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Traces of Early Neolithic Settlements, Hunting Structures, Roads and Cultural Places in South Syria and N-Jordan visible on high-resolution Satellite Images

Barbara Theilen-Willige[1*], Verena Willige-Kottke[2] & Edward Andrew Dubowski[3]

[1]Waldstrasse 11a, 23683 Scharbeutz, Germany.
[2]Zaunerstrasse 7, 80997 München, Germany.
[3]Mansfield, Nottinghamshire, England, United Kingdom.
Corresponding Author (Barbara Theilen-Willige) Email: Barbara.Theilen-Willige@t-online.de*

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ABSTRACT

Based on high resolution satellite images like the World Imagery files provided by ESRI and Google Earth by Google were used a base for a systematic inventory and categorization of pre-historic traces in the east of the Jabal al Druze massif in S-Syria and NE-Jordan. The traces of Late Paleolithic and Early Neolithic cultures were digitized and analyzed using ArcGIS Pro, QGIS and digital image processing software embedded in ArcGIS Pro, in ENVI, ERDAS and SNAP software. Landsat and Sentinel 2 data were included to assess the environment setting. Digital Elevation Model (DEM) data were added to derive morphometric maps. Digital processed Landsat images were used for a better understanding of the hunting routes and roads placement, as well as the DEM data. Although many pre-historic traces are not visible anymore because of the overprinting land use, "kites", as well as hunting routes and smaller settlements are detectable on the satellite images. "Wheels", cluster of wheels, and settlements, as well as different stages of later settlements, were digitized. However, the purpose of some of the pre-historic features can only be assumed. The hunting routes are aligned nearly parallel in NNE-SSW to NE-SW- directions, tracing the movement trails of wildlife at that time. The remains of neolithic culture are unique and should be preserved as far as possible, may be as part of a cultural heritage tourism.

Keywords: Archaeology; Early Epipalaeolithic; Natufian/Neolithic Structures; Kites; Wheels; Meandering Walls; Geoglyphs; Burial Site; S-Syria; N-Jordan; Remote Sensing; GIS.

1.0. Introduction

The investigation area is comprising the eastern areas of the Jabal al Druze massif in the As-Suwayda Governorate in S-Syria including the Al-Safa volcanic field, and extended towards south to N-Jordan, the "Black Desert" of Jordan, known locally as the Harra (Figure 1).

Pre-historic, Late Paleolithic (ca 25-17,000 BP) and Early Neolithic sites, were identified on high-resolution satellite images in South-Syria and N-Jordan providing evidence for widespread prehistoric occupation of the area and indicating a long-term occupation chronology lasting from at least since ca. 12,650 BC onwards [1, 2]. There is abundant archaeological evidence of Late Epipaleolithic (Natufian) and Neolithic communities because thousands of tumuli, stone fences and circles are covering large areas [3, 4]. The Natufian, spanning the time range from ca. 15,000–10,200 BP (uncalibrated), occupies an important position within the prehistory due to the temporal position of the Natufian just prior to the Early Neolithic domestication [5]. The archaeological record indicates evidence for greater levels of sedentism and more elaborate preparation of foods relative to earlier time frames [6, 7]. Characteristic for the Late Natufian settlement is a smaller number of larger sites, suggesting that population aggregation was less common, possibly owing to environmental changes associated with the Younger Dryas climatic changes.

There is still an information gap in Southern Syria and Northern Jordan for the Epipalaeolithic / Neolithic Periods. The emergence of the Natufian culture is documented around 13,000 B.P. The Natufians were foragers and later

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became farmers. The late hunter-gatherers who inhabited the Near East had a variety of subsistence strategies and types of annual schedules, ranged from semisedentary groups to small mobile bands [6, 7]. The establishment of sedentary Natufian villages marked a major organizational departure from the old ways of life, characterized archeologically by Early Neolithic cultivators [8]). This sequence of changes can only be understood within the context of the entire region and the shifting palaeobotanical conditions during this period. During the Late Natufian even larger communities were established. Natufian base camps are characterized by semi-subterranean dwellings (pit-houses). The foundations were built of stone and the upper structure was probably brush and wood. Domestic structures were about 3 to 6 m in diameter [8].

Traces of archeological sites visible on aerial photographs on satellite images described by the local population as “Works of the Old Men” are difficult to identify from the ground. This stands in contrast to their apparent visibility from the air [3, 4]. In addition, they demonstrate specific geometric patterns and extend from a few tens of meters up to several kilometers, evoking parallels to the well-known system of geometric lines of Nazca, Peru. Some of the structures overlay each other, either to reinforce or repurpose them. From the ground point of view, the majority of the features look like an assembly of random rocks. From the air-perspective, they become large, elaborate structures in the shapes of wheels, kites, and gates. Thus, the use of high-resolution satellite images such as provided by Google Earth /Google, or World Imagery data / ESRI offer a unique chance to map these archaeological features.

The Epipalaeolithic / Neolithic periods are sparsely documented in Southern Syrian and N-Jordan areas for several reasons:

- Difficult access to nowadays remote areas with few infrastructures,
- Security issues for researchers during the past decades,
- Erosion and sedimentation of archaeological sites by water (flash floods) and wind (dune fields and eolian covers),
- Newer constructions (settlements and roads), water management and agriculture covering the ancient places,
- Re-use of construction material.

1.1. Study Objectives

This study aims to contribute to the following steps:

1) Systematic inventory and digitization of traces of neolithic structures based on high resolution satellite data,
2) Structuring and categorization of the kite-geoglyphs, neolithic settlements, roads, cultural places based on satellite images and references of previous archaeologic work,
3) Environmental inventory such as the topographic and geologic conditions,
4) Suggesting and pointing out areas for further archaeologic investigations in the field,
5) Proposing of archaeologic sites for cultural heritage tourism.

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Of course, the evaluation of satellite data has its limits. Some features simply become not visible on the images. The human factor has to be considered as well as some features simply might not have been recognized and detected. The use of AI is not developed enough so far to distinguish the features such as roads and hunting routes and walls from lava flow traces or dyke intrusions. The later land use of the area covered and overprinted many traces of neolithic heritage. The modern street and water management constructions hinder pre-historic mapping as well. Thus, the inventory of neolithic traces cannot be complete, but the attempt is important because of the ongoing, continuous expansion of agriculture and settlement areas covering and partly destroying pre-historic relics. Therefore, it is crucial to map and digitize pre-historic features now as much as possible before they are not visible anymore.

2.0. Geographic and Geologic Overview

The height levels range from 300 to 1720 m in the Jabal al-Druze massif. This massif is extended about 80 km in NNW-SSE- direction and about 60 km in width. The elongated massif is subdivided in the northern part by smaller central valleys oriented in NNW-SSE direction whereas the southern part is characterized by an abrupt height difference at the eastern border of about 700 m, resulting in steeply incised valleys. The massif is surrounded by flat-undulating lava plateaus with height levels between 600 to 700 m (Figure 1). Volcanic cinder cones and aligned plugs form conical hills and elongated ridges.

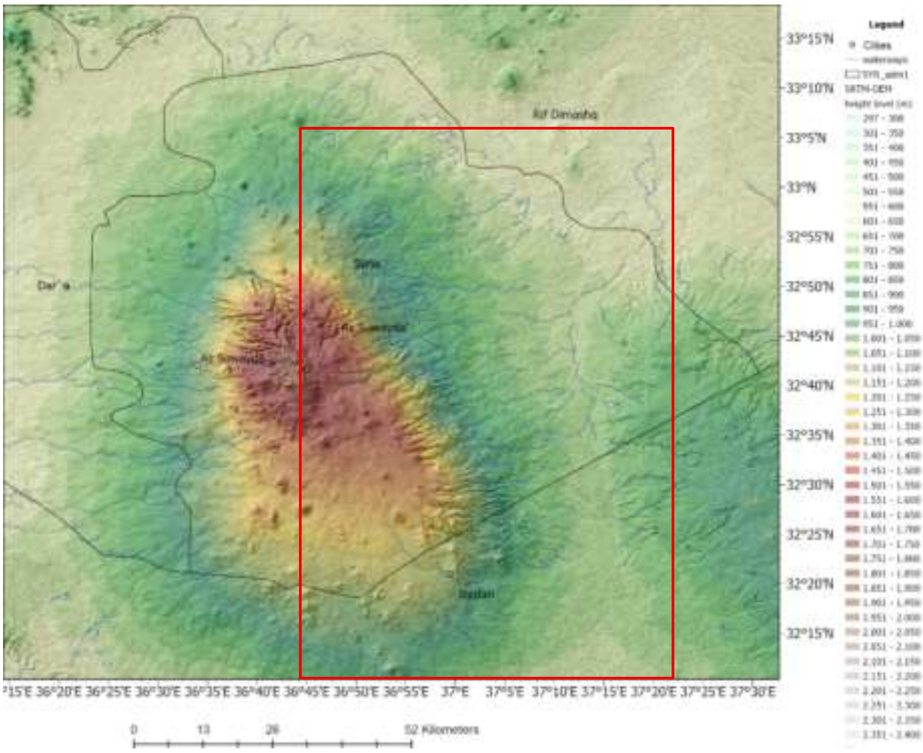

Figure 1. Height level map of the investigation area (red outline) derived from SRTM DEM data [8].

The study area has a semi-arid Mediterranean climate characterized by hot, dry summers and mild and rainy winters. Nearly all the rainfall occurs in the winter and spring season [9]. The mean annual precipitation ranges between 400 and 600 mm with considerable variation from year to year. In the absence of permanent rivers or bodies of water, rainfall, valleys and springs feed the man-made pools and reservoirs. In practice most of the rainfall ends up flowing out of the area through small seasonal wadis or is contained within depressions where it forms seasonal lakes. The lakes and wadis can in some years contain water until the early summer, but thereafter, remain dry until the winter [10].

Geologically the area belongs to the Jabal al-Arab (or Jabal al-Druze) volcanic province. The Jebel Arab volcanic province occupies all the southern part of Syria and continues to Jordan. It is the great basin overfilled by basaltic flows with volcanic cones and chains. The average altitude of the volcanic plateaus ranges about 700 - 800 m with highest volcanoes in the Jabal al Druze massif reaching more than 1800 m. The age of the basalts dates from the Early Miocene up to historical and nearly recent time. The majority of the basalts erupted from volcanic chains concentrated on the NNW-SSE trending extension faults (Figure 2) [11].

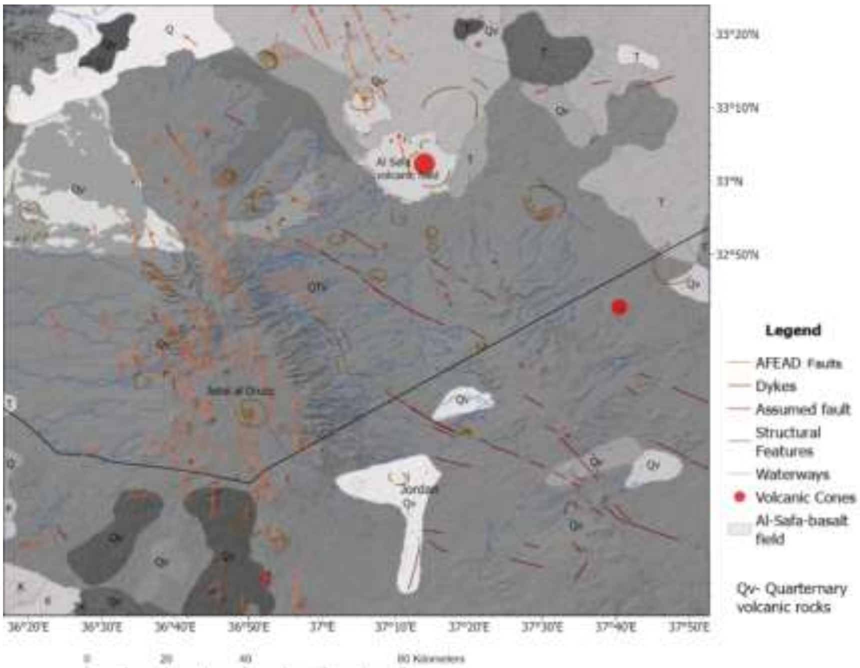

Figure 2. Map of volcanic features based on shapefiles provided by [12], including Active Faults of Eurasia Database (AFEAD_v2022)-fault zones [13] and volcanic features digitized by Theilen-Willige for this study.

3.0. Research Methodology

This study deals with the evaluation of optical satellite data as well as of Digital Elevation Model (DEM) data and DEM derived morphometric maps such as height level, slope and drainage pattern maps (stream order). Various factors and parameters derived from thematic layers gained from satellite data and references such as the global kite project [14] were combined in a GIS database to achieve additional knowledge about the environmental conditions of the investigation area and traces of neolithic structures.

3.1. Optical Satellite Images

Digital image processing of Landsat TM and 8 /9 (the Operational Land Imager - OLI), and Sentinel 2 data was carried out by merging different Red Green Blue (RGB) band combinations. Special attention was focused on the creation of RGB images including Landsat 8 / 9 thermal bands 7 and 10. Further on, "Principal Component" analysis (PCA) was carried out. This technique compresses variance data in multispectral images into one or two

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principal components, thereby enhancing the difference in rock types. A Landsat 8, Level 2 SP-image was processed in ERDAS Imagine using Independent Component Analysis (ICA). The L2SP collection means that the satellite imagery has been processed for Surface Reflectance values. As digital image processing software served further on the Sentinel Application Platform (SNAP) / ESA and ENVI as well as the processing tools integrated into the geoinformation systems ArcGIS Pro / ESRI and QGIS. The data were provided by [15] and [16]. The high-resolution satellite images such as Google Earth images as well as the World Imagery data implemented in ArcGIS Pro software from ESRI were used as base for detailed mapping. It is necessary to zoom in as much as possible to detect the archaeological features. Based on the high-resolution satellite images the main visible features related to neolithic structures were digitized.

Figure 3 shows an example of how the World Imagery images provided by ESRI were digitally enhanced by using ENVI digital image processing software.

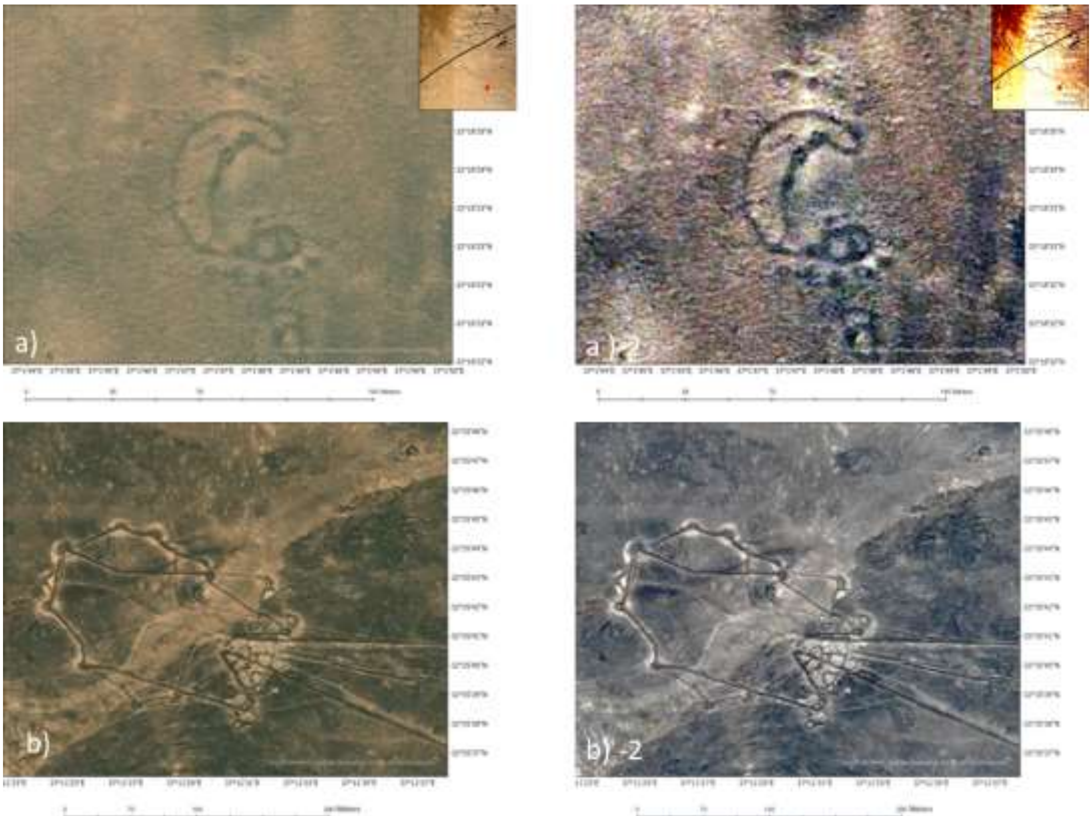

Figure 3. Digital image enhancement of World Imagery images using ENVI software.

3.2. Evaluation of Digital Elevation Model (DEM) Data

Digital Elevation Model (DEM) data such as from the Shuttle Radar Topography Mission-SRTM, from ASTER and the Advanced Land Observing Satellite (ALOS PALSAR) were used to derive morphometric maps such as hillshade or slope gradient maps or to calculate the drainage pattern. These maps were included in a Geo Information System (GIS) embedded environment using ArcGIS Pro 3.7 and QGIS 3.4 software. The data were downloaded from [15] and [17].

4.0. Results and Discussions

It has long been recognized by explorers and researchers in S-Syria and N-Jordan that its prehistoric structures can be divided into several distinct types based on their morphologies as viewed from above [1, 3, 4]. In the following chapters the different structures are presented following the terminology of previous authors.

4.1. Wheels

Thousands of 'wheels and wheel-like structures have been identified in the investigation area, receiving their name because of their appearance. The wheels constitute circular stone arrangements, radiating from a central point and encompassed by a circular rim. Their outline may be deformed, for example, in the shape of a paint splat [18]. Their original purpose is still in discussion. Several types of pre-historic wheel-structures can be identified as presented in Figure 4. The main features of wheels comprise a roughly circular or elliptical outline, inside which enclosures are divided by mostly straight walls, arranged like the spokes of a wheel [1]. Though these "spokes" sometimes come to a central point, they often converge around one to three sub-circular central enclosures. The wheels are often encircled by a series of smaller enclosures. They are divided into irregular sections and often contain a number of burial cairns. Their outline is characterized by "black dots" that obviously consist of basaltic rocks. Some have "dots" inside the wheel; others outside. The larger wheels show even more rings of black dots. The size varies between 60 to 120 m in diameter. In many observed cases the wheels were used by later generations to build their communities, so that in those cases the original wheel can nowadays only be traced by the outline of the black dots and rests of "spokes".

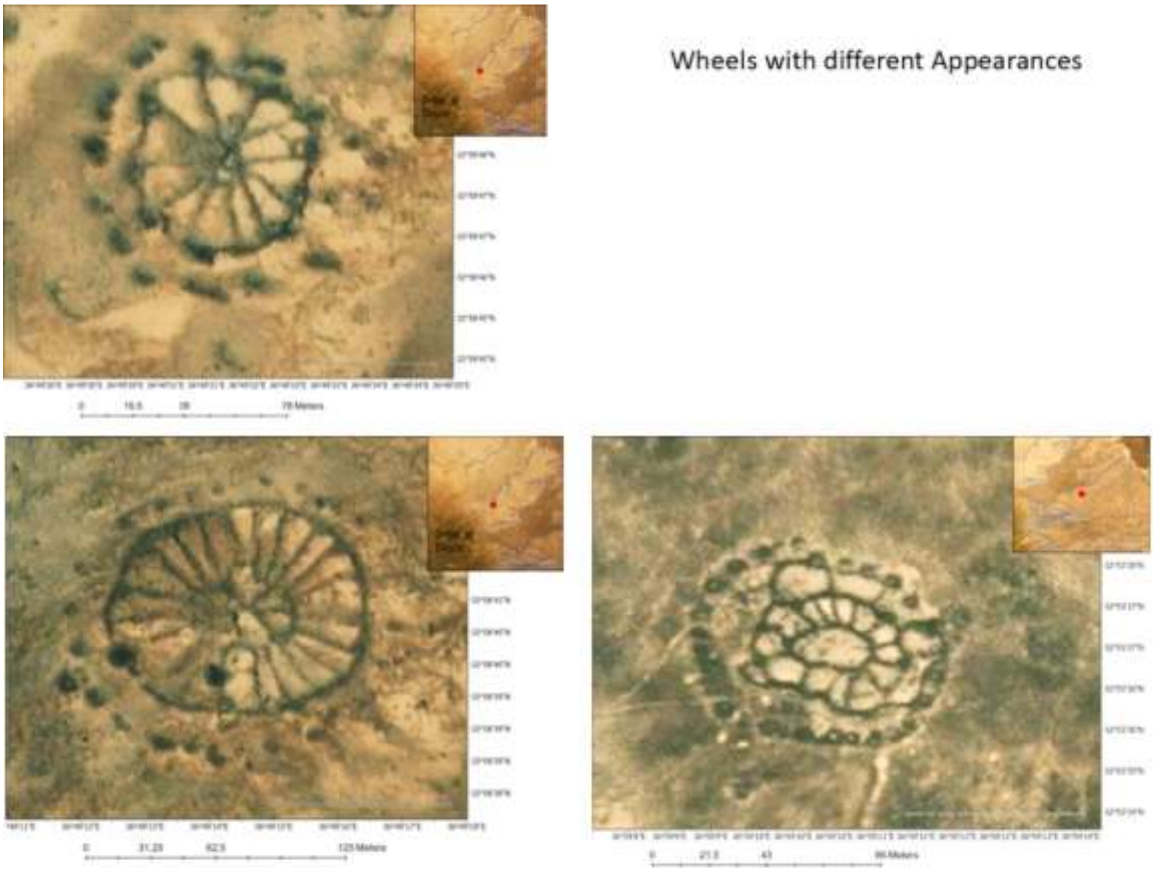

Figure 4. Types of wheels as visible on World Imagery satellite images.

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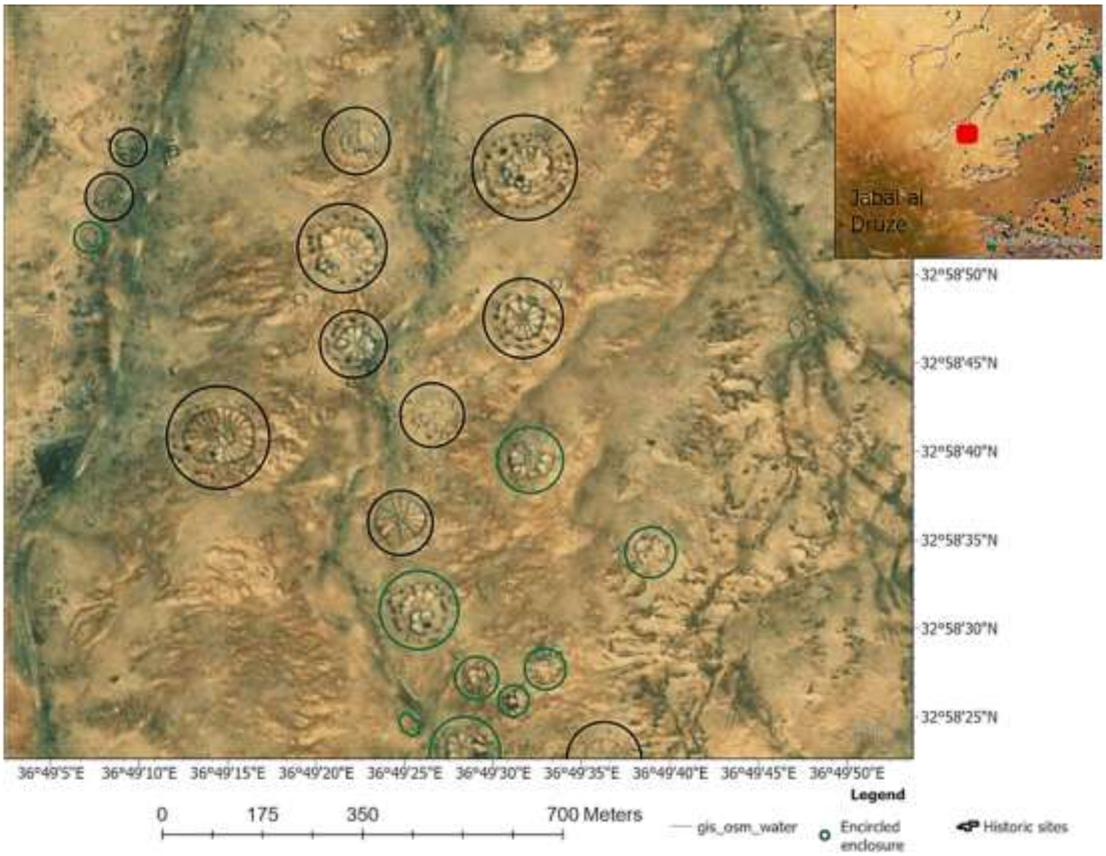

Figure 5. Clusters of several wheel types and encircled enclosures.

The wheels often occur in clusters (Figure 5). It can be assumed that these wheels served as cultural or possibly religious meeting points as they occur isolated or in clusters of several wheel structures and there are often no traces of settlements nearby. Some are just covered by sediments, others are eroded. Most of the wheels are situated along riverbeds, others on the basaltic lava fields above.

4.2. Encircled Enclosures

Increases in the scale of the built environment had a significant impact on Natufian landscapes. Natufian architecture included rounded pit houses, with foundations made of local, undressed stones and retaining walls supporting the perimeter of the structure [19]. In general structures were not isolated, but clustered with others. The Neolithic era was considered as a break with the past and the abandonment of the traditional, many thousands of years-old hunter-gatherer way of life, in favor of a reliance on food production by means of agriculture and stock raising in permanent villages [20].

At the beginning It can be assumed that the development of neolithic settlements is related to the wheels because of their surrounding rings of blocks, observation points and traps as well as their cultural / religious meaning as shown in Figure 6. The development of settlements (as derived from the evaluation of satellite images) because of their shape and their stepwise coverage and overprinting of the wheels is presented in Figures 6 and 7.

Those forms of settlements were termed “encircled enclosure clusters” by [1]. Encircled enclosures are comprised of a randomly clustered set of sub-circular or sub-elliptical enclosures. They occur in clusters concentrated along

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larger riverbeds, the water supply determining their position. Nowadays, the archeological sites are often crossed by recent streets, agriculture and water channels and, thus, they are often not visible on the ground surface anymore.

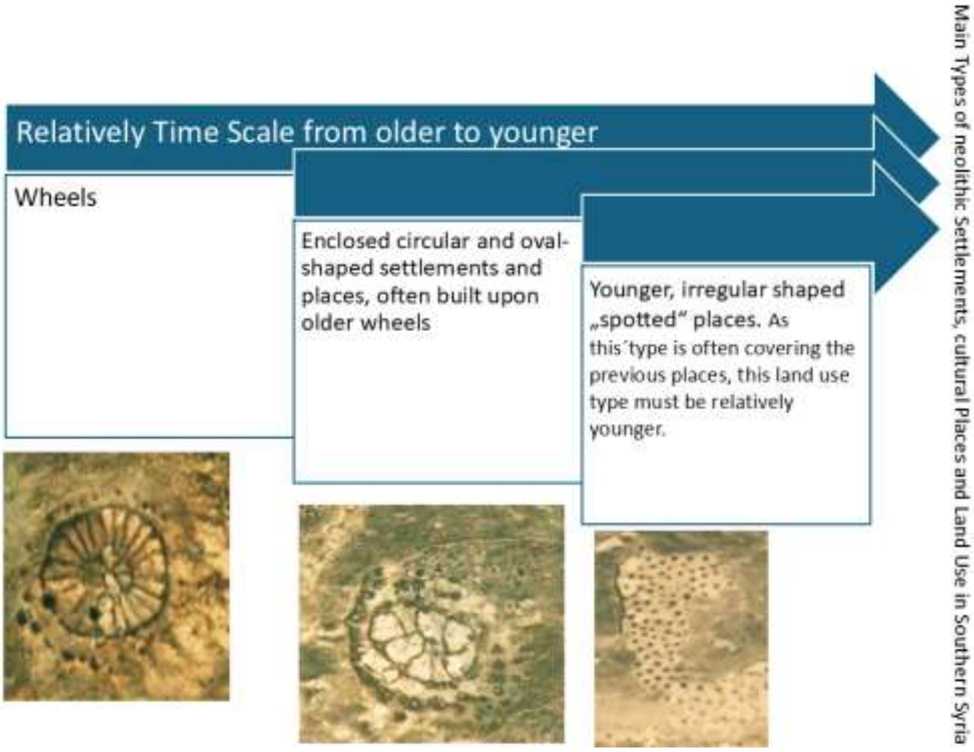

Figure 6. Development of neolithic and younger settlements.

Figure 7. Stages of development from wheels to irregular external forms.

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The wheel-like villages with circular outline that developed based on and around the ancient wheels were mapped as far as possible as shown in Figure 8. Of course, this inventory cannot be complete because not all of them are visible on the satellite images or simply are not preserved anymore. About 4700 of these circular structures were digitized in the investigation area in S-Syra and N-E-Jordan. Assuming communities about 20-50 persons lived within the settlements [20] and multiplying the number with the digitized round villages might help to get an idea how many people lived in this area in the east of the Jabal al Druze massif, provided that they lived permanently in the small communities. However, such a calculation can only be a rough or even a wrong estimate. The high mobility and migration at that time has to be taken into account.

Nevertheless, the density of the traces of small communities leads to the conclusion that this area was relatively densely populated during the late Epipaleolithic (Natufian) and Neolithic time periods. As wildlife could not provide enough nutrition to sustain the population of that time, domestication had to be the consequence. Animal wildlife declined due to overhunting. With changing climatic and environmental conditions even, the domestication might not have been enough to provide sufficient food.

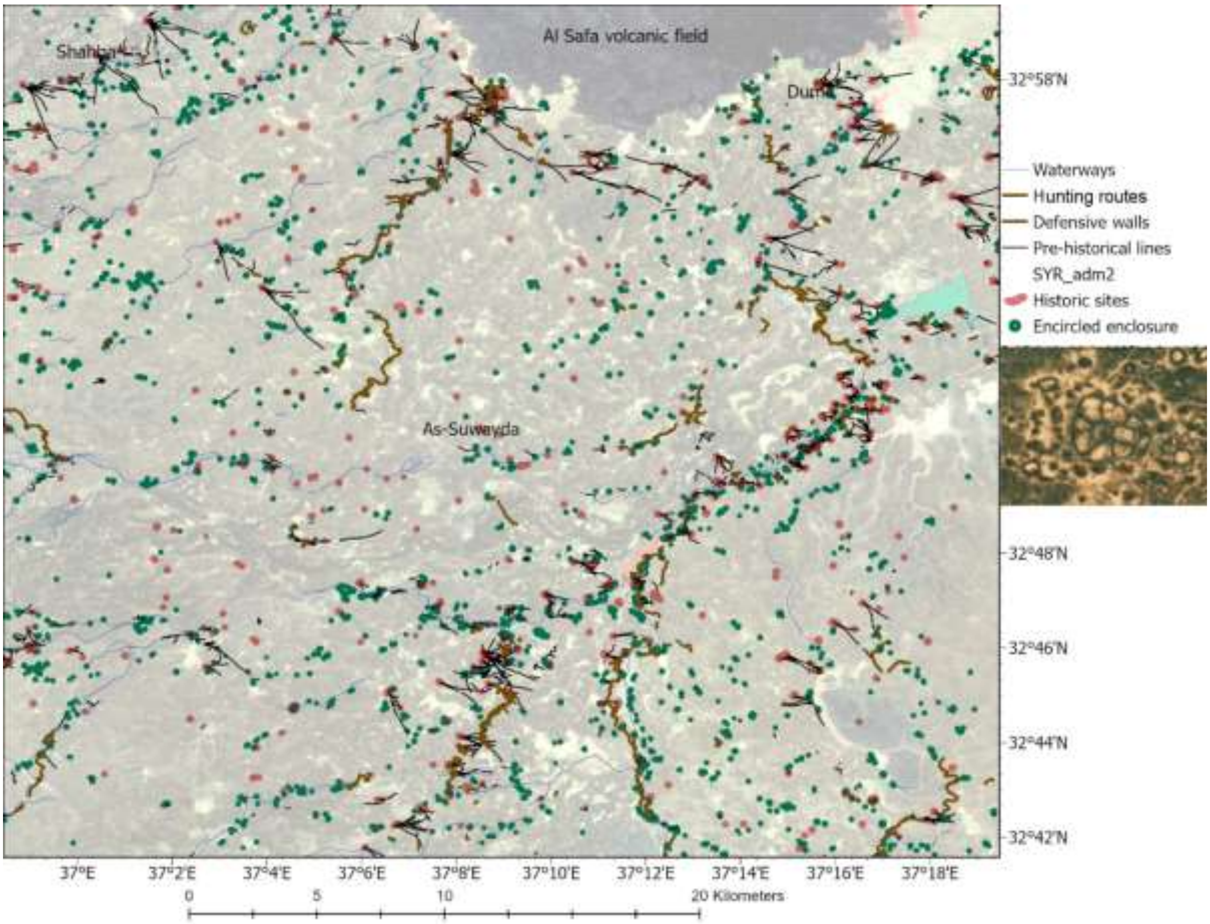

Figure 8. Traces of wheel-like shaped communities (green points) with a circular outline (based on existing wheels or using the same construction) like the one on the picture.

The so-called spotted places (because of their appearance on the satellite images) seem to be younger as they cover the older neolithic settlements. Their age cannot be determined without field investigations and ground truth work.

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4.3. Kites

The next common features are the so-called kites. These features (collectively named by the Bedouin tribes as the "Works of the Old Men"), occur in the northern Arabian Desert and throughout the entire Arabia region, from Syria across Jordan and Saudi Arabia to Yemen [3], [21]. They are characterized by a "large, wide kite head and long tails". The lines spreading from the head, the so-called tails, can reach up to 6 km in length, and enclosures can spread over several hectares [14]. Usually, the tails form a funnel that goes into the head. Other heads are shaped like keyholes, trumpets, pendants, bullseyes, and even circles and rectangles divided into quarters. The simplest structure of a desert kite has a triangular shape, consisting of two or three very long, low walls built of stones and arranged in a V-shape. They appear on the current surface as random linear stone pilings with no clear construction arrangement. 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 built [14].

The smaller kites usually show only two or three tails on the satellite images whereas the larger ones have a minimum of three to five tails that are connected to each other. The longer tails have often a second one parallel to each other.

Several possible functions for the kites have been suggested ranging from cultic, religious, strategic to hunting and herding [1, 4, 21]. The heads of kites with different sizes and ages probably had several functions over the time (Figure 9). It can be derived from the evaluations of satellite images that the area of the larger heads was used for purposes such as observation, protection, house construction, hunting, herding and grave sites. The smaller kite heads with an arrow-shaped or circular outline were obviously used for hunting and herding only. Kites were used to push herds of animals into these enclosures [4]. They are characterized by nearly parallel tails whenever the morphologic situation is suited. Within this type of kite, no settlement traces could be observed.

The Natufians used a variety of technologies including nets, traps and bows and arrows to capture a wide spectrum of large and small wild animals. Large prey included aurochs, red deer, fallow deer, and wild boar, but the small-bodied mountain gazelle was the staple species [19], especially the mountain gazelle, a stationary antelope with a small home range that varies from a few to as many as 25 square kilometers.

A larger home range can be inferred for Gazella subgutturosa, the dominant species in the Syria-Arabian desert, moving regularly before winter to south and returning in spring. Recent experiments suggest that animal behaviour is a significant parameter for clearly understanding the efficacy of the tails with low stone alignments: gazelles (Gazella dorcas), for instance, tend to follow and run along even quite low linear features of the landscape [14]. In addition, observations of springboks and gazelles in general suggest that these antelopes do not leap, unless frightened, over low vertical obstacles.

Heads are often situated in strategic positions like crests and along steeper slopes. The advantage of overlooking a larger area from the heads led later to the use of the larger heads as settlement area, taking advantage for example of

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the better protection feasibility because of walls and watch-out posts or the already available construction material. Whereas in the northeast of the Jabal al Druze massif kites with a star-loke outline are dominating, the outline of the kites is more functional and simpler in the southern Syrian and NE-Jordan areas. The forms of smaller herding and hunting-kites are prevailing. Figure 10 provides an example of such a simpler kite with an almost "curli-flower"-like outline of the head without visible traps and watch-out posts.

It was observed that different generations of heads were constructed upon each other as demonstrated in Figure 11, where two overlapping heads are visible. Upon the circular head (Figure 11, 1) with about 18 "black dots" the second head (2) was built with a nearly pentagonal outline with only 5 "black dots".

Figure 12 shows examples of later settlements in the area of kites. The area of the heads was later often covered by settlements (Figure 12 a and b).

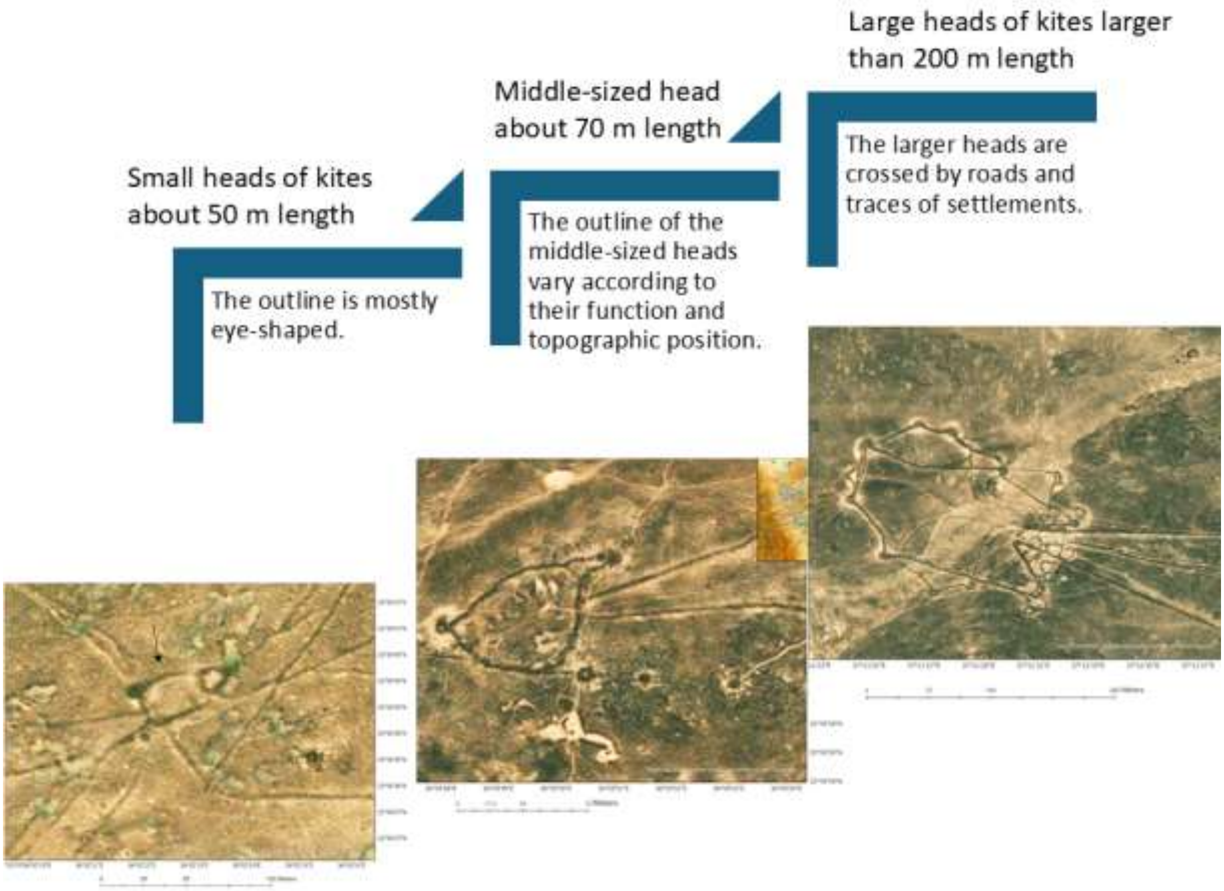

Figure 9. Different sizes and shapes of kite heads with varying numbers of trails.

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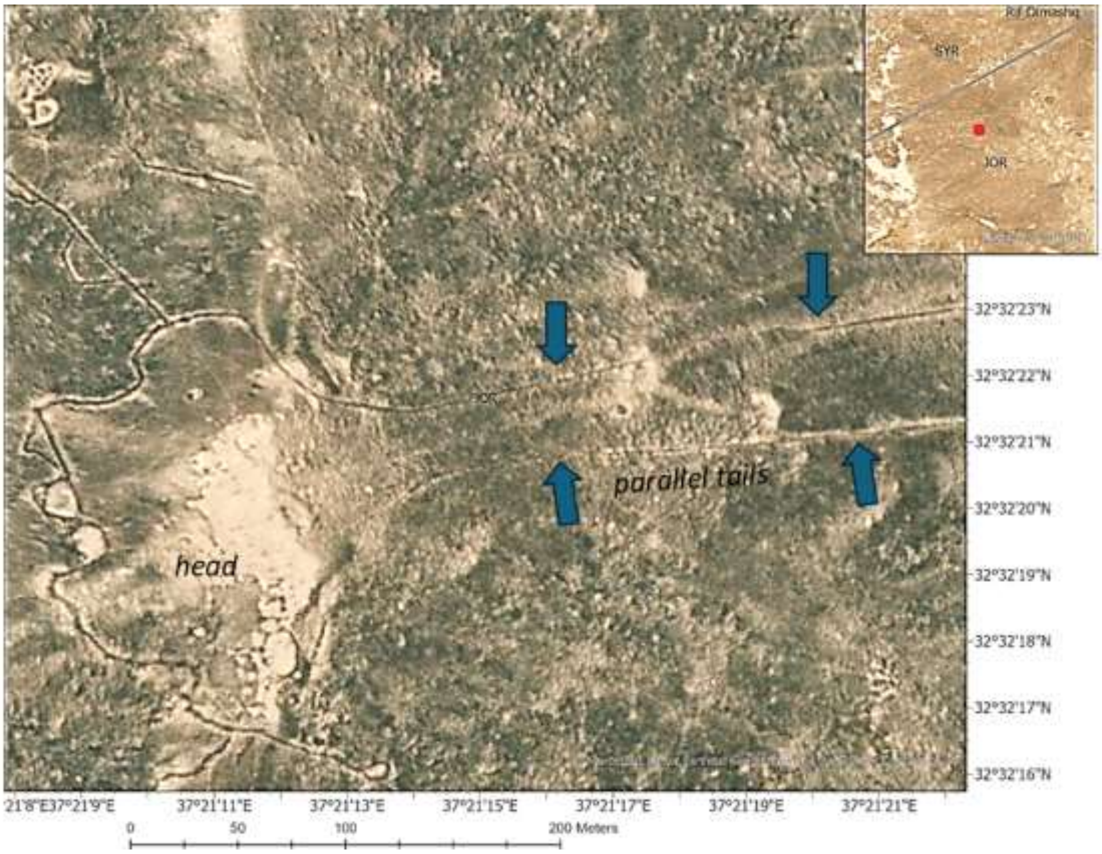

Figure 10. Hunting-kite with a "curli-flower"-shaped head and parallel tails.

Figure 11. Kite- overlay: Head 2 was built upon head 1. A new road is crossing this kite at its center.

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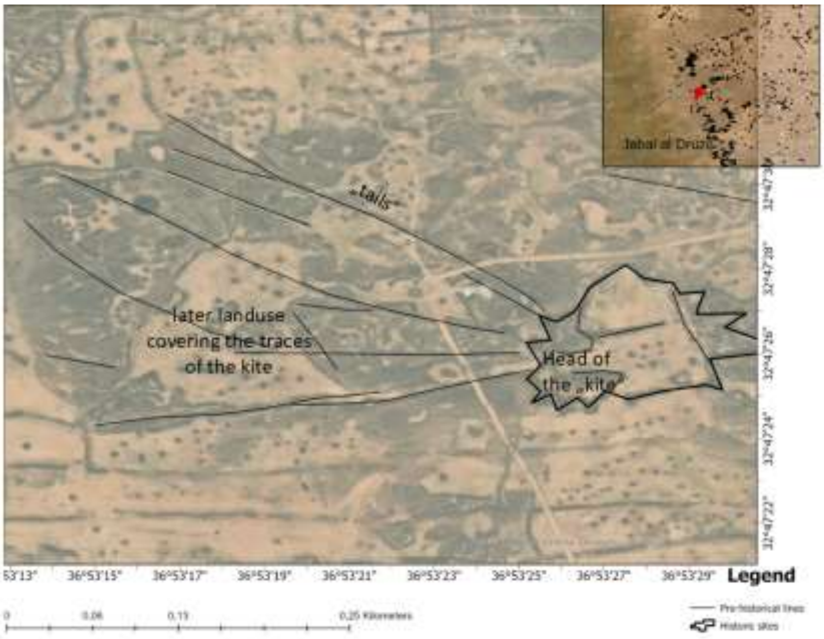
(a)



(b)

Figure 12. (a) Kite in the east of the Jabal al Druze massif, (b) Kite area covered by later settlements and land use.

From the satellite image observations, it can be derived that the main orientations of the kites with their tails vary depending on the local surface conditions and drainage network. The placement of the heads related to the trail varies accordingly. The positions of the heads (whether down-hill or up-hill) were adapted to the geomorphologic setting such as their position towards riverbeds and depressions. Migration routes of animals played an important role in the planning of the tails and roads as well. The most important factor influencing in their placement seems to have been their orientation towards the larger riverbeds and basins filled with temporary lakes providing water for the animals. When digitizing and analyzing the occurrence and position of kites it becomes obvious that the head of the kites often have a strategic position such as at observation point at the top of river slopes. When looking at the

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3D perspective view of the eastern slopes of the Jabal al Druze massif (Figure 13), the concentration of kites at the slopes seems to support the assumption that the kites were placed there besides wildlife occurrence and hunting conditions because of strategic reasons. Most of the heads are situated near the cliffs and upper slopes looking downward to the area below, whereas their tails are situated on the higher areas. The heads of the kites are oriented towards the lower riverbeds, thus, having a good overview of the area. This is confirmed when looking at the slope gradient map of this area (Figure 14) confirming the position of many of the heads of the kites near the crests of slopes.

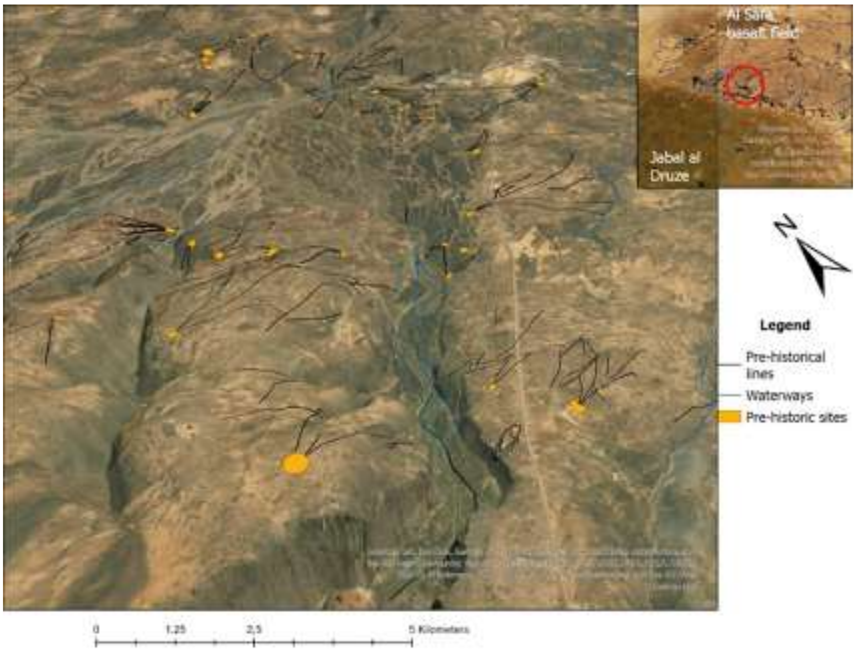

Figure 13. 3D World Imagery (ESRI) perspective view of kites indicating their position in strategic areas (10 x height amplification).

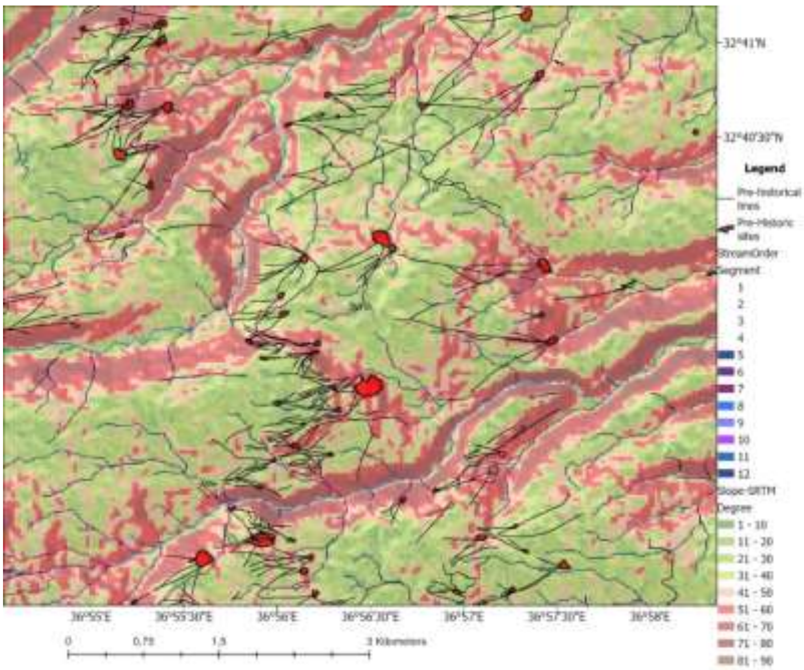

Figure 14. Slope gradient, drainage pattern, and kite positions on crests.

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The slope gradient map reveals the steeper slopes in red colors. Figure 14 confirms the position of the heads of the kites near the crests of slopes in the east of the Jabal al Druze massif. Along the E-W-oriented valleys the heads of the kites are placed on the western and eastern ends of the tails.

There is another phenomenon that can be observed: double-kites sharing the trails from one head to the other head (Figure 15). Thus, observation information of both sides could have been exchanged faster by using the same tails. It facilitated hunting by leading the animals to both heads.

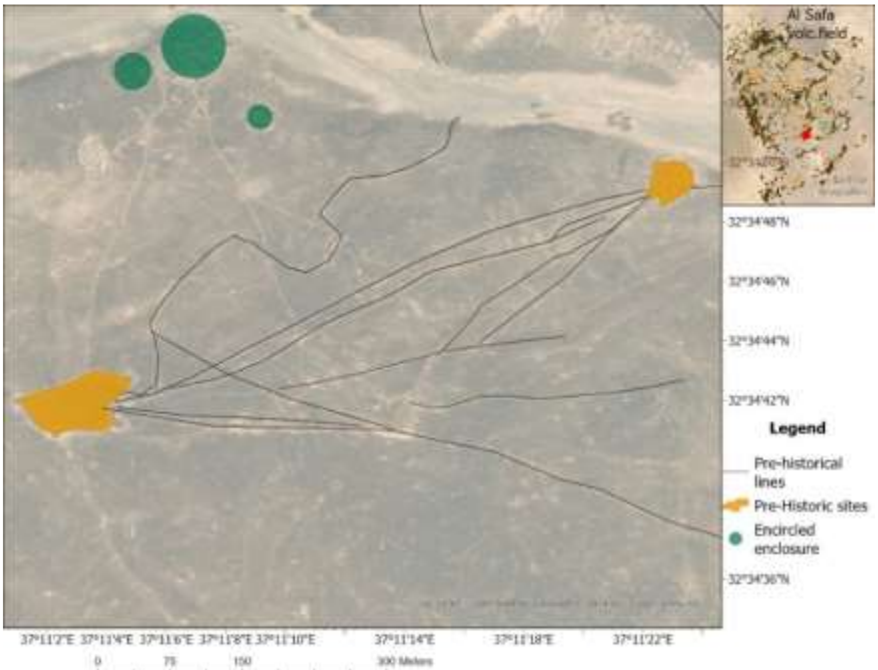

Figure 15. Double-kites sharing trails and a meandering wall (rounded line above the linear trails).

A contrary observation can be made in lower flat area bordering higher volcanic fields and basins / depressions within the lava fields. The heads of the kites are positioned at the slopes whereas the trails are stretched on the flat surface below (Figure 16). Thus, there was a good overview from the head's point of view over the lower, flat area. The black, small, hollow dots around the heads, on the satellite images are interpreted as traps for the hunted animals, may be some serving as watch-out posts as well. This up-hill position has the advantage of good hunting conditions whenever animals were trapped in the kites because of steeper, slopes above.

The topographic cross section in Figure 17 visualizes such position of heads using an example from S-Syria.

Even in the basaltic fields with rough topographic conditions (abrupt changing of ridges, hills and smaller basins) kites were built, taking advantage of the smaller depressions as a natural wildlife trap. How the ancient people succeeded in kite constructions with their linear tails in the terrain of the surface-rough lava fields is remarkable.

Figure 18. presents a 3D perspective view of the eastern area of the Jabal al Druze massif. It is clearly visible that the kites occur concentrated along the upper slopes of the massif, taking advantage of the living environment of the wildlife in this area, especially of wild goats and ibexes.

The density of visible kites with their tails was calculated in ArcGIS Pro to confirm their occurrence in clusters (Figure 19). The density map shows the highest density of tails at the eastern foot-slopes of the Jabal-Al Druze

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massif and the Al-Safa volcanic field as well as at the northern border of Jordan. The NS to NNE-SSW and NNE-SSW orientation of the areas with the highest densities becomes obvious. This might be explained by the topographic and strategic position, hunting conditions, wandering routes of gazelles, and by surface water and groundwater availability for the nearby villages.

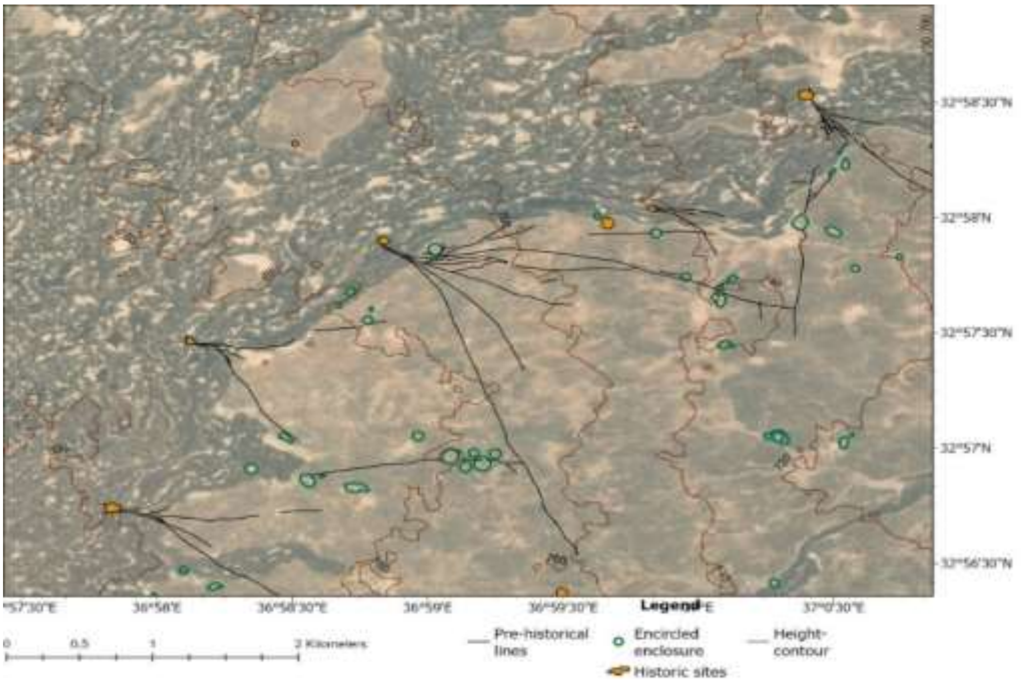

Figure 16. Heads of kites at upper areas in the basaltic field (left side). In the background: World Imagery file of ESRI.

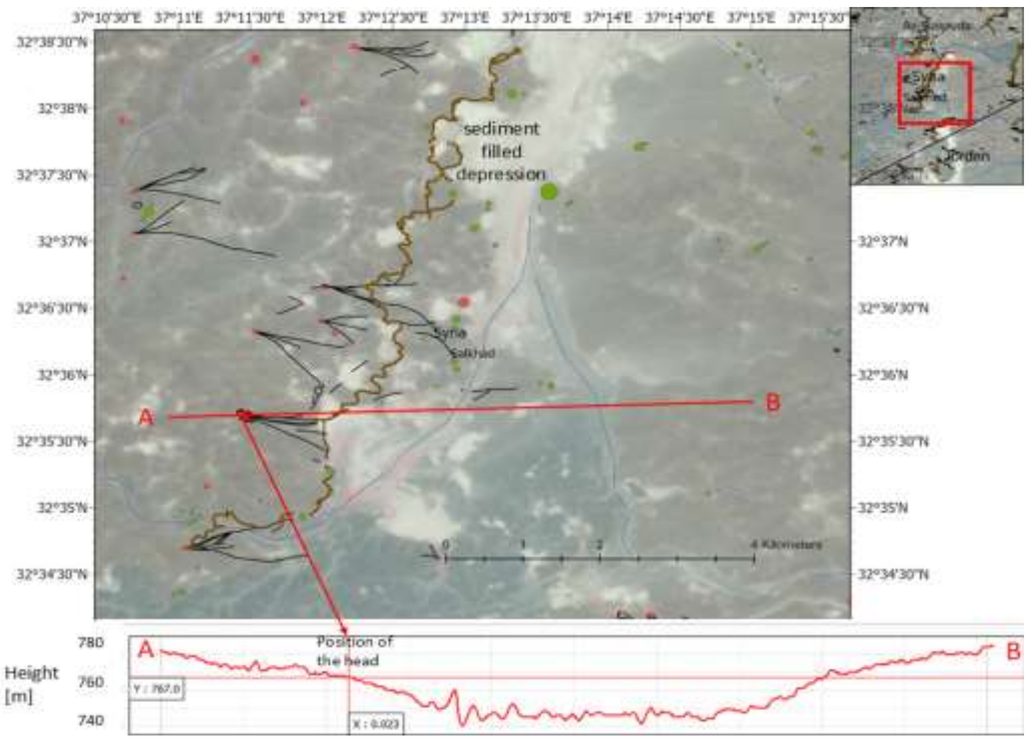

Figure 17. Topographic E-W- cross section to visualize the position of the heads directed to the upper slopes.

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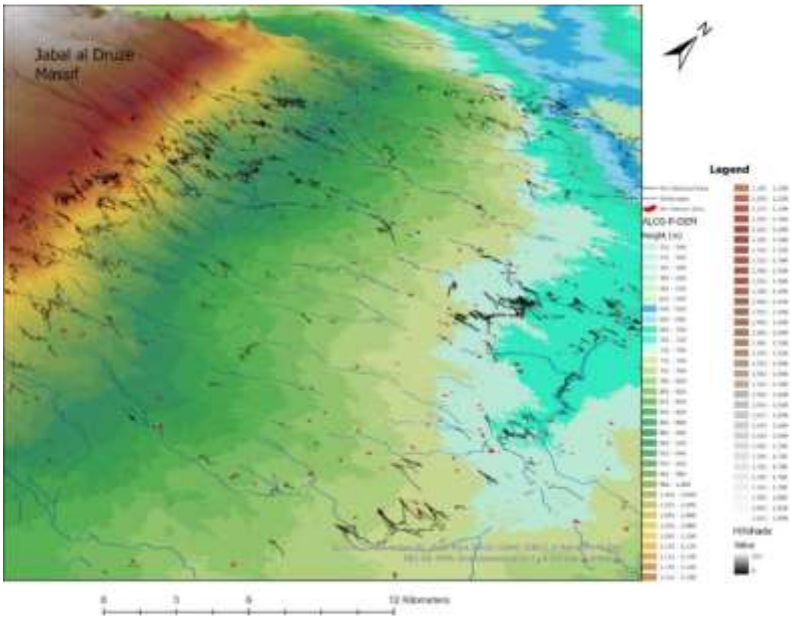

Figure 18. 3D perspective view of the height level map showing a concentration of kites at the eastern slopes of the Jabal al Druze massif.

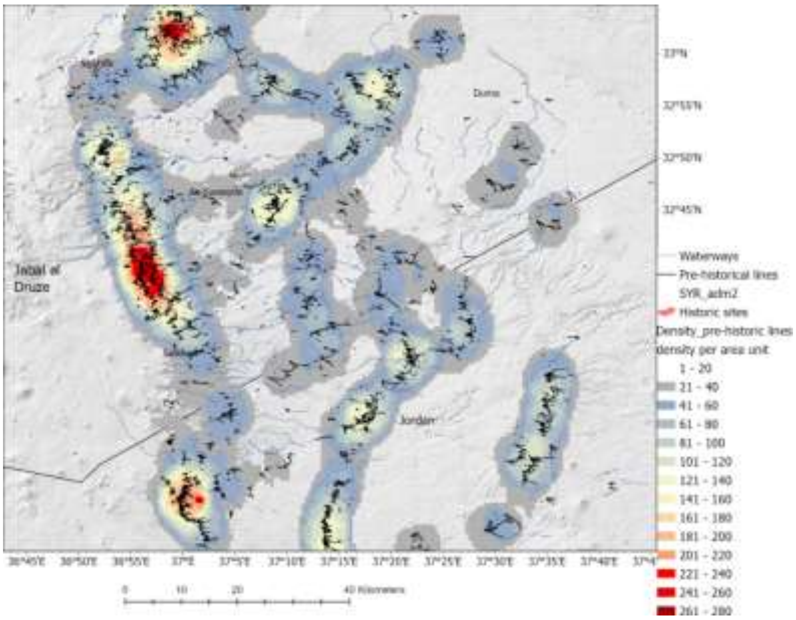

Figure 19. Density of kites and tails per area unit.

Based on the line segment direction-tool implemented in QGIS the orientations of the tails were analyzed from different areas and presented in rose direction diagrams (Figure 20 a and b). The diagrams clearly reveal that E-W-, WNW-ESE- and NW-SE- directions are prevailing, depending on the morphologic setting. Moves during hunting or of social units along about east-west transects were easier, as these routes took advantage of the north-south layout of mountain ranges and vegetational belts [8].

When analyzing the structure and outline of the kites with the star-like outlines of the middle-sized and larger heads and the shape of the tails, there is a strong similarity to the appearance of comets (Figures 21 - 23). Comets in the

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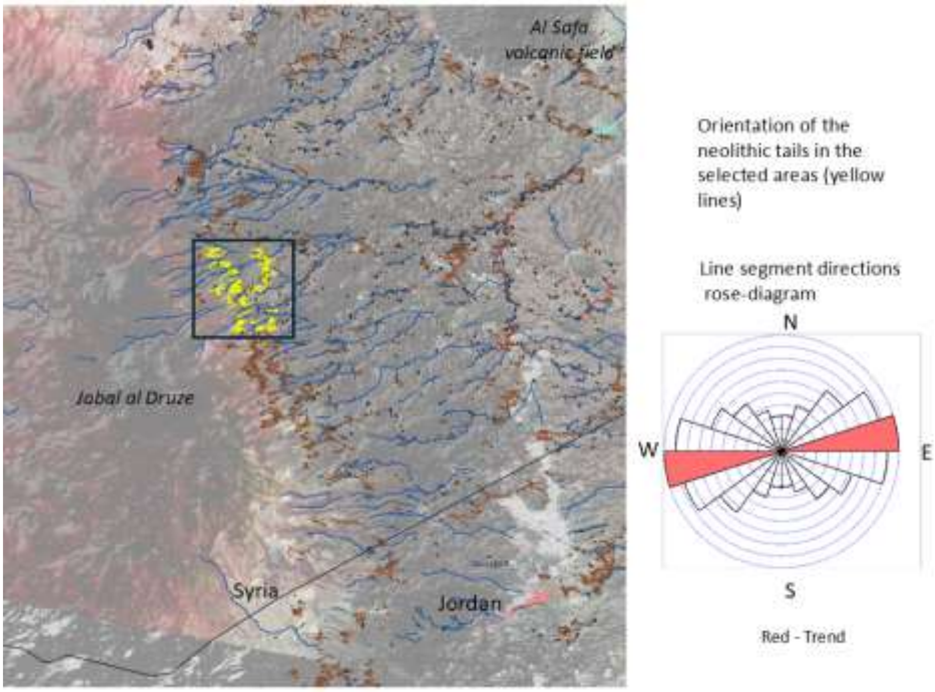
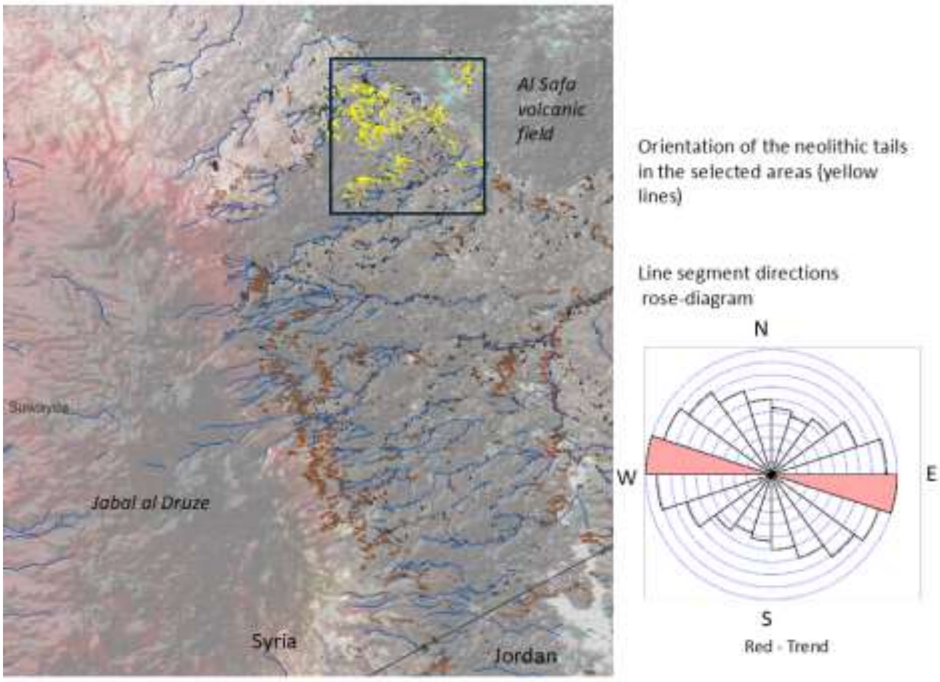
Early Neolithic times have been documented by several authors [22], [23], [24]. It is assumed that at about 12,800 cal BP (calibrated years before the present), earth collided with the extensive debris tail of a giant disintegrating comet, derived from a Centaur, one of a large crowd of up to 300 km-wide cometary bodies in unstable orbits between the giant planets [23]. This collision resulted in multiple airbursts at >50 documented sites across at least five continents.



(a)



(b)

Figure 20 (a), (b). Main orientation of the tails presented in rose diagrams.

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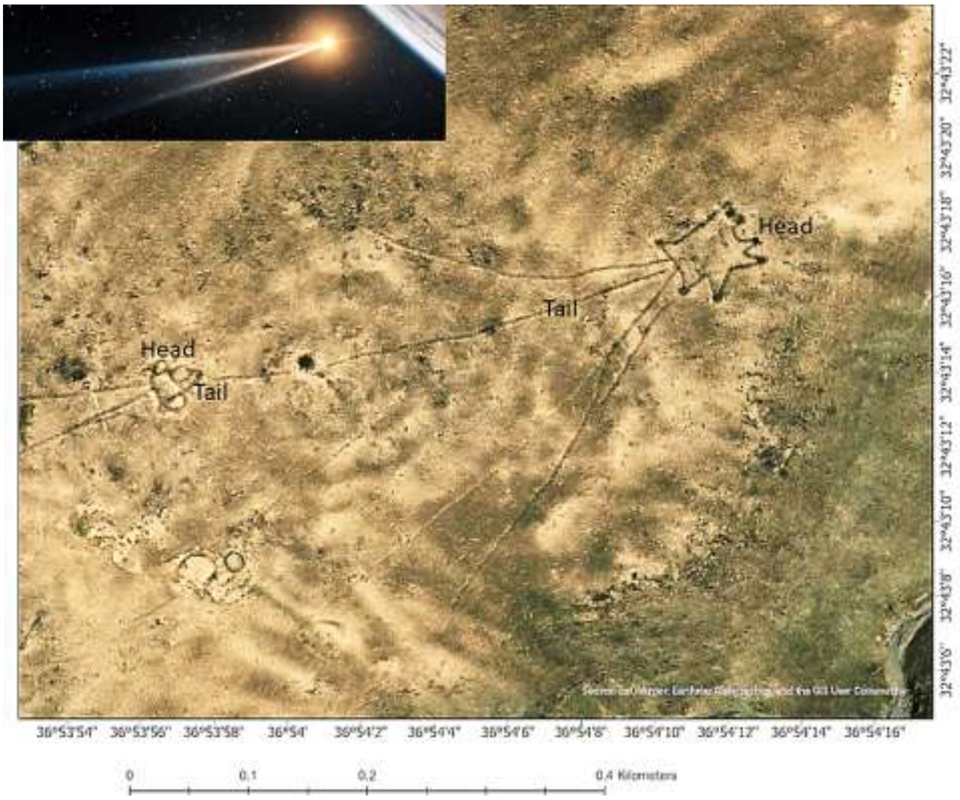

Figure 21. Comparison of comet and kite shapes.

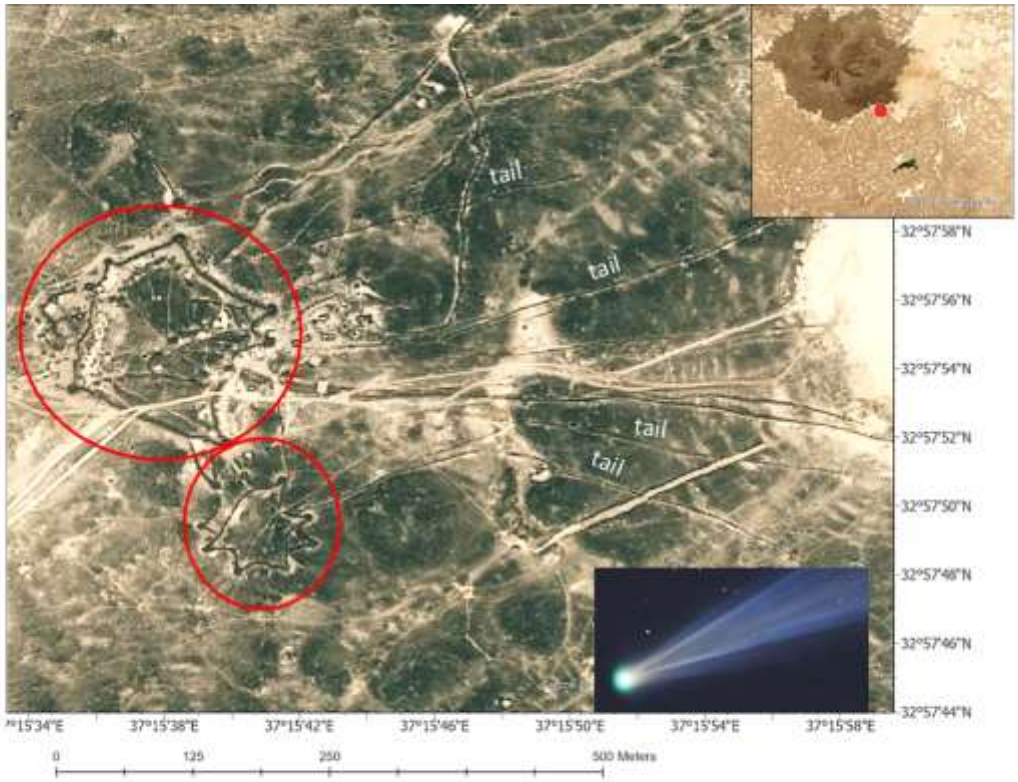

Figure 22. Star-like heads of kites and tails arranged like those of comets.

The collision of the cosmic bodies with the Earth's atmosphere caused an impact event that triggered a cascade of secondary effects, including a brief impact winter and severe Younger Dryas (YD) climate change (span: ~12,800–

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11,500 cal BP- calibrated years before present) along with possible contributions to the megafaunal extinctions and human population declines after which numerous smaller fragments may strike the ground forming transient surface craters [23]. This assumption is supported by the presence of high concentrations of platinum-rich dust at thirty sites throughout the Northern hemisphere [25]. A (~100 km) progenitor comet in a low inclination, short-period orbit was at that time giving rise to Comet 2P/Encke and the Taurid meteors through a cascade of disintegrations. Cascading fragmentation was probably the prime disintegration process [25].

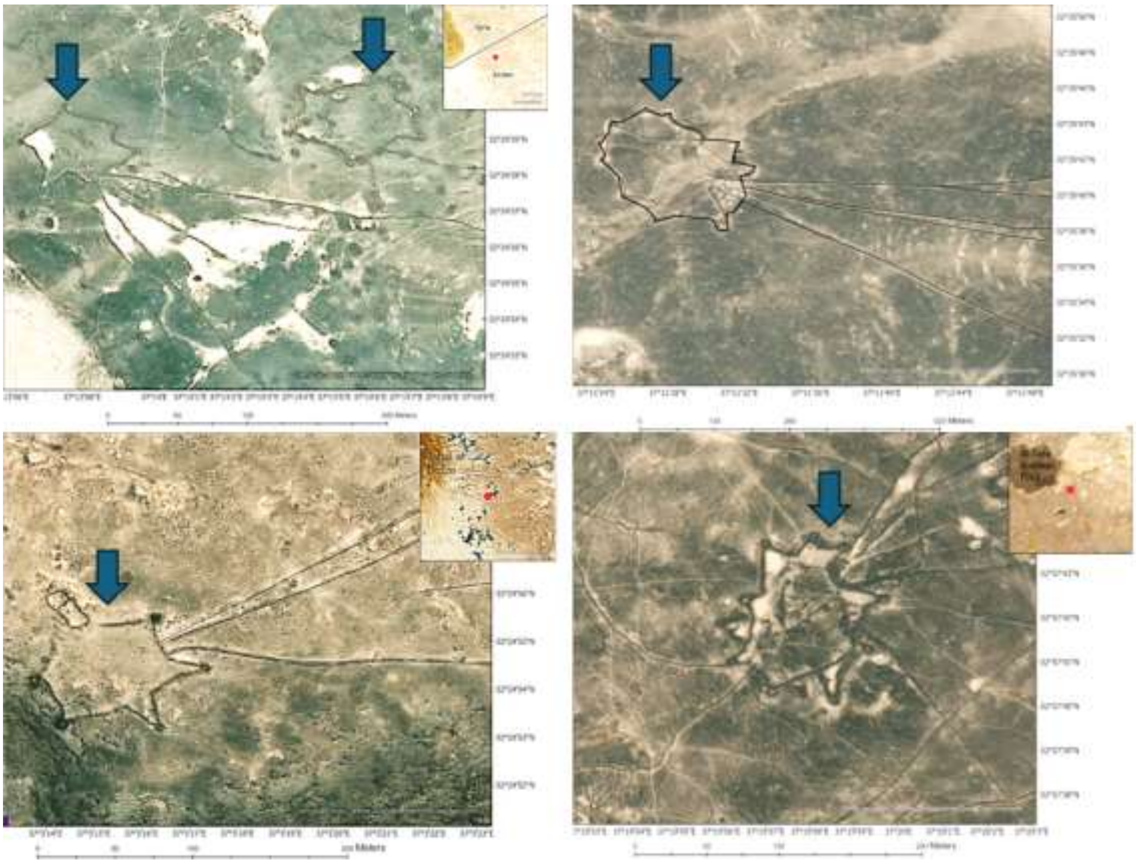

Figure 23. Star-like heads of kites with various shapes and sizes.

At Abu Hureyra, a well-studied archeological site in northern Syria about 330 km in the NW of the investigation area, the onset boundary of the Younger Dryas climatic episode ~12,800 years ago shows evidence supporting a near-surface cosmic airburst impact that generated temperatures > 2000 °C [24]. The impact might have caused / supported the transition from hunting / gathering to cultivation, indicative of earliest agriculture, one of the most significant cultural transformations in human history [23].

The evidence also indicates a significant drop in the area's population, and changes in the settlement's architecture to reflect a more agrarian lifestyle, including the initial penning of livestock and other markers of animal domestication [24]. These cosmic events would have been observed by the neolithic population and have left a deep impression. The question arises whether the construction of the kites was inspired or influenced by observations of such cosmic events and impacts. Astronomic observations played an important role in the neolithic culture. Figure 24 visualizes the kites in the SW of the Al Safa volcanic field where the heads of the kite were placed nearly all towards NW. The same can be observed in N-Jordan.

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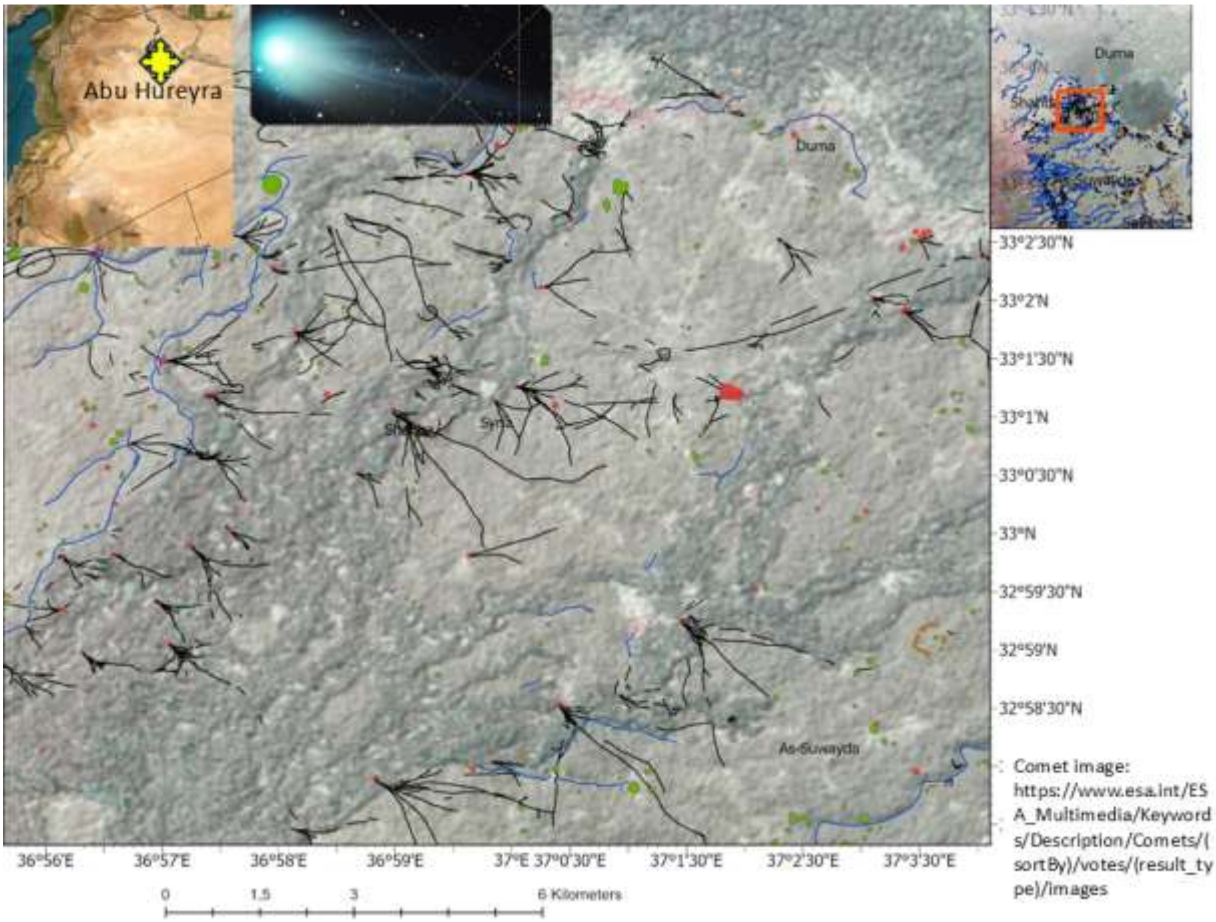

Figure 24. Main orientation of the heads (red points) and tails (black lines) in the southwest of the Al Safa volcanic field towards W to NW (Neolithic villages: green). Heads and trails of the kites are mainly oriented in WNW -ESE and NW-SE direction. The image of the Comet 12P/Pons-Brooks (a 'Halley-type' comet with an orbital period of roughly 71 years and a nucleus approximately 30 km wide - ESA 2026.) was included to demonstrate the similarity of the image of a comet to the kites.

Could it be possible that the observation of a comet or several fragments of the comet passing the sky was one of the reasons for the kite-architecture? In this case the larger kites with a comet-like structure would represent geoglyphs. The answers to some of these questions might perhaps be solved by future archaeological, astronomical and geological / mineralogical research.

4.4. Roads and Meandering Walls

Black, narrow lines on the satellite images were mapped as traces of roads and walls. From the appearance on the satellite images can be derived that there are different types of roads, see Figure 25:

- Straight, linear, extended roads (up to several kilometers) detectable as black, narrow lines on the satellite images, often cutting straight through hills, ridges and valleys,
- So-called meandering roads with irregular contours, considering and adapting to the topography and,
- Hunting, herding walls, and potential defensive walls against wild animals and enemies (Figure 26).

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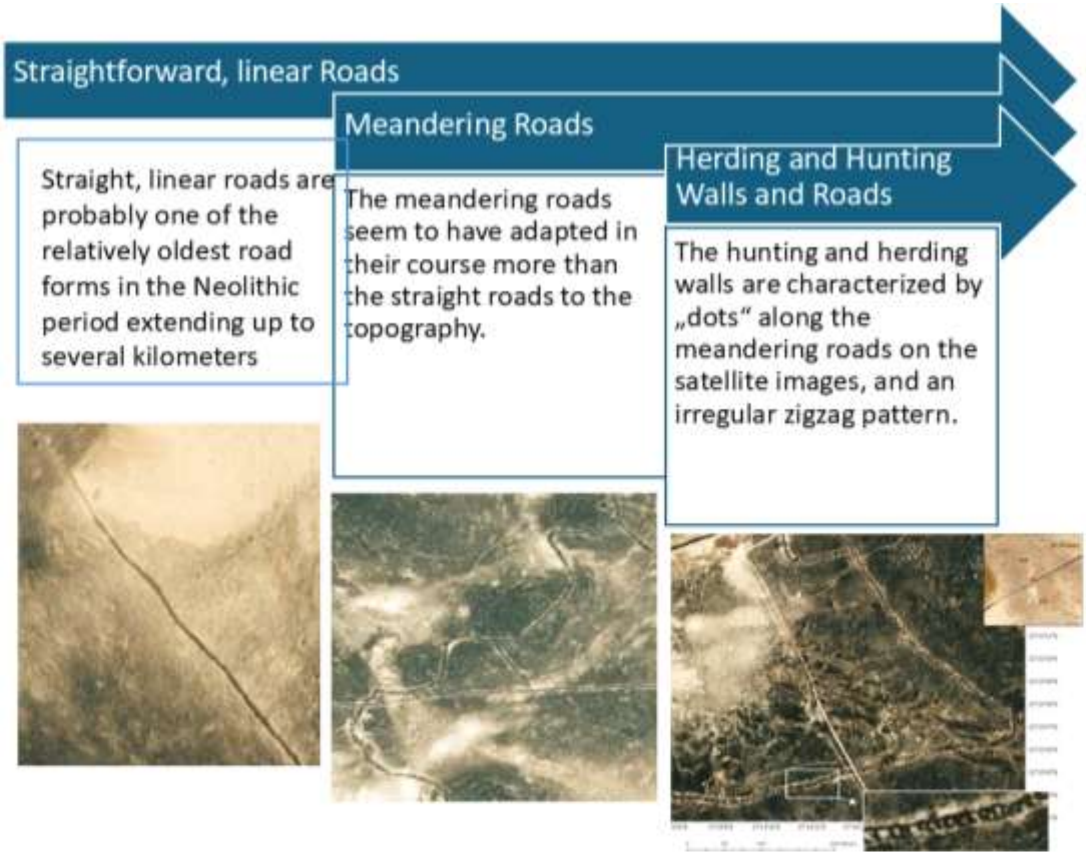

Figure 25. Types of roads and walls.

The straight, linear roads reach lengths of several kilometers, what confirms the assumption that the people of that time had a relatively high mobility using the roads for an extensive trade network, wide ranging procurement activities and knowledge exchange.

The meandering roads and walls switch in their course in their shape of meandering walls to linear, straight roads and vice versa. The meandering roads and walls seem to have been planned very carefully and strategically in a sophisticated way, based on observations of the environment, especially the life conditions of animals and the topography. Kites and meandering roads were situated along and across migration routes of gazelles (Gazella subgutturosa) from Saudi Arabia north to Syria and back [26]. The planning of the routes considered the position of basins, depressions and riverbeds. The basins and depressions were probably temporary ponds and lakes at that time in the late phases of the Epipaleolithic, or shallow lakes ringed by freshwater swamps fed by springs that attracted both humans and the fauna upon which they preyed (mainly gazelle) [7].

Figure 26 shows an example of the meandering roads and hunting walls and Figure 27 provides an overview of the digitized meandering roads and hunting walls, oriented mainly in N-S-, NNE-SSW- and NE-SW direction and their density distribution. The position of the meandering roads and walls traced the main routes of gazelles at that time. With the bends and curves mainly in E-W-direction along the meandering roads, it was an optimal strategy to hunt the gazelles moving from south to north and vice versa.

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Figure 26. Meandering roads visible on World Imagery satellite images / ESRI. The bends and curves are oriented mainly in E-W-direction.

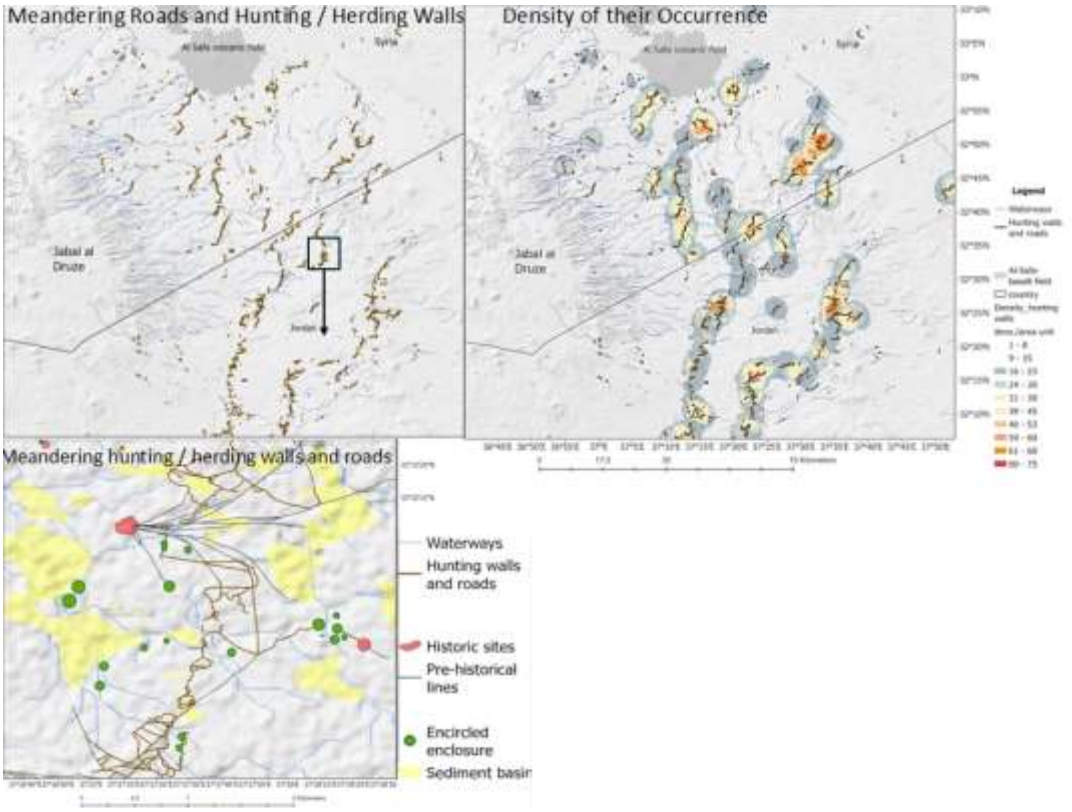

Figure 27. Visible traces of meandering roads and hunting/herding walls on satellite images, with sediment-filled basins and river beds serving as water sources for hunted animals.

Black dots along the meandering walls (Figure 28) are assumed to be partly watch posts, usually built on the outer face of the walls. Another explanation could be that some of the black dots are the remnants of traps for the hunted animals. Ground-truth work would clarify this. The hunting / herding walls and routes were carefully planned based on complex, sophisticated observations of the animal behavior and environmental conditions aiming to trap the animal prey in the bends.

Figure 28. Meandering wall segments along the riverbed.

The people responsible for the planning and construction of the roads were aware of the risks of flash floods. In flash flood prone areas ancient roads in higher levels surrounding the flooding prone basins and depressions parallel to their outline can be observed. They were mostly avoiding the placement of kites, roads and villages directly within the sediment basins. They placed them at the borders of the riverbeds and sediment basins and at the valley slopes (Figure 29). Meandering walls can be observed at the crest of steeper slopes along larger valleys, and surrounding hills to hunt for example the wild goats coming down from the hills. The position of the meandering walls was merged with thermal Landsat RGB images (RGB combining the spectral bands 7, 10 and 11, Figure 29 a and c) and Principal Component (PC) images (Figure 29 c) of the investigation area. The combination of thermal bands was chosen to enhance the visualization of sediment basins prone to flash floods during the winter season and of Holocene basalt fields.

The hunting routes adapted to the geomorphological, geological / lithological setting in the investigation area as demonstrated in Figures 30 and 31. The ancient road planners avoided the areas as well with the relatively youngest volcanic activities and roughest surfaces. Figure 31 shows a digital processed Landsat image enhancing the different lithologic units, in this case lava flows different in age and composition, in green colors. The hunting routes border the lava fields.

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However, the main reason for the N-S-, NNE-SSW- alignment of the meandering walls and kite distribution were besides the topography the hunting conditions. As mentioned before, the gazelles were wandering regularly along these directions.

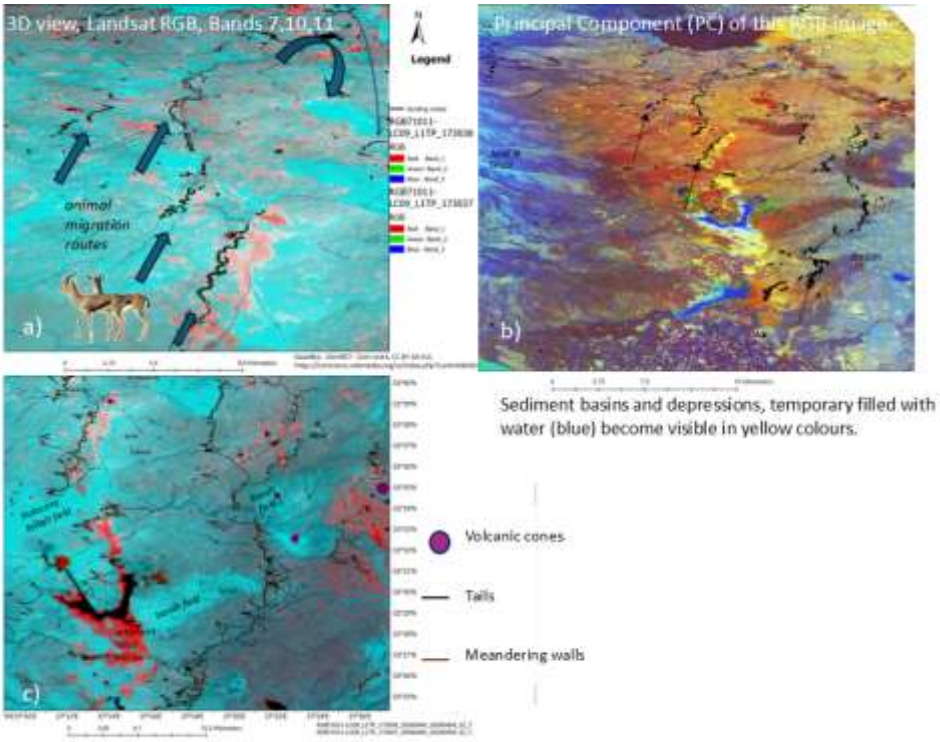

Figure 29. (a) 3D view of Landsat thermal image showing hunting walls, sediment basins, and basalt fields; (b) Principal Component (PC) scene; (c) amplified view of (a).

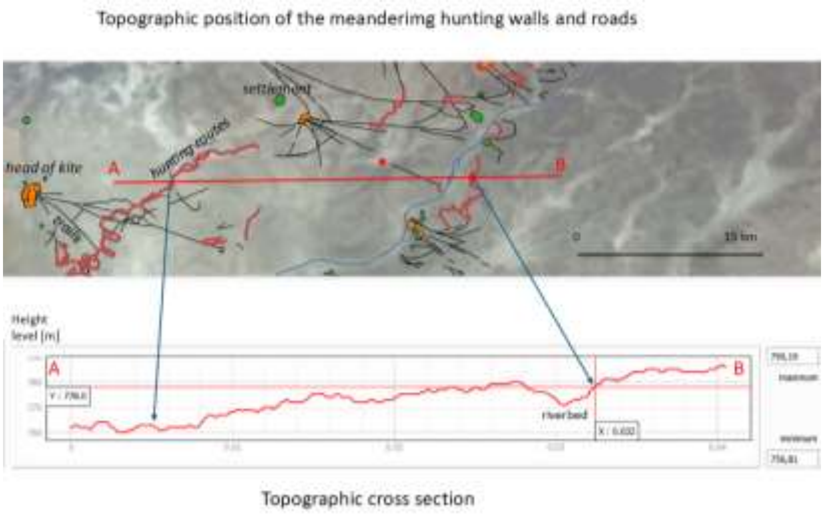

Figure 30. Topographic cross section indicating the position of the hunting routes at the valley slopes.

The scene of Figure 31 was processed in ERDAS Imagine using Independent Component Analysis (ICA) on a Landsat 8 Level 2 SP image. The L2SP collection means that the satellite imagery has been processed for Surface Reflectance values. The ICA methodology is considered a signal unmixing process and was applied to try to discriminate the geological structure, drainage and the variations within the lava fields caused by differences in

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eruption time and between those from vents and those from fracture systems. In this False Colour Composite image, the extent of drainage systems (pinks) from Jabal al Druze are apparent as are significant drainage channels (blue lines) within the lava fields. Lava shows up as green and orange.

Figures 32 and 33 are presenting structures probably built for herding domesticated animals.

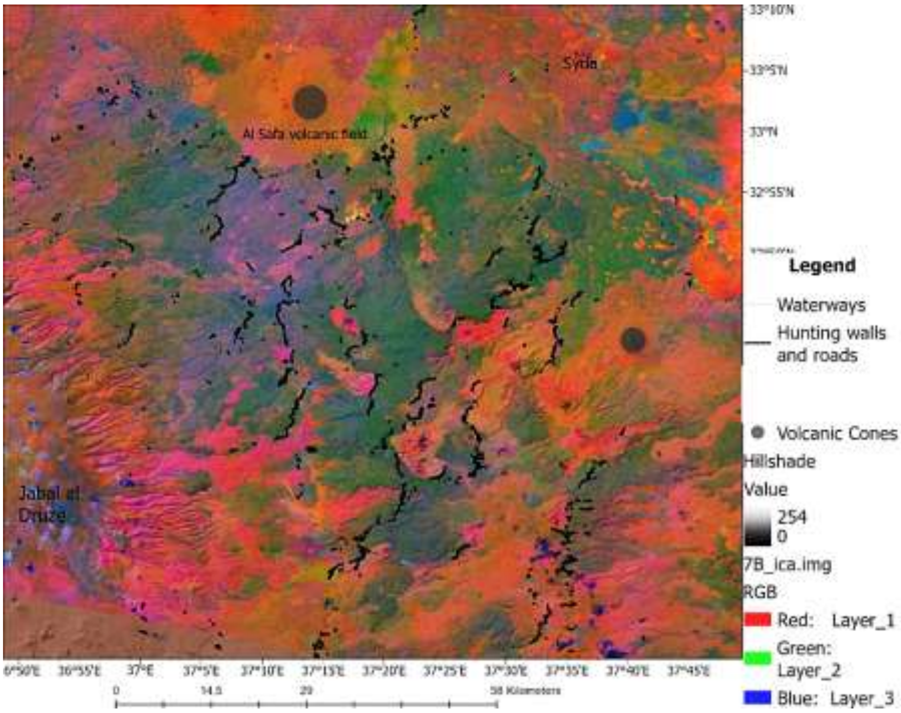

Figure 31. Landsat 8 L2SP digital processed image created by Ted Dubowski.

Figure 32. Hunting/herding walls (left) and meandering walls (right) used to guide wild and domesticated animals into secured areas enclosed by stone walls.

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The next Figure 33 presents an example of another secured area for domesticated animals.

Figure 33. Secured area for hunting and herding.

4.5. Burial and / or Cultural Sites (?)

There are some archaeological features that are not possible to explain without field work. The red encircled features in Figure 34 are assumed to be related to burial sites or to cultural / religious places? The same is assumed for the semi-circled structures visible in Figure 35. This study can only point out the areas that should be investigated in the field to find out their purpose and meaning, if possible.

Figure 34. Traces of burial sites?

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Figure 35. Semi-circled structures

The next Figure 36 shows a so-called pendant according to its morphology, the purpose of it is not known. A cultural / religious purpose is assumed.

Figure 36. Pendant (named according to their shape [1]) and a meandering wall.

Many areas with wheels or round encircled structures like in Figure 37 have oval-shaped structures nearby. The use of these structures is not known, probably related to herding. Sometimes these oval-shaped features occur isolated as well.

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Figure 37. Oval- to circular-shaped wheel structures near villages, possibly used for herding purposes.

5.0. Conclusion and Future Recommendations.

Based on evaluations of satellite images, DEM data and references, an inventory of the main archaeological features could be carried out as many of them are well preserved and visible on high-resolution satellite images. The digitized pre-historic features allow some insights into living circumstances at the time of their creation.

1. The evaluations indicate a relatively dense Natufian population with a high residential mobility what can be derived from the density of settlements, roads and hunting infrastructure. In the Early Natufian phase, the region likely supported the densest and probably the highest population sizes [26], [27].

2. After digitizing the kites. hunting routes and walls with their sophisticated arrangements in numerous bends and curvatures, adapted to the environmental conditions, the hunting intensity at the investigation time becomes obvious. Parts of the hunting / herding routes were described as Open-Kites in the scope of the Global kite project [14, 29]. This intensity led to overhunting and decimation of wildlife and as consequence, to changing land-use patterns. The archaeological records indicate evidence for greater levels of sedentism [6], [28]. On the satellite images structures could be identified that might have been used for herding domesticated animals.

3. The similarity of larger kites with a star-like-shaped head and several tails to the appearance of comets at the sky raises the question whether observations of cosmic impact events at that time influenced the construction and outline of these kites. In this case, the larger kites could be described as geoglyphs.

4. The inventory of archaeological sites based on satellite data is meant to contribute to a data base that might support the planning of later archaeological field work, for example to clarify questions related to functions.

5. The archaeologic cultural heritage sites in the study area are prone to changes in the land use, to extension of agriculture areas, to water management measurements and settlements which are strongly needed for the supply of the recent population. However, the traces of the pre-historic and later cultures are unique.

6. May be some of these unique Neolithic sites could be a part of heritage tourism in future as archaeologic remains are often the primary draw for visits of tourists [30]. Based on the evaluations of satellite data sites suited for cultural heritage tourism are suggested (Figure 38). Perhaps this form of use could help to preserve the most important archaeological sites.

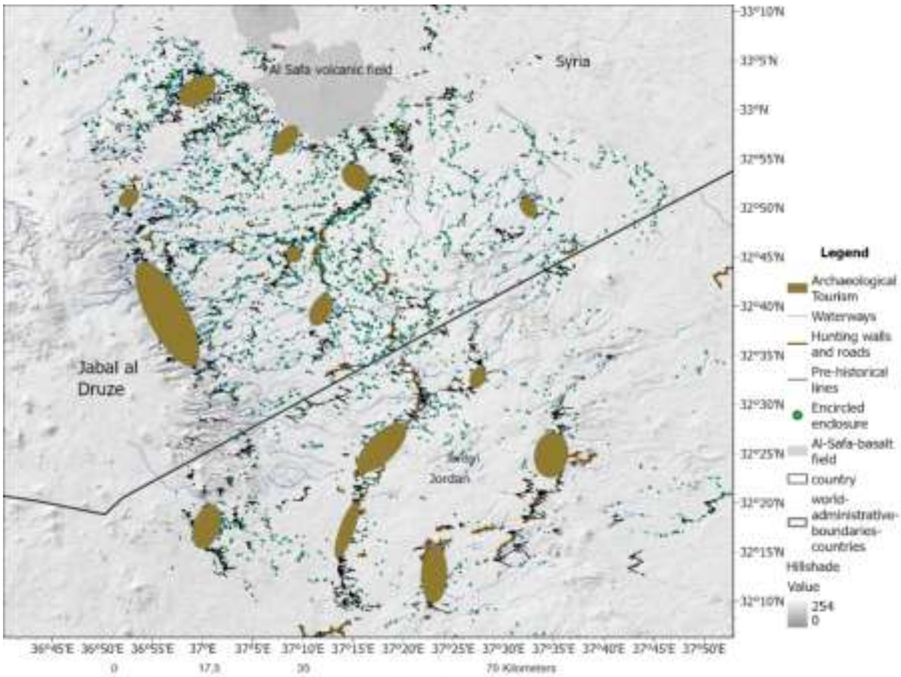

Figure 38. Proposed sites for archaeological tourism.

Declaration

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Competing Interests Statement

The authors have declared that no competing financial, professional or personal interests exist.

Consent for publication

The authors wrote and edited the manuscript and consented to the publication of this research work.

Availability of data and material

The sources of the material such as satellite and DEM data are cited in the references. AI was not used.

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