; black lines: faults, colored bold lines: eruptive fissures; bold brown line: Al-Fahda flow field; thin brown line: eastern border of the Harrat. The kites studied here are marked by numbered yellow pins while the white pins with letters mark the next kite chain to the west in an area not available in high resolution. Kite positions in Saudi Arabia are marked with green pins labeled SA).

and flowing water is restricted to wet winters. A streak of a 10 km wide swath of reddish aeolian sediment almost buried some of the kites between 31°55.4'N and 31°50'N along our profile (Fig. 1).

1.2 Occupational history

Archaeological surveys began in the 1920s (Field 1960; Betts 1982, 1993, 1998a). Traces of human presence date back to Paleolithic times (Betts 1988b). During the Last Glacial the area was much wetter as documented by a high level of Lake Lisan, the predecessor of the Dead Sea (e.g., Landmann *et al.* 2002; Abu Ghazleh & Kempe 2009) when also local lakes existed in the Harrat (Rollefson 1982; Rollefson *et al.* 1997). After a sharp post glacial regression, lake levels rose again (Neev & Emery 1995) from 14–10.5 ka ago and beginning at 8.5 ka BP, probably also improving conditions on the Harrat. Excavation conducted at Dhuweila in the central Harrat documented occupation at around 8.25 – 8.19 ka BP, 7.45 – 7.03 ka BP and 5.51 – 4.44 ka BP (Betts 1998b) (stage 1 and 2 belonging to the pre-pottery Neolithic-B, or PPNB). Jawa, an Early Bronze Age 'city' with massive basaltic defense walls, is the most impressive archeological site in the Harrat (Helms 1981; Betts 1991).

During Roman times, roads, towns and border forts were built along the Limes Arabica (e.g., Kennedy & Riley 1990) such as the fort at Azraq, the large towns of Umm Al-Jimal, Sama Al-Sirham and Umm Al-Qutain (e.g., de Vries 2000; Kennedy 1993), and the castle of Qasr Burqu' E of the Harrat (Gaube 1974), all built from basalt. Between the 1st century BC and the 4th century AD early Arabic tribes left Safaitic inscriptions and petroglyphs of camels, horses, lions, ostriches, gazelles and of various hunting (Fig. 2) and riding scenes (e.g., Ababneh, 2005), sometimes overwritten by modern inscriptions or even images of trucks.

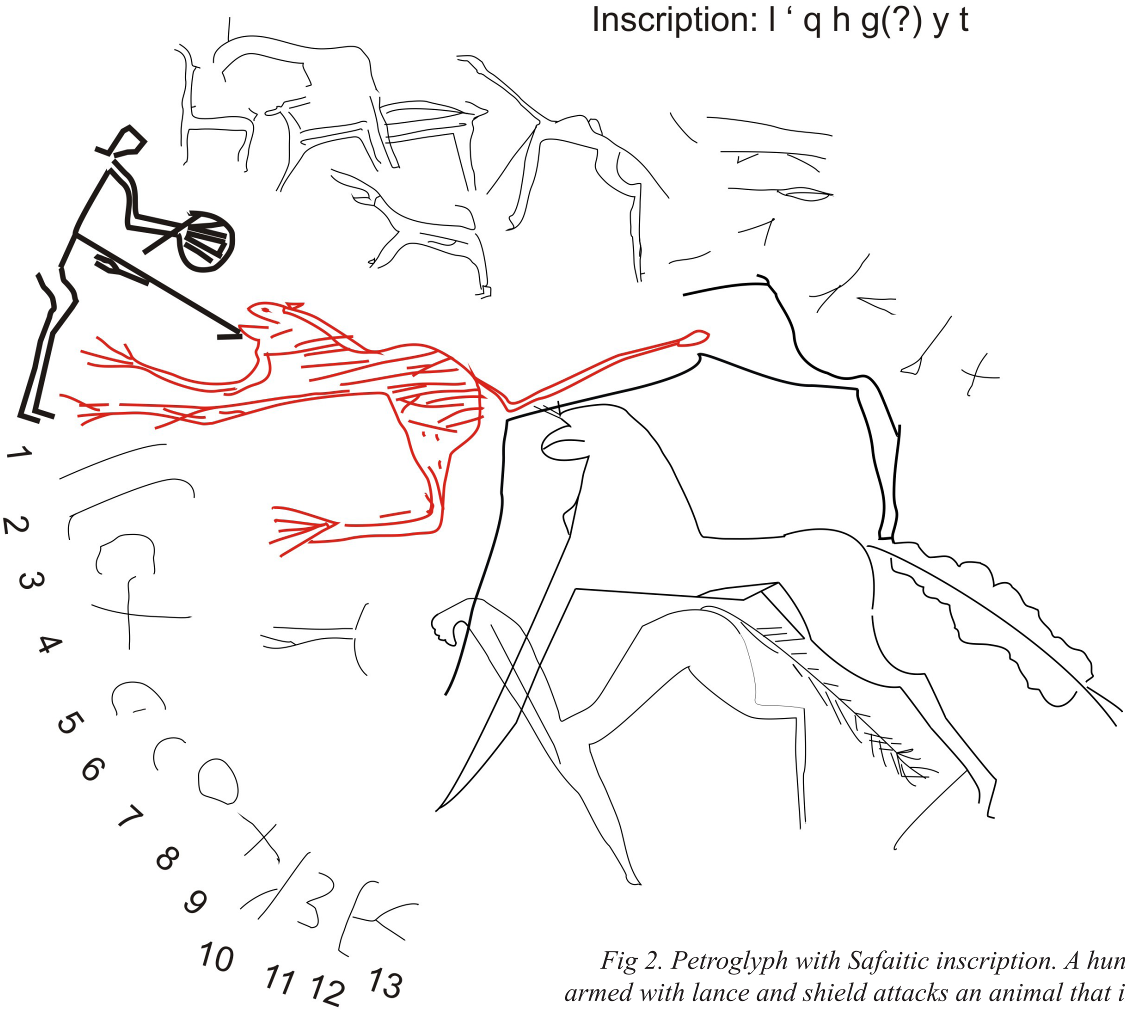

Fig 2. Petroglyph with Safaitic inscription. A hunter armed with lance and shield attacks an animal that is most probably a hyena (round head, stripped fur). Two complete horses with elaborate tails stand to the right. A third horse is incompletely drawn. In the background a herd of goats and to the right a camel (?) is seen. The hunters name probably reads "rbt son of bgt". The other parts of the inscription still need translation. The inscription dates this hunt to about 2000 BP.

1.3 'Desert kites'

First noticed by pilots in 1925 (Maitland 1927; Poidebard 1928) the 'desert kites' are the most enigmatic archaeological structures of the Harrat (e.g., Helms & Betts 1987). Kites are also known from Syria (e.g., Echallier & Braemer 1995), Saudi Arabia (Kennedy 2009), the Negev (e.g., Holzer *et al.* 2010), and from the Aralo-Caspian region (e.g., Betts & Yagodin 2000. But Jordan apparently has most kites and Betts (1998c, fig. 10.10) gives a map with about 300 of them. Most Jordanian kites consist of pairs of straight or curved 'guiding walls' that narrow down at a sill. Behind follows an irregular polygonal, star-like shape, giving the whole structure the appearance of a child's kite. At corners, small circular stone walls are placed, so called 'blinds', interpreted by e.g. Betts (1982, 31) as "*series of hides to conceal the hunters*." Further she says: "*Kites form long chains joined at their extremities of their trailing walls, the chains stretch for many kilometers across what must have been the seasonal migration routes of the desert fauna.*" Echallier & Braemer (1995) suggested that kites were used for animal herding, but most agree that the kites were used to hunt gazelle.

The PPNB camp-site Dhuweila (7th millennium BC) was association with kites (Betts 1998b) and over 90 % of the recovered stage 1 and 2 Dhuweila bones – >11,000 pieces – belong to the genus *Gazella*; domestic animals are entirely missing (Martin 1998). Furthermore >80 rock carvings recovered show horned animals, probably gazelle (Betts 1998d).

At Jawa, cattle and sheep/goat bones already dominate over gazelle, suggesting that their hunt was continued, albeit not the main protein source in Middle Bronze Age times (Helms 1981). Furthermore, the water system of Jawa succeeded kite walls, also suggesting their Neolithic age (Helms & Betts 1987, 45). Some rock carvings may show kites, some without animals, others with animals possibly representing gazelle and hunting dogs (Betts 1998d, figs. 7.12, 7.14). Among them is the 'Cairn of Hani' (Harding 1953; Field 1960, fig. 32a) showing on one side a hunting scene with animals between guiding walls driven by a human and assembled in a kite enclosure characterized by circular 'blinds'. On the other side of the boulder an archer shoots at horned animals and a human with a whip directs hunting dogs. The rock carries also a Safaitic inscription; if it was not added later, it would date the cairn to between the 2nd century BC and the 4th century AD. Observations in the 19th century from Syria by Musil (1927 and 1928, cited by Betts 1998d, 156), demonstrate the long-term usage of kites for hunting. However, Musil reports that the gazelle were forced to jump walls with pits or ditches behind, where they would break their legs. Pits and ditches, however, have not been reported from any of the hunting kites on the Harrat (Betts 1998c). Comparison of the Harrat kites with those of the Aralo-Caspian region (dating from the 1st millennium AD) substantiates the conclusions that kites were used to intercept migrating animals occurring in large numbers, such as gazelle. No firm evidence exists that the kites were used to hunt other animals such as onager, oryx or ostriches. The most likely animal hunted is *Gazella subgutturosa marica* (Goitered Gazelle), a migrating species now extinct in Jordan, and Betts (1993, 10) summarizes: "*The steppe was not extensively, re-used until the late Pre-Pottery Neolithic-B in the second half of the seventh millennium BC. In this period, there was emphasis on exploitation of particular resources, at this time gazelle. Gazelle was hunted in large number in the harra (Helms and Betts 1987; Betts 1988a, 1989). Hunting camps were located within reach of gudran* (i.e. rain pools)*, but choice of site location was also influenced by the proximity of hunting ground and landscape suitable for the construction of 'kites'…. With the introduction of sheep/goat herding in the early sixth millennium B.V., open country became more useful….*"

2. Materials and methods

Here we give details of a specific set of kites, their geological context and evaluate their interrelationships, and survey the area for other anthropogenic features. We took advantage of a high resolution (about 0.5 m pixel^{-1}) strip of Google Earth images east of 37°59' (datum WGS 84) that contains a set of >40 kites following the eastern border of the basalts (Fig. 3). Distances were obtained with the Google Earth ruler and areas with the Photoshop CS4 extended program. All walls were redrawn as Google Earth vectors: guiding walls in white (Fig. 3), others in yellow. Walls

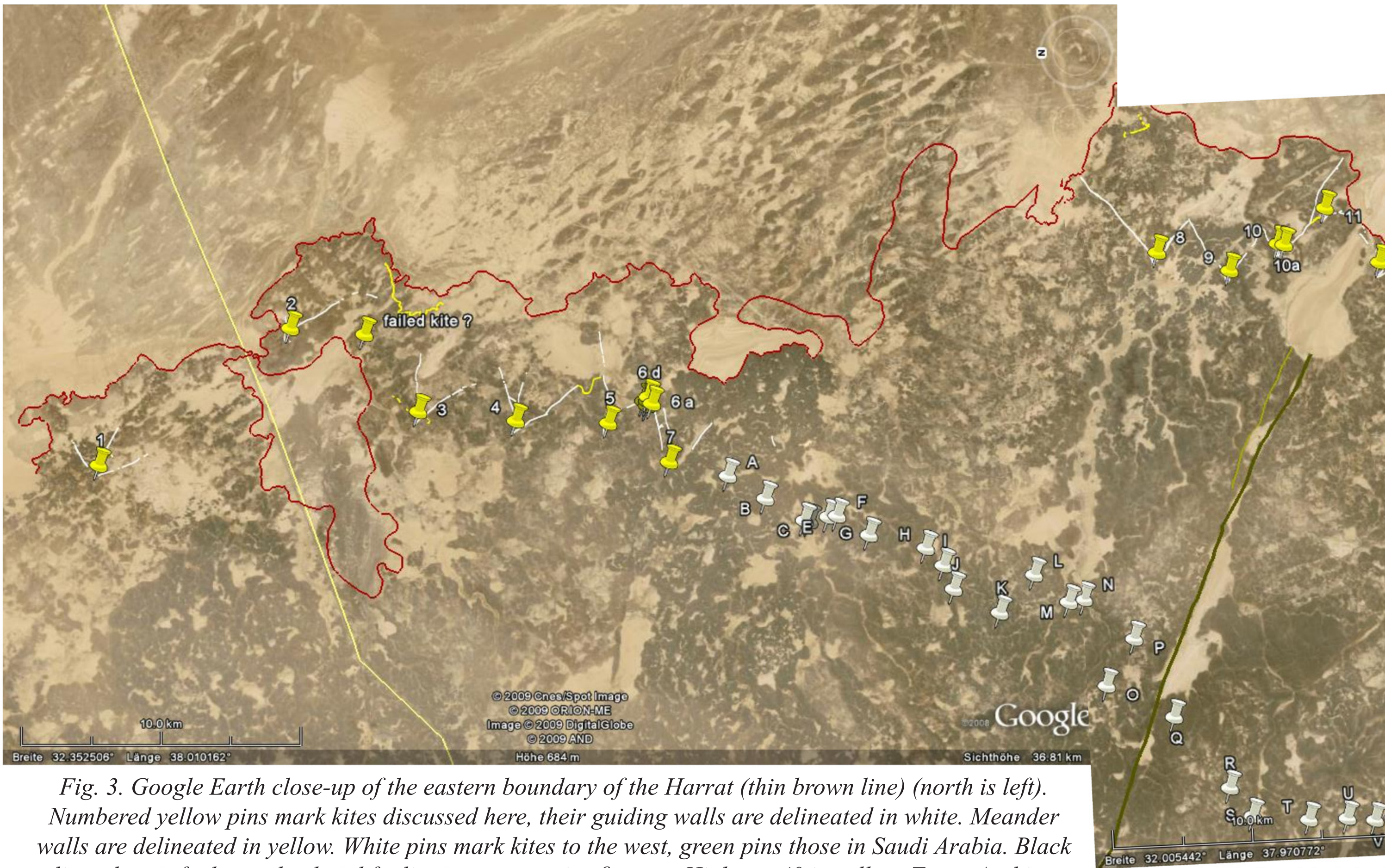

Fig. 3. Google Earth close-up of the eastern boundary of the Harrat (thin brown line) (north is left). Numbered yellow pins mark kites discussed here, their guiding walls are delineated in white. Meander walls are delineated in yellow. White pins mark kites to the west, green pins those in Saudi Arabia. Black lines denote faults, and colored fat lines trace eruptive fissures, Highway 40 in yellow, Trans-Arabian Pipeline in light blue.

appear on Google Earth as dark traces because they are erected from basalt blocks. In collecting them, the underlying loess is exposed and the dark wall is often paralleled by light lines on one or both sides of it. Where walls run across playas they are better visibly while they become obscure when running across dark rock outcrops. No kites occur in the Hamad (Betts 1993). Paths appear as light lines, four wheel tracks appear as double light lines and bulldozed trails are not only wider but also marked by rock piles on both sides or with on-echelon edges. National Road 40 (Amman – Bagdad) crosses the area in the N and the old Trans-Arabian Pipe Line in the S (Fig. 1). In February 2009 we inspected a few of the structures in the field (Kite 3 and a few wheelhouses, Fig. 4).

3. The kites

3.1 General situation and structural stratigraphy

East of 37°59' (Fig. 1) in the high resolution area within Jordan we identified 43 kites (Figs. 1 and 2, yellow pins), significantly more than the 17 kites recorded by Helms & Betts (1987, fig. 17), more than see on the published topographic maps (Royal Jordanian Geogr. Center 1997) and contradicting the assumption (Betts & Yagodin 2000) that most kites occur in the western and central Harrat. In the lower resolution area 46 further kites occur to the west (white pins). These kites form two parallel chains, the eastern one including kites 8 to 43 (distance 47 km) and western one from 1 to 7 and from A to 44 (including a shorter intermediate chain from BA to BC) (distance 78 km). 17 more kites were found in Saudi Arabia, marked by green pins extending these chains.

Averaged distances between kites amount to:

- Kites 1 to 7 (n = 6; excluding Kite 6 because it may not be a kite at all) 5.54±2.40 km;
- Kites 8 to 43 (n = 32; excluding several kites of older generation, i.e., no. 10a, 26, 37 and 43) 1.62±0.94 km;
- Kites A to 44 (n = 38; excluding kites D and AHa because they appear to be older kites) 1.64±0.73 km (max 3.34, min 0.31 km).

The distance of 1.6 km reminds of the distance covered by 1000 double paces, i.e. that of the Roman mile (1.479 km) or the statue mile (1.609 km). Thus the original positions may have been spaced out by 1000 double paces and then the exact positions were adjusted to the possibilities the terrain offered. This close spacing was given up after some time and many of the kites were 'decommissioned' by extending the guiding walls of neighboring kites. This allows constructing a structural stratigraphy (Table 1). Column 1 lists all kites N to S, columns 2 and 3 gives the kites that supersede the original kite by

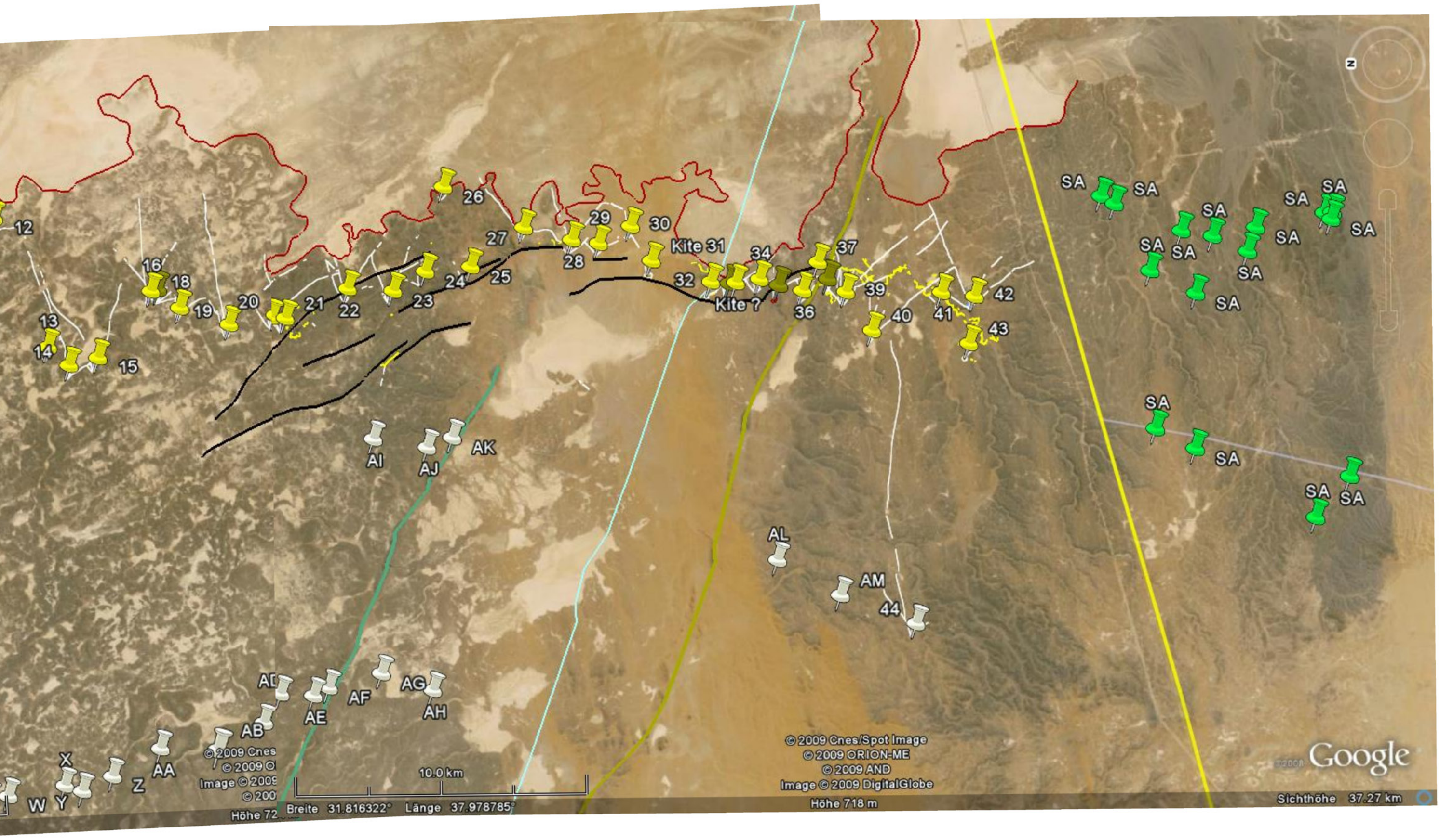

Fig. 4. Southeast-ward view of the enclosure wall of Kite #3 in the field. Note the N-guiding wall at the horizon as it approaches the gate to the enclosure (off the picture to the right). Note also the dilapidated nature of the walls and the loess strip along it from which the stones were collected to build the wall.

the extension of their guiding walls. In the northern chain all kites remained active. In the more closely spaced southern chain the number of active kites was diminished at least twice. Of the original 36 kites only 19 finally remained functioning. In case of Kite 10 and 10a (one of the least altered original kites), less than 200 m apart, 10a was completely cut off by the southern guiding wall of Kite 10 (Fig. 5). Kite 10a is one of the most original kites because it seems to have been abandoned even before obtaining its final guiding walls.

Table 1: Stratigraphy of kites.

Phase 1	Phase 2	Phase 3
1		
2		
3		
4		
5	5	
6	5	
7		
8		
9		
10	10	
10a	10	
11		
12		
13	14	
14	14	
15	14	
16	16	19
17	16	19
18		19
19	19	19
20	21	19
21	21	19
22		
23	23	
24	23	
25		
26		
27		
28	28	
29	28	
30	31	
31	31	
32		
33	33	
34	33	
35	35	
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39	39	39
40	40	39
41	40	39
42	42	42
43	42	42

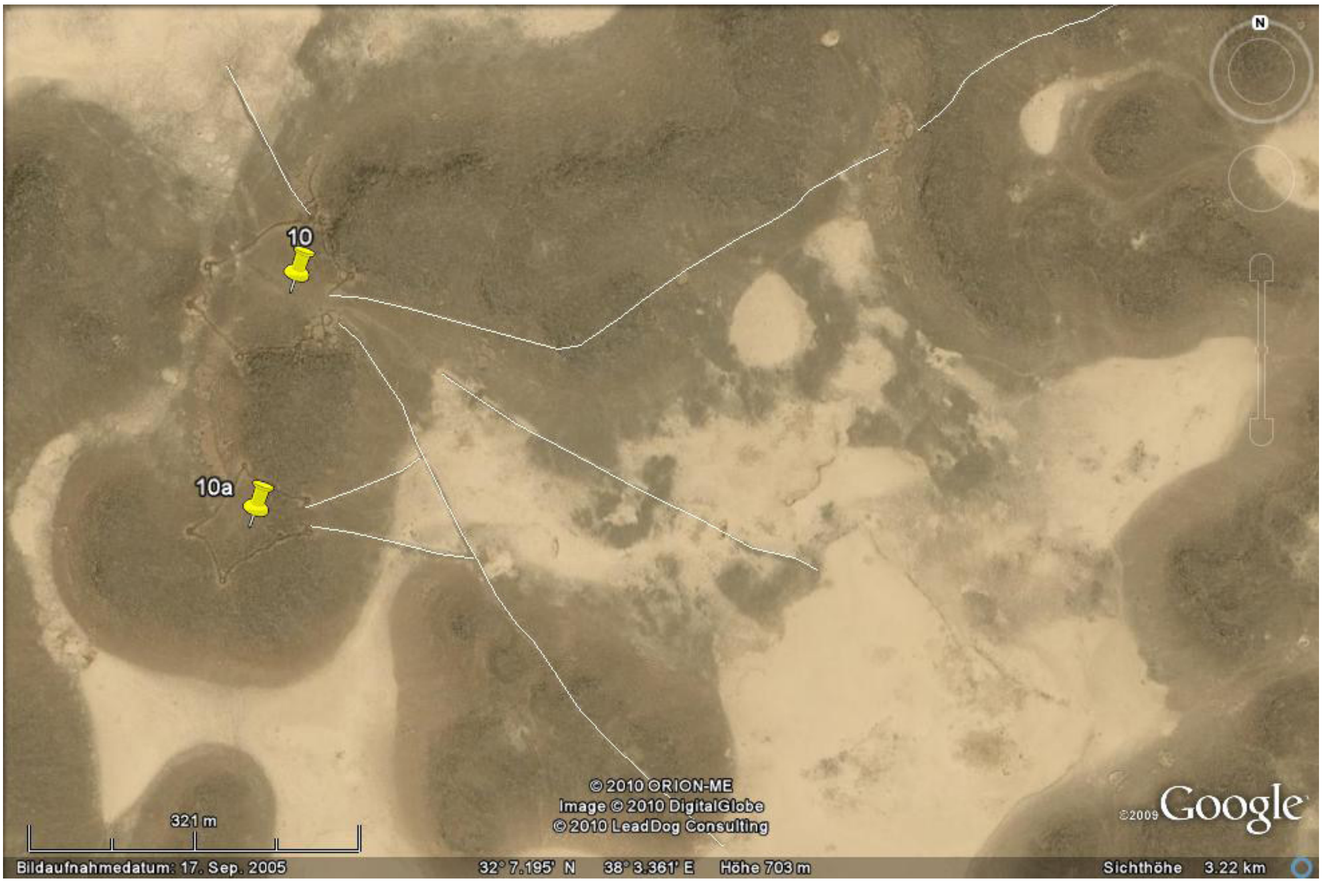


Fig. 5. Google Earth picture of kites 10 and 10a. Note that the southern guiding wall of kite 10 closes off kite 10a and that no traces are visible suggesting that kite 10a walls were formerly longer.

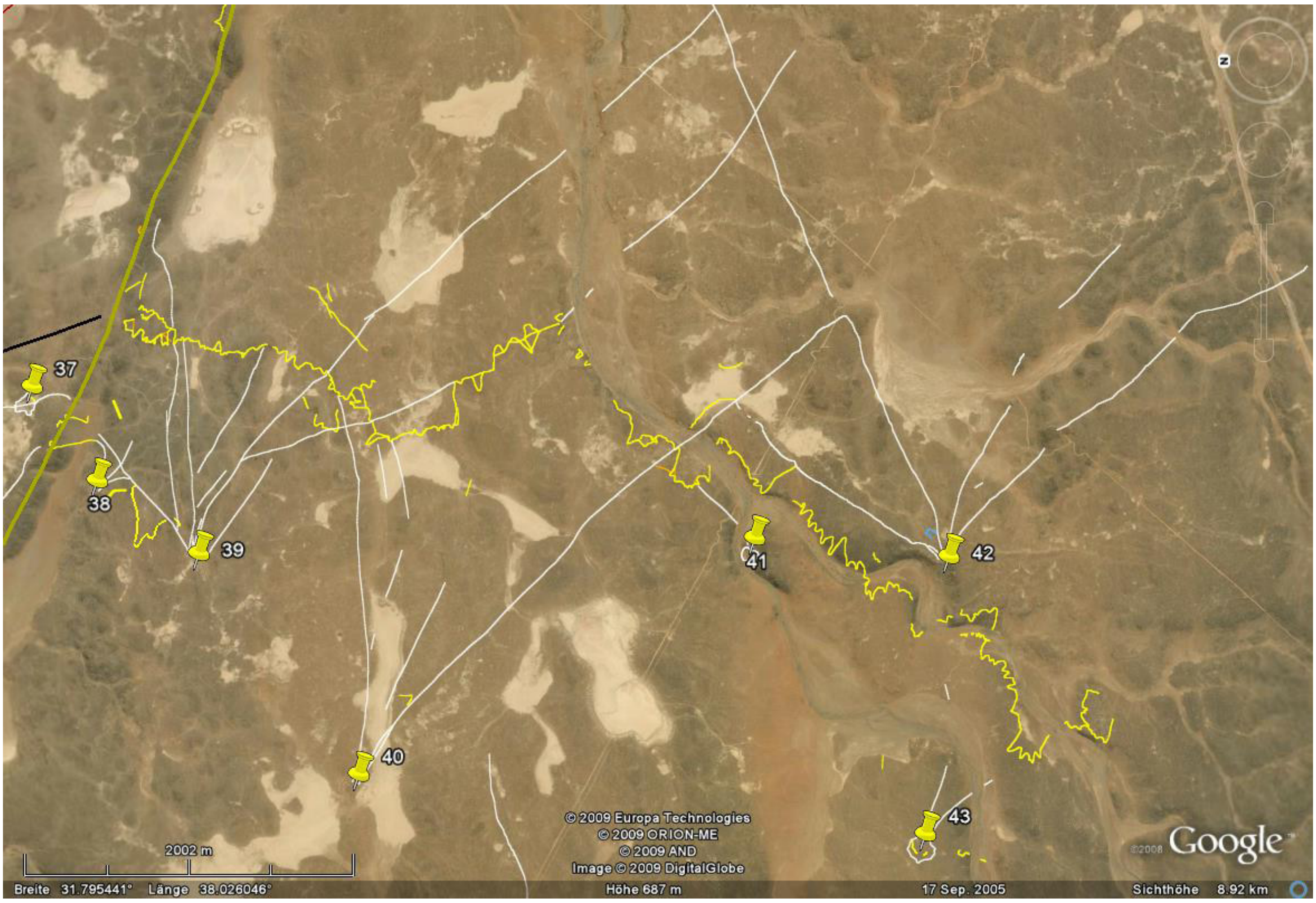


Fig. 6. Google Earth picture of meander walls (in yellow) between kites 37 to 43. In the south the meander walls follow the wadi, crossing it several times. In the north the walls cross the lava plain. Several later-erected walls cut off meanders (in orange) (north is left).

3.2 'Meander' walls

In addition to kites and their guiding walls a second class of walls is present that meander back and forth (Fig. 3 in yellow), thereby closing off dells between lava hills. They seem to funnel migrating animals into certain paths or leading then into bag-like constrictions. A km-long wall runs parallel to the Harrat border between 32°24.475'N/38°3.522'E and 32°23.383'N/38°2.530'E. A second section extends between 32°20.829'N/38°0.565'E and 32°20.357'N/38°0.759'E that forms one large W-oriented pouch erected along the crest of a lava rise that ends in four small 'fingers'. Our observations suggest that the meander walls predate the construction of the kites.

Fig. 6 shows the longest meander wall systems (>7 km end-to-end; 31°49.5'N/38°2.1'E and 31°46.3'N/38°0.4'E; between Kites 38 and 43). It runs back and forth between an escarpment (a fissure eruption) in the north and Wadi Al-Sheikh (or Wadi Ibn Waqqad) in the south. This system of walls bared a primary migration route through the Harrat between the Hamad in the east and the Azraq Basin. It exploits even small surface features, curving W where the area is flattest along a series of small playas in the center of the depression. The walls obviously served to keep the gazelle in the wadi and to hunt them at convenient constrictions and at the ends of W-oriented pouches. Fig. 6 also shows that some kite guiding walls cut across the meander walls or incorporate them into their scheme, thus proving that the kites belong to a younger and radically different hunting technique.

3.3 Guiding walls of kites

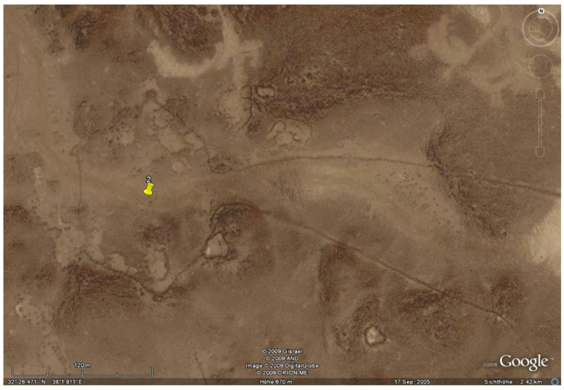
In contrast to meander walls, guiding walls run more or less straight across playas or lava knolls, changing direction at distinct angles if necessary. The longest kite guiding wall is that of Kite 44 with a length of 10.57 km, longer than any previously reported wall. It runs W from 31°48.291'N/38°0.416'E (in the high resolution area) and ends at 44 at 31°47.823'N 37°53.831'E (in the low resolution area). Each kite normally has a northern, central and southern wall. We measured all the walls in the high resolution strips and, choosing the longest of each (many guiding walls show minor or major alterations), calculated average lengths of all of the guiding walls. Kites 6, 10a, 26, 37 and 43 were excluded (10a was replaced by nearby Kite 10; Kite 26 is not in line with the main chain; Kites 37 and 43 are smaller, bag-like structures presumably of an older generation because the S wall of Kite 35 was extended to cross # 37; Kite 44 was also excluded because it belongs to the second chain to the west, but Kites 1 and 7 were included, even though their enclosures do not appear in high resolution). The northern walls have an average length of 2.00±1.35 km (n = 39), the central walls have an average length of 0.78±0.66 km (n = 25) and the southern guiding walls a length of 2.06±1.31 km (n = 38). The gape width of the kites (distance between the outer tip of the northern and southern guiding walls) was 2.17±1.15 km (n = 38). Again excluding the kites listed above and any parallel walls the total length of northern, central and southern guiding walls sums up to 73.94, 17.27 and 77.39 km, respectively and an overall length of guiding walls of ca. 150 km for the easternmost kites of the Harrat.

Playas may offer an opportunity to date these walls by ^{14}C of OSL because some of the kite walls seem to sink below the playa surface, reappearing on the other side. This indicates that they have been buried in sediment since their time of erection.

3.4 Kite enclosures

The shape of the kite enclosures appears to be either *design-dominated*, having strict symmetric and geometric pattern, or *terrain-dominated*, taking advantage of the *in situ* morphology. Kites 2 and 10a are design-dominated, forming a hexagon with four 'blinds' on the far corners and a 5-tip star, respectively (Fig. 7), but most of the studied kites are terrain-dominated. This is because they open toward the E and it was necessary to find W-inclined places behind a sill so that advancing animals cannot see (or smell) what lies beyond. Available places are further reduced by the need to build a continuous chain of kites. The W-facing slopes become steeper S-wards because there faults with W-facing escarpments occur (Fig. 1). Fig. 6 gives some kite shapes in detail. A common feature is that all have inward concave enclosure walls. The only exception is Kite 2 (Fig. 7), that also does not show any signs of later alteration and is also missing a central wall. Could this have been an early "test-kite", that proved not as effective as the other designs and was abandoned early on? The same arguments apply to Kite 10a that has never been altered.

The average size of the kite enclosure including all buildings stages (i.e., n = 69) is 1.75 ±0.85 ha (coef. of var. 48.8%). The largest kite was # 31 with 4.27 ha and the smallest # 42 with 0.23 ha. The circumference (mean 615 ± 188 m coef. of var. 31.6%) is largest for Kite 31 (1,056 m) and smallest for Kite 42 (228 m). This large number of cases, compared to the number of kites included here (n = 40; excl. # 1,6,7), is caused because many of the kites have different building stages that were evaluated individually (for complete statistics see Kempe & Al-Malabeh 2010). The entrance width varies between 10 m (# 26) and 76 m (# 37). None of the entrances show signs of having been closed in later stages or that the rocks have been



Kite 2

Kite 3

Kite 10a

Kite 14

Kite 21

Kite 26

Kite 36

Kite 42

Fig. 7. Selection of Google Earth images of the kites discussed here (note common 120 m scale bar at lower left. Kite 2 and 10a are examples of design-dominated ground plans. Kite 3 illustrates that wheel houses may be structures of a younger period. Kite 14 has the most blinds and is of a very regular shape. Kite 21 is situated behind a steep sill and elongated to make use the available space. Kite 26 is of an older circular design, placed directly at the border of the Harrat. Kite 36 is an even older pouch-like design, build before 'blinds' were used. Kite 42 is the one furthest south that has been enlarges, taking advantage of the morphology. It is also one with very long guiding walls and being in service even in the third phase of prolongation of guiding walls.

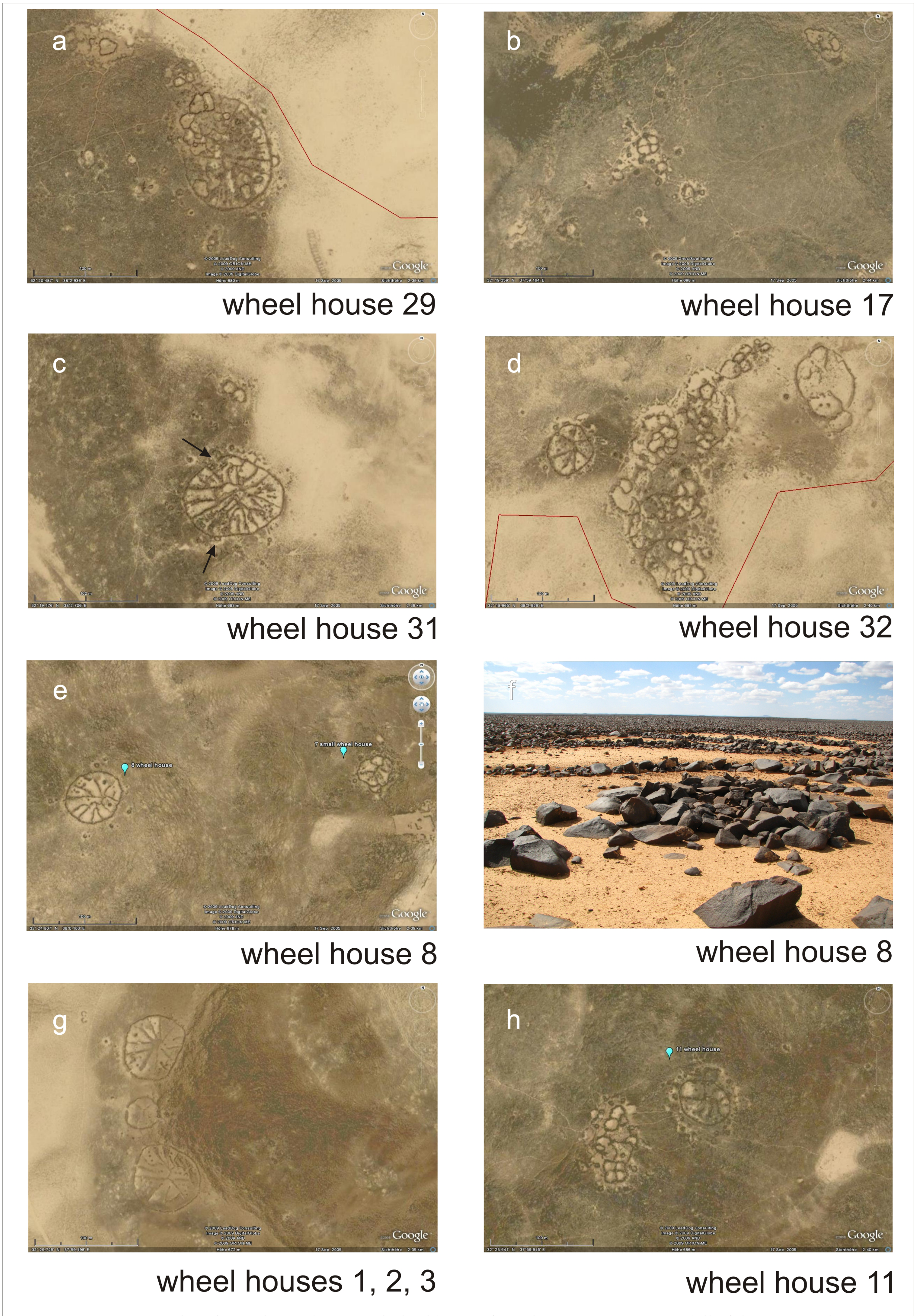


Fig. 8. Examples of Google Earth views of wheel houses from the investigation area (all of the same scale).

Fig. 9. Panoramic view of wheel house 1 on the ground looking south (32°29.763'N / 37°59.450' E; 67 x 54 m, 12 spokes.) Image: Kempe.

removed to form temporary closures. This observation excludes the possibility that the enclosures could have been used to keep domesticated herds (as suggested by Echallier & Braemer 1995).

Kites 37 and 43 do not have any blinds and may represent an early stage of kites, succeeding the meander walls (similar to 'Type C' of Helms & Betts 1987, fig. 14). The star-like type ('type D' of Helms & Betts 1987, fig. 14) has 'blinds' at their ends and the largest number found was 14 for Kite 14. These blinds are always stone circles, 2 to 5 m across. If they are elongated, the long axis, up to 12 m long, is parallel to the enclosure wall.

Many of the kites show later alteration, enlarging them, diminishing them or adding or subtracting 'blinds'. But also location and gate width was changed. Later alterations include erection of structures inside the enclosure with or without incorporation of the kite walls. A detailed analysis of all observed alterations is given by Kempe & Al-Malabeh (2010).

4. Other anthropogenic features

4.1 Places for living

The studied area shows, apart from the km-long hunting structures, an astounding number of traces of human usage present in many different categories (used possibly for dwelling, water management, agriculture, herding, storing, manufacturing, way marking, religious ceremonies or burying). However, which pattern served for what remains often open to debate.

The terms 'jelly fish house' (Helms 1981, pl. 9) or 'wheel house' (WH) describes a circular structure with radial spokes (Fig. 8). 32 WHs are seen in the high resolution area. Their area can change by a factor of 20. On average, WHs measure 51.1(±18.0) x 42.8(±15.0) m in diameter (excluding other detached outside structures) with an average area of 1,730 m^2. Field inspection of some of the well preserved WHs showed that their walls could not have been much higher than a metre (Fig. 9; # 8, 32°24.804'N/38°0.015'E). Some of the WHs have satellite rings, in size similar to kite blinds. Often they are positioned on small lava rises. They seem to be concentrated between Kites 1 to 4 and 5 to 8. One WH is built inside a kite enclosure and another inside the runway of the animals, suggesting that they are younger than the kites.

Other structures, more common than WHs, can be described as 'agglomerated houses' (AH), quasi-circular structures formed by an agglomerate of 'rooms' attached to each other. Some of these houses form elongated clusters; others are more centrally organized complexes. AH seem also to be younger than kites since some of them destroy kite features.

At an even higher number of places rocks have been moved to form clearings. Most of them lack peripheral walls, some contain stacks of rocks. Modern clearings are larger and rectangular to accommodate current Bedouin tents and their cars and trucks.

4.2 Circular paths

The most enigmatic finding of our Google Earth studies is 103 'circular paths' (Fig. 10). They also occur further W and S of the Saudi border. Some are almost circular, others elongated, one is a dumbbell and in one example there are two circles within each other (Fig. 11). On average these paths measure 43.3±17.7 m times 31.7±13.7 m. The longest measures 117 m and the largest measures 106 x 90 m. The paths have been cleared of stones and the loess below lets them appear in a lighter color than the surroundings. These paths are much more pronounced than the usual webbing of paths crisscrossing the landscape. Also, they appear to be very regular in their width, about 1 to 1.5 m wide. They encircle in almost all cases an unaltered piece of the Harrat surface. Rarely is any structure found inside them. Some circles are within stone shot of a settlement, others are several hundred metres off. Twice we found kite guiding walls running across them (Kite 36 at 31°49.76'N/38°1.62'E and Kite 42 at 31°46.167'N/38°1.835'E), suggesting that they are older than the kites. In a few other cases, circular paths are overlain by later houses.

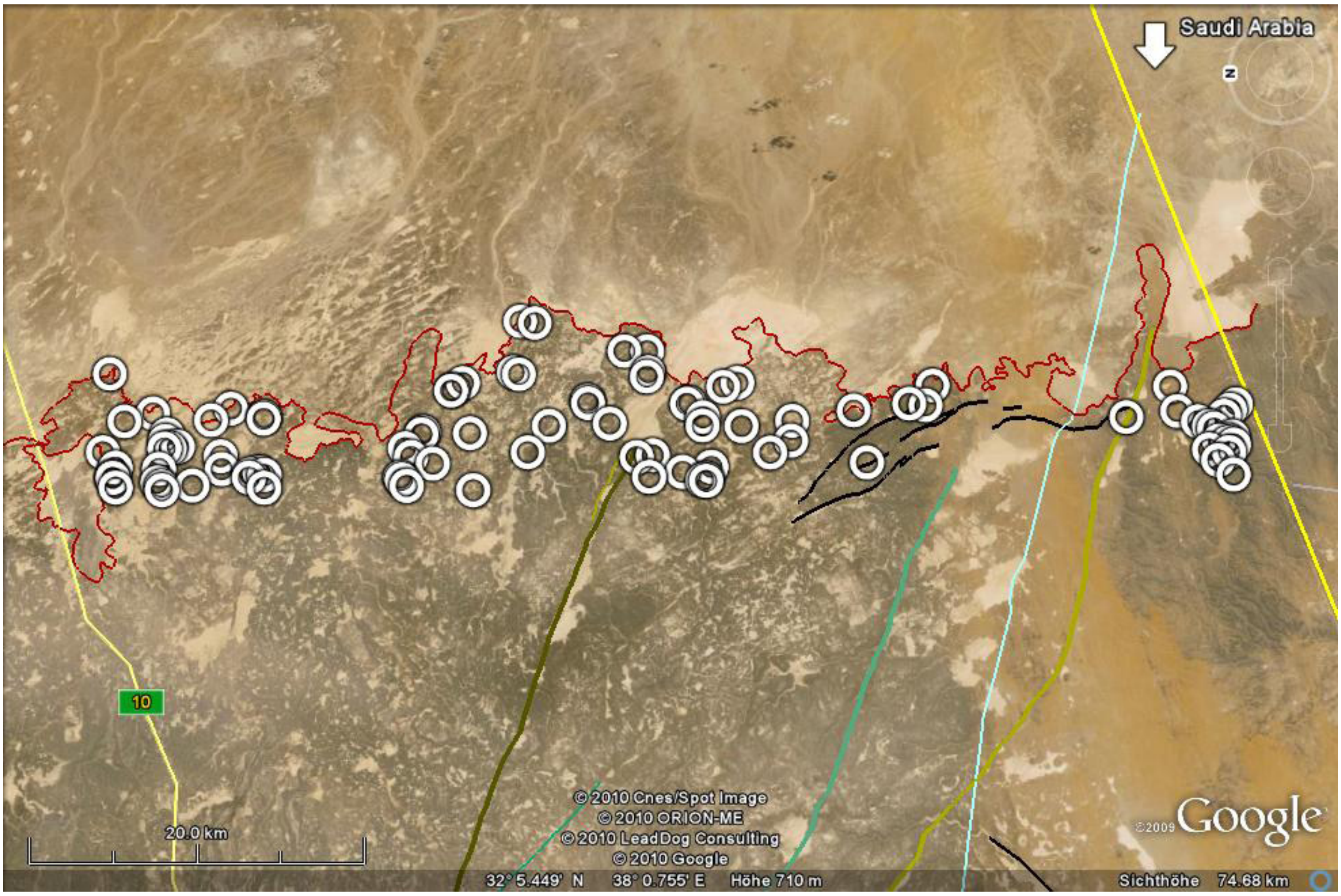


Fig. 10. Positions of circular paths along the eastern border of the Harrat in the Google Earth high resolution strip (north is left). For explanation of geological features see Fig. 1.

Why are there so many of these and what have they been made for? Many reasons come to mind; none is conclusive: training tracks for hunters or their dogs, circles to thrash wild grain harvests or religious processional courses. We may never know, but they definitely are wide-spread phenomena that add curiosity to the Harrat and its prehistoric times.

4.3 Other structures

Seven 'pearl-string enclosures' were found. They are walls formed by strings of small stone circles. The longest wall is a large rectangle, enclosing an entire playa having a perimeter of 1,700 m. Others are much smaller and circular, one is u-shaped. They could have had agricultural purposes.

'U-shaped' structures are small, with a 3 to 6 m long base and two 2 to 5 long arms. They occur in a few places along playas and may also have had agricultural purposes.

More than 20 examples of a quite characteristic feature, consisting of a large rock pile accompanied by one string (or two) of smaller mounds were noticed (Fig. 11a). They seem to be graves, associated to an older tomb of an important forefather.

The area contains also many modern structures, like corrals to keep sheep over night. Other features include forts, reservoirs, airplane orientation marks, airports (next to Jabal Aritain for example) and a multitude of bulldozed tracks.

5. Conclusions

The 'desert kites' of the Jordanian Harrat are a singular phenomenon both concerning their number and their developmental complexity. They illustrate the intensive use of a rough area, now seen as a forbidden rock desert. Archaeological investigations (Ch.1.3) suggest that they date to Prepottery Neolithic times (e.g., Betts, 1998c) and that they served for rounding up and killing gazelle in large numbers. Safaitic inscriptions could suggest that some were still used in early historic times (Harding 1953) and even later. Fundamental questions arise that concern the early building stages and the structural stratigraphy, the exact functioning of the kites and the social background of their creators.

5.1 Structural stratigraphy

Our investigations and earlier analyses (Helms & Betts, 1987) indicate that the technique to hunt gazelle evolved in several steps. The observations in our study area (particularly in its south) suggest the following stages:

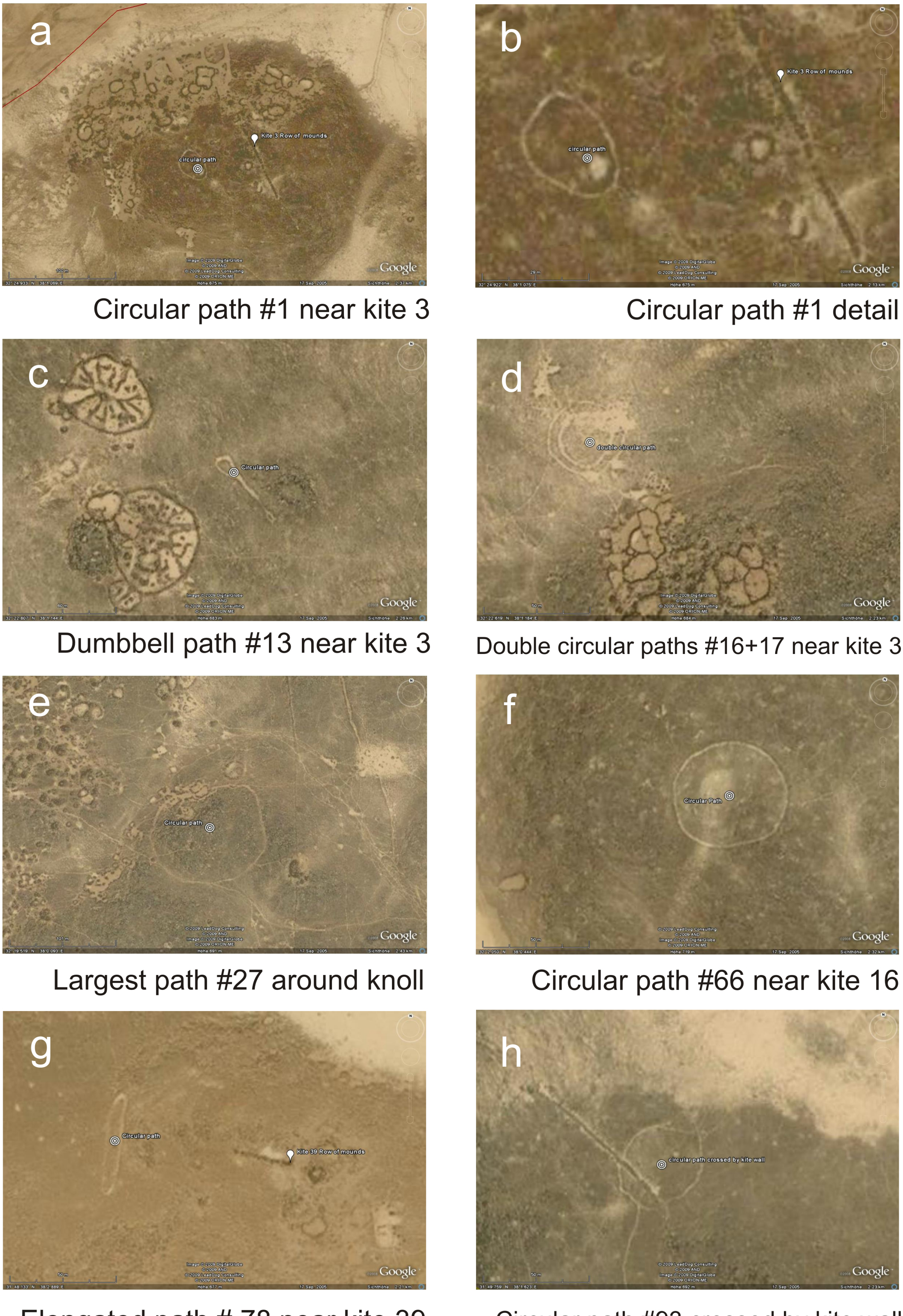


Fig. 11. Selection of several circular paths visible on Google Earth. Note the varying scales; (b) is an enlargement of (a). In (h) the southern guiding wall of kite 36 crosses the circular path.

1 First was a system of meandering walls as obstacles at places of E–W gazelle migration. Multiple W-directed indentations ('pouches') possibly served as places where gazelle would collect and could be hunted easily. Other walls follow the flanks of a wadi, in order to keep gazelle in the wadi and focus them to certain hunting stations.

2 Next, bag-like walls, still without blinds (Kites 37 and 43), were erected at flat places that do not have sills.

3 Then circular enclosures were built next to the Harrat border with a few blinds such as Kite 26 (Fig. 6b). Their guiding walls were relatively short, but placed beyond a sill.

4 In the main period consecutive chains of kites were planned (by a master planner?) and erected, effectively controlling the entire eastern rim of the Harrat. The guiding walls were now straight, extending for kilometres across the terrain irrespectively of its character. Meandering walls were integrated, if appropriate.

5 The last stage of usage was the prolongation of guiding walls, decommissioning some of the neighboring kites of step (4). The walls are now touching each other and the animals following them must have arrived at one or the other kites with no chance to bypass the wall system. In the kites themselves alterations were made, adding blinds or cutting them off. In a few cases, the kite entrances were shifted.

6 With the advent of herding culture the kites were not necessary or not all necessary any more and WHs, AHs and corrals were built within the kite areas, a few of them destroying even sections of the kite walls.

The two chains of kites discussed here are not the only ones in the Harrat. Further west, several more chains exist. Chain after chain of kites was constructed. But what would be left to hunt if already the first chain was a continuous concatenation of walls?

5.2 Mode of operation

In the literature, several hypotheses are given as to how the kites were used. The most common is that the 'blinds' were 'hides' for the hunters. However, the description of 'ditch-hunting' of gazelle in historic times in Syria (compare Simpson, 1994) gives, to our opinion an interesting clue. This method involved driving gazelle along guiding walls into constrictions towards breaches with ditches across them. In their panic the animals would jump into the ditches, hurting themselves so that they could be killed in large numbers. None of the kites discussed here or those described by Helms & Betts (1987) and Betts (1998c) further W, seem to have had ditches. In the described kites, the enclosures are quite large, many hundreds, if not thousands of animals could have been trapped within. They would, in fact have made a good aim for hunters. However, the 'hides' were invariably placed at the tip of the ray-like extensions, i.e. the hunters would be stationed the furthest away from their prey. Furthermore, they would be sitting inside of stone circles and would need to scramble in and out of there if they wanted to swap stations. Therefore we suggest a different mode of operation: The 'blinds' in fact served as ditches, i.e. the animals that would collect in the enclosures because they followed the guiding walls would be frightened, so that they would dash towards the furthest points of the enclosures and jump the wall there. Instead of gaining free terrain, they would find themselves in the tight space of a 'blind'. *Gazella* (even though also called 'jumping gazelle'; Walther, 1990) do not like to jump across obstacles and presumably they cannot jump up and forward if not having a certain runway. Therefore they may have found themselves in "a tight spot" and as more and more gazelle followed, many of them were disabled and could later be easily taken out of the 'blinds'. The inward curved walls of the enclosures would allow the hunters to get close to the center of the enclosure and shoot at animals at close range, thereby setting them off in panic towards the ray-tips. This concept would, to our opinion, explain much better how the kites were operated than previous interpretations. In this way a few hunters could 'harvest' many gazelle without running high personal risk. All animals jumping the walls aside of the 'blinds' would escape and could be intercepted by the next chain of kites a few km further west.

5.3 Social structures

The building of hundreds of kilometres of walls in the Harrat, all of the same concept that result in an almost 100 % closure against animal movement must have involved an overall planning. The builders must not only have been internally organized and must have had enough man-power but they must also have had a long-term control over the area to embark on such an endeavor. We wondered if building these kite structures would actually have a high enough caloric return to justify this expenditure of man-power. We therefore calculated the calories need to build kites (calculation courtesy W. Dreybrodt, Bremen):

The weight (W) of a 1 m high (1 m = h_w), 1 m long and 0.5 m wide (A = 0.5 m^2) wall built from basalt (ρ·= 3000 kg m^{-3}) with an airspace fraction of 0.3 (F) is equal to

$$W = A*h_w* \rho*(1 – F) = 1050 \text{ kg}.$$

The energy (E) (with G = 9.81 ms^{-2}) needed to lift this mass (i.e. each stone has to be lifted to about 1 m (h) before it can be carried to the wall and deposited there is:

$$E = W*h*G = 10{,}300\ J, \quad \text{or } (1J = 0.239\ cal)$$

$$E = 10{,}300 * 0.239\ 10^{-3} = 2.46\ kcal$$

If the stones are 10 kg each, then for 1 m of wall, 1050 kg 10 kg^{-1} = 105 stones are needed. For each stone one has to bend over and lift the body (50 kg) back up; thus additionally

$$E = 105*50kg*1m*9.81ms^{-2} = 51{,}500\ J = 12.3\ kcal$$

are needed. In total about 15 kcal at least are needed per metre of wall. The efficiency of muscular work is about 0.25 and thus

$$1/0.25*15\ kcal = 60\ kcal$$

are needed per metre of wall, or 60,000 kcal per kilometre. Meat has a caloric value of 1,280 kcal kg^{-1}. Thus, 1 km of wall is equivalent to 46.9 kg of meat, i.e. in the range of the usable weight of three gazelle (if, for example, a Dorca gazelle is taken as standard that has a weight of around 20 kg). Assuming that per day about 500 kcal can be invested into work (half of that assumed for very heavy work) then 1 km of wall can be erected in 120 man days. Taking the average length of the enclosure perimeter (0.62 km), northern (2.00 km) and southern (2.06 km) guide walls together (= 4.68 km) then a kite can be erected in about 562 man days; or, if ten people cooperate, within 56 days or one hunting season. The investment would then be equal to about 220 kg of meat or about 15 gazelle, i.e. it would be highly profitable even at short-term.

Thus, the kites may have been built within a few years and, if hundreds of gazelle were hunted per year, they would have returned the caloric investment within a very few years.

The extension of some kite guiding walls across the openings of neighboring kites (phase (5) above) may have been triggered by the depletion of gazelle so that fewer kites were necessary or by the decrease of the number of people still living from hunting (or both). It could also be hypothesized that the final kite chain stage was used to exclude gazelle entirely from the area so that domesticated animals had the full use of the vegetation.

Many more questions need to be asked; for example where did the people building and using the kites have their camping sites, how did they preserve the meat and how did they transport the meat to markets (if that was one of the aims of the operation)? Who was organizing the building of the kites and who designed the master plan?

5.4 Sustainability

The high density of the kites also raises the question of sustainability. How long could the kites have been used with profit without depleting the gazelle to a point that the return would not sustain the hunting community anymore? The effective barring of animal migration by multiple kite chains and gap-less guiding walls could diminish the migrating herds within a few years almost to the point of extinction. But even after a near-extinction, the number of gazelle may have recovered if large-scale hunting would cease. This would explain the use of the kites in later times as described above. We were shown a head of a Dorcas gazelle (*Gazella dorcas,* Linnaeus, 1758) in Ruweished shot recently in the area. The introduction of fire arms, non-sustainable pleasure hunting and overgrazing have finally led to the extinction of gazelle in Jordan.

5.5 Heritage issues

Our study of the Google Earth images also shows how the area and its archaeological heritage are impacted by modern man. The area is crossed by the Trans Arabian Pipeline (TAP) (Fig. 1) and the Iraqi Pipeline (passing from Karouk in Iraq through Ruweished and Safawi to Haifa). To construct the pipelines, tracks and fort-like buildings had to be built. Wide, straight, characteristic double-tracks were bulldozed through the area, regardless of archaeological structures for oil exploration seismics (King, 1990). Other single-lane bulldozed tracks crisscross the area, intended to make the area accessible to the trucks of the modern sheep herders and reservoir basins have been bulldozed into the playas. More tracks are made by pickups. But most scaring is the random bulldozing that is seen along the national road 40 that crosses the area from Safawi to the Iraqi border and it seems only a matter of time before a substantial part of the archaeological heritage is lost irrevocably.

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