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# The Use of Desert Kites as Hunting Mega-Traps: Functional Evidence and Potential Impacts on Socioeconomic and Ecological Spheres

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## Abstract

For almost a century there has been debate on the functional interpretation of desert kites. These archaeological structures have been interpreted as constructions for animal hunting or domestication purposes, sometimes for both, but with little conclusive evidence. Here, we present new evidence from a large-scale research programme. This unprecedented programme of archaeological excavations and geomatics explorations shows the unequivocal and probably exclusive function of kites as hunting traps. Considering their gigantic size, as well as the significant energy and organization required to build them, these types of traps are called mega-traps. Our research is based on five different field studies in Armenia, Jordan, Kazakhstan and Saudi Arabia, as well as on satellite imagery interpretation across the global distribution area of kites throughout the Middle East, the Caucasus and Central Asia. This hunting interpretation raises questions about the transformation of the landscape by human groups and the consequent anthropogenic impacts on local ecological equilibrium during different periods of the Holocene. Finally, the role of trapping in the hunting strategies of prehistoric, protohistoric and historic human groups is addressed.

**Keywords** Desert kites · Hunting strategies · Holocene · Arid zones · Trapping · Geomatics

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## Introduction

Desert kites, or simply kites (Fig. 1), are often visible on the present-day surface of arid and semi-arid zones and their gigantic size is clearly perceptible in aerial photographs. These archaeological constructions made of stone alignments were first recognized in the 1920s by aviators, and were initially interpreted as fortresses, enclosures for domesticates or hunting traps (Maitland, 1927; Poidebard, 1928, 1934; Rees, 1929). Since then, very few in-depth studies have been carried out to assess which of these hypotheses could explain their exact function. Other questions

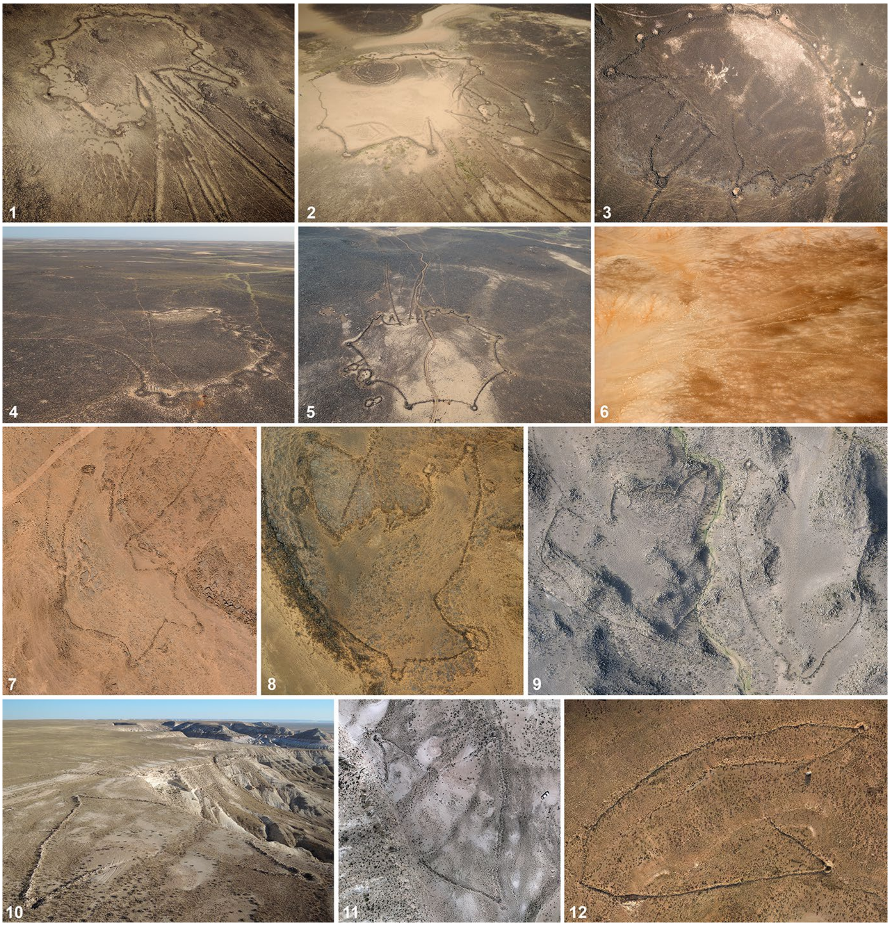


**Fig. 1** Aerial views of kites excavated by the Globalkites team. 1–5: kites from Harrat al-Shaam, NE Jordan (1: JD215, 2: JD139, 3: JD223, 4: JD600, 5: JD174); 6: kite JKSH 05 from Jibal al-Khashabiyeh, SE Jordan; 7, 8: kites from Nefud, Saudi Arabia (7: AB136; 8: AB549); 9: kites AM14 and AM15 from Aragats, Armenia; 10–12: kites from Ustyurt, Kazakhstan (1, 2: oblique and zenithal views of KZ54; 3: KZ95). All pictures were made by kite aerial photography by OB and ER, except 6, which is an aerial picture taken from a helicopter by Don Boyer ©APAAME, photo ref: APAAME_20141020_DDB-0326

related to their functioning, chronology and widespread distribution in many regions of the Middle East and Central Asia also remain unresolved (see Crassard et al., 2015 for exhaustive references).

The development of open-access platforms for satellite imagery, such as Google Earth and Bing Maps, dramatically renewed interest in kite studies in the 2010s, when these structures, visible on high-resolution satellite imagery, became observable to virtually anyone (e.g., Kempe & al-Malabeh, 2013; Kennedy & Bishop, 2011). In order to record the significance of this phenomenon, we set up a research project that revealed thousands of previously unknown structures on satellite images (the Globalkites project, see www.globalkites.fr; Crassard et al., 2015).

The Globalkites' definition of a kite includes three main features: the driving lines, which are multiple—usually two—long stone walls or stone alignments (also called 'antennae', 'arms', 'guiding walls' or 'tails'). These driving lines converge towards an enclosure (also called 'head') flanked by smaller, generally circular, structures called cells (or 'compartments', or '*logettes*', also known as 'hides' or 'blinds'). The nature of the driving lines and enclosures is in some specific cases related to topography, and they sometimes blend into the surroundings, when a cliff or a natural line in the landscape plays a guiding role, obviating the need to construct a wall or a stone alignment.

The combined presence of these three elements (driving lines, enclosures, and cells) distinguishes kites from other constructions with the similar, very widespread principle of long walls converging on a structure designed to enclose or trap animals. Kites are one of the most imposing constructions ever built across the world by humans in prehistory: driving lines can reach up to 6 km in length, and enclosures can spread over several hectares.

The geographical distribution of these structures (Barge et al., 2014, 2020; Crassard et al., 2015) is now known to cover a very large area (Fig. 2). They have been detected mainly in the deserts of Syria and Jordan (Helms & Betts, 1987; Legge & Rowley-Conwy, 1987; Échallier & Braemer, 1995; Kempe & al-Malabeh, 2010, 2013; Morandi Bonacossi & Iamoni, 2012; Zeder et al., 2013; Morandi Bonacossi, 2014; Betts & Burke, 2015; Abu-Azizeh & Tarawneh, 2015); Saudi Arabia (Kennedy, 2012); Armenia (Barge & Brochier, 2012; Barge et al., 2016b; Brochier et al., 2014; Gasparyan et al., 2013); and Kazakhstan and Uzbekistan (Barge et al., 2016a; Betts & Yagodin, 2000). Furthermore, kite-like structures—not meeting all of the Globalkites' kite definition criteria—are known in neighbouring regions, such as Israel (Bar-Oz et al., 2011a, b; Holzer et al., 2010); Yemen (Brunner, 2008, 2015; Skorupka, 2010); Egypt (Perevolotsky & Baharav, 1991); and Libya (Giannelli & Maestrucci, 2018). The Globalkites project has contributed to increasing the number of known kites from a few hundred to more than 6050 (on March 1st, 2020), as a result of the observation of satellite data, and has also brought to light kites in new regions such as Iraq, Lebanon and Turkey. These new data have led to a profound reassessment of the spatial extent of what we have called the 'kite phenomenon' (Barge et al., 2020), which was previously largely underestimated (Barge et al., 2015a, b; Crassard et al., 2015).

Since the 1920s, the functions of kites have been debated. Essentially known from aerial observations, desert kites have been interpreted, after rare and

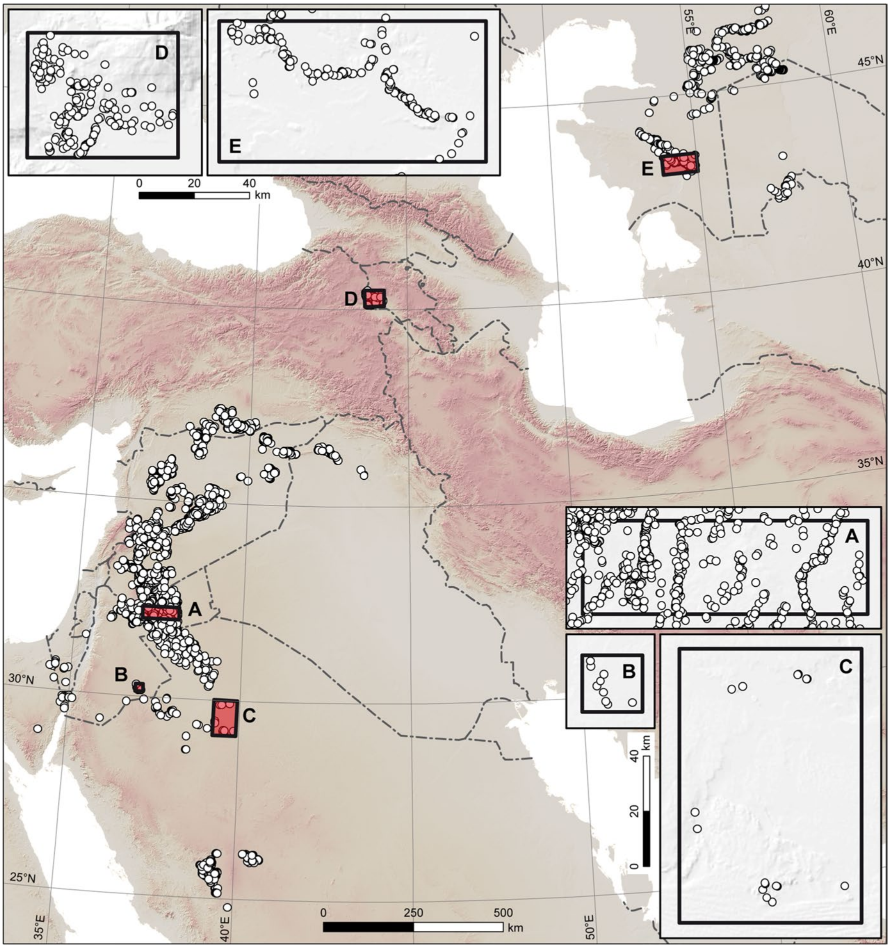


**Fig. 2** Desert kite distribution and the five regions ('Windows') of fieldwork

preliminary explanations as dwelling or defensive structures, as hunting devices and to a lesser extent as constructions for animal husbandry (Fowden, 1999; Maitland, 1927; Rees, 1929). Since the development of archaeological fieldwork on the ground, the issue has been more directly addressed, but rarely, and with relative success. Only few excavations of V-shape kites from the Negev (Bar-Oz & Nadel, 2013; Bar-Oz et al., 2011a; Holzer et al., 2010), and of a potentially kite-related dwelling site (Kuran, northern Syria: Zeder et al., 2013), have led to an interpretation of kites as mass-killing traps for wild game. This hunting function can also be found in various ethnographic sources, including travellers' accounts from the sixteenth to the twentieth century, describing gazelle hunts in Jordan and Syria (Burckhardt, 1831; Wright, 1895; Sinclair & Fergusson, 1902; Musil, 1928; Doughty, 1931/1990; Legge & Rowley-Conwy, 1987, 2000; Simpson, 1994; Jabbur & Conrad, 1995). Studies in Arabia and in the Sahara also described complex systems of trapping with such mass hunting installations (Baroin, 2006; Bin Aqil, 2004; Chapelle, 1957; Desombre, 1946; Sergeant, 1976).

In contrast to a cynegetic interpretation, other researchers have proposed a use of kites by transhumant societies as animal pens. Some have also suggested a progressive adaptation of these structures as animal enclosures for domesticates or wild animals on the way to being domesticated (Échallier & Braemer, 1995), and the idea that they were part of a livestock management strategy has been corroborated through interpretations of rock art (Jabbur & Conrad, 1995; Rees, 1929).

At a functional level, most scholars thus favour the hypothesis of use for hunting purposes (Bar-Oz et al., 2011a, b; Holzer et al., 2010; Meshel, 1974; Rosen & Perevolotsky, 1998). Despite this general consensus, the suggestion of a possible pastoral use (Échallier & Braemer, 1995; Fowden, 1999) persists in the archaeological literature, maintaining lingering doubt and uncertainty. Some authors challenge the hunting function of kites, and advocate herding or multi-purpose uses (Svizzero & Tisdell, 2018a, b). The functional interpretive status quo is due to an obvious lack of available factual evidence, resulting in a reliance on theoretical constructions (for a complete review of the different arguments from the literature, see Crassard et al., 2015). Until now, the hunting interpretation relied essentially—if not exclusively—on comparative and deductive reasoning. The descriptions and interpretation of late-nineteenth and early-twentieth-century travellers' stories are actually cited as comparative evidence in order to assert the existence of large-scale hunting devices, and then related to archaeological kite structures. However, these descriptions never entirely match the archaeological situation. Moreover, it is puzzling that these modern structures are not identifiable in the present-day landscape, as the kites are clearly older than a couple of hundred years. Again, the fact that these historical structures and their use have not left any traces in the modern Bedouin memory (in Jordan, for example) constitutes a serious limitation to the use of these references for establishing parallels with archaeological kites. On the other hand, analyses of rock engravings depicting kites associated with anthropomorphic and zoomorphic representations in Jordan (Betts & Helms, 1986; Échallier & Braemer, 1995; Harding, 1953), Syria (Van Berg et al., 2004) and Uzbekistan (Betts & Yagodin, 2000, p. 37) were not convincing enough to favour either of the functional hypotheses. The function of cells has hardly ever been explored in detail, beyond initial suggestions that regularly considered them to be hunters' hideouts. Considering the limitations of interpretive evidence, the functional question has not been fully resolved.

Based on a whole array of new evidence, here we propose a factual and conclusive definition of the function of kites as exclusive hunting mega-structures for trapping game. Our analysis is based on fieldwork carried out in five different distribution regions in Armenia, Jordan, Kazakhstan and Saudi Arabia. These different aspects are discussed in this paper in the light of trapping strategies and the broader hunting strategies adopted by human groups in the past. Finally, the ecological impact of the role of such hunting strategies on local biomass and landscape is examined. This research focuses specifically on evidence from archaeological investigations—especially excavation results—and on the implications of these data for the interpretation of these enigmatic structures.

## Material and Methods

### Study Areas: Five Windows

In order to apply a global approach to the kite phenomenon, five sample areas (or 'Windows') were defined, taking into account kite distribution and data availability (from fieldwork, satellite imagery and bibliography). For each Window, general typologies were documented based on the 24 descriptors used for statistical analyses of satellite imagery. The Windows were then recorded by Geographic Information System (GIS) surveying at a regional and local scale, adding more data to existing national archaeological maps.

### The Northeastern (NE) Jordan Window (Fig. 2a)

In northeastern Jordan, the Harrat al-Shaam basaltic desert hosts one of the highest concentrations of kites in the world, and presents very specific characteristics (Barge et al., 2015a). To date, 1281 kites have been recorded on Jordanian territory, representing an impressive proportion of more than one fifth of the currently known kites in the whole distribution area. This NE Jordan Window is entirely located in the Al-Mafraq governorate, over a surface of 103 × 34 km. The interpretation of satellite images led to the recording of 537 kites, organized in a pattern of seven linear associations ('chains') following a north–south orientation, and roughly parallel to each other. However, this pattern must be interpreted with caution as it is likely to result from gradual formation and transformation (through progressive modifications and additions of new kite constructions through time), rather than a synchronous use of all the kites of the different chains. The vast majority of these kites (83%) present an opening toward the east. We excavated 12 kites by opening 45 test pits in this Window.

### The Southeastern (SE) Jordan Window (Fig. 2b)

Investigated since 2013 as part of the French–Jordanian South Eastern Badia Archaeological Project (SEBAP), at the eastern edge of the Al-Jafr Basin, the 1000 m-high limestone plateau of Jibal al-Khashabiyeh yielded a short north–south oriented chain of eight kites, all also opening towards the east (Abu-Azizeh & Tarawneh, 2015). These structures, of which three were excavated, are isolated and located approximately 130 km from the main distribution of northeastern Jordanian and northern Saudi Arabian kites. This SE Jordan Window is the smallest, covering a rectangle of 10 km in width and 20 km in length.

### The Saudi Arabia Window (Fig. 2c)

This sample of 17 kites extends over a 66 × 99 km Window and is bounded by the northern fringe of the Nefud Desert. It represents the southern extension of the highest kite-density region in the basaltic deserts from Southern Syria to Northern Saudi Arabia. Five kites were excavated here, generally with north-facing openings.

### The Armenia Window (Fig. 2d)

This 2500 km$^2$ Window encompasses the total number of kites detected with satellite imagery in Northwest Armenia, along the fringes of Mount Aragats (Brochier et al., 2014). The 205 kites are an isolated group in the Lesser Caucasus, several hundreds of kilometres from the concentrations of kites in the Middle East to the southwest and in Central Asia to the northeast. A total of 49 kites were documented in the field, six of which were excavated. Their general orientation usually follows the local topography and shows a more varied pattern than in Jordan, although kite orientation in Armenia may possibly be correlated with animal migration corridors (Chahoud et al., 2016).

### The Kazakhstan Window (Fig. 2e)

The 149 kites from the Kazakhstan Window (100 × 50 km) are distributed along the southwestern cliff (the chink) of the Ustyurt Plateau. This specific geological feature influenced the aspect of these kites as the cliff itself was regularly used as a substitute for enclosure limits. This Window contains only two cases of 'double-arrow' kites, a specific type that is more common in the northern part of the plateau.

## Site Identification, Surveys and Excavations

The aim of the present study is to report the results of the archaeological excavations, that is, the structural specificities of kites, and more particularly of cells. Here, we present the general methods used in the scope of this article. More in-depth studies on the dating of kites, zooarchaeological and geoarchaeological studies, satellite imagery interpretation and geostatistics will not be treated in detail here, as they have been and will be addressed elsewhere (Brochier et al., 2014; Barge et al., 2015a, b, 2016a, b, 2020, in press; Crassard et al., 2015; Chahoud et al., 2015, 2016; Abu-Azizeh et al. in press).

Satellite imagery provided considerable quantities of data which were analysed by geomatics using GIS. Three different scales were studied. The global scale consisted in the observation of high-resolution satellite imagery which recorded the kites on the basis of 24 descriptors (e.g., elevation, enclosure size, number and length of driving lines, number of cells, break of slope), leading to a multiple-factor analysis. A sample of 600 kites was selected with respect to the general geographical distribution, and these 24 descriptors were analysed. A geo-statistical analysis of this sample, combined with other observations, such as zoological or environmental factors, led to the identification of regional peculiarities which potentially provide functional and chronological information. The regional or micro-regional scales were useful for grasping issues related to implantation in a given environmental setting, territorial structuration and the functioning of kites. The last scale of work was the scale of the kite itself: high-precision Differential Global Positioning System mapping and kite aerial photography leading to Digital Surface Models, photogrammetric rendering of topography and archaeology, documentation of superimposed archaeological features, and archaeological excavations.

Archaeological excavations were the main operations in the field for unravelling the structural peculiarities and ultimately the function of the kites. In total, 83 soundings were carried out in the five Windows between 2013 and 2018 (Table 1). They mainly took place inside the kite cells as the latter rapidly proved to be promising sectors for stratified contexts. Each excavated cell was usually hand-excavated in a half or a quarter of its total surface area, in order to understand the architecture and filling dynamics and to look for datable materials. All the sediments were systematically dry-sieved (0.5 cm mesh) in order to retrieve any archaeological material.

## Results

### The Difficult Issue of Kite Long Walls Acting As Driving Lines

The length of the long driving lines of kites ranges from less than a hundred metres to several kilometres, with a median length of about 300 m in Armenia, or more than 500 m in northeast Jordan (Barge et al., 2015a, fig. 11; 2015b, fig. 5). Most of the time, they appear on the current surface as random linear stone pilings with no clear construction arrangement (Fig. 3a). They generally do not exceed 40–50 cm in height, and judging from the stone collapse in the immediate vicinity of these lines, it is likely that they did not exceed heights of 60–80 cm at the most when they were

**Table 1** Inventory of the archaeological operations in the five Windows

| Windows | Total number of kites | Kites directly observed in the field | Excavated kites | Total number of soundings | Including soundings specifically made in cells (pit-traps) |
|---|---|---|---|---|---|
| NE Jordan | 537 | 38 | 12 | 45 | 31 |
| SE Jordan | 8 | 8 | 3 | 6 | 6 |
| Saudi Arabia | 17 | 10 | 5 | 6 | 5 |
| Armenia | 205 | 49 | 6 | 12 | 8 |
| Kazakhstan | 149 | 53 | 11 | 14 | 14 |
| Total | 916 | 158 | 37 | 83 | 64 |


**Fig. 3** Excavations of driving lines. A1 and A2: in a *qa'*, during and after excavation of kite JD223 (S2 sounding) from NE Jordan—the driving line is slightly covered by upper layers of silts from the sedimentary accumulation of the *qa'*; A3: view of the section of the same sounding; B1 and B2: two views of a sounding of kite JGHD 02 from SE Jordan—the driving line is constructed on this desert pavement, being almost entirely visible from the actual surface

in use. This characteristic begs the question of the efficiency of such low walls or stone alignments for driving animals to the final convergence point where the enclosure is located. Divergent opinions have been expressed on this matter (see Helms & Betts, 1987; Échallier & Braemer, 1995 for opposed views).

Recent experiments suggest that animal behaviour is a significant parameter for clearly understanding the efficacy of these low stone alignments: gazelles (*Gazella dorcas*), for instance, tend to follow and run along even quite low linear features of the landscape (Holzer et al., 2010). Attempts to trap gazelles in the Negev have been accounted to be successful using a simple strip of white plastic laid on the ground (Holzer et al., 2010, p. 815). Observations of gazelle (*Gazella subgutturosa*, *Procapra gutturosa*), hemione (wild ass) (*Equus hemionus*) and caribou (*Rangifer tarandus caribou*) behaviour revealed that they tend to run parallel to walls/fences/railroad/pipeline in Mongolia and Canada (Dyers et al., 2002; Ito et al., 2005, 2013, 2017; Kaczensky & Walzer, 2008) and thus could be easily directed by driving lines toward the enclosure trap. Barrier effects are observed on Mongolian gazelles that do not cross fenced railway even though they have the ability to do it (Barrientos & Borda-de-Água, 2017; Ito et al., 2005, 2008, 2013, 2017). In addition, observations of springboks and gazelles in general suggest that theses antelopes do not leap, unless frightened, over low vertical obstacles and can be kept in a pen 1.5 m high (Walther, 1968; Bigalke, 1972, p. 336). Wildlife conservation recommendations include creating an opening in fenced or enclosed reserve areas, in order to create an escape gate for wild herbivores crossing over. These escape openings are chosen depending upon the occurrence of species, migration routes and presence of animal funnelling topography. In these cases, wild ungulates, even though they are able to jump over fences, would follow fences, railway, or pipeline and would cross when an opening (gate, ramp) was available (Hammer, 2001; Harington & Conover, 2006;

Knight, 2014; Seiler & Helldin, 2006; Van Riper & Ockenfels, 1998). In addition, experiments aimed at capturing large herds of modern hemiones were successful using a system of asymmetric bow-shaped funnel design (driving lines) in Kazakhstan (Levanon et al., 2013).

Other arguments about the low stone alignments relate to specific observations based on the inherent topography and landscape of the various studied regions. In the basalt lava fields in northeastern Jordan, it has been argued that the efficiency of the low walls may be increased by clearing paths alongside the construction (Helms & Betts, 1987, p. 50; Betts, 1998, p. 203). On the other hand, in southeastern Jordan, the visual impact of the white limestone used for the construction of the walls, contrasting with the dark flint-strewn surface, might have been sufficient to drive animals, without building walls or paths (Abu-Azizeh & Tarawneh, 2015, p. 111).

Moreover, interruptions and gaps are often observed in the layout of these long walls. These openings do not seem to result from the destruction of walls over time and are likely to have existed since the initial construction of the kites. Ethnographic records provide multiple examples of the use of discontinuous walls in hunting structures, where built constructions are sometimes replaced by organic superstructures, such as branches or sticks with feathers or small flags (Frison, 1987, 1998; Ingold, 1980; Lubinski, 1999). This is the case, for example, in Armenia, where driving lines are commonly interrupted by a rocky crag, which is part of the structure. In Kazakhstan, kites along the high cliffs of the Ustyurt Plateau regularly use natural boundaries to replace constructed driving lines or enclosures. Other Kazakhstani examples show driving lines made of discontinuous aligned cairns. In the Jibal al-Khashabiyeh study area in southeastern Jordan, interruptions in driving lines are related to the scarcity of stones for construction in the flat and desolate plateau landscape. The walls are much more carefully built at the final approach to the enclosure, where excavations of the driving line itself yielded a fine double-faced wall, including a layout of standing stones (Fig. 3b). At these locations, the height of the walls is often more than 40 or 50 cm and width can reach 60 cm. Special attention was therefore paid to the strategic extremity of driving lines, in close proximity to the enclosure.

Furthermore, in livestock management literature, driving lines are not suggested for guiding livestock or funnelling them toward enclosures (e.g. Aland & Banhazi, 2013; Barber, 1981; Borg, 1993; Legel, 1990). Enclosure types have been the subject of numerous studies in archaeology, ethnography and zootechny, and show no similar use of enclosures with driving lines regarding livestock (Chahoud et al., in press).

These observations take on special significance in the light of compelling evidence of hunting from excavations of the kites' surrounding cells, described in the following sections. New data point to a still hypothetical, communal hunting strategy divided into two distinct and complementary phases: an initial 'passive' phase in which rudimentary stone alignments would have been sufficient to guide a herd of calm grazing animals, and a second 'active' phase at the approach of the final convergence point and the enclosure. However, modern observers have also documented collective hunts with a more active aspect from the very beginning, with the driving of calm wild game from far away to the trapping device where the struggling animals become more agitated (Frison, 2004; Testart, 1984). The combination of our results with a better knowledge of animal behaviour, in addition to experimentation—which is obviously difficult to implement—and direct ethnographic observation, will provide a clearer and more vivid reconstruction of the dynamics of hunting strategies and kite functioning. Agent-based modelling of animal movement could also be of great interest. The experimental approach (Lewis et al., 2012) provides computer-based simulation models of animal behaviours (Tang & Bennett, 2010) outside and inside the kites. This could contribute to understanding the functioning dynamics of traps, their consequences for animal populations and the impact of communal hunting on subsistence strategies.

## The Underestimated but Crucial Role of 'Cells': An Exclusive Trapping Function

Our excavations in Armenia, Jordan, Kazakhstan and Saudi Arabia present a new picture of kites, particularly in terms of the previously undetected aspect of the cells located around kite enclosures. After excavation, these cells turned out to be hollow structures, genuine chimney pits made of rough fieldstones, generally reaching depths of several metres (Abu-Azizeh & Tarawneh, 2015; Barge et al., 2015a; Brochier et al., 2014, in press; Abu-Azizeh et al. in press), which refutes the hideout interpretation of their potential function. The enclosure itself was in fact a continuation of the driving lines, leading to these cells, which are in reality trapping pits, or pit-traps. The current visible features of cells are filled pits of varying depths. Our numerous excavations showed that they are generally rather shallow on the Ustyurt Plateau (Kazakhstan), but this is an exception among the places we excavated. Depending on geological, morphological and climatic contexts, their fillings preserve stratigraphies containing not only biogenic materials necessary for radiometric dating, but also environmental data for relative chronology, whereas archaeological objects are extremely rare, if not absent. As the cells appeared to be pits dug from what is still in most cases the current surface, other soundings were dug in other parts of the kites to verify this structural peculiarity of the cells. Soundings were excavated along enclosure walls, the exterior parts of cells, and across driving lines. In these cases, the stratigraphic relation with the present-day surface was tested, and excavations showed that only the cells were hollow features. These systematic particularities observed on each of the 64 excavated cells from 37 kites studied in the five regions confirm a hunting use. Consequently, we suggest calling these kite cells (wherever located) 'pit-traps'. It is worth noting that such pits have been observed before in single-cell kite types from the Negev in Israel (Holzer et al., 2010; Nadel et al., 2013); such structures could be called single-pit-trap kites.

In the Harrat al-Shaam Desert (NE Jordan Window), two specific areas were selected for fieldwork, one in the western part (Fig. 4a, b), and one in the eastern part (Fig. 4c–e). The western area encompasses various groups of kites showing recurrent characteristics throughout the entire Window, but also many complex cases of overlapping structures. The eastern area shows a slightly different picture, with less complexity in terms of reuse and superimposition, and more

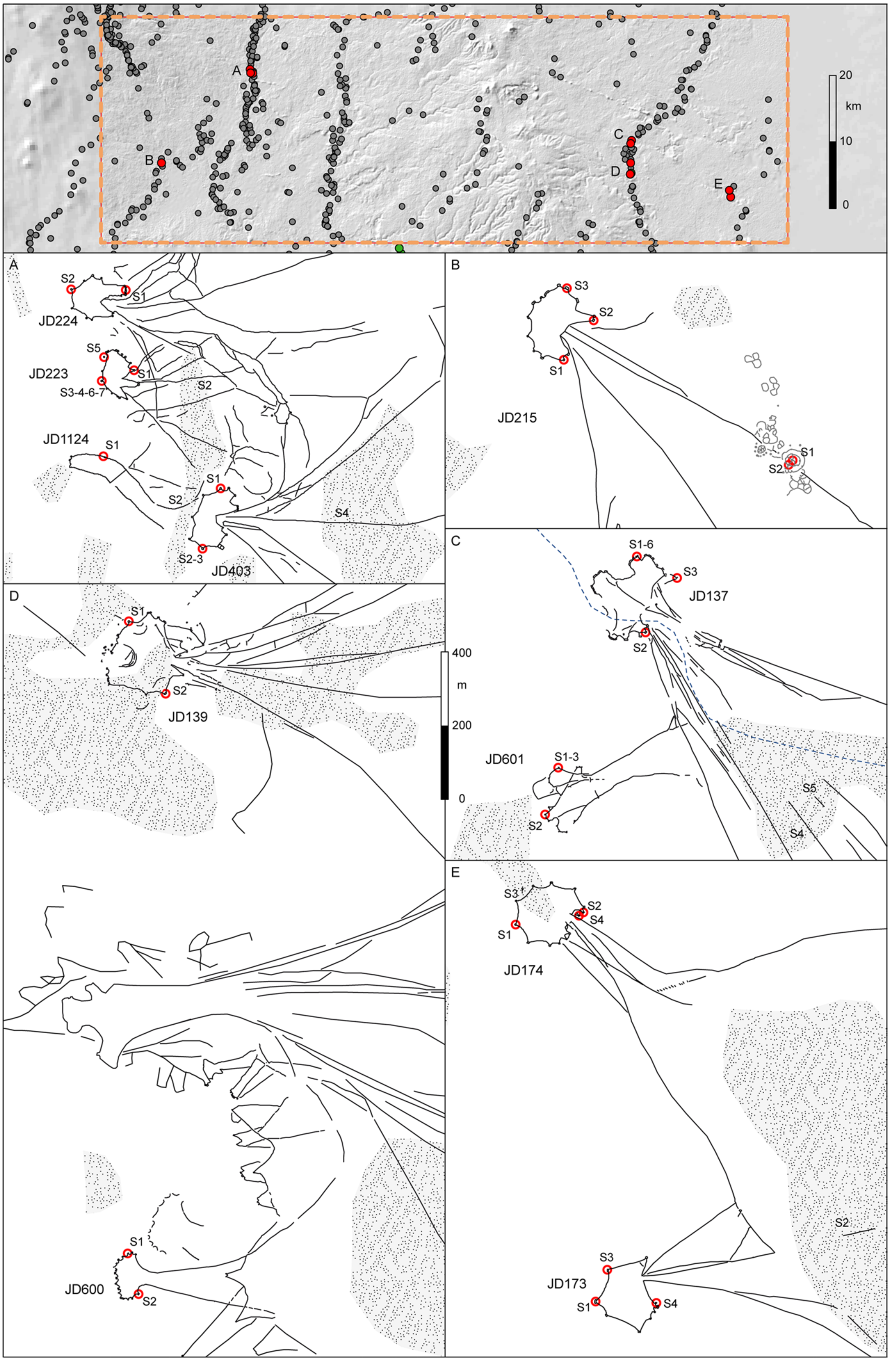


**Fig. 4** Harrat al-Shaam Desert (NE Jordan Window). Top: general map of the chains of kites; bottom: maps of kites with excavated pit-traps in red


**Fig. 5** Examples of excavations of pit-traps in the NE Jordan Window. 1, 3, 4: S3 sounding in kite JD223; 2: S1 sounding in kite MW2

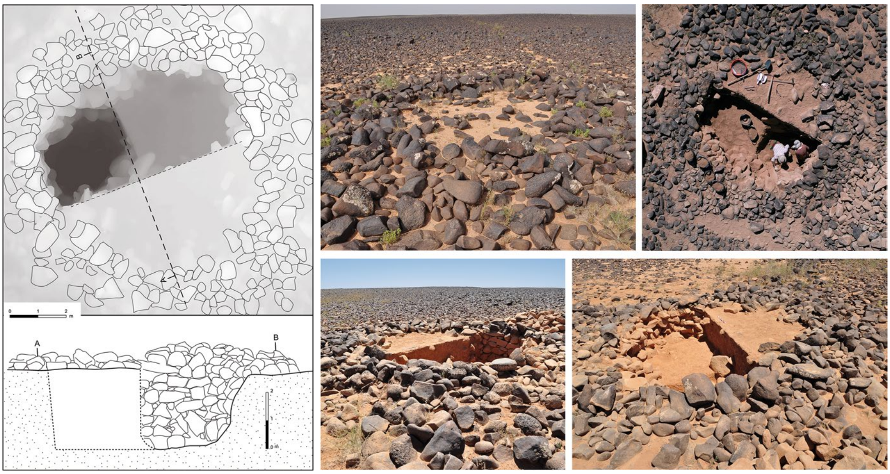


**Fig. 6** Excavation of pit-trap S1 in kite JD174 (NE Jordan Window). Drawings: photogrammetric model of the excavated pit-trap and section; photos, clockwise from top left: JD174 S1 pit-trap before, during and after excavation

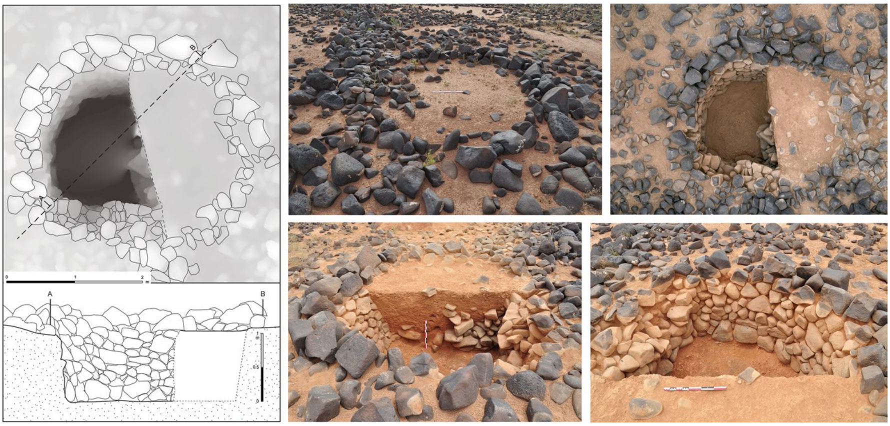

**Fig. 7** Excavation of pit-trap S1 in kite JD601 (NE Jordan Window). Drawings: photogrammetric model of the excavated pit-trap and section; photos, clockwise from top left: JD601 S1 pit-trap before, during and after excavation

pristine kites propitious to individual kite investigations and to understanding undisturbed structures. Excavations focused on three kite features: pit-traps (31 soundings), enclosures (four soundings) and driving lines (six soundings). Pit-traps were proportionally selected according to their spatial location in relation to the kite entrance: proximal, lateral and distal. The depth of each sounding varied from one feature to another, between 5 and 35 cm in driving line and enclosure excavations and up to 250 cm from the present-day surface to the bottom of pit-traps. The variations in floor depth indicate shallow walls for driving lines and enclosures in contrast to very deep pit-traps. These pits may vary in depth according to their location within the kite and construction methods (Figs. 5, 6 and 7). Sometimes pit-traps were built directly on the basaltic outcropping bedrock, and in most cases they used the slopes and natural topography, taking advantage of elevations naturally lower than inside the enclosure. However, most of the pit-traps were dug into substratum deposits. Generally, the accumulation layers in the filling of pit-traps show similar depositional processes for all the studied kites in this area. Three main units were recorded: (1) a pit-trap floor made mostly of the natural basalt bedrock on which the walls were constructed along an original pit dug in the natural sediments under the desert pavement of the Harrat al-Shaam, which is the same as the one observable today; (2) collapse of walls and sediment fill due to surface runoff, bioturbation; and (3) runoff accumulation induced by wind activity. Driving line and enclosure walls were constructed with a maximum of three courses, whereas pit-trap walls contained up to 14 courses of stones. Most driving line and enclosure walls were built directly on the desert pavement, whereas pit-trap inner walls were built in lower depressions or pits and were thus better preserved than the former. Walls were erected using basalt blocks from the surrounding area, and built with no bonding materials in uneven courses or in a string pattern from the inside of the pit-trap and scattered piles to reinforce the outer height of the pit walls.

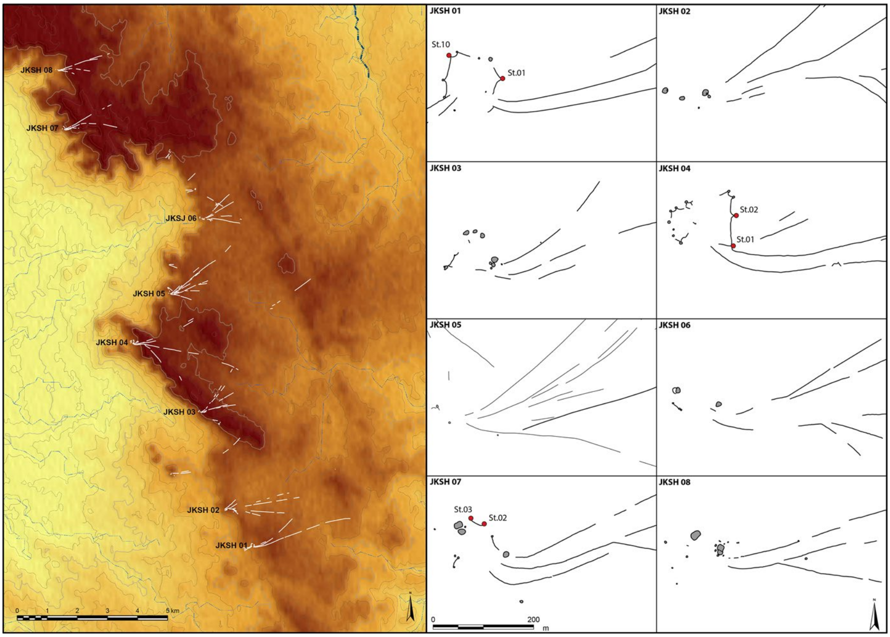


**Fig. 8** Jibal al-Khashabiyeh (SE Jordan Window). Left: general map of the chain of kites; right: maps of kites with excavated pit-traps in red

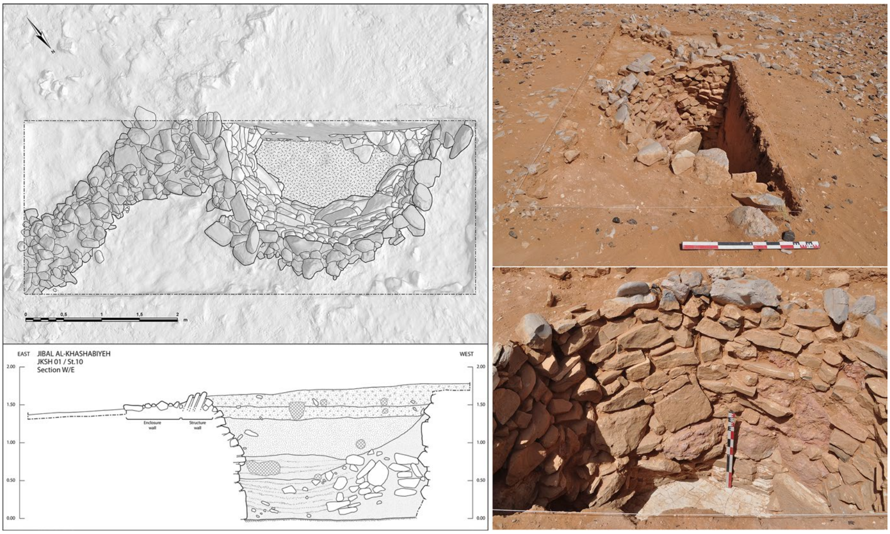


**Fig. 9** Excavation of pit-trap St.10 in kite JKSH 01 (SE Jordan Window). Drawings: photogrammetric model of the excavated pit-trap and W/E section drawing of the pit filling; photos: JKSH 01 St.10 pit-trap after excavation

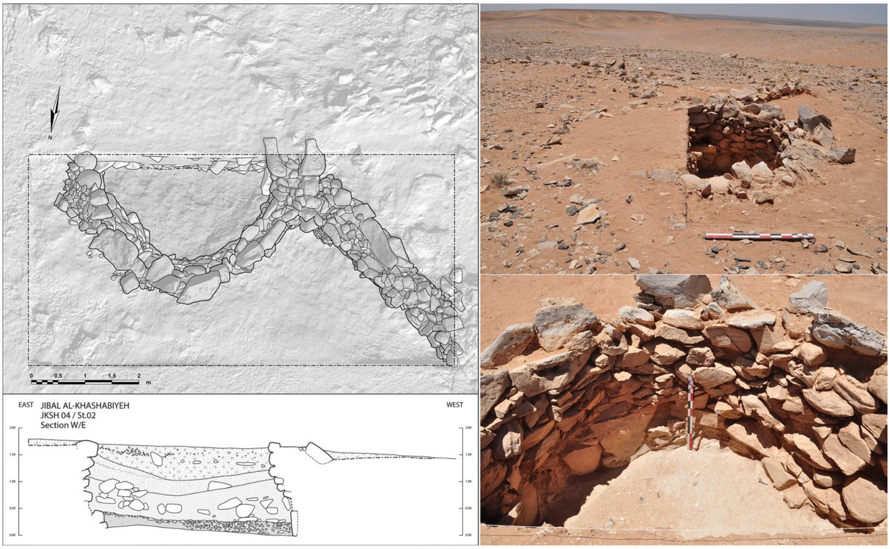


**Fig. 10** Excavation of pit-trap St.02 in kite JKSH 04 (SE Jordan Window). Drawings: photogrammetric model of the excavated pit-trap and W/E section drawing of the pit filling; photos: JKSH 04 St.02 pit-trap after excavation

At Jibal al-Khashabiyeh (SE Jordan Window), the remains of an enclosure surrounded by smaller circular cells were identified at three of the eight kites constituting the chain (JKSH 01, 04 and 07). These remains were absent from the five other kites as they were destroyed by the heavy erosion of escarpment slopes (Fig. 8). The excavation of two pit-traps at each of the three better-preserved kites showed that the structures were also dug from the present-day surface of the desert pavement. Their depth ranges from 140 to 180 cm from the surface, and they are usually very well preserved below the surface (Figs. 9 and 10). This confirms the results of previous excavations of an isolated kite at site JGHD 02 in Jibal al-Ghadiwiyat, where the same specificity was found (Abu-Azizeh & Tarawneh, 2015). At Jibal al-Khashabiyeh, large tabular slabs were selected from the locally available limestone materials and were generally placed vertically at the bottom of the inner walls of the pits. Alternatively, large spherical boulders, which are characteristic rock formations in the area, were incorporated into the stone lining at the base of the pits. The remaining elevation was composed of limestone blocks of irregular size, arranged in a rather opportunistic but well-organised way, similar to that observed in excavations in NE Jordan. In all cases, the wall facing of the pits was set directly on the limestone bedrock, and in two instances, the soft limestone bedrock itself was slightly dug out in the central part of the pit to add extra depth to the structure. Significant quantities of fallen stones were removed from the pit fill during excavation, indicating that the structures initially had higher walls. The calculation of the volume of fallen stones inside one of these pits (JKSH 01/St.01), using photogrammetry for 3D model processing, enabled us to reconstruct an original wall height of about 2 m, from the lower

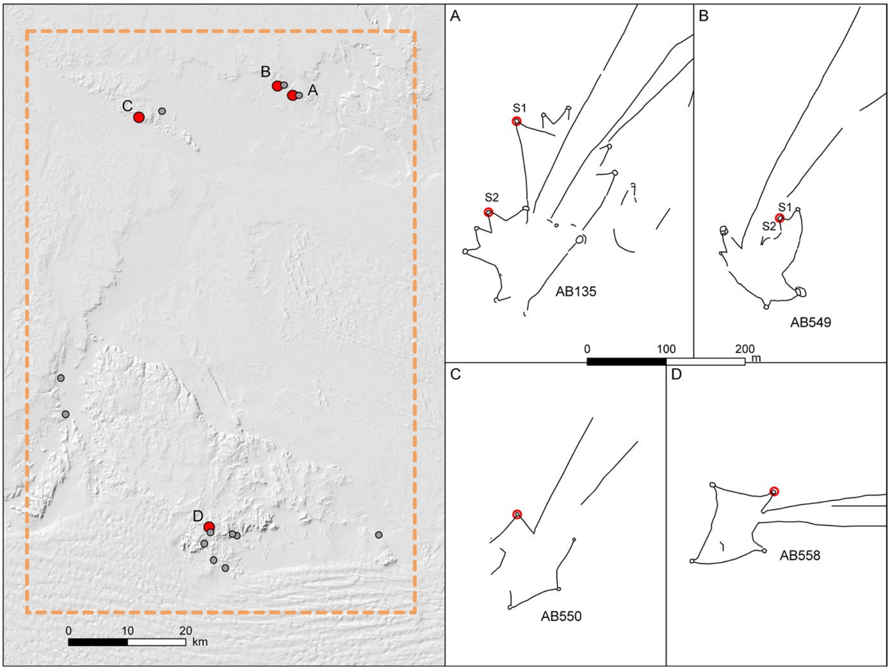


**Fig. 11** Nefud Desert (Saudi Arabia Window). Left: general map of the distribution of kites; right: maps of kites with excavated pit-traps in red

part of the pit-trap, up to the highest point of the wall above the present-day gro und.

The structural specificities of pit-traps from the Nefud Desert (Saudi Arabia Window, Fig. 11) are very similar to those observed in Jordan. The six excavated pit-traps from five different kites were all deeper than the present-day elevation of the inner enclosure, although depths were less impressive in most cases than those observed in Jordan. The depth of the pit-traps ranges from 25 to 75 cm (Fig. 12).

In the Armenia Window, the eight excavated pit-traps from six kites in various parts of the distribution area (Fig. 13) produced the same results as in other regions of the Middle East and Central Asia. Pit-traps can be particularly deep in the Mount Aragats area. The deepest pit-trap excavated was in AM4 kite, pit-trap L1 (Figs. 14, 15), with a total depth of 306 cm. The shallowest one was excavated in AM15 kite, pit-trap L1, with a depth of 125 cm. Construction materials there consist of particularly large and heavy volcanic blocks, which potentially require a large group of builders. These basaltic blocks delimit the rim of the pit with a liner made of stone facing. On the outside, a second facing of stones either rests on the ground surface or is lightly dug in. Above the pit, a double facing wall of variable height is then observed, outlining a slight corbel towards the centre. This unstable part has in all cases largely collapsed, so it is not possible to estimate its original extent. The rugged topography of the volcanic flows on which kites were generally constructed was used to take advantage of localised breaks of slope and to set up certain

**Fig. 12** Pictures of excavated pit-traps in the Saudi Arabia Window. Top: pit-trap L3 in kite AB135; center: pit-trap L1 in kite AB549; bottom: pit-trap L1 in kite AB550

pit-traps. In such cases, the wall shared by the enclosure and the pit-trap was built on the break of slope, while the base of the other walls was situated lower down the slope. This layout reduces digging work on the substratum. On the other hand, the more pronounced the slope, the higher the external walls. The latter contain numerous courses which can only rarely be observed as the walls have generally collapsed and only imposing quantities of scree are visible today. This type of pit-trap is also observed elsewhere, but it is more frequent and the structures are more imposing in Armenia than in other regions.

Finally, the kites we studied on the Ustyurt Plateau (Kazakhstan Window) also present pit-traps at the edge of their enclosures. Fourteen pit-traps from 11 different kites were excavated (Fig. 16). The Ustyurt kites are divided into two groups: 'simple' kites which sometimes incorporate the cliff plateau in their construction and gigantic 'double-arrow' kites. Statistical analyses of simple kites showed

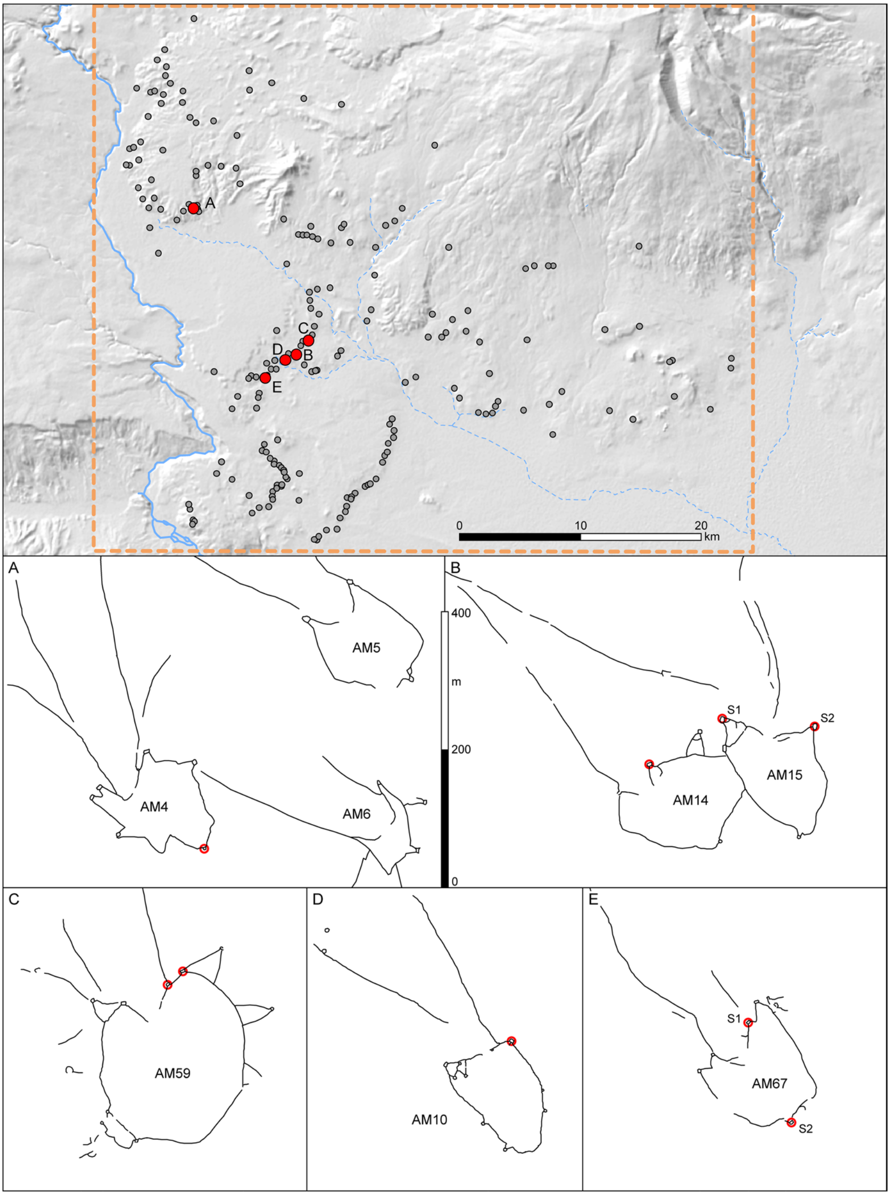


**Fig. 13** Mount Aragats (Armenia Window). Top: general map of the distribution of kites; bottom: maps of kites with excavated pit-traps in red

strong convergences with Armenian kites, despite the fact that they are geographically very far apart (Barge et al., 2015a, b). Some of the excavated pit-traps are dug deep into a hard biocalcarenite substratum. Other types contain limestone spalls in rather thin tabular slabs, resulting in specific arrangements. The inner

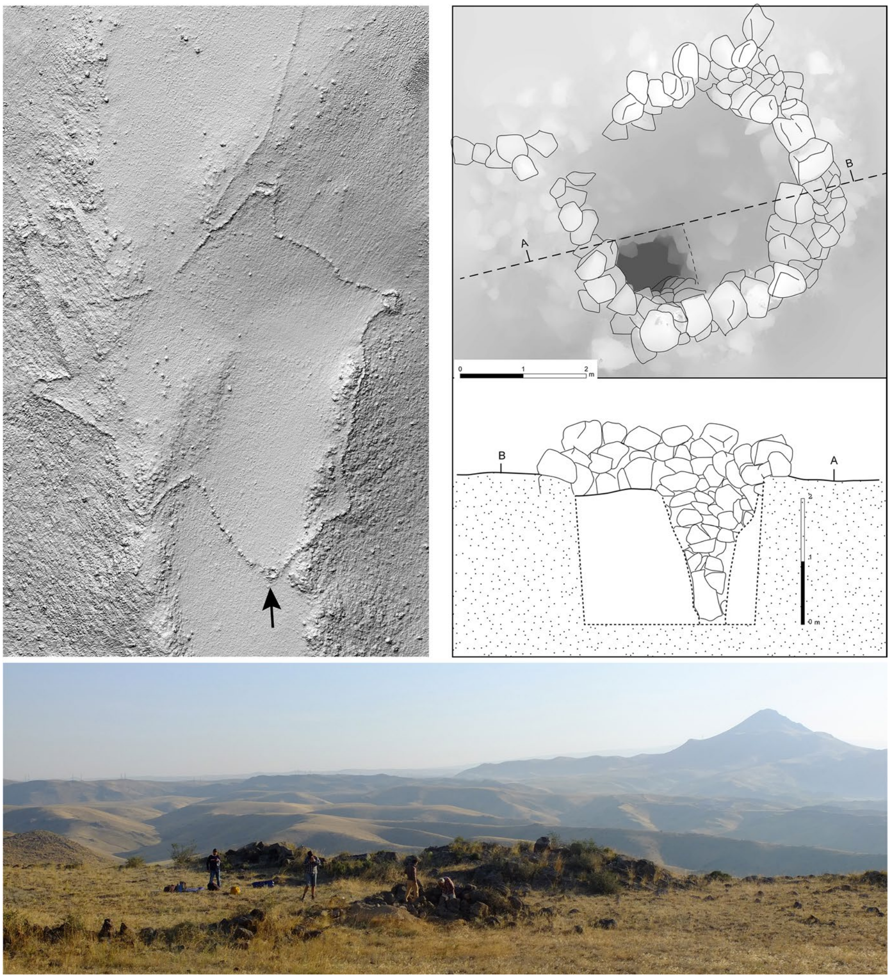


**Fig. 14** AM4 kite in Armenia. Top left: Digital Surface Model of AM4, L1 pit-trap is indicated by the arrow; top right: photogrammetric model of the excavated L1 pit-trap; bottom: general view of the L1 pit-trap at AM4

part of the pit is delimited by vertical slabs, which are generally so large that they line the pit in just one row, from the bottom to the surface (KZ500; Fig. 17). Smaller slabs were then piled up to build the upper part of the pit-trap above the ground. The peripheral piling presents a slight shift in each row towards the centre of the pit, forming a corbelled structure (KZ333; Fig. 18). The connections between the enclosure and pit limits are often marked by very large slabs. On the enclosure side, the shifted piling is sometimes constructed along a two-metre length, forming what could be interpreted as a ramp. The very short stratigraphic sequences observed in the shallow pit-traps (65 cm to 140 cm) did not provide datable elements, in spite of meticulous wet sieving of massive soil samples. The

**Fig. 15** Excavated pit-traps in Armenia. Top and centre: AM4 kite, pit-trap L1, before and after excavation; bottom: AM50 kite, pit-trap L11, before and after excavation

largest sedimentary fillings yielded rare wood charcoals and a few bird eggshell fragments.

In almost all cases (e.g., 99% in Jordan), pit-traps are located on the external edge of the enclosure. The enclosure walls are in contact with pit-traps at two points;

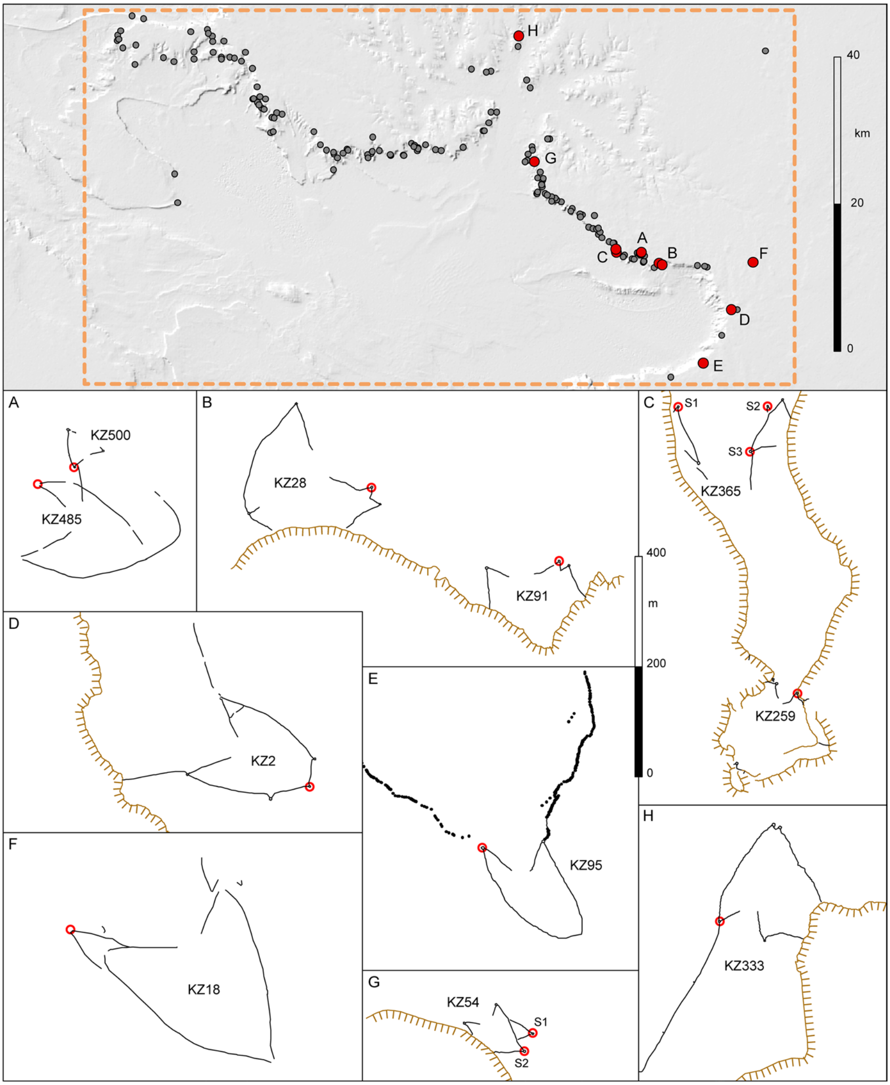


**Fig. 16** Ustyurt Plateau (Kazakhstan Window). Top: general map of the distribution of kites; bottom: maps of kites with excavated pit-traps in red

the part of the pit-trap wall between these two points represents about a quarter of its circumference and shows the same height all round. This general principle was observed in every case, but some variations in construction modes were nonetheless recorded. It is probable that these variations are linked to the available raw materials, the geological context and how the rocks break. The pit can also be created using localised breaks of slope (Fig. 19). This partially or totally obviates the need to dig substratum layers; in this case a higher wall is built at the external part, sometimes from the bottom of the pit. The almost systematic presence of a continuous

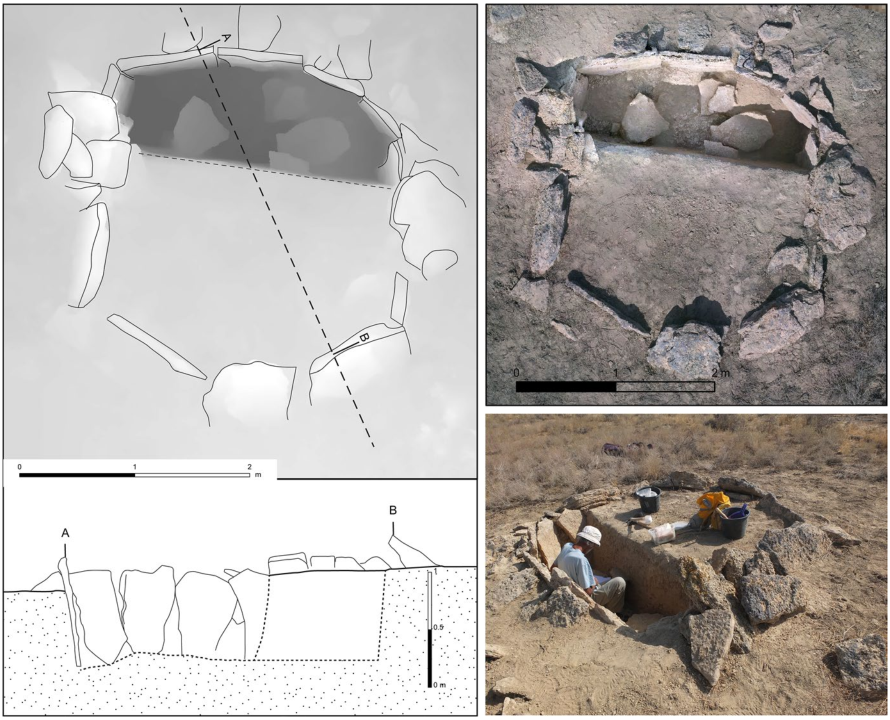

**Fig. 17** Excavation of pit-trap L1 in kite KZ500 (Kazakhstan Window). Drawings: photogrammetric model of the excavated pit-trap and section of the pit filling; photos: before and after excavation

wall around the entire periphery of the pit-trap is noteworthy; this is above ground level, and includes the junction point of the pit-trap with the enclosure, where an open access to facilitate driving the animal into the trap might be expected. An overall analysis of enclosure layout and the location of pit-traps provides evidence for a better understanding of the unexpected presence of this feature, as an integral part of a hunting strategy.

## Layout of Pit-Traps in the Kite

Pit-traps are not randomly distributed inside the kite. They are always connected to and positioned on the external side of the enclosure wall. We also note that they are generally situated at specific points of the alignment; in fact, their position determines the plan of the kite. We can distinguish four different types in the kite plan (Fig. 20; see also the typology in Barge et al., 2015a). Pit-traps can be:

1. *Tangential* The pit-trap is adjacent to the enclosure wall in a section where it is rectilinear or slightly curvilinear;
2. *Angled* The pit-trap is in the angle formed by the change in direction of the enclosure wall;

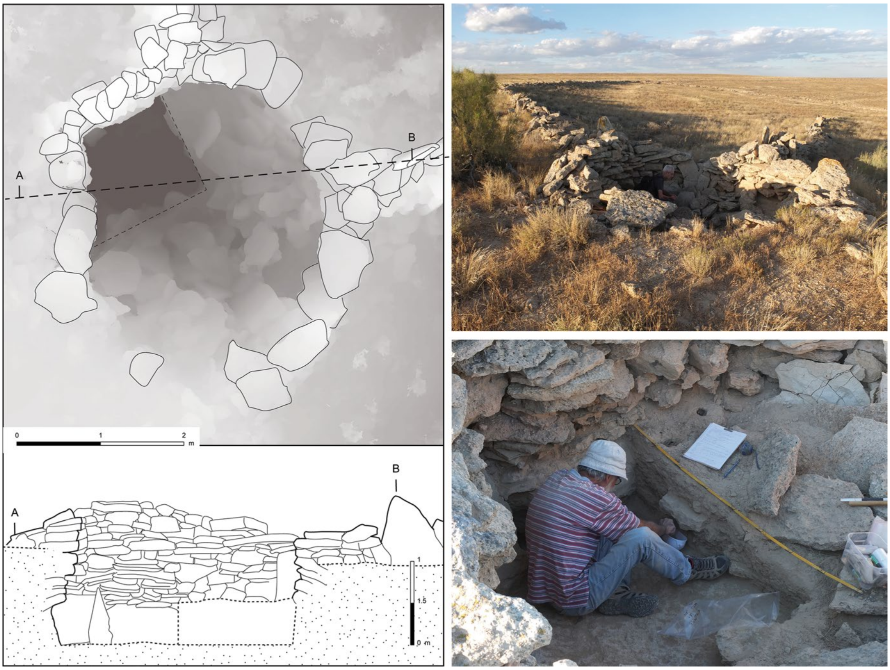


**Fig. 18** Excavation of pit-trap L1 in kite KZ333 (Kazakhstan Window). Drawings: photogrammetric model of the excavated pit-trap and section of the pit filling; photos: before and after excavation

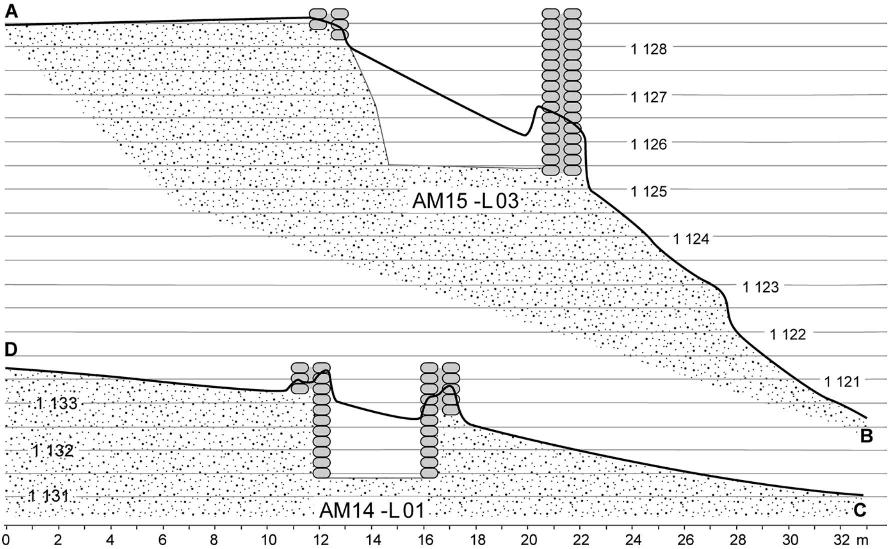


**Fig. 19** Examples of pit-traps implemented in different contexts (Armenia)

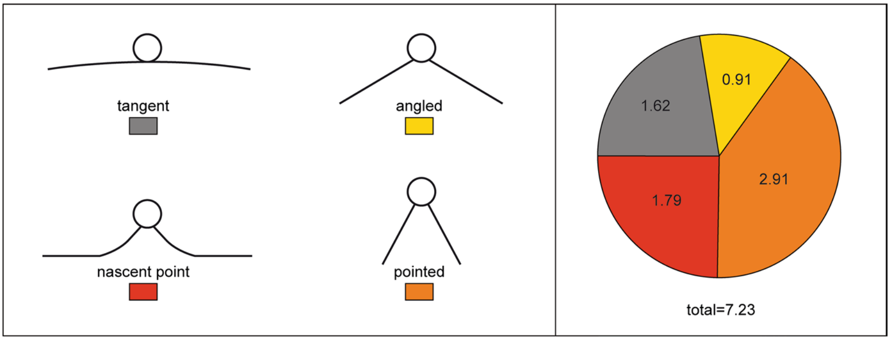


**Fig. 20** Insertion of pit-traps in the enclosure: **a** types of layout, **b** average number of the different types of pit-traps per kite

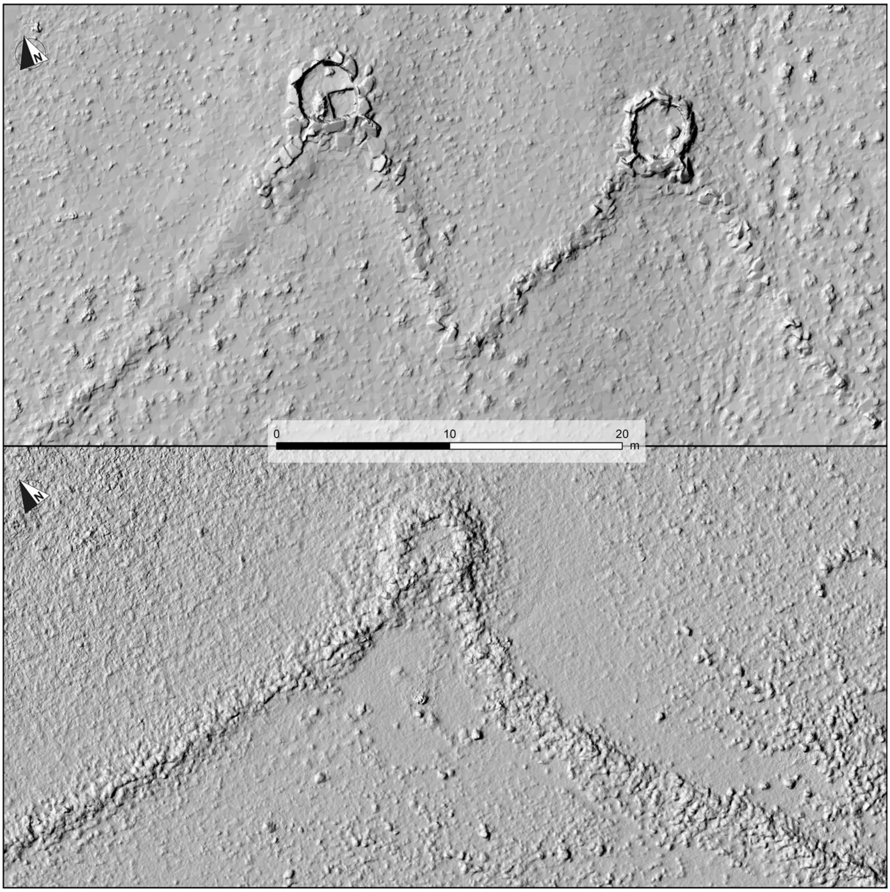


**Fig. 21** Examples of pointed type and nascent-point layouts (Digital Surface Model): **a** kite KZ28, two contiguous pointed pit-traps, **b** kite JD174, a nascent-point pit-trap

3. *Pointed* The pit-trap presents the same angled position, but the latter is inferior to 90°. The threshold of 90° (obtuse/acute) is admittedly arbitrary, but it enables us to differentiate pit-traps situated at the extremity of an appendage of the enclosure towards the exterior, with a pointed shape;
4. *In a nascent point* The enclosure walls clearly curve towards the exterior over a short distance, defining a marked decentralisation of the pit-trap towards the exterior. The layout outlines a nascent point.

Of these four configurations, the latter three define an inflexion point in the layout of the wall enclosure, which facilitates driving the animals and cornering them towards the pit-trap. This function of forcing the animals to move towards the pit-trap is more efficient when the walls form an obtuse angle. The two latter types (Fig. 21), which present very similar forms, clearly indicate a deliberate promotion of this function. In both cases, the arrangement is symmetrical, and both walls run into the sides of the pit-trap. In the case of pointed pit-traps, the two walls form an acute angle. For the nascent-point type, they gradually curve towards the pit-trap. These layouts limit the possible directions of displacement and promote the movement of animals towards the pit-trap through which the axis of symmetry runs.

The number of pit-traps of each type in the distribution area varies according to region, but those favouring the guiding of the animals are clearly preferred (Fig. 21b). Out of a sample of 600 kites at the scale of the distribution area, the relative frequency of tangent pit-traps is only 22%, whereas fewer than 5% of the kites comprise only tangent pit-traps, and half of them contain none at all. Conversely, 81% of the kites contain at least one pointed pit-trap and nearly half comprise one nascent-point pit-trap. The latter two forms, pointed and nascent-point pit-traps, are rather similar from a morphological viewpoint. Considered together, they are almost omnipresent (89% of kites comprise at least one of these two pit-trap types). Seventy-one percent of the kites are mainly formed by these pit-trap types and more than a third are exclusively formed by them.

These data show that the construction of pointed or nascent-point pit-traps was clearly preferred. Thus, the general shape of enclosures depends above all on the position of pit-traps, which create a layout propitious to forcing animals to move towards them. Now that we have identified the pit-trap as a deep pit and the ultimate

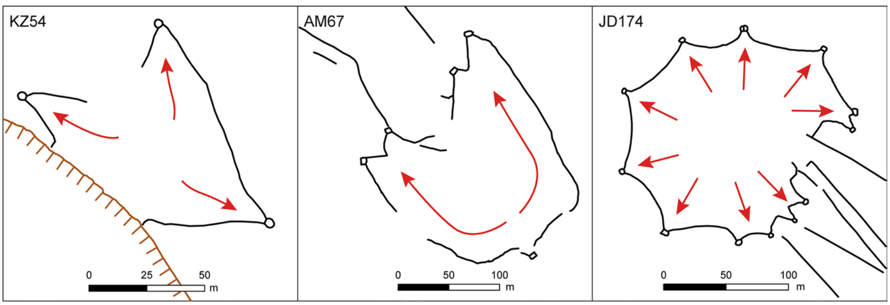


**Fig. 22** Examples of kite layouts consisting of pointed or nascent-point pit-traps (KZ54, AM67, JD174)

trapping device, rather than a partition, it is easy to recognize the details of enclosure layout as elements facilitating the guiding of animals. This is illustrated by the three following examples, taken from three different regions of the extension area (Fig. 22).

Kite KZ54 is made up of three pointed-pit-traps, two in proximal position in relation to the entrance, and one in distal position. The very simple overall triangular shape encourages the concentration of animals in the three corners of the triangle with pointed pit-traps.

The overall shape of kite AM67 is roughly circular, but the two proximal indentations each comprise two pointed-pit-traps. A small, poorly developed point (which could be considered a nascent point) occupies the distal part. For this kite, it appears that animals could circulate all around the enclosure, almost without obstacles, to encourage trapping in the more developed proximal points.

Kite JD174 consists of a dozen pit-traps, most of which are nascent points, regularly distributed around the enclosure. In this case, no direction was identified and the whole circumference of the kite appears to be a potential kill site. Regularly spaced nascent points were created to arrange spurs propitious to cornering the animals and driving them towards the pit-traps.

Throughout the area of distribution, although few in number, there are pit-traps built at the extremity of points, called blocked points. A wall marks a separation between pit-traps and the enclosure, which we are unable to interpret from a functional perspective. In Harrat Khaybar, several pit-traps built side by side at the extremity of points are regularly observed: 72% of kites have at least one group of contiguous pit-traps, which are very rare elsewhere, except in the Palmyra region where 42% of the kites have them.

## Explaining Closed Pit-Traps

The above-mentioned configuration is clearly intended to force animals to follow a specific route that leads to the pits. Pits thus appear to be a major functional component of kite infrastructures. The fact that cells/pit-traps are delimited by a wall protruding from the ground around their entire periphery, and that no gap or passageway is left at the junction of the enclosure, seems to be functionally significant. Rather than blocking access to the pit, we argue that the purpose of this wall was to conceal the animal's or herd's view of the pit from the interior of the enclosure.

At kite JKSH 01 in Jibal al-Khashabiyeh, the excavated pit St.01 presents a subcircular diameter varying between 4 and 5 m. As previously mentioned, our calculations reconstructed an original pit-trap wall height of about 0.50 m above the surface (while the pit was dug out to a depth of 1.50 m from the surface). Such a low wall would in fact totally obstruct visibility for short-legged animals, which would only be able to see the pit very close up. Figure 23 shows an example depicting *Gazella subgutturosa* with a height at withers ranging from 0.58 to 0.79 m. In this example, a 0.58 m-high gazelle would begin to see the pit-hole at a distance of about 1.28 m, while a specimen with a height of 0.79 m could begin to see it at a distance of about 3.37 m. At the bottom, a comparative illustration emphasizes the greatly increased

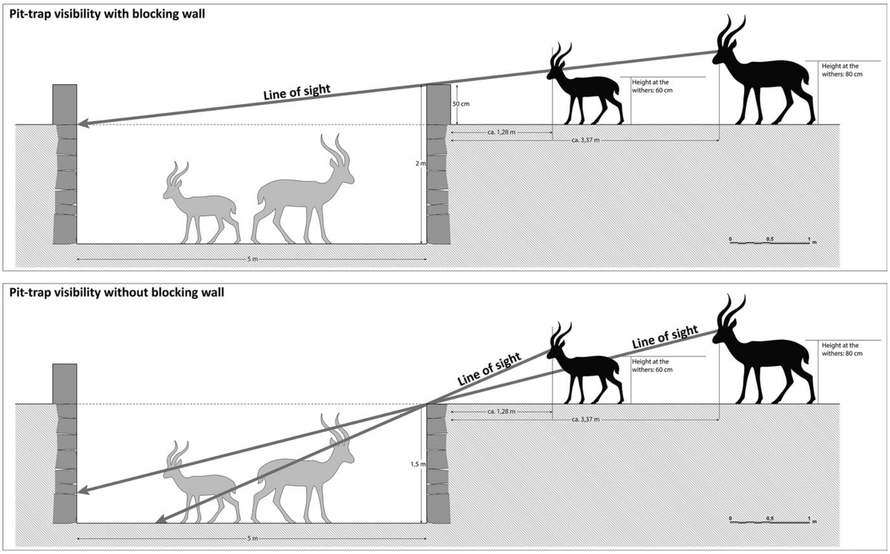


**Fig. 23** Illustration of pit-trap visibility for small mammals from the interior of the enclosure. The example presents a comparative depiction of the line of sight for minimal and maximal height of gazelle (*Gazella subgutturosa*: 0.58–0.79 m height at withers: Kingswood & Blank, 1996, p. 2), with and without the presence of the low wall surrounding the pit

visibility of the pit-hole for animals standing at the same distance without the presence of the low wall.

Escaping the enclosure would ultimately require the animals to jump across the wall. While the funnel effect of the 'star-shape' of the enclosure would naturally drive them towards the pit-trap as a privileged exit location, the wall surrounding the pit constitutes an additional and complementary device, effectively securing the hunting strategy. The wall conceals the pit until the very last moment when it is too late to change trajectory, especially as when goitered gazelle are in imminent danger they will not stop to assess the risk and do not run in front of the predators (Blank, 2018).

When ambushed, gazelles panic and will run towards an escape opening avoiding obstacles, thus following the suggested route of the star-shaped funnel. On encountering a vertical obstacle, they tend to jump over it if hustled. A galloping gazelle could jump a height of between 0.5 m and 2 m, depending on the species. The eyesight of gazelle is very keen, but a frightened gazelle would not have enough time to assess the risk and change strategy or direction, and would therefore jump into this pit-trap as intended. Animals in the herd will follow and run together (Blank, 2018; Kingswood & Blank, 1996; Walther, 1968).

The wall would serve to camouflage the pit-trap. Although gazelles are reluctant to jump over vertical barriers except when they are endangered and have no other choice, they can leap over horizontal obstacles very commonly and for long distances (Walther, 1968; Bullock, 1974; Ito et al., 2013). In a dangerous situation they would jump over the pit's wall without having time to assess a horizontal long leap due to the lack of visibility of the pit. Without the wall, animals would be able to see the hole and assess its depth from quite some distance, allowing them to avoid it and thus not jump at the precisely-planned point towards which the star-shaped funnel has served to guide them.

## The Choice and Use of Complex Topographies

Generally speaking, kites are situated in elevated regions, but without marked topographic differences. They are practically never sited on abrupt slopes and are only rarely present in gently-sloping regions. They are located in massifs without significant altitudinal differences and are thus absent from high mountainous terrains. On the other hand, they are often present in topographically complex regions, with compartmentalized relief with a wide variety of slopes and orientations.

The existence of kites in these regions with specific topographic characteristics can be explained by the scale of construction. We observe that local topography was always carefully chosen and used, regardless of the specificities of the different terrains.

Localised topographic irregularities were sought out by kite constructors to position the enclosure, namely the presence of more or less marked different-angled slopes with diverse orientations, compartmentalizing the enclosed area. In addition, small mounds, rocky snags or short ravines were sometimes associated with such irregularities, adding to the complexity of the topography. In comparison, the space between the driving lines appears to be much more open. The presence of a break of slope at or near the entrance was first noted and observed in Jordan (Helms & Betts, 1987), or in Syria (Morandi Bonacossi & Iamoni, 2012), quite some time ago. It was interpreted as representing an intention to conceal the entrance of the enclosure from running animals until they effectively entered the enclosure. A visibility test at kite entrances using very high-resolution (5 cm) Digital Surface Models (DSM) confirms this interpretation (Fig. 24): the interior of the enclosure only becomes significantly visible in the immediate proximity of the entrance. This break of slope at kite entrances is observed in more than 81% of cases at the scale of the distribution area based on satellite information. We have also often observed this feature in the

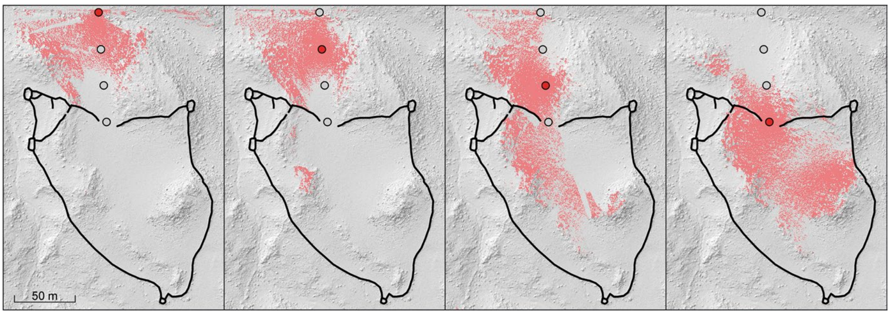


**Fig. 24** Visibility simulation of the approach to the entrance of enclosure AM15: viewsheds from a height of 1 m, calculated at 30 m intervals

field. In Armenia, driving lines follow the relatively open slope of basalt flows and the enclosure is located on the chaotic slope base of lava flows. In Jordan, this layout is often inverted: driving lines spread out over the vast *qa'*, then climb the bordering slopes to the enclosure built on top of the plateau. In both cases, the entrance is positioned at the point of convexity. This configuration is appropriate for use as a 'semi-trap', meaning a passive structure that needs to be 'activated' by human presence (Testart, 1984). In a similar way, kite constructors frequently used breaks of slope to position pit-traps. A high proportion of pit-traps were built immediately below a break of slope, so that the pit is out of sight from the enclosure. The pointed layout, which, as we saw above, plays an important role in limiting animal movements, most often takes advantage of the compartmentalization of space as a result of topographic complexity.

As a result of this topographic complexity, visual range inside and in the vicinity of the enclosure was always limited. From a given point, we can only observe a limited part of the kite, as the other parts are concealed by the irregularities of local relief. It is possible to quantify this observation with an inter-visibility calculation from a high-resolution DSM (Fig. 25). In theory, all the walls are visible in a flat area, but on average only 9 to 39% of the walls are visible from inside the enclosure. The compartmentalized relief on which the kites are sited in each case (seven examples taken in the five observation windows) thus defines numerous areas that are concealed from animals inside the enclosure. Without precise knowledge of the functioning of the kite (number, position and behaviour of hunters, number, position and behaviour of animals, etc.), it is difficult to determine the exact role of this limited visual range. However, it appears obvious that concealing obstacles from animal perception must have played an important role in trapping techniques.

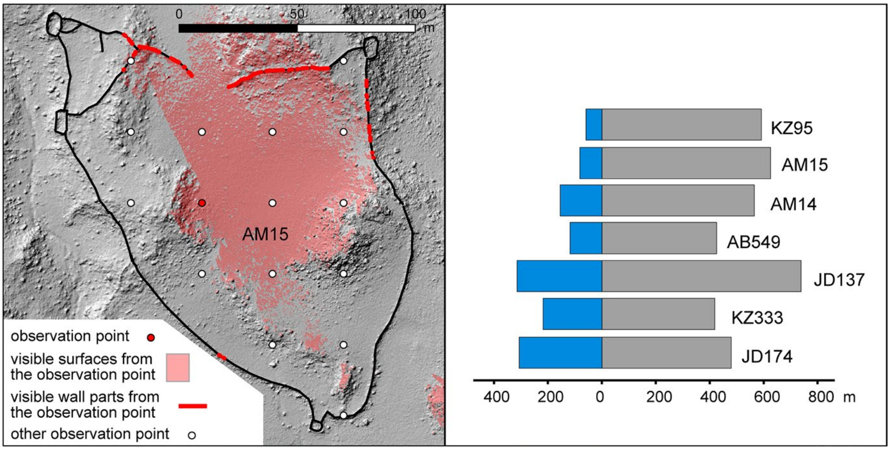


**Fig. 25** Calculation of inter-visibility between regularly distributed observation points (30 m apart) and the enclosure walls. **a** From each point, we calculated the visible portions of space from a height of 1 m (average size of the gazelle) and we identified the corresponding wall sections; we then calculated the length of visible and non-visible walls from each point and we established average values for all the points located inside the kite enclosure. **b** Average of visible and non-visible lengths for seven kites

Curved driving lines and hidden enclosures in the topography are efficient because the animal tends to go forward or escape toward open areas when it does not see a closed endpoint or obstacle.

The fact that kites were skilfully built to conceal numerous areas is thus an indicator of the use of these enclosures for hunting, although this visibility test applied to enclosure walls shows that the proportion of these concealed areas varies from one region to another (a very limited portion of the enclosure is visible in Armenia, where the presence of rocky snags results in a very compartmentalized relief, whereas a much larger proportion of the enclosure is visible in Jordan, where the landscape is more open). Topographic complexity is thus decisive for the way animals moved inside the enclosure. The number and the position of pit-traps is also decisive. The variety of kite morphologies and variations in topographic complexity suggests that operative modes may have differed from one region to another.

## The Orientation of Kites in the Landscape

Our analysis shows that kite orientation is not random. Consistencies observed in the different regions suggest that kite layouts are not incidental, although rather varied configurations are observed on an inter-regional scale. Frequently, kites are predominantly oriented in the same direction. From this perspective, the case of Harrat al-Shaam is exemplary, where the almost exclusive opening of kites towards the east was underlined very early on (Helms & Betts, 1987). The same constancy is observed in the north of the Ustyurt Plateau, where constructions are oriented towards the north (Barge et al., 2016a), whereas they are generally west-facing in the centre-west of Saudi Arabia in the Harrat Khaybar (Kennedy et al., 2015), or in Central Syria near Tell al-Rawda (Barge & Moulin, 2008). For kites in southern Syria, we observe a dual east-southeast and west-northwest distribution (Échallier & Braemer, 1995), whereas orientations seem to be more varied in the region of Palmyra (Morandi Bonacossi, 2014), where the relief is more marked. In Armenia, where topographic relief is also very marked, the kites tend to be oriented in the direction of the slope, with the enclosure downwards (Barge & Brochier, 2012). However, this does not mask a preferential northwest orientation.

In order to judge the importance of this topographic parameter, all the kites in five different regions were taken as samples and their orientation was measured (bisector of the driving lines). These five regions are comparable in size and were chosen because they present relatively marked altitudinal differences. The average slope of the region, delimited by the convex envelope of all the kites taken into consideration, is a value, among other possible values, enabling us to measure the steepness of the relief. In this way, the five regions are ranked in a rather gradual way, as follows, from least to most marked topographical relief: North Ustyurt (Kazakhstan); Harrat al-Shaam (Jordan); region of Al-Qaryatayn (Syria); Aragats (Armenia); and the chains to the northeast of Palmyra (Fig. 26). The observation of the circular distributions of kite orientation in each of these regions clearly shows that kites tend to display more varied orientations on the most rugged terrains. Furthermore, all the regions present a predominant orientation. The previously assumed interpretation

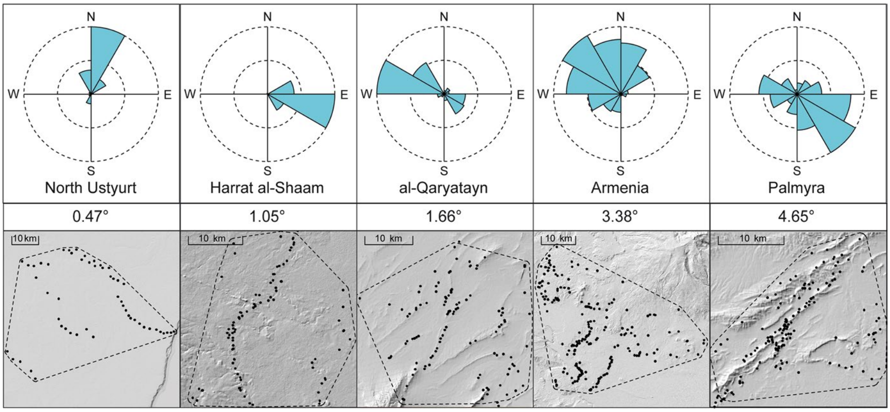


**Fig. 26** Orientation and relief in the five test regions: orientation of kites (top); average slope of the area delimited in dotted lines (middle); distribution of kites (bottom)

of kites opening in the opposite direction to that of animal migration routes (Betts & Yagodin, 2000; Morandi Bonacossi, 2014) thus seems to be confirmed. Indeed, herds of wild ungulates still migrate in the northernmost regions of the kite distribution area. In Armenia, the direction towards which kites open is opposed to the present-day seasonal route of large-sized herbivores (Chahoud et al., 2015). This is also the case on the Ustyurt Plateau (Barge et al., 2016a; Chahoud et al., 2016). This observation of systematic preferential kite orientation and the existence, in at least two cases, of wild animals migrating in the opposite direction within the kite distribution zone, is an additional reason for attributing a hunting function to kites, especially when animal ethology confirms, in the case of goitered gazelle, that these animals have a good learning capacity: they memorize their migration routes and areas of grazing and tend to return to the same locations each season (Ito et al., 2013; Nandintsetseg et al., 2019).

However, kite orientation is also influenced by topography. When the terrain is rugged (Armenia and the Palmyra region), animals tend to follow broad lines and to take routes along valleys or slopes which diverge from overall migration directions. This accounts for the wide variety of kite orientations. In such cases, the topography presents diverse opportunities for the location of the entrances and kites are comprised of many different elements (see above). Conversely, when the topography is more monotonous (north Ustyurt, Harrat al-Shaam, and, to a lesser extent, the region of al-Qaryatayn), nothing constrains the choice of orientation but topographic opportunities are rare, limited mainly to modest scarps and secondary ranges. These topographic features, in particular breaks of slope, were often used for installing kite entrances, and kites were aligned perpendicular to their orientation, forming chains. The latter are still observed in sectors where topographic relief is not very marked (Fig. 26), to the north of Ustyurt, in Harrat al-Shaam, and to a lesser extent, in the region of al-Qaryatayn. In the north of Armenia, kites are dispersed where relief is marked, but they are aligned in the south on flow fronts with less accentuated relief. The hypothesis of the existence of chains is a more plausible explanation than that of a hermetic barrier, which implies, on the one hand, a connection between kites (which has still not been observed), and on the other hand, that they are all contemporaneous (which has not been demonstrated).

We also frequently observe that the orientation of a limited, but nonetheless significant, number of kites is opposed to the predominant orientation of a region. In the five selected test regions, this is clearly the case in the regions of al-Qaryatayn and Palmyra. Two explanations can be advanced to account for this arrangement. Certain authors (e.g. Morandi Bonacossi, 2014) interpret this as a sign of migration in the opposite direction during a different period, but, with one exception (Southern Syria), this cannot explain the marked dissymmetry in the layout of circular distributions. Other authors suggest that they may be part of ‘no-return’ strategies, to capture frightened animals when they attempt to turn back (Échallier & Braemer, 1995).

## The Size of Enclosures

If kites had a pastoral use, we would expect them to be equivalent in size to enclosures clearly used for pastoral activities. A significant sample (n = 58) of pastoral enclosures from the numerous structures dispersed among kites in the protohistoric town of Al-Rawda in Syria (Barge, in press) was selected for geoarchaeological analyses, which confirm their pastoral function (Brochier, in press). They enclose smallish areas with a median size of 143 $m^2$, the interquartile range being (109–173 $m^2$). Such a size is broadly equivalent to the sizes cited in the literature devoted to similar pastoral structures in Europe, the Near East and Africa (e.g., Boles, 2017; Braemer & Sapin, 2001; Davidovich et al., 2014; Rendu, 2003; Schou, 2014; Ur & Hammer, 2009).

In southeastern Jordan, a detailed analysis of pastoral nomadic campsites was undertaken at a micro-regional scale in the area of Al-Thulaythuwat. Eighty-five pastoral nomadic campsites were identified, including a total of 227 stone enclosures characteristic of temporary settlement in arid margins (Abu-Azizeh, 2010, 2013, 2014). The typological approach involved a detailed structural analysis. It distinguished a wide variety of layouts and organizations, based on the number of structuring spaces, their type, the presence or absence of specific features and the general layout and plan of the units (see Abu-Azizeh, 2014, p. 193, fig. 4 for details of the typology). Simple stone enclosures, with no domestic features and dwelling areas in cells (n = 58), denote structures exclusively used for herding and corrals for livestock. The surface areas of these 141 corrals show a median value of 89 $m^2$ (interquartile range: [54–183 $m^2$]), with only a few exceptional occurrences ranging between 370 and 1014 $m^2$ (n = 8), and a single case with a surface area of 1678 $m^2$. This is consistent with what was observed in the vicinity of the Al-Rawda site in northern Syria. In comparison to the surfaces of a sample of 610 kite enclosures between Kazakhstan and Harrat Khaybar in Saudi Arabia (median: 8665 $m^2$, interquartile range: [4254–17,144 $m^2$]), the pastoral enclosures show differences ranging between factors of 10 to 100 (Fig. 27). The size of kite enclosures thus seems to be inappropriate for pastoral use, compared to the known cases from present-day and

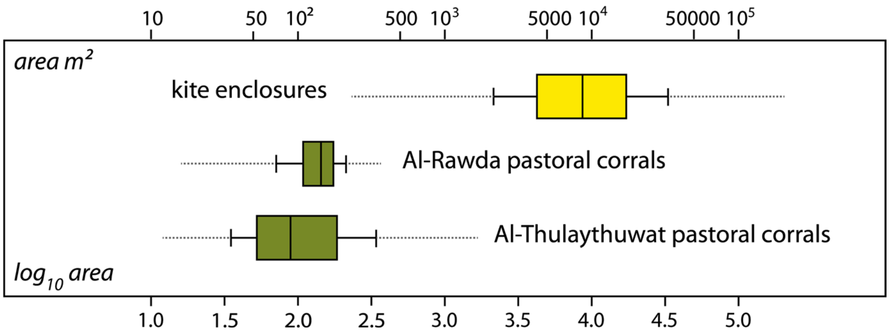


**Fig. 27** Comparison of the surface area of two pastoral coral samples with the surface area of kite enclosures. These boxes are constructed with log-transformed values. Boxes show median, Q1 and Q3; whiskers correspond to the first and ninth decile (solid line) and minimum and maximum values (grey dashed line)

prehistoric periods. Therefore, surface area should not be used as an argument for pastoral use.

## Discussion

### Comparable Structures in Other Contexts

The desert kites of the Middle East and Central Asia are currently being subjected to more detailed studies. In addition, other types of large-scale trapping structures have been observed and excavated elsewhere. In Sweden and Norway, similar huge trapping constructions were used to hunt herds of cervids (reindeer, moose) with drive lines and funnel-shaped traps leading to pitfalls, cliffs or rivers. These structures were mainly in use in the Viking and early medieval periods (Blehr, 1987; Jordhøy, 2008; Olsen, 2013). 'Y-V-W-profile pits' and '*Schlitzgruben*' structure types have also recently been discovered in Western Europe, particularly in France and Germany (Friederich, 2013). These pit-trap structures were intended for trapping wild animals, such as aurochs (*Bos primigenius*), but do not present driving lines. They are currently under study and an impressive corpus of radiocarbon dates already confirms an early date, between the Western European Mesolithic and Neolithic periods (Achard-Corompt & Riquier, 2013). In North America, extensive literature describes multiple hunting techniques based on driving animals through fences/walls towards enclosures, in order to kill prey with weapons or by forcing them to jump into pits or cliffs. Caribou (*Rangifer tarandus*) hunting by Arctic Inuit groups in recent times took the form of driving animals into a U-shaped trap where other hunters lay in wait, to kill the animals in semi-circular blinds (Benedict, 2005; Brink, 2005). Ethnographic accounts reveal that collective hunting of pronghorn antelope (*Antilocapra americana*) was carried out in the Great Basin (USA) up until the nineteenth century AD, with large structures made of drive lines and corrals (Brink, 2013; Hockett & Murphy, 2009; Steward, 1938, 1941, 1943). In the woods and mountains of Montana and Wyoming (USA), V-shaped wooden traps were also still used for bighorn sheep (*Ovis canadensis*) up until the nineteenth century AD in communal hunts (Loendorf & Stone, 2006). These traps, made of wooden fences, were constructed near sheep bedding and mating areas. Archaeological research has also yielded several ancient driving structures (e.g., Frison, 1998, 2004; Hockett et al., 2013; Kornfeld et al., 2010; O'Shea et al., 2013). For instance, communal hunting techniques are inferred from the bison (*Bison occidentalis*) remains found in North American Paleoindian sites ('bison jumps' and 'bedbones'; Gordon, 2002). In South America, encounters of Inca royal drive hunts are reported during the sixteenth century AD in Peru, involving large numbers of hunters of wild camelid herds, which were driven inside a corral made by men joining hands (Cobo, 1990; Rowe, 1946), or using structures made of funnel-shaped stone lines constructed between rocks or outcrops (Custred, 1979). In Patagonia, guanaco (*Lama guanicoe*) were hunted during communal and mass hunting seasons, at the beginning of the Late Holocene (Santiago & Salemme, 2016). Finally, in Japan, trap-pit hunting strategies are documented from at least 40,000 years ago, and up until relatively recently. Hundreds of sites have been recorded and excavated, mainly in southern Honshu and southern Kyushu. A strong tradition of research on this topic has been embedded in Japanese archaeology for several decades (Imamura, 1996; Sato, 2012), and will be inspiring for comparative approaches. Among all these examples worldwide, it is important to distinguish traps with pit-traps from the others. Based on our definition of desert kites (that is, the systematic presence of pit-traps), mega-traps with this feature are of particular interest for understanding how such structures were used, and whether or not they required the presence of hunters. Comparative approaches with all the other types of communal hunting mentioned here, with or without pit-traps, will certainly shed light on the functioning and management of such mass-killing events.

## Which Species were Hunted with Kites?

Ethnographic literature (from the nineteenth and twentieth centuries) describes hunting and culling scenes of gazelles in structures similar to kites, and the transport of whole carcasses to settlements (Aharoni, 1946; Burckhardt, 1831; Legge & Rowley-Conwy, 1987, 2000; Musil, 1928; Wright, 1895; Yagodin, 1998). Other ethnographic studies in the Sahara and Arabia describe nomadic herder societies who practised collective hunting, trapping and mass culling of several kinds of game in kite-like structures (Baroin, 2006; Simpson, 1994). For prehistoric periods, wild animals like *Antilopinae*, ibex, equid and ostrich are varieties of game (in terms of ethology and ecology) susceptible to being trapped (Chahoud et al., 2015). The profusion of *Gazella* bones in Middle Eastern prehistoric settlement sites, from the Late Pleistocene to the Neolithic/Bronze Age periods, indicates that they were the most hunted ungulate species, alongside the Persian fallow deer in Mediterranean regions, and the onager in mountains and steppes (Bar-Oz, 2004; Chahoud & Vila, 2011; Gourichon et al., 2006; Helmer et al., 2004; Martin, 2000; Martin et al., 2009). A zooarchaeological synthesis of hunted species in Holocene Armenia shows that wild species are rare from the Early Bronze to the Iron Ages and include the Bezoar goat (*Capra aegagrus*), the mouflon (*Ovis orientalis*), the red deer (*Cervus elaphus*), and the goitered gazelle (*Gazella subgutturosa*). According to historical and contemporary observations, kites were found in the migration corridors of these wild animals, and were therefore probably used for hunting an important quantity of game during herd migration (Chahoud et al., 2016). Almost no faunal remains have been found in a kite during archaeological excavations. Only a few settlement sites associated with meat processing could be related to mass-killing structures such as kites (Zeder et al., 2013).

## Impact of Kite Hunting on Ecologically Vulnerable Environments and Holocene Societal Changes

Considering the concentrations of kites in the Middle East and Central Asia, the development of these trapping mega-structures made a spectacular human impact on the landscape. Depending on their biomass, herds probably adapted and made changes in the choice of migration routes, which would have had repercussions on the positioning of kites. Ecological consequences are part of a chain reaction with possible overexploitation of the biomass and possible extinctions of species at a micro and macro-scale. The dating of kites in the five regions is still ongoing (radiocarbon and optically stimulated luminescence), but the first results indicate that they were used from the end of the Early Holocene in the Middle East to the Middle Holocene in the Caucasus and Late Holocene in Central Asia (e.g., al Khasawneh et al., 2019; Barge et al., 2016a; Abu-Azizeh et al., in press). Climate change during these periods and an evaluation of its impact on trapping activities is currently under study.

Relationships between humans and wild animals have changed considerably throughout time. Human conceptions of the wild are dependent on several cultural (social, religious, etc.) and environmental (subsistence, climate, landscape, etc.) criteria. Studying hunting activities can contribute to understanding some of these human–animal links. Hunting is not solely for subsistence (Sergeant, 1976), but also reveals the human socio-cultural sphere and the intellectual process of embracing animal behaviours and the environment (Helmer et. al., 2004). From the Neolithic onwards, these conceptions of the wild became more complex, due to a crucial change in human–animal relationships: the Neolithic period in most parts of the world was marked by animal and plant domestication and the evolution of sedentary and mobility patterns (Vigne, 2011). Domestication progressively led to larger settlements and demographics. Environmental exploitation became more intensive, mostly for land clearance for new settlements, pastures, and agricultural fields. This period was marked by the progressive decrease or even sometimes the extinction of wild animal species, as the latter were either affected by human-induced environmental changes or by excessive hunting to meet the needs of growing human populations. This decline was also due to an increase in symbolic behaviour related to food production and social organization (Akkermans & Schwartz, 2003; Price & Gittleman, 2007). Hunting activities intended to trap mobile herds (with mega-traps) or solitary wild game are pre-planned and require group or community organization (well thought-out strategies); adapted hunting techniques for capturing an animal (process); knowledge of regional ecology and animal ethology (know-how); and a specific need and/or desire for the outcome (decision-making) (Chahoud et al. in prep.). Hunting techniques evolved with changes in subsistence strategies. Several forms of hunting can be inventoried depending on capture techniques, the number of hunters involved, the use of different tools for the kill and the number of wild game hunted (Das & Kolack, 2008). Several aspects of the workings of these structures remain unclear, such as the precise migration routes of wild game in the past, capture zones, the need to shift from individual to collective hunting, the relationship of these features with settlement sites, human mobility related to collective hunting and prey exploitation. The choice to continue hunting when domestication was already well-established in the society, in some cases from a very early time, is clearly related to individual and group adaptive responses (Chahoud et al. in prep.).

## Conclusion: Towards a Study of Trap-Hunting in Human History

This detailed analysis shows that kites are mega-structures that were carefully and specifically designed and built to progressively drive animals from a state of freedom in the open landscape along driving lines, to captivity in a specific chosen location. However, the new elements presented here indicate that the final intention was not the kite enclosures themselves, but the smaller pit-traps (cells) surrounding them. This fundamental change in our perception of kite layout and organization definitively favours the hunting strategy rather than the herding function involving the corralling of domesticated animals.

Among the whole range of hunting strategies used by human groups throughout the history of humanity, trapping (as a 'passive' or 'semi-active' hunting strategy) was probably frequently exploited (e.g., Billard & Bernard, 2016; Sato, 2012; Speth, 2013). Trapping animals can involve little investment, in terms of material, know-how or effort, and a whole range of traps are still in use around the world today (e.g., Anell, 1960; Bateman, 1988; Mérite, 2011). Nonetheless, the case of kites is somewhat different, as the building and management of pit-traps may have required considerable investment, as well as good knowledge of animal behaviour.

If archaeologists have, up until now, only occasionally invested research in the broad trapping topic, this is probably because very little evidence of such traditions has survived (Shaffer et al., 1996). As a consequence, the trapping abilities of human groups are almost unknown in the archaeological record. Only 'active' hunting strategies are currently widely studied, mostly because they are the only archaeologically observable hunting strategies. Thus, a whole aspect of hunting techniques, traditions and methods is totally overlooked by archaeologists, and the study of trapping cultures is not even considered, due to a lack of awareness of their very existence. The large quantities of stone tools (lithic weapons), for instance, available at innumerable sites around the world, have given rise to manifold interpretations of active hunting technologies, economies and patterns. This is an unwitting example of a pitfall in anthropological research: namely, 'forgetting' a whole section of primitive food-procurement strategies due to the absence of evidence.

We argue here that desert kites mark a profound change in human strategies for trapping animals during the Holocene period. These constructions were vast mega-traps terminating in killing devices—the pits. Their location, size, and orientation were carefully chosen to maximise their effectiveness in specific topographies. Our initial results suggest significant scope for future interdisciplinary studies investigating the complex relationships between human groups and their surroundings. Such relationships clearly involved extensive and profound knowledge of animal behaviours that, nonetheless, may have resulted in unintentional effects, such as ecological damage, the 'artificialization' of natural environments, loss of diversity, and anthropogenic species extinction.

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## Declarations

**Conflict of interest** The authors declares that they have no conflict of interest.

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