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Research Paper

Identification and examination of gravel-sized ventifacts in Abdia village, south of Damghan; with implication on paleoclimate

Mehdi Sarfi* 

School of Earth Sciences, Damghan University, Damghan, Iran
m.sarfi@du.ac.ir

Mehrdad Naghusi

School of Earth Sciences, Damghan University, Damghan, Iran
mehrdad.naghushi@du.ac.ir

Houshang Khairy

School of Earth Sciences, Damghan University, Damghan, Iran
h.khairy@du.ac.ir

Mohsen Yazdi-Moghadam

National Iranian Oil Company-Exploration Directorate, Tehran, Iran
mohsen.moghadam@gmail.com

Abstract

The present study aims to identify and examine gravel-sized ventifacts in the vicinity of Abdia village, located in the southern part of the city of Damghan. To collect samples required for the present study, an area approximately four km wide was logged. Nearly 200 gravel-sized ventifacts with an average size of 36 mm in diameter were collected from above-ground surfaces. The ventifacts collected for the present study were found within unconsolidated sedimentary structures. The identification of a variety of ventifacts including rubbing pits, vortex pits, facets such as dreikanter and einkanter, spheroid ventifacts, and worm-shaped gravels (rillstones) distinguishes the study as there have been no previous reports on the aforementioned ventifacts in Iran. The data analysis also shows that the studied area had a different, moist climate in the late Pleistocene–early Quaternary(?). However, the passage of time along with the formation of a dune and desert pavement in the area has brought an arid climate with strong winds, which is an appropriate environment for the formation of gravel-sized ventifacts.

Keywords: Ventifacts, Paleoclimate, Gravels, Damghan, Abdia

Introduction

Ventifacts are one of the most significant phenomena observed in wind-prone areas. According to Bryan (1929), ventifacts are rocks in which the abrasion of wind, sand, and silt has created grooves, pits, ablations, stripes, fractures, polish, and different types of facets. As a type of sedimentary phenomenon, the formation of ventifacts is indicative of a terrestrial environment with long-lasting cold or warm patches and negligible vegetation (Várkonyi and Laity 2012; Durand and Bourquin 2013). As ventifacts indicate the direction and intensity of wind in a given environment, identifying them in modern and ancient environments is important

(Knight 2008). The study of ventifacts can play a key role in the identification and reconstruction of palaeoenvironments, including aeolian, fluvial, and alluvial settings. This is particularly important since ventifacts lose their distinguishing shape by transport, and most of the identified ventifacts within geological reports are almost in situ or have insignificant transport distances (Knight 2008; Durand and Bourquin 2013). Ventifacts in the present time have been largely developed within desert pavements. The development of desert pavements is due to deflation, which is the erosion of fine-grained grains such as clay and silt and the preservation of gravel-sized grains on the surface. Although

*Corresponding author

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these grains were initially far apart in the development of desert pavement, deflation would gradually create a relatively uniform pavement consisting of gravel grains (Cooke 1970) (Fig. 1a-b).

Ventifacts exhibit significant diversity and variability in terms of size, material, and shape. The primary factor influencing the size and shape of ventifacts is the origin and initial geology of the parent sedimentary structures. For example, grain size tends to be larger within the proximal deposits and decreases towards the distal. The parent rock composition, along with factors such as wind intensity and direction, also plays a significant role in the final shape of the ventifacts (Durand and Bourquin 2013; Ning et al. 2019; McKenna Neuman et al. 2023).

Ventifacts have been studied since the late nineteenth century. Numerous reports of diverse ventifacts have been

published from all continents (Sharp 1949; Babikir and Jackson 1985; Clark and Wilson 1992; Youngson, 2005; Cabral et al. 2006; Lagerbäck 2007; Gillies et al. 2009; Demitroff 2016; Knight and Burningham 2019). Although two-thirds of Iran is covered in arid and semi-arid environments, the present study - according to the author's knowledge and literature review - is the first description of ventifacts in Iran (Fig. 1). The only existing report briefly mentions the presence of ventifacts in the meteorites and rocks of the Lut Desert (Maghsoudi 2020). In particular, the goals of the present study are as follows: 1) to present a case study and description of ventifacts in the study area which is the Abdia village, south of the city of Damghan, 2) to analyze the provenance and the depositional setting of the ventifact-bearing sediments, and 3) to investigate the palaeoclimate of the study area.

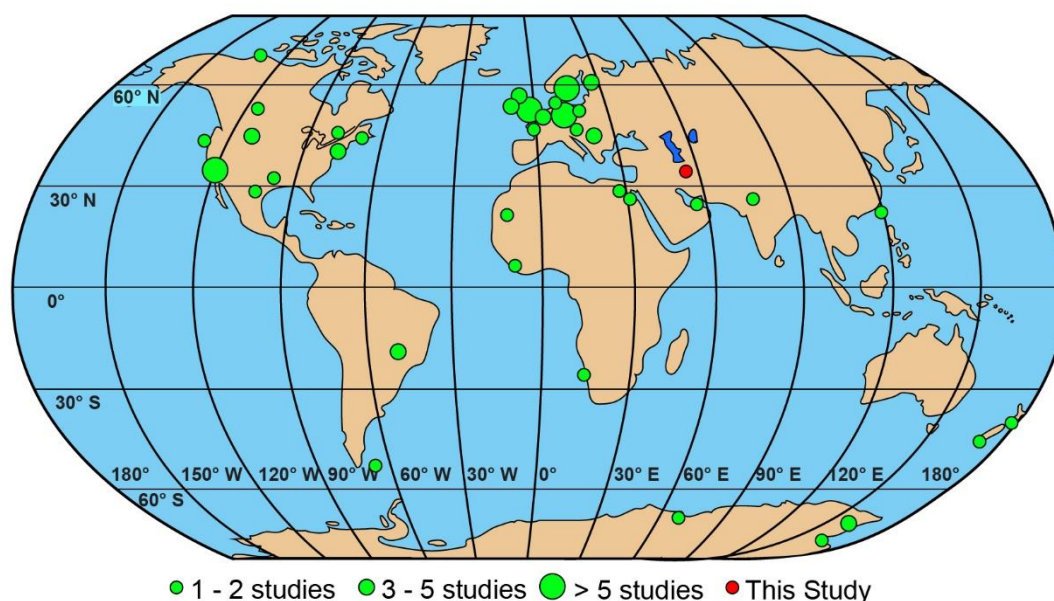


Fig 1- Distribution of studies related to ventifacts according to the previous literature. (modified after Knight 2008).

Geological Setting and Climate of the Study Area

The study area is located in the vicinity of Abdia Village, south of Damghan, Iran. The region is approximately situated at the border between the structural zones of Alborz and Central Iran (Fig. 2a). The northern parts of Damghan and the study area are covered by the Alborz Mountain range consisting of formations from pre-Cambrian to the present time. The area is comprised of various lithologies such as limestones, dolostones, and clastic rocks. At its closest, the studied area is only 16 km away from the Alborz Mountain range in the region called 'Simekuh'. The Central Iranian range is exposed at 26 kilometers to the south of the study area in a region called 'Panj Kooch'. The region consists of igneous, metamorphic (schists and slates), and sedimentary rocks mainly attributed to the Cenozoic era. The Damghan

and Atari faults have been suggested as the boundaries between the Alborz and Central Iran zones (Alavi 1972). Damghan Plain, located between the Alborz and Central Iran zones is mostly covered by alluvial and fluvial deposits. The Haj Ali Qoli Playa, also known as Chah-e Jam, is to the south of the study area.

The collected data from the Damghan Synoptic Meteorological Station indicate an average temperature of 14.7 degrees Celsius in the Damghan Plain and low-elevation areas. The average annual precipitation and the evaporation rate in the plains are 133.5 and 261.6 millimeters, respectively. Additionally, the average annual wind speed and the average recorded annual storm speed are approximately 15.2 and 25.6 kilometers per hour, respectively.



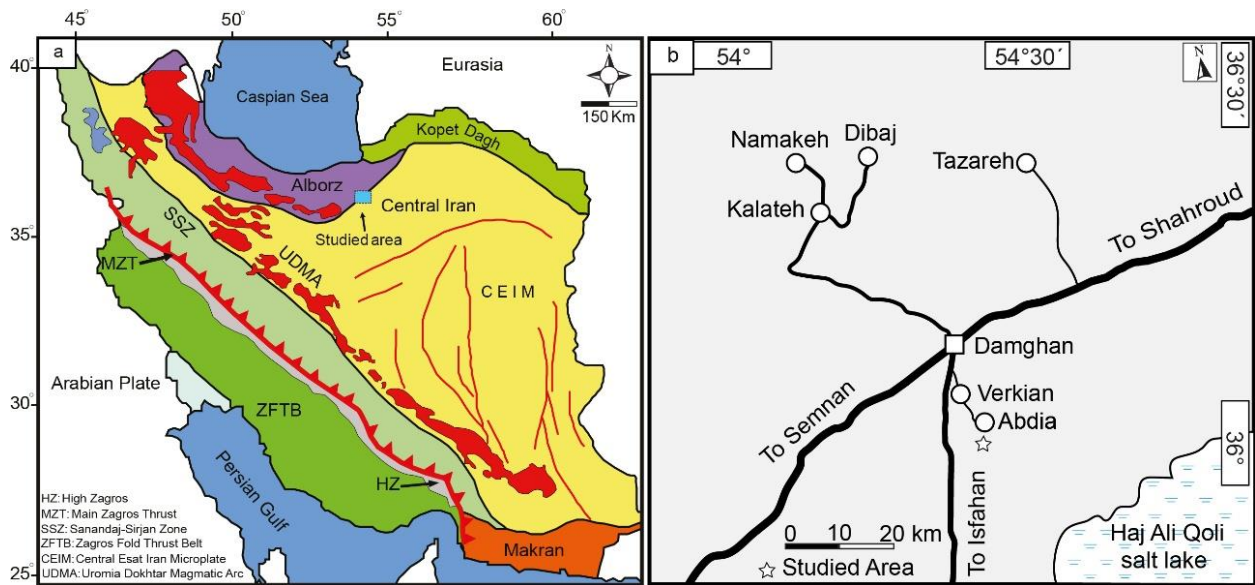


Fig 2- a. Overall view of the tectonic subdivisions in Iran (the studied area is shown with a rectangle). **b.** Roads leading to the study area.

Materials and Methods

The study area is located 13 kilometers to the south of the city of Damghan, in the proximity of Abdia Village. The access road to the study area is off the Damghan–Isfahan main road, on the local route leading to the village of Abdia. The identification of gravel-sized ventifacts was done by logging an area of four kilometers long (Fig. 2b). Following detailed examinations, more than two hundred gravel-sized grains with the characteristics of ventifacts were collected from the ground surface in unconsolidated sediments. These samples were then carefully studied and photographed. In order to study the composition of the deposits, two shallow boreholes were drilled two kilometers apart with a depth of approximately one meter. The deposits located in the boreholes were randomly sampled to study their grain size distribution and composition. The entire measurements were conducted using a caliper and reported in millimeters. The samples passable for educational use and future research are preserved in the geology laboratory of Damghan University. The rest of the gravel-sized ventifacts were returned to the study area to maintain the geological diversity. A combination of loupe magnifiers, hardness test, and hydrochloric acid – when necessary – was used to identify

the composition of deposits.

Results and Discussions

Ventifact Types

Ventifacts can take various shapes and sizes depending on the initial deposit characteristics. Moreover, wind intensity and direction also play a significant role in the ventifacts’ final shape (Durand and Bourquin 2013). Generally, gravel ventifacts tend to have a bipolar shape: The upper surface is smooth and flat, while the lower surface exhibits irregularities (Fig. 3a-b). This bipolarity distinguishes the gravel-sized ventifacts in the geological records and within palaeo-conglomerates (Whitney and Dietrich 1973). In some cases, the lower and upper facets of the ventifacts can have a similar texture, which is mostly associated with fluvial environments. Apart from their bipolarity, ventifacts mostly have a polished and glossy surface. Although the aforementioned feature is not observed in all gravel-sized ventifacts, it can be a significant aid in their identification. It should be noted that single gravel can exhibit diverse ventifact shapes. Generally, the various shapes observed in gravel-sized ventifacts can be classified as surface shapes and general shapes, both of which will be discussed in detail (Fig. 3c-f).

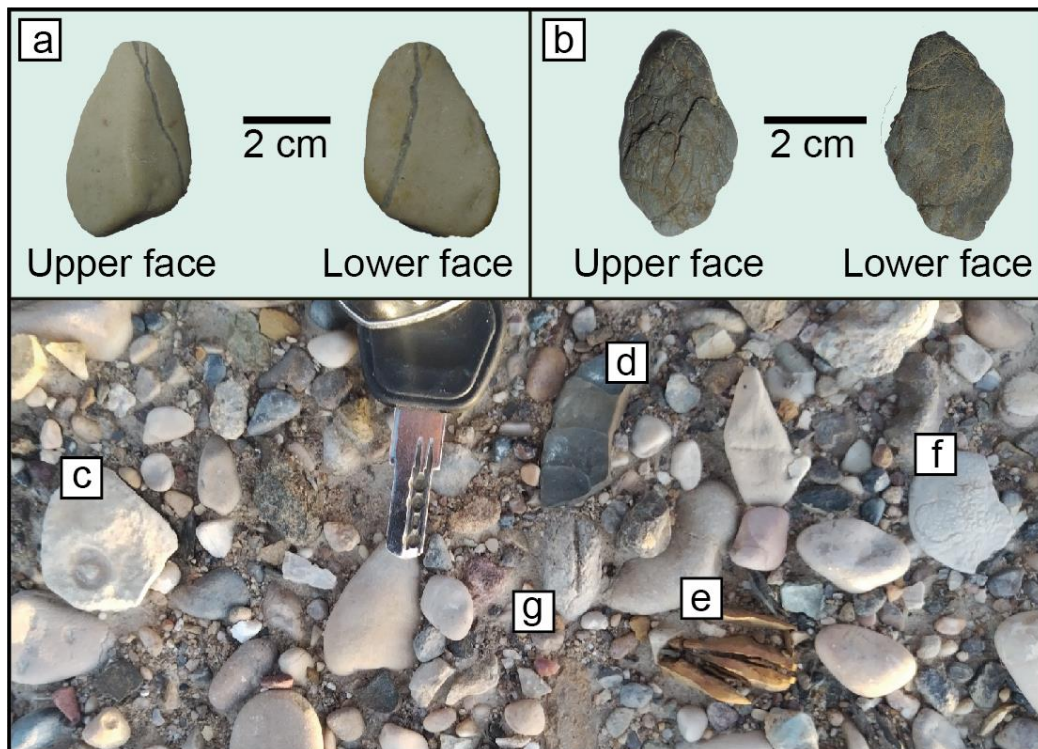


Fig 3- a, b. The polarity of the ventifacts is distinguished by their upper and lower faces. Close view of desert pavement showing different types of ventifacts. c. Pit. d. Faceted ventifact. e. Limestone. f. Rillstone. g. Groove pits.

Surface shapes

These shapes generally include pit, flute, and groove features (Fig. 3g). Pit surfaces typically have irregular, relatively circular depressions with a grain diameter from 1 millimeter to 25 millimeters (1 inch). Flute surfaces are generally concave and have a U-shaped cross-section. Grooved surfaces are usually more wide and have open ends on both sides. Cavity-bearing ventifacts can be divided into two types of vortex and rubbing pits. The following section is a further discussion of the surface shapes of gravel-sized ventifacts.

Vortex pits

The exact provenance of these pits is not well-established. According to Whitney (1978), these pits are formed due to wind erosion along a relatively vertical axis on the rock surface. The presence of a protrusion in the center of the gravel and beneath it is an appropriate indicator of this type of pit, in the case of reservation. The formation spot of these pits is relative to the gravel's overall shape, and as the gravel is overturned a symmetrical concave pit is created on the opposite surface. Moreover, the wind erosion can create a funnel-shaped pit in the gravel which would lead to a vortex ventifact (Fig. 5a-d). In some cases, corrosion would create a pit on the surface of the gravel which is caused by the

centrifugal motion of the sand grains. This process would eventually lead to the development a funnel-shaped pit on the gravel. Incidentally, the presence of sand grains leads to a smooth and polished surface on the gravel (Durand and Bourquin 2013).

Rubbing pits

These pits are typically circular and have sharp edges. They have a diameter of 5 to 15 millimeters and resemble the impression of a ball on a clay surface. These pits are not observed on the surface of quartz gravel (Fig. 5e-h). Unlike vortex pits, these pits are seen on the bottom surface of the polarized ventifacts. These pits are similar to those formed by tectonic pressures. However, their formation and the absence of pale halos (iron leaching) distinguish them from pits resulting from tectonic pressures (Durand and Bourquin 2013). These pits are formed relatively similar to the impact of erosion of water, occurring in an aeolian erosion environment. At the onset of aeolian erosion and the emergence of gravels following the fluvial deposition, finer grains move among the coarse gravels and create the pits (Fig. 4). An important characteristic is the completely irregular concave rubbing beneath these grains that do not follow any specific pattern.

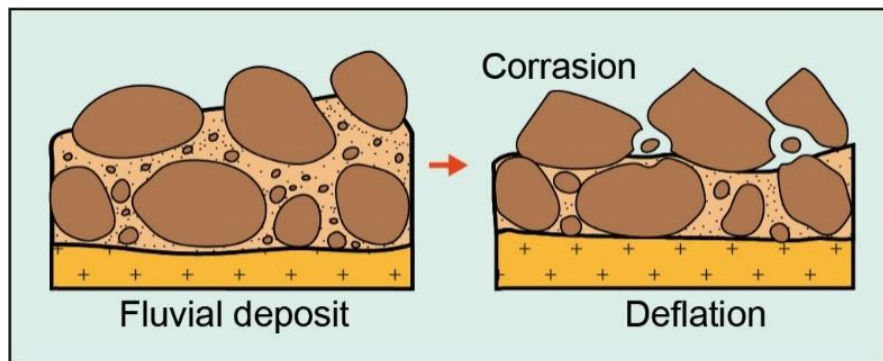


Fig 4- Schematics of the Rubbing pits' genesis in aeolian settings.



Fig 5- Ventifact surface shapes. a. and b. Coarse limestone vortex pits. c. and d. Fine-grained sandstone vortex pits. e-h. Limestone rubbing pits.

Rillstone

These ventifacts have peculiar patterns of narrow and delicate vermiculate grooves on their surfaces (Fig. 6a-f). These patterns can be observed in many present-day deserts. Although some studies and travelers have attributed the formation of this phenomenon to wind erosion (Whitney and Dietrich 1973), the origin of these rocks has been known for a long time. Researchers have considered their initial formation as solutinal microstructures (King 1936; Cailleux 1942; Bourke et al. 2007). These forms are not among true ventifacts and their formation is not directly influenced by wind. However,

as they are often associated with ventifacts, they are usually considered in studies related to ventifacts. This phenomenon is mostly observed in limestones and dolomites and is the result of microsolution by dew droplets, occurring mostly during nights in coastal and semi-arid areas. The movement of dew droplets under conditions without wind flow occurs due to gravity, where solutinal microstructures are created with a radial form. Parallel and labyrinthine patterns are created respectively in regions with moderate wind with constant direction, and those with strong winds in varying directions (Durand and Bourquin 2013).

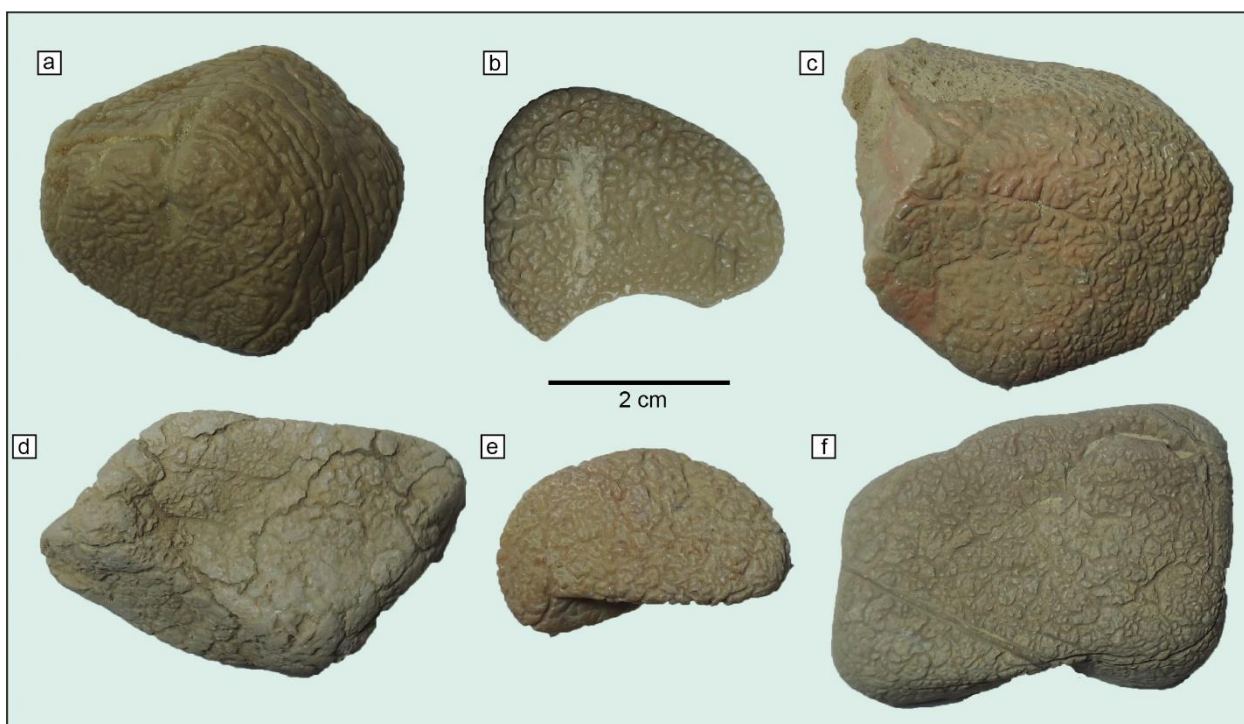


Fig 6- a-f. Rillstone gravels featuring vermiculate traces on carbonate surface.

General shapes

The size of ventifacts can vary significantly depending on the initial size of the parent rock, ranging from several-meter-sized boulders to millimeter-scale ventifacts (Durand and Bourquin 2013). The outer margins of ventifacts are generally angular and irregular, making it easy to distinguish gravel-sized ventifacts from fluvial deposits and rendering their *situ* position. However, caution should be exercised in examining carbonate rocks since irregular and angular margins can also be caused by mechanical abrasion and chemical corrosion (Sugden 1964; Durand and Bourquin 2013). In the following section, the main types of studied ventifact shapes will be reviewed. It should be noted that many of these gravel-sized ventifacts can also have surface shapes.

Faceted ventifacts

Facets are the most significant of the ventifacts, and the German term "windkanter" is a precise reference to them. Facets typically have a polyhedral shape that can be flat, convex, or concave. The number of faces or edges in ventifacts typically depends on the initial gravel shape and the aeolian properties of the region. Similar faces and facets

can also form due to tectonic activities or short-distance transport. However, careful consideration is needed due to the nature of the deposits (Durand and Bourquin 2013).

Trihedral or pyramidal ventifacts – also known as dreikanter – the formation of which is usually attributed to the tectonic separation of grains from the parent rock (Fig. 7a-j). These ventifacts have smooth vertical faces but exhibit arcs in lateral faces. Identifying these ventifacts is relatively easier compared to that of the grains transported in the fluvial environments. The Dreikanter are distinguished by their sharp and smooth edges created by wind. Triherdal formations can also be the result of mechanical processes, fluvial displacement, or detachment from a parent rock due to impact. Therefore, they are not a reliable indicator for ventifacts.

Einkanter are another type of faceted ventifacts that are mainly characterized by the presence of a keel or a sharp edge parallel to the longest axis of the particle (Gillies et al. 2009). Some gravel-sized ventifacts have a triangular cross-section, with one surface being more elongated by wind erosion (Fig. 7k-m).

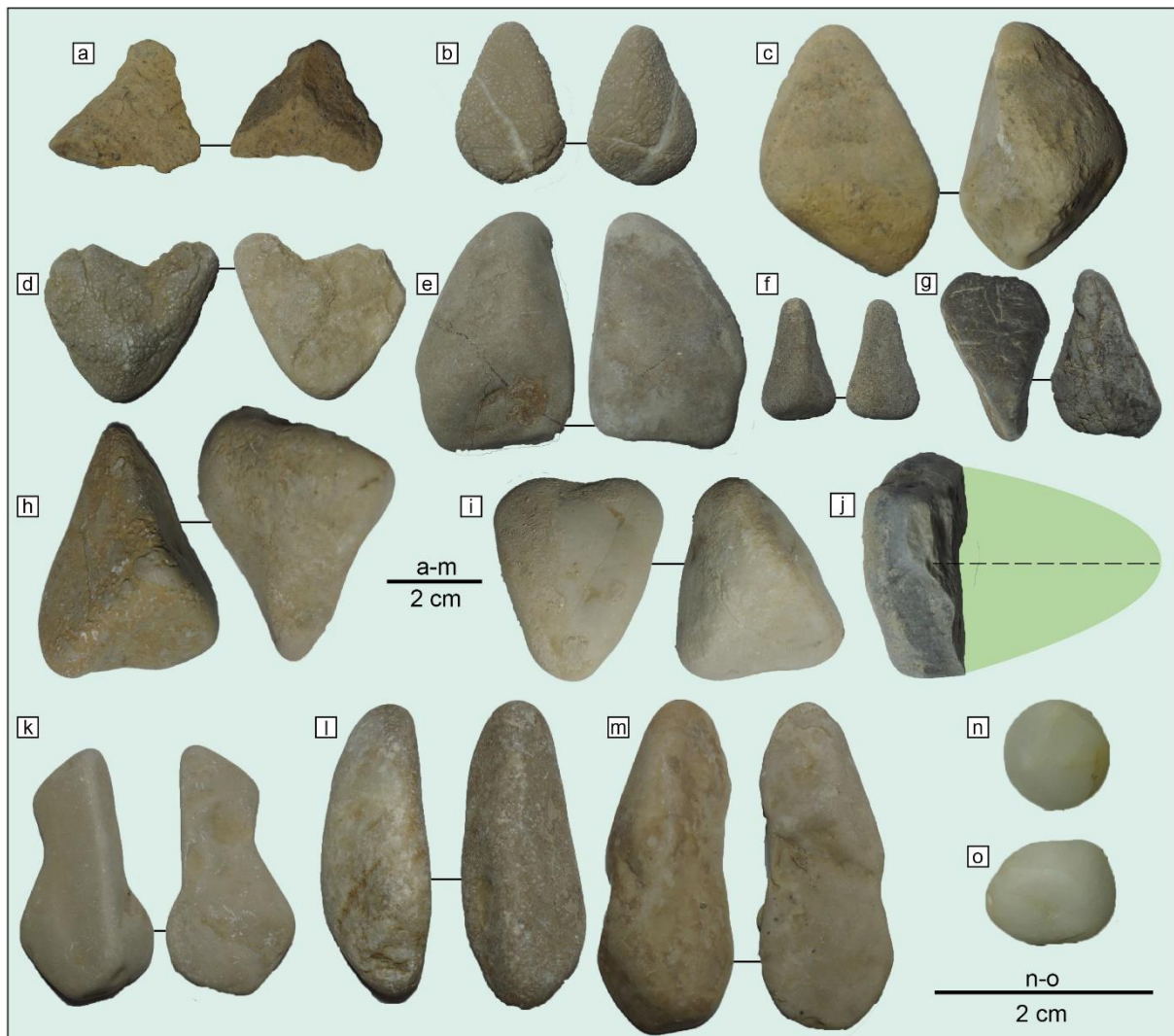


Fig 7- Faceted ventifacts in various forms featuring upper and lower faces (excluding j, n., and o.): a-j. Dreikanterers. k-m. Einkanterers. n. and o. Spheroids.

Spheroid Ventifacts

These forms are commonly found in quartzites and have a small to medium size. They exhibit a high degree of sphericity, primarily associated with severe sandstorms in arid environments (Fig. 7n-o). These sandstorms cause abrasion and collision with larger grains, ultimately resulting in spherical shapes (Várkonyi and Domokos 2011).

Texture and depositional features

The size and shape of grains are the two main elements of a depositional texture. The study of sediment grains in the research area indicates the largest and the smallest extracted grain size to be respectively 80 (cobble) and 8 millimeters (pebble). The average size of measured grains was approximately 36 millimeters, which categorizes them all as gravel. Furthermore, the common shapes of the grains include discoidal, hemispherical, and elongated. All of the extracted gravel grains were from sedimentary rocks, and no evidence of igneous or metamorphic rocks was observed. Approximately, 75 and 25 percent of the gravel-sized grains

are constituted of carbonate rocks – mainly limestone – and detrital sedimentary rocks, respectively. Fossil fragments including crinoids, brachiopods, ammonitids, fusulinids, nummulitids, and stromatolites were identified in the deposit grains.

Provenance Analysis and Depositional Setting

According to the sedimentological studies and their shape and texture, the provenance of the deposits in the studied desert pavement (Fig. 8) can be attributed to a combination of alluvial and fluvial currents. The formation of the deposits in an alluvial fan is ruled out due to their geometry, their considerable distance with high-altitude regions, and the linear patterns in the vicinity of adjacent depositional environments – such as the Haj Ali Qoli playa to the south and the Damghan alluvial fan to the north. Therefore, a permanent or seasonal fluvial system should have been active in the study area in the initial stages of their formation. The identification of provenance is also crucial due to the location of the study area at the boundary of the Alborz and Central

Iran zones. The study of depositional grains and their correlation with stratigraphic formations plays a vital role in determining their provenance. The record of fragments such as stromatolites, fusulinids, brachiopods, ammonitids, alveolinids and nummulitids – respectively belonging to Soltanieh, Dorud, Mobarak, Lar, and Ziarat formations - indicates the provenance of the studied deposits to be the Alborz zone. This observation is consistent with the

proximity of the study area to the Alborz Mountains and its topography. The size of the gravel sediments, reaching a maximum of 80 millimeters, along with the termination of the sediments at Haj Ali Qoli playa, indicates moderate energy within the median to the distal part of the fluvial system. According to Knight (2008), the studied ventifacts with an average size of 36 millimeters can be classified among mesoscale ventifacts.



Fig 8- Desert pavement in the study area (Abdia village, South of the city of Damghan)

Paleoclimate Investigation

The studied deposits are located three kilometers south of the Abdia village in a semi-arid region that has been significantly altered by human activities, especially pistachio orchards. The presence of desert pavement and the horizontally positioned gravel-sized ventifacts indicates considerable climatic changes – especially as the diagenetic processes have had little influence on the unconsolidated state of the deposits. This indicates considerable climatic changes in the late Neogene and Quaternary(?) of the study area. The results of this study reveal the area to have been influenced by permanent and seasonal fluvial currents, likely in the late Neogene and Late Pleistocene. The aforementioned fluvial currents likely reached as far as the Haj Ali Qoli Playa. These climatic conditions and age interpretation are confirmed by the identification of early hominoid stone tools and evidence from the Late Pleistocene and Middle Paleolithic in the proximity of the study area (Vahdati Nasab and Hashemi 2016). According to this study, the large exposure of lithic artifacts, 8.5 km in length was recorded in the southern outskirts of the modern city of Damghan, indicating

that climatic conditions during the Late Pleistocene were significantly different from to present, and the presence of numerous water resources and associated vegetation permitted hominin populations to occupy currently arid areas. Other studies are also in accordance with this interpretation (Vaezi et al. 2019), moreover, the identification of palynomorphs, and in particular the occurrence of dinocysts including *Operculodinium* cf. *eirikianum*, and *Bitectatodinium tepikiense* in east of Damghan within late Neogene deposits indicates that the region had a relatively moist climate during this time (Fathalizadeh et al. 2022). In subsequent periods, the aforementioned fluvial currents had ceased, giving way to dry conditions with significantly strong winds. The aeolian processes during this period had likely eroded the smaller grains from the area, gradually forming the desert pavement. Concurrently – or after the aforementioned process – sand dunes covered the region, and the simultaneous presence of wind activity and sand deposits led to the formation of various gravel-sized ventifacts in this area (McKenna Neuman et al. 2023). It should be noted that currently, there are no sand



dunes in the study area. However, the observable records in the regions of Khors and Hasanabad – approximately 30 kilometers away – are indicative of aeolian activities and the presence of sand dunes. Moreover, elderly habitants of the Abdia Village recall the presence of dunes in the area approximately sixty to seventy years ago. Therefore, the region's climate has become slightly moist compared to the previous dry period, likely due to human activities of well drilling, extensive agriculture, and desert greening projects.

Conclusion

Ventifacts are one of the most significant features observed in wind-prone regions, occurring in desert or cold polar areas. Gravel-sized ventifacts – when observed in detrital deposits – can significantly contribute to the reconstruction of ancient environments. The present study aimed to examine gravel-sized ventifacts in the Abdia Village, located in the south of the city of Damghan. In total, more than two hundred gravel-sized ventifacts were collected from the ground surface and within unconsolidated sediments present in a desert pavement, and they were carefully examined. The average size of the ventifacts is 36 millimeters and are mostly composed of carbonate rocks and sandstones. No igneous or metamorphic ventifacts were found in the studied area. Due to the proximity of the study area to the boundary of the Alborz and Central Iran zones and the texture and structures within the recorded ventifacts, the provenance of the deposits was identified as fluvial-related to the Alborz zone. The observed types of ventifacts include dreinkanter and einkanter facets, rubbing and vortex pits, spheroids, and rillstones. The aforementioned gravel-sized ventifacts were studied and examined in Iran for the first time. Finally, the examination of deposits and the shapes of gravel-sized ventifacts indicates relatively significant climatic changes in the late Quaternary(?) and late Pleistocene. The fluvial deposits, likely at the end of the late Pleistocene or the beginning of the Quaternary(?), suggest a more wet climate in the study area compared to that of the present time. However, the subsequent coverage of the area by sand dunes, the formation of desert pavements, and the creation of gravel-sized ventifacts between the aforementioned periods indicate a drier climate.

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