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Geomorphology of Meso-Yardang Formation and Evolution in Fahraj Plain, SE Iran: The Role of Stream Incision, Sandblasting, and Nebkha Transformation

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Abstract

The purpose of this study is to investigate on meso - yardags of Fahraj Plain in SE Iran. The playa on which the yardangs have taken shape has been divided into northern and southern parts as a result of incision by Nesa ephemeral stream . Detailed field investigations were performed and samples were taken to determine the texture, mineralogy and chemical characteristics of mudrocks comprising the yardangs. In addition, morphometric measurements on 51 yardangd were carried out and analyzed. The study demonstrated that stream incision has played a major role in creation of these yardangs. And some or all of them are the product of Nebkha transformation considered as an important agent. Sandblasting has played a crucial role in creation and evolution of these landforms and undercutting at nosal and lateral parts of yardangs by sandblasting is destroying them via mass wasting process. Yardang formation has progressed up windward (retrogressively) in the northern playa and down windward (progressively) in the southern playa.

Keywords; Yardangs, Fahraj Plain, Nebkha Transformation, Sandblasting, Geomorphology

Introduction

Yardangs are typical wind eroded landforms that are formed in the majority of world's major deserts (Dong et al, 2013). They develop where wind erosion dominates over fluvial processes (Laity, 2009, Zahabnazouri, 2022) and usually occur in hyperarid regions). They may also occur in subhumid to cold regions such as central Eroupe (Sebe et al, 2011). They may also form in unconsolidated materials and have been reported in all continents except Astralia. Yardands develop in response not only to sandblasting and to deflation, but also to vorticity within systematic and complex air currents that flow over, around and across rock obstacles (Bred et al, 1985). Yardangs may be seen as tight arrays, separated from one another by either U- shaped or flat – bottomed troughs, or as widely spaced, highly – streamlined features on wind- beveled plains and vary greatly in their scale, development and spatial extent (Laity, 2009). Their stream-lined form develops by wind erosion in rock or sediment in order to minimize drag and maximize aerodynamic efficiency (Greeley and Iverson, 1985).

Yardangs are customarily unstable. They either grow as a result of corridor downcutting or diminish in size through erosion. In reality, however, the difference between corridor downcutting and yardangs denudation determine whether they are growing or diminishing (Barchyn and Hugenboltz, 2015, Zahabnazouri, 2025). In high denudation conditions and/ or in large fractions of immobile sediment they would be short-lived (Barchyn and Hugenboltz, 2015).

Yardangs have been classified in size from micro-yardangs (some meters in height and length) to meso-yardangs (some meters in height and length) and mega-yardangs (tens of meters in height and several kilometers in length) (Cooke et al, 1993, Halimov and Fezer, 1989 and Mc Cauley et al, 1977 b). Mega- yardangs and meso-yardangs differ in their aerodynamic form and scale and probably in the relative roles of abrasion and deflation (laity, 2009). The highest yardangs occure in those conditions where immobile sediment is not present in corridors (Goudie, 2007).

Although the majority of yardangs are streamlined in shape, however, many different shapes of them have been reported. As an example, Halimov and Fezer (1989) classified the yardangs of Qaidam basin into pyramids, long ridges, streamlined whalebacks, mesas, saw- toothed crests, cones, hogbacks and low, streamlined whalebacks. In all, depending on such factors as materials characteristics, wind conditions, the relative importance of acting processes as well as the age and topography, yardangs take different forms, the most typical of which are streamlined ones.

Local topography, supply of abrasive particles and time are considered as the main factors necessary for yardangs occurrence (Bread et al, 1989). Minimal soil and vegetation cover, prevalent monodirectional winds and scarcity of sand have usually been considered as the preconditions for their development (Mccally et al, 1977; Whitney, 1983; laity, 1994 and Goudie et al, 1999), and of the main three underlying processes of yardangs development (abrasion, denudation from nonaeolian processes and deflation), abrasion is likely responsible for the majority of erosion (Laity, 2009). Noneolian processes of mass wasting, weathering and runoff erosion are also common and reduce yardang height (Dong et al, 2012). Deflation and erosion from suspended sediment may be important in favorable materials (Carling, 2013).

Although yardangs may develop on any type of rock (Goudie, 2006), however, a favorable condition for their occurrence is the presence of soft deposites, typically observed in areas of ancient lake basins (Paillar et al, 2016). This is why the majority of them have tacken shape on relatively soft lacustrine and playa deposits. In another words, deposits which are relatively soft and easily sculpted, yet cohesive enough to retain steep slopes, are ideal for yardangs development (Greeley and Iverson, 1985). Playa deposits have such characteristics. Hence, Laity and Bridges (2013) believe that playas are favorable environments for yardang development as a result of: (i) the presence of sand, (ii) the dry environment, (iii) a weak vegetation cover or lack of it and (iv) the presence of friable and erodible sediments.

Examples of yardangs formed in playa or playa-liked deposits include yardangs in Ebro depression of Spain (Guttierrez,2003), yardangs carved in Holocene lacustrine beds in Mali (Riser, 1985), yardangs of Mojave playa in California (Clavke et al , 1996), yardangs formed in lake and swamp beds in Kharge of Egypt (Goudie et al, 1992), yardangs of Holocene lake beds in Farafara of Egypt (Embabi, 2002), yardangs in clay and silts of Lut desert in Iran (Gabriel, 1938 and), yardangs of Quaternary alluvium and lake beds in Hamoun of Afghanistan and eastern Iran (Goudie, 2006), yardangs of Qaidam Basin in northwestern China (Li et al , 2016), the famous Lop Nor Yardangs 9Goudie, 2007), some yardangs in Um al-Riman depression north of Kuwait (Al- Dousari et al , 2009), the Kara Bora yardangs in Tajikestan (Goudie, 2007) and yardangs of Western Desert in Egypt near Abu Bollas escarpment (Kroplin, 1993).

All playa environments, however, are not fit for yardang development. The generation of yardangs requires the existence of large playas greater than 0.03 – 0.14 km^2 in area (Al-Dousari, 2009) and the size of playa and the time and degree to which it remains flooded may be limiting factors in the development of yardangs

(Al- Dousari, et al , 2009). It is an interesting point that basins are areas of sand sea development rather than surface aeolian erosion (Goudie, 2007). Hence, creation of yardang fields on playa surfaces may not be considered as a usual and common happening.

Although yardangs have occupied a very small part of land surface, they are important landforms from several aspects : (i) they may be considered as indicators of environmental change (especially paleowinds direction), (ii) they are a major source of dust in some areas, (iii) they are considered as interesting features for geotourism purposes and, finally, they are present in some other celestial bodies like Venus ,Mars and probably Titan and are important for understanding the conditions of these celestial bodies. However, despite these points, yardangs have received limited attention (Livingstone and Warren, 1996 and Bridges and Laity, 2013) and are little – studied and poorly – understood desert landforms (Ward and Greeley, 1984). In addition, although they are not a widespread landform, they are one of the very which are unique to deserts (Livingstone and Warren, 1996). In all, there are many open questions about yardang formation and development in playas such as the relative role of active processes, the lack of yardang in some playas having sand dunes, the relative role of fluvial erosional and deposition and the role of groundwater which the future investigations must seek to answer.

2- The study area

The Fahraj plain lies at SE Iran. It also lies at a distance of about 60 km east of Bam town which was devastated during a strong earthquake in. There are two towns (Fahraj and Narmashir) and tens of villages in this plain. The main road linking Kerman province to Sistan and Baluchestan Province passes from this area and another major road extends from Narmashir towards Chahbahar port at the coast of Oman sea. Also, there are many asphaltsic roads connecting the villages. Citricuture and palm gardening are the main livelihoods of residents. Groundwater is the main source of water which is extracted by several tens of qanats lying on alluvial fans, playa surface as well as in the yardang field.

Compass plot of annual wind direction and magnitude during the 1970 -2003 Period in the Lut desert (Ehsani and Quiel , 2008) It is assumed that the studied area is a part of a corridor from north of Lut towards Indian Ocean. The main control on yardang formation in this area seems to be the existence of these strong unidirectional winds which determine the location and orientation of yardangs. A regional wind system which is called “the wind of 120 days” blows during May to

September in east- central Iran (Kehl, 2009 and Goudie , 2007). Given pressure gradient of air in the Ice Ages has been much larger than today, it is assumed that the much stronger winds during those ages have played a major role in creating the yardangs of this plain. According to Kehl (2009) there is geomorphic evidence that during last Glacial, central Iran experienced stronger winds than present.

The Fahraj plain is bounded from the north by low hills which separate it from Lut desert and is bounded from the south by Jabal Barez high mountains with picks being up to 3700 m in height. The Nesa stream with a catchment of about … km^2 originates from these mountains. This stream builds a larg alluvial fan at the south of plain and enters the playa at the west of plain. Nesa stream crosses and cuts this playa from west to east.

Geologically, the high Jabal- Barez mountains at the south are comprised of Eocene volcanic rocks as well as several dioritic and granodioritic intrusions ( ). These rocks are highly uplifted as a result of compressional tectonic forces. There is an active fault just at the mountain front and the low hills at the north which separate this plain from Lut are also comprised of Eocene volcanic rocks . The plain surface is mainly covered by sediments carried by streams originating from the southern mountains. These sediments are boulder and gravel in size at the mountain fronts and gradually become finer towards the medial part of the plain where they become sands, silts and clays making up the playa unit.

The gross morphology of the studied area is comprised of mountains, bahada and playa units. The bahada which is comprised of alluvial fans surrounds the central playa. The playa, partly covered by dat of gardens and, as result of stream incision, it is divided into two parts which are considered as northern and southern playas. A major part of bahada surface is covered by desert pavement and the distal zone bordering bahada and playa (sand skirt of alluvial fans) is the main source of blown sands which have abraded the playa surface and created the yardangs.

At the northern playa, there are three zones of yardangs, mixed yardang-Nebkha s and nankhas from its southern limit at the bank of Nesa stream towards the north. The height of yardangs decreases from the bank of Nesa stream towards the north and there is ample field evidence showing development of yardans from the south (at stream bank) towards the north. In contrast, the southern playa is weakly eroded at the stream bank (Fig), so that wind erosion and creation of yardangs is observed at a distance south of the bank. Here, the yardangs are less developed and, towards the south, give their place to a zone of active transformation of Nebkha s to yardangs (Fig), as will be discussed later.

3- Methods

To study the yardangs, a preliminary geomorphological map of the study area was prepared, using aerial photos as well as Google Earth image, and all major geomorphological units were mapped (Fig). Subsequently, field studies were carried out for ground- trothing as well as inspection of aeolian features, sampling and morphometric measurements.

To determine the main chemical, textural and mineralogical composition of mudrocks comprising yardangs. Samples were taken for each kind of analysis (chemistry, grain size and mineralogy) samples were taken from shifting sands on playa surface. All textural samples were air dried and passed through a 2mm sieve. Particle size distributions were determined by the pipette method. The samples were free of organic matter and did not contain coarser than sand particles.

The PHs of samples were potentiometrically measured in solutions obtained from decanted sediment/dionized water suspensions (1:2.5 ratios). ECs were also measured on sediment/deionized water suspensions (1:5 ratios). The suspensions were shaken overnight, centrifuged for 15 min at 3000 rpm and decanted. ECs were measured in clear solutions. Determinations of soluble salts were performed by centrifugation from sediment/ water suspensions (1:5 ratios) . Mg^{+2}, Na^{+} and Ca^{+2} ion concentrations were used to calculate the SARs of samples. Mineralogicall analysis was carried out by X-ray diffraction (XRD) using a D4-Bruker apparatus with the following canditions: 2T/ th; start time: 1S and tube: Cu. The results of sample analysis are presented in Table1.

To study the morphometrical parameters of ……yardangs, the maximum lengths, widths and heights of yardangs were randomly measured in the field (Table) and, using SPSS software, their statistical characteristics and ratios were determined. In addition, the relationships between morphometrical variables were investigated.

4. Results

4.1. Aeolian geomorphology

4.1.1. Sands

The main source of sand in this area is the basal parts of alluvial fans bordering the playa. Given the mudrocks comprising yardangs contain some sand, these sand are also released during

Sandblasting and are considered as the second source of sand in this area.

Since the predominant winds blow from the northwest, the sands moving across the northern playa mainly come from the northern bahada surface and are trapped by the Nesa valley at south. They eventually are transported by floods to the Lut desert.

The main source of sand at southern playa is the alluvial fan of Nesa stream. However, since the source is mainly located downwind, there are few sands to abrade the surface of this playa. Blown sands from the basal part of this fan accumulate as major sand dunes and Nebkha s at the south of southern playa (Fig).

Mineralogically, almost all of the sands are igneous in origin. Quartz is the main fraction comprising up to 70% of grains.

4.1.2. Sanad dunes

Nebkha s are the most frequent aeolian sand dunes in this area (Zahabnazouri et al, 2021). They occur both in northern and southern playas and are present in eastern, northern and western parts of the northern playa. They range in size from small sandy mounds about 1m in height and several meters in length up to huge dunes comprised of several shrubs with more than 5 m in height and 20 m in length. The shrubs are comprised of Tamarix, and according to field evidence, the needle-like leaves of these shrubs as well as their sticky exudations play a major role in stabilizing the shifting sands and occurrence of Nebkha s (Yamani et al, 2012; Maghsoudi et al, 2012).

There is a Nebkha field in the southern playa which separats the scattered yardangs from the vegetation ?free bahada surface at south. Nebkha s are best developed where there is a sandy cover over the playa mudrocks. Seemingly, in these conditions the humidity is preserved from evaporation by the coarse surficial layer. There are few sand dunes in inter-yardang spaces and occasionally ecodunes are observed ahead of some yardangs (Fig).

4.2 Yardangs

There are yardangs in the northern playa, the majority of them occure in its north part. The number of yardangs in the southern playa is much less in number and they are estimated to be about cases.

According to field observations, some yardangs are destroyed as a result of wind erosion or destruction by human and some new ones develop by transformation of Nebkha s.

The density of yardangs varies from about cases to less than about cases per km^2. Their density is highest in parts of northern playa and lowest in the texture of four samples taken from the rocks forming. These yardangs is sandy clay loam to sandy clays (Fig). Hence, sands are generally more abundant than clays and silts in these deposits. The small extent of this playa is considered to be the main reason. The authors consider these rocks as mudrocks and the high values of sands in these mudrocks makes them more vulnerable wind erosion, because ballistic impact release sand grains more easily than clays (Laity, 2009; Kamali and zahabnazouri, 2018). Dewatering fissures, 1-2 m apart, are usually present in these mudrocks (Fig). They facilitate block collapse of the undercut parts of yardangs (Fig). In some cases, the presence of calcrete nodules in mudrocks which are more resistant with respect to wind erosion, have led to creation of micro-yardangs on lateral surfaces of these meso-yardangs (Fig).

4.2.1 Yardang shape

Generally yardangs shape is highly variable owing to variations in lithology, wind characteristic and yardangs age (Laity, 2009). In another words, the shape of yardangs is the result of a complete interplay of internal factors such as lithology and structure, and external factors including flow field, surrounding topography and the supply of agents of abrasion (Greeley and Iverson, 1985). Hence, the main agents affecting the form of yardangs may be classified into (i) the characteristics of material, (ii) the abrading particles and (iii) the local environment (Bridges and laity , 2013). There are both streamlined and non-streamlined meso- yardangs in this area, streamlined ones develop wherever the mudrocks are homogenous. As expected, they resemble inverted ship's hull. In this area, the most frequent yardangs, however, belong to flat top forms which have been called mesas by Halimov and Fezer ( ). They usually have vertical to overturned nosal and lateral parts which are commonly the result of abrasion at the lower parts of slopes (Fig). The exposure of a sandy basal layer lying under mudrocks commonly intensifies basal undercutting as well as pronounced overhanging in frontal and lateral sides (Fig). The result is ubiquitous collapse features ahead and around these yardangs.

Undercutting is mainly observed up to 2 m in height at windward and lateral slopes. Windward faces are commonly blunt, steep, undercut and sometimes higher than other parts. The lee ends are usually narrower, lower in height and covered by sand streamers. Given abrasion is more intense at the yardang noses, collapse features are common in these places. This process shortens them with the passage of time. So, they eventually develop into low hills and stacks (Fig). No pyramid form was observed in this area.

The prevalence of undercutting at the foot of these yardangs represents active abrasion via sanablasting at present and, unlike the Qaidom basin in China ( ), here the playa mudrocks are horizontal. Hence, dip of layers does not play a role in shaping these yardangs.

4.2.2. Yardang size and morphometry

The size parameter of yardangs include their length, width and height. Since these parameters, especially width and height are not constant features, their maximum amounts were meatured. Yardags, height depends on relative rates of corridor and summit lowering. In weaker rocks, both rates are higher and vice versa. Hence, it is hard theoretically to relate yardang height to differences in corridor and summit lowering (Brookes, 2008). In addition, the length of yardangs depends upon the length of playa over which yardangs develope (Goudie, 2007). Small playas such as the studied one only lead to small yardangs.

The morphometric parameters of 51 cases of yardangs in the studied area are presented in Table. Accordingly, their lengths varies from 59.1 to 2.5 m with an average of 20.5 m. Their widths ranges from 18.3 to 1.7 m, with an average of 6.0m. The height of these yardangs ranges from 85 m to 1.6 m, averaging 5.3m. Frequency distributions of lengths, widths and heights of yardangs are presented in Fig and their main statistical characteristics are given in Table .

The length to width ratios of yardangs (Table) range from 20.0 to 1.0 with an average value of 5.2. The length to height ratios (Table) range from 12.5 to 0.5 with an average value of 4.0. Also, the width to height values range from 2.6 to

0.3. In Table their main statistical characteristics are compared with some other areas. The length/width, length/height and width/height ratios of the studied yardangs are presented in Figure . The average orientation of yardangs is . In comprise the average orientation of Lut mega-yardangs at the north of studied area is

4.2.3. Processes

Yardangs result from several processes including wind abrasion, deflation, fluvial incision, dessication cracking, weathering and mass movements (Goudie, 1999 and laity, 1994). The significance of these processes in determining the ultimate form varies according to climate and yardang,s lithology and structure (Laity, 2009). However, since the relative role of these processes in general and in different locations is not uncertain, investigating their role in a particular area seems necessary. In this area, signs of undercutting at the foot of lateral and headward slopes of yardangs (Fig)as well as the presence of micro-yardangs (Fig) and flutes indicate that at the present time wind abrasion via sandblasting not only is taking place but also plays a major role in shaping the yardangs. It also plays an indirect role in mass movements and shrinking the yardangs. According to undercutting signs, abrasion is limited to the saltation transport height which riches up to ~2m in height. In addition, it is supposed that the differential pressures applied on yardang surfaces produce secondary currents which transport suspended particles over the surface ( ) . These particles act as subsidiary erosion agents.

Deflation may be considered as another process affecting yardang creation and evolution. However, it removes loose particles released by weathering agents on yardang or inter-yardang surfaces. Given the nortern parts of southern playa located at the banket of Nesa stream which lack a major source of abrading sands, contain insignificant signs of wind erosion, it is concluded that deflation is unimportant in this area in comparison with abration.

In this area clay-rich drapes and (Fig) are the main vestiges of runoff erosion. Gullies carved at the steep banks of Nesa stream show no evidence of wind erosion. In all, there is not sufficient evidence attesting the role of deflation on yardang development in this area.

Deep undercutting’s at lateral and facial slopes by sandblasting have led to the predominance of mass movements in the forms of falls, collapses and topplings (Fig). This process is facilitated by the presence of vertical dehydration fissures in mudrocks.

4.3.Inter-Yardang space

In this area, as a result of long distances between yardangs, the inter yardang spaces are usually flat and covered with coarse sands and small lag gravels forming mega-ripples. These surfaces are important because they are zones of erosion and transportation rather than deposition (Laity , 2009). The widths of inter –yardang paces vary from about m to about 1 km and the relative surface occupied by yardangs is about on average, indicating low density of yardangs. Supposedly, the main reasons include low density of Nebkha s creating them as well as the prevalence of slope failures which have led to their shrinking and disappearance.

5. Discussion

5.1. Transformation of Nebkha to yardang

Field evidence in this area clearly attests to the transformation of Nebkha s to yardangs(Fig). There ara sufficient numbers of forms between Nebkha s and yardangs in this area (Fig). Observations in this area as well as other areas in Kerman region, such as in Lut plain ( ) and in Rafsanjan plain ( ) indicate that in these desert areas Tamarix bushes that are the main species forming Nebkha s cologne wherever there is a coarse (usually sandy) layer over clay layers. The main places having such conditions are playas having a cover of shifting sands. In such conditions the clay layer acts as an impervious layer over which moisture accumulates and te surficial sandy layer that is pervious helps rapid infiltration of water to the ground and lacks capillarity potential which transports water to the surface and evaporates it. Once a bush is colonized, shifting sands accumulate around and in it and as explained by a Nebkha takes form. However, in the presence of Nebkha , while the under – Nebkha playa is preserved from wind erosion, the surrounding bare surfaces are under wind erosion, mainly by sand blasting process. Hence, with the passage of time, the surface of playa away from Nebkha becomes gradually lower than under the Nebkha . This condition exposes the roots of tamarix and leads to its parchness. Actually, the bush parches gradually taking many years. However, afterwards , the sands stabilized by the bush erode away and the exposed part of playa would be higher than nearby surfaces and less *whoud not be eroded by sandblasting process. From this stage onwards*, its height gradually decreases as a result of higher erosion rates in nearby surfaces. Also sandblasting and deflation which in Nebkha – stage have given it a nearly-aerodynamic shape make it more and more aerodynamic. In addition, as its height increases due to erosion of nearby surfaces, its tail extends._Along with these processes, head erosion and collapse take place, so the net change in length of yardang depends upon the difference between the rate of inter-yardang space lowering which elongates it via tail extension and frontal erosion and collapse. Observations in the studied area indicate that sometimes sandy layers lying under the surficial mudrocks are exposed as a result of inter-yardang surface erosion or basal erosion. This condition intensifies abrasion in the basal part of yardang,s face and lateral slopes. The result is rapid collapse and disintegration of yardangs (Fig).

In transformation process of Nebkha to yardang , there is a transient form in which the Tamarix bush is not present but the sands comprising the Nebkha are more or less present and the underlying playa which is higher than the surroundings resamples a yardang,s such a morphology is a transient form between Nebkha and yardang and we suggest the "Nabyard" name (taken from "nab" of Nebkha and "yard" of yardang) for them. In comparison with Nebkha and yardangs. Nabyards are short-lived. Hence, they are much rarer than yardangs and Nebkha s. The process of transformation of one landform to another may be entitled " landfrom transformation". It is supposed that this subject deserves attention in feature geomorphological investigations. In fact, inverted reliefs ( ) are a special kind of landform transformation in which a new land from with opposite appearance to the primary one takes its place.

In addition to field evidence on transformation of Nebkha s to yardangs, some other evidence on transformation of Nebkha s to yardangs, some other evidence may also be presented which support this process: (1) The random scattering of yardangs and the presence of some patches of yardangs in some places is almost the same as Nebkha distribution (2) there are remains of Tamarix roots in the upper parts of mudrocks comprising yardangs, (3) the sizes of yardangs generally is conformablae with the expected sizes of yardangs generally is conformable with the expected sizes from transformation of Nebkha s and (4) the flat-topness of the majority of these yardangs supports this origin. In all, development of yardangs requires initial selective incision of substrate by wind erosion in order to isolate positive forms from nearby surfaces which become inter-yardang surfaces (Broakes , 2001). Nebkha s make this condition possible.

In Kuwait, the Nebkha s are sometimes associated with yardangs and Al – Doxsarietal(2009) speculate that this spatial relationship is due to ovailability of a source of Aeolian particles to caeve the yardangd and corridors. However, this spatial relationship may be due to the transformation of some Nebkha s to yardangs. Obviously, in a Nebkha field all Nebkha s do not transform simultaneously to yardangs and the coexistence of them is axiomatic

It is supposed that the majority of classic streamlined meso-yardangs may have such an origin but the presence of yardangs in hyper arid and vegetation –free deserts as well as in Mars ( ) indicate that other mechanisms of yardang generation do exist, some of them are introduced by …………..

5.2. The role of stream incision

There are about a dozen of playas in Kerman region which both are vast in extent and contain sand dunes but lack yardangs. The prime example is Kerman playa which is partly covered by sand dunes that lack yardangs. Their common feature is the lack of incision by incoming streams.

Evidently, if the stream incision not been taken place in Fahraj playa there would only be sand dunes, and yardangs had not been formed. This is because as a playa becomes incised by crossing streams; (1) it dries out and becomes vulnerable to wind erosion ,(2) sediment deposition by incoming streams which covers aeolian erosional landfrom is truncated, (3) the smooth surface of playa which is less suitable for wind erosion becomes uneven and liable to wind erosion, (4) the incised stream course may act as a sink for plenty of sands which otherwise would accumulate on the surface of playa and preserve it from wind erosion , and finally,(5) as Laity and Bridges (2013) have expressed, the lowering of water table which forms the base level of aeolian erosion supports yardang developments considering stream incision in Fahraj playa has started from the east and progressed towards the west, the eastern parts of it were firstly exposed to wind erosion . In reality, incision in western part is younger in age and less in amount. This is why the western parts lacks yardangs.

5.3. Mode of yardang progression

In northern playa, such evidence as (1) the relative position of sand source (at north) and sink (at south), (2) the relatively severe wind erosion of northern bank of Nesa valley, (3) the presence of yardangs even just at the bank of stream , (4)the placement of yardangs at south and Nebkha s at north as well as (5) the gradual decrease in height of yardang from the stream bank towards the north, all, attest to the point that yardang formation was firstly started at south and progressed towards the north (upwindward), The main reason is the presence of a steep slope (river bank created by incision) for transporting sands and sandblasting at the southern edge of this playa.

In contrast, in the southern playa in which the topographic barrier (Nesa valley scarp) lies at the north, transport limited amounts of sands present in mudrocks and development of yardangs ,which are much lesser in number than in northern playa, has started from the north and progressed toward the south (down windward). Hence, from the point of progression of yardang formation, we deal with two modes, in one of them yardang formation has progressed up windward and in the other downwind ward. So, the authors propose retrogressive and progressive yardang formation respectively for these two modes. In progressive mode, commonly the blowing sands face a topographic barrier and yardang formation starts from this topographic barrier and progresses down windward. Supposedly, mega-yardangs of Lut ( ) and Egypt ( ) have formed in this fashion. In retrogressive mode, yardangs firstly appear at the surface of a topographic scarp upwind of a sand sink (valley or depression) and gradually appear on the upwindwards of the exposed surface. In author words, in progressive mode, yardangs become more younger and gradually decrease in height and wipe out downwindward, while in retrogressive mode they become younger and gradually disappear upwindward.

Conclusions

According to this study : (1) incision of playas by entering streams increases the probability of yardang formation via drying out the playa deposits, truncating fluvial deposition, creating topographic barriers or gradients for aeolian erosion , inhibiting the accumulation of sands on playa surface and lowering the water table.(2) yardangs may develop from Nebkha transformation and the 'nabyard' name was suggested for the transitional landform between Nebkha and yardang, (3) sandblasting has played a major role in creation of Fahraj yardangs and the roles of weathering, fluvial erosion and deflation seem to be subsidiary with respect to sandblasting.(4) undercutting by sand blasting, and presence of a basal sandy layer and desiccation cracks in playa mudrocks whih cause mass wasting in lateral and frontal parts of yardangs play a major role in shaping and evolution of these yardanngs. (5) high amounts of sand in playa deposits of Fahraj plain make them vulnerable to wind erosion and (6) yardang formation may progress in upwind or downwind directions. So, retrograde and prograde modes of progression is suggested for these modes respectively.

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